NATIONAL SCHOOLS

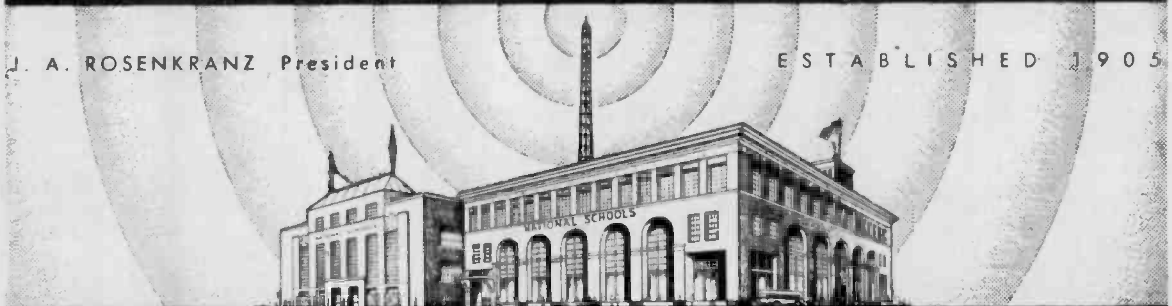
LOS ANGELES, CALIF.

EDUCATION COOPERATION SERVICE

PIONEERS OF PRACTICAL TRAINING SINCE 1905

Practical Technical Training In
RADIO·TELEVISION
AND ALLIED ELECTRONICS

J. A. ROSENKRANZ President ESTABLISHED 1905



NATIONAL SCHOOLS ★ LOS ANGELES 37, CALIF.

LESSON NO. 1

THE ELECTRON

MIRACLE-WORKER OF A MODERN WORLD

The great science of Radio and Electronics has provided us with a vast communication network, extending throughout the far corners of the earth. It has produced the communication and navigation equipment that enables our giant oceanliners and airliners to carry passengers and freight over otherwise perilous routes, safely and on schedule.

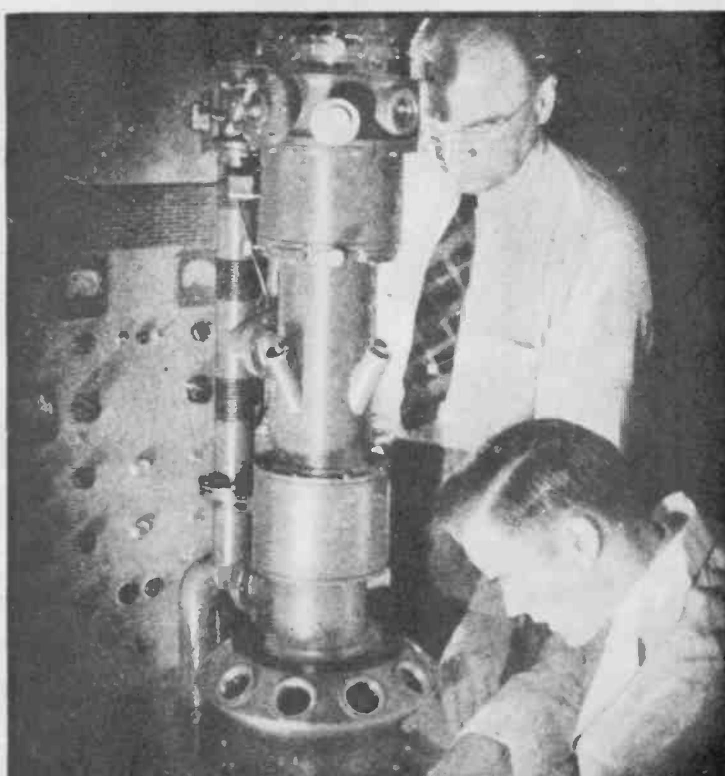


FIG. 1
THE ELECTRON MICROSCOPE AIDS IN RESEARCH CONDUCTED IN MANY FIELDS

In the field of industry and medicine, Electronics has made possible the welding of sheets of metal in a matter of moments, without the application of external heat; thermally glueing and treating featherweight plywoods to attain great strength; examining, testing, weighing, grading, sorting and counting manufactured products accurately and in split-second time; controlling the operation of machinery and mechanisms of all descriptions; identifying and matching colors; isolating, analyzing and destroying virus and bacteria; miracles in the

FIG. 2
ELECTRONICS MADE THIS MODERN BROADCASTING EQUIPMENT POSSIBLE

field of medicine and surgery; and thousands of devices that help make this a better world in which to live.

This comparatively young industry,comprising Radio and Electronics, has experienced the most rapid and spectacular growth of any of our major industries; and further developments of great importance are assured in the very near future. You acted wisely, therefore, when you decided to make Radio and Electronics YOUR career --- a career in which the possibilities for opportunity and advancement are limitless.

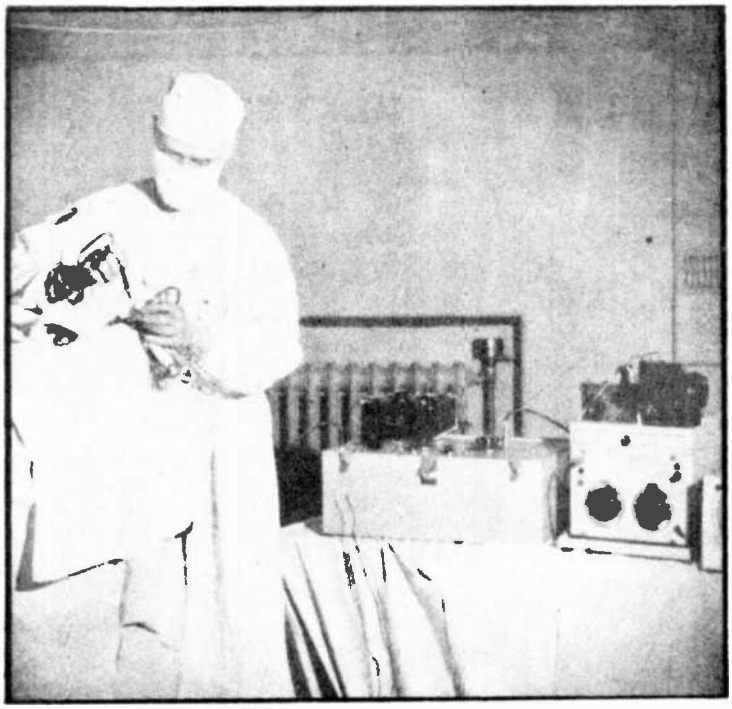


FIG. 3
SURGEON TESTING THE ACTION OF HUMAN BRAIN WITH THE ELECTROENCEPHALOGRAPH AND 60-CYCLE STIMULATOR. RESEARCH AS THIS WOULD NOT BE POSSIBLE WITHOUT ELECTRONICS.

In this lesson we are going to turn back the pages of history, briefly reviewing the most outstanding developments of this great science, and showing you how man harnassed the electron to work for him. You will also learn about the nature of the electron and its behaviour under different conditions.

PROGRESS THROUGH THE AGES

Ever since the dawn of human life on this planet, man has been striving to learn more about the things with which he lives; with which he works; and, unfortunately, with which he fights. Always, so that he could make a better world for himself and his descendents. to live in. So that he could make life a little easier. So that he could secure the necessities and luxuries of life by some means other than by the sweat of his brow, or the labor of animals.

THE AGE OF BRUTE FORCE: Throughout the many centuries preceding the beginning of the 19th century (1800), man was living in the age of "brute force." The amount of work he could dc was limited to that which he or his animals could perform by their own strength. His means of travel and transportation were animal-drawn vehicles and sail-powered water craft. His means of communication was restricted to visual or audible signals. The necessities of life were hard to obtain, and luxuries were very few indeed.

Even in these comparatively backward centuries, scientists, experimentors, alchemists, and other technically inclined men, were working constantly to improve the lot of man's existence. In fact, as early as 600 B. C. Thales of Miletus, one of the "seven wise men" of early Greece, discovered that a piece of amber, when rubbed with a woolen cloth, would attract light bodies due to a form of electrification which we now call "static electricity". The efforts of these thou-

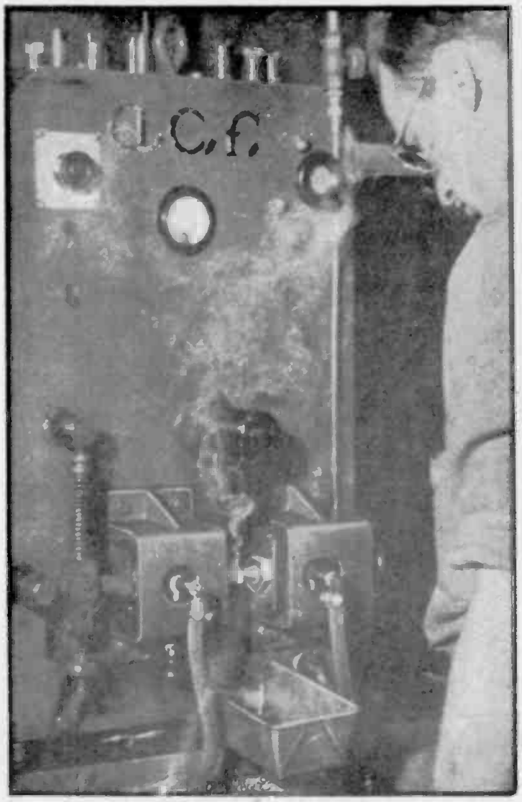


Fig. 4
HARDENING SMALL, PRECISION PARTS IN PHOTOCELL-CONTROLLED FURNACE

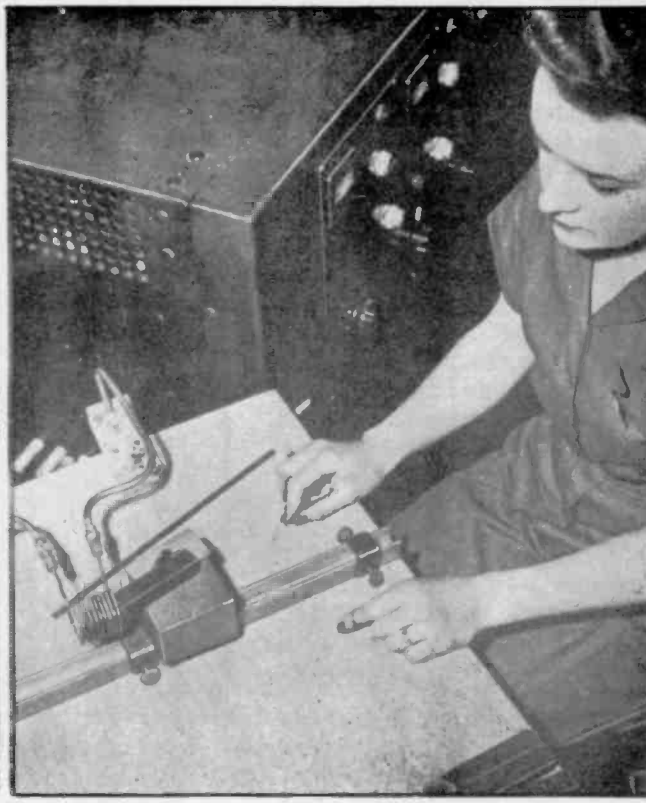


Fig. 5
INDUCTION HEATING EQUIPMENT BEING USED FOR BRAZING CARBIDE TOOLS

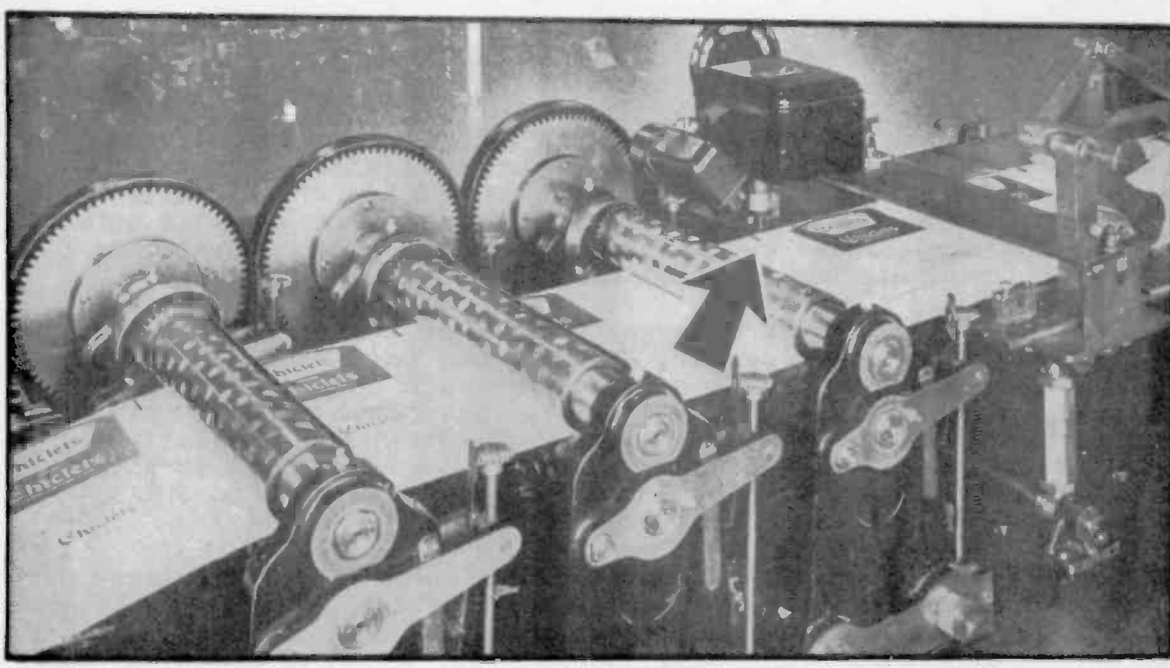


Fig. 6
PHOTOELECTRIC CONTROL USED TO INSURE HAIRLINE PRECISION REGISTER OF SEVERAL COLORS IN PRINTING OPERATION.

sands of men --- many of them forgotten in the passage of time --- reached their goal in the 1800's.

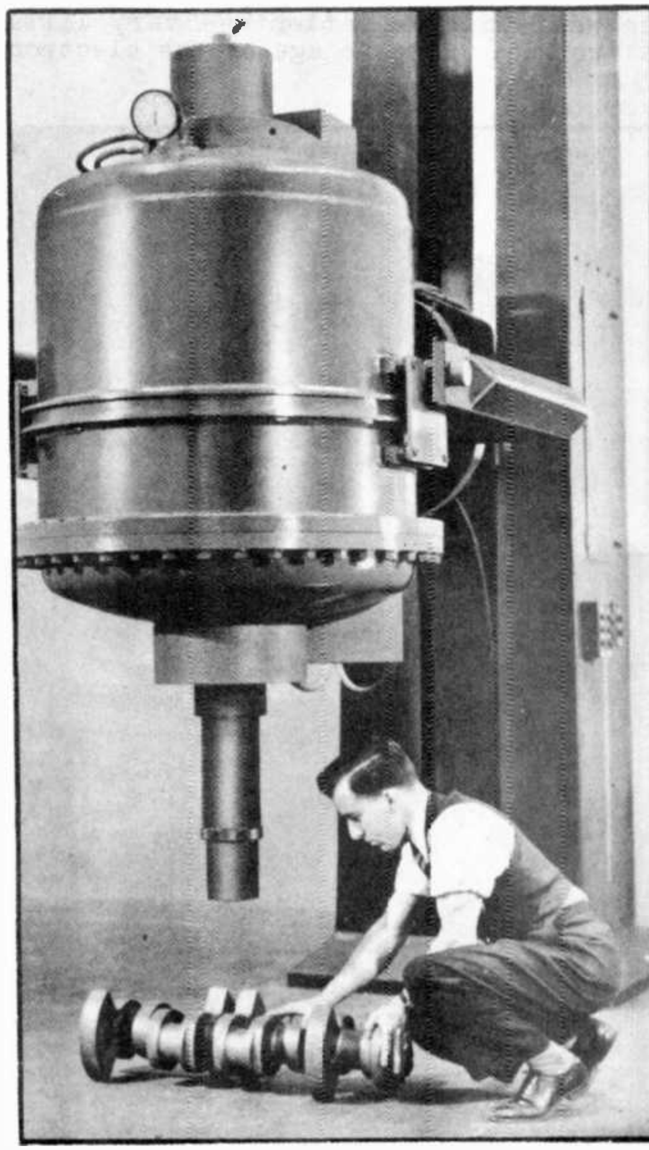


FIG. 7
INDUSTRIAL X-RAY UNIT USED TO RADIOGRAPH CASTINGS AND OTHER MANUFACTURED PRODUCTS OF VARIOUS THICKNESS FOR POSSIBLE DEFECTS.

THE MACHINE AND ELECTRICAL AGE: The steam engine of James Watt --- the electrical developments of Joseph Henry, Benjamin Franklin, Samuel B. Morse, Alexander Graham Bell, Thomas Edison, Guglielmo Marconi, and many others --- lifted the human race from the age of brute force into the age of steam power; the age of electricity; the age of the internal combustion engine. This made it possible for man to work, travel, and communicate, by means of inanimate and never-tiring machines.

A new way of life was thus opened to all men; a life which saw man lifted from the centuries of "brute force" existence. Necessities of life became easier to secure; luxuries such as had never before been imagined by the wildest dreamers, became available in great quantity --- and then became necessities instead of luxuries. The electric light;the telegraph; the telephone --- luxuries not so many years ago --- necessities, today.

THE DAWN OF THE AGE OF THE ELECTRON: The beginning of the 20th century saw the Wright Brothers place the internal combustion engine in a crude kite-like affair, and make the first airplane flight. The "horseless-carriage" (automobile) became a reality. In 1904 J. A. Fleming utilized for the first time the "Edison effect" in a vacuum tube detector;and five years later Dr. Lee De Forest added a control grid to the Fleming valve, making possible the amplifiers which were to open the world of the electron for man's inspection and use.

Neither Edison, Fleming, nor De Forest realized the importance of their discoveries with respect to the great science, "radionics" --- in fact, they did not even use the term "electron" in connection with the vacuum tube --- and no one had any accurate idea of the underlying principles of the vacuum tube at the time of Edison's work on the subject. Even after the vacuum tube had been applied to its first tasks --- those of amplifying in long-distance telephone lines, and in radio communication --- very little was actually known about why it worked. But the age of the electron was dawning.

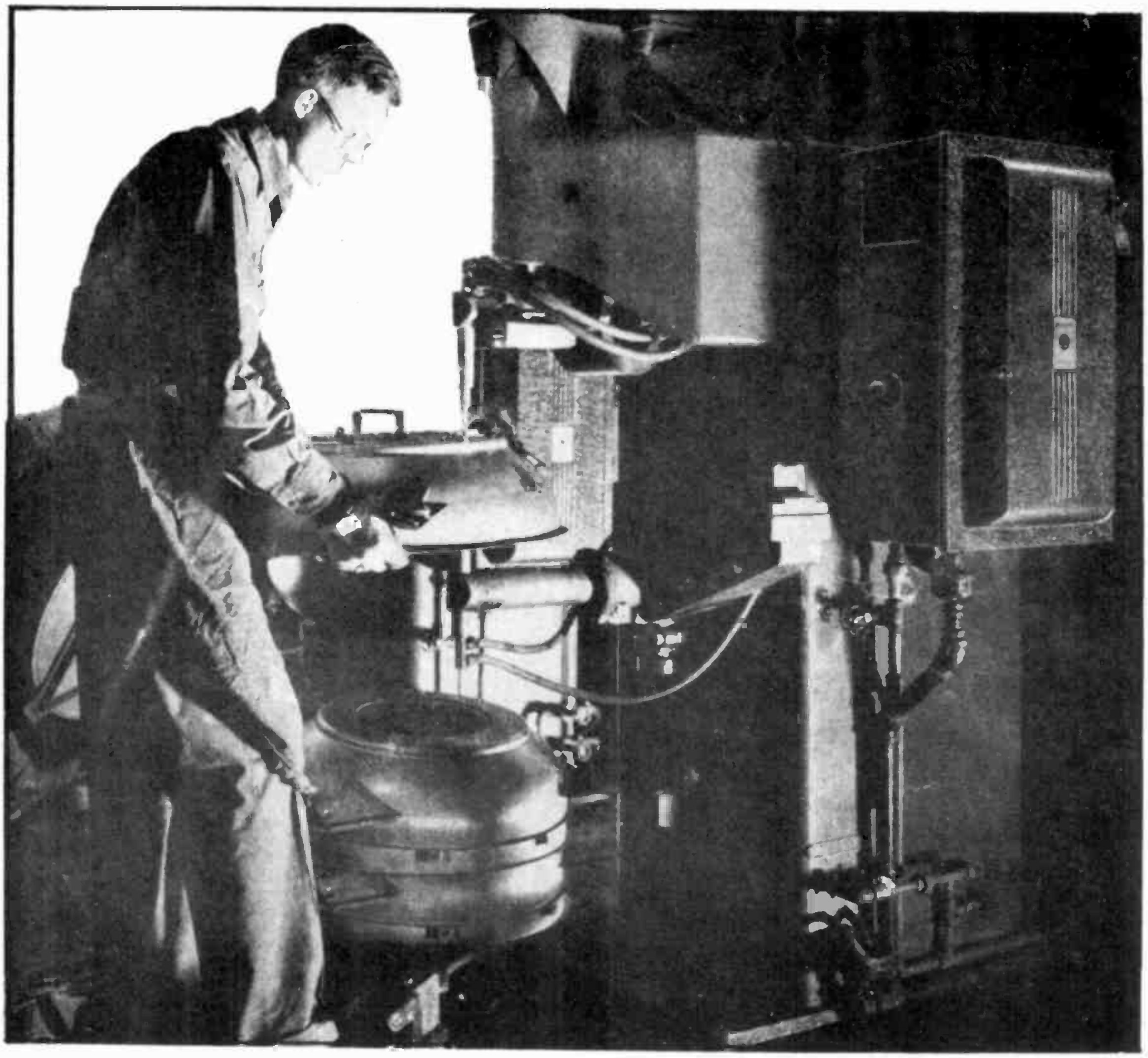


FIG. 8

AN IGNITRON TUBE CONTACTOR IS USED IN THIS ELECTRIC WELDER TO MAKE AND BREAK WELDING CURRENT AS HIGH AS 10,000 AMPERES --- WITH NO ARC, NO NOISE, NO MOVING PARTS. BECAUSE IT CAN BE TIMED MORE ACCURATELY THAN MECHANICAL DEVICES, THIS ELECTRONIC CONTROL ENABLES AN OPERATOR TO PRODUCE STRONGER AND MORE UNIFORM WELDS, AT GREATLY INCREASED PRODUCTION RATES.

The past two decades have seen much of the mystery lifted from the electron and its tubes. Scientists have now found most of the answers, and rapid progress is being made toward discovering the answers to the remaining mysteries concerning the electron. WE ARE NOW LIVING IN THE AGE OF THE ELECTRON.

Various illustrations throughout this lesson tell you their own story of some of the many marvelous things that are being done by putting the electron to work in radionic equipment.

YOUR ENTRANCE INTO THE FIELD OF RADIONICS AND ELECTRONICS

As you begin your studies and work in the fascinating and profitable field of radionics and electronics, you will naturally be interested in what these fields comprise, and in learning something of the

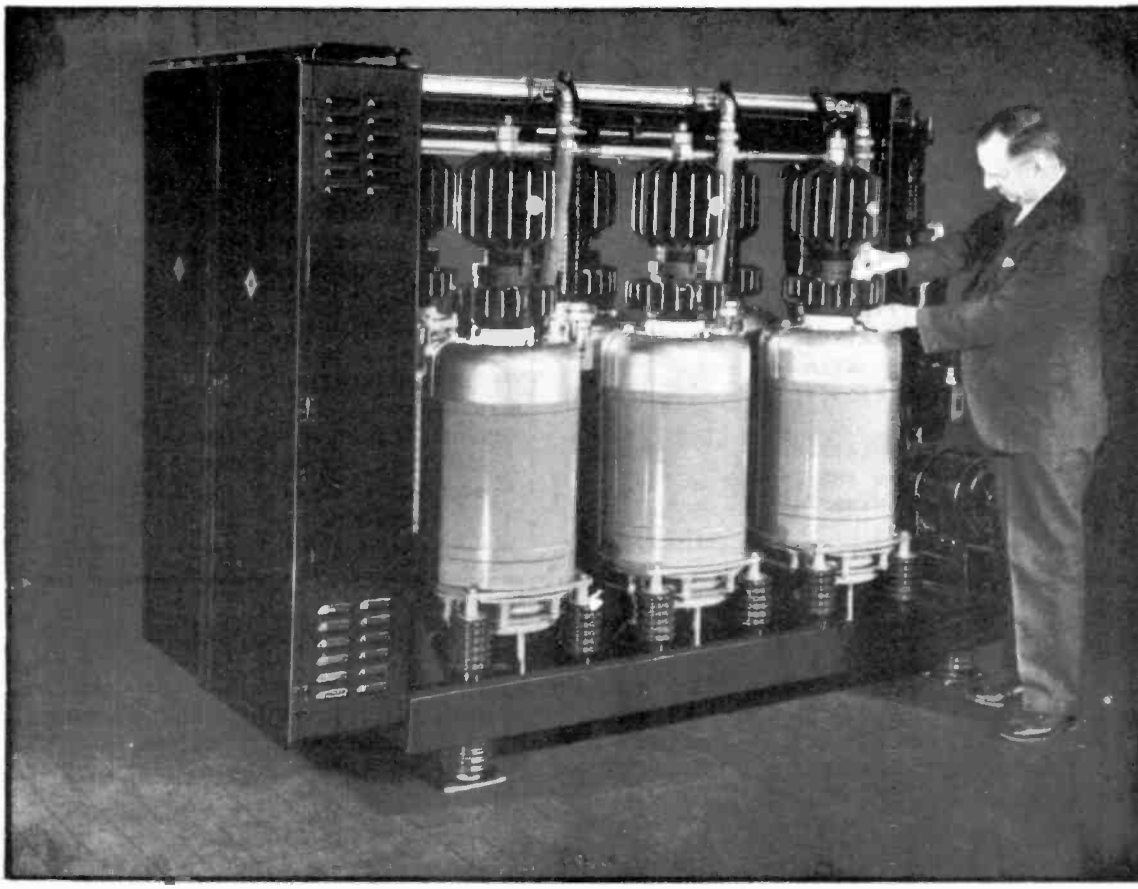


FIG. 9
MERCURY-ARC POWER RECTIFIER DESIGNED FOR INDUSTRIAL USE. THIS ELECTRONIC APPARATUS CHANGES ALTERNATING CURRENT (A-C) TO DIRECT CURRENT (D-C).

very basic principles which make it possible for the electron to become your servant. You will also be interested in the exact distinction between the terms "radionics" and "electronics". These terms have been used so much of late that the beginner in the field might well be at a loss as to their exact meaning.

WHAT IS RADIONICS? The word "radionics" has been coined during the past few years, and is now applied to all apparatus and devices in which the electron plays a major part. By referring to the chart on page 8, you will see that the field of Radionics comprises two major fields --- Radio and Communication, and Electronics. You will observe further that the field of radio and communication consists of many branches, including receivers, transmitters, sound amplifiers, television, etc. You will see also that the field of electronics consists of many branches including automatic control devices, induction heating, welding, etc.

Electrons and electronic tubes are made use of in all phases of radionics. And the present tendency is to apply the term "industrial electronics" to electronic applications other than those employed in communication and allied work; and to use the word "radionics" as the all-embracing term to include all apparatus employing electronic tubes, regardless of application.

RADIONICS

- **RADIO & COMMUNICATION**
  - Radio receivers
  - Radio testing equipment
  - Radio servicing
  - Sound amplifiers
  - Broadcast transmitters
  - Code transmitters
  - Broadcast operating
  - Commercial operating
  - Sound motion pictures
  - Television
  - Frequency modulation
  - Aviation radio and direction finding
- **ELECTRONICS**
  - Automatic control devices
  - Automatic alarm systems
  - Counting, sorting, grading, matching, weighing, etc.
  - Color analyzing and matching
  - Microscopy
  - Welding
  - X-ray
  - Induction heating
  - Diathermy
  - Geophysical exploration
  - Signalling and synchronizing
  - Power rectification and inversion, etc.

THE "ELECTRONIC TUBE" ---- HEART OF ALL RADIONIC EQUIPMENT

Figs. 10 and 11 will give you an idea of the shape and structural features of some of the tubes that are used in the field of communication and electronics. Besides these, there are many more; and you will become intimately acquainted with all of them as you advance in this course of training.

In the following tabulation, some of these tubes are listed by name, and a brief account is given of the different important jobs that each of them will do. Some of the technical terms appearing in this tabulation may be strange to you at this time, but rest assured that you will be using them yourself with a sense of pride and complete familiarity before long.

NAMES AND APPLICATIONS OF ELECTRONIC TUBES IN COMMUNICATION AND INDUSTRY

TUNGAR OR RECTIGON:

1. Battery-charging installations.
2. Voltage rectifier for a-c generator sets.

KENOTRON:

1. Broadcast and television.

PLIOTRON:

1. Radio transmitters.

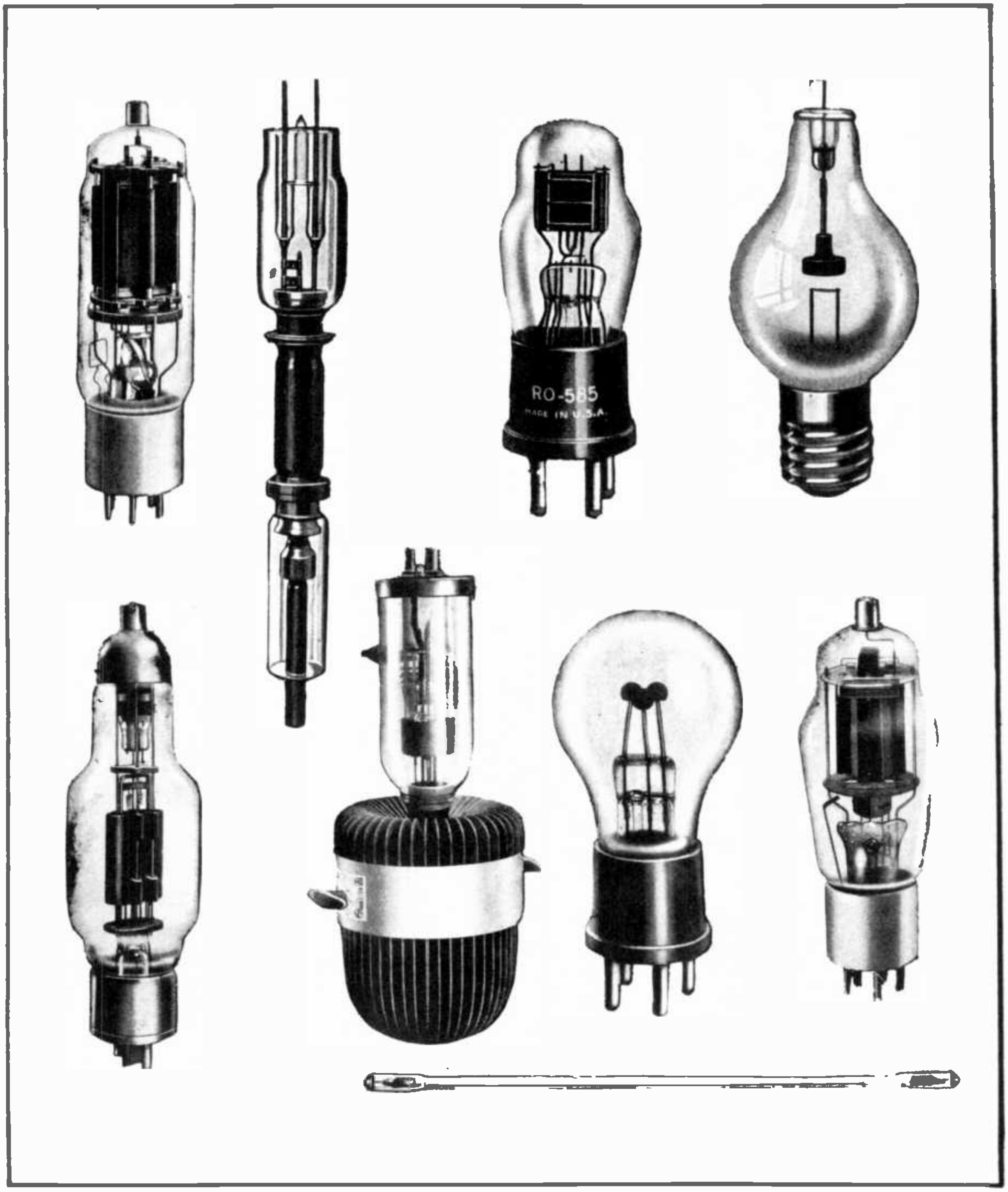


Fig. 10
IN TUBES AS THESE ELECTRONS ARE RELEASED FROM THEIR MATERIAL "PRISONS" AND PUT TO WORK.

2. Induction heating.
3. Diathermy.
4. Industrial control applications.

MAGNETRON:

1. Magnetically - operated switch in electronic control circuits.

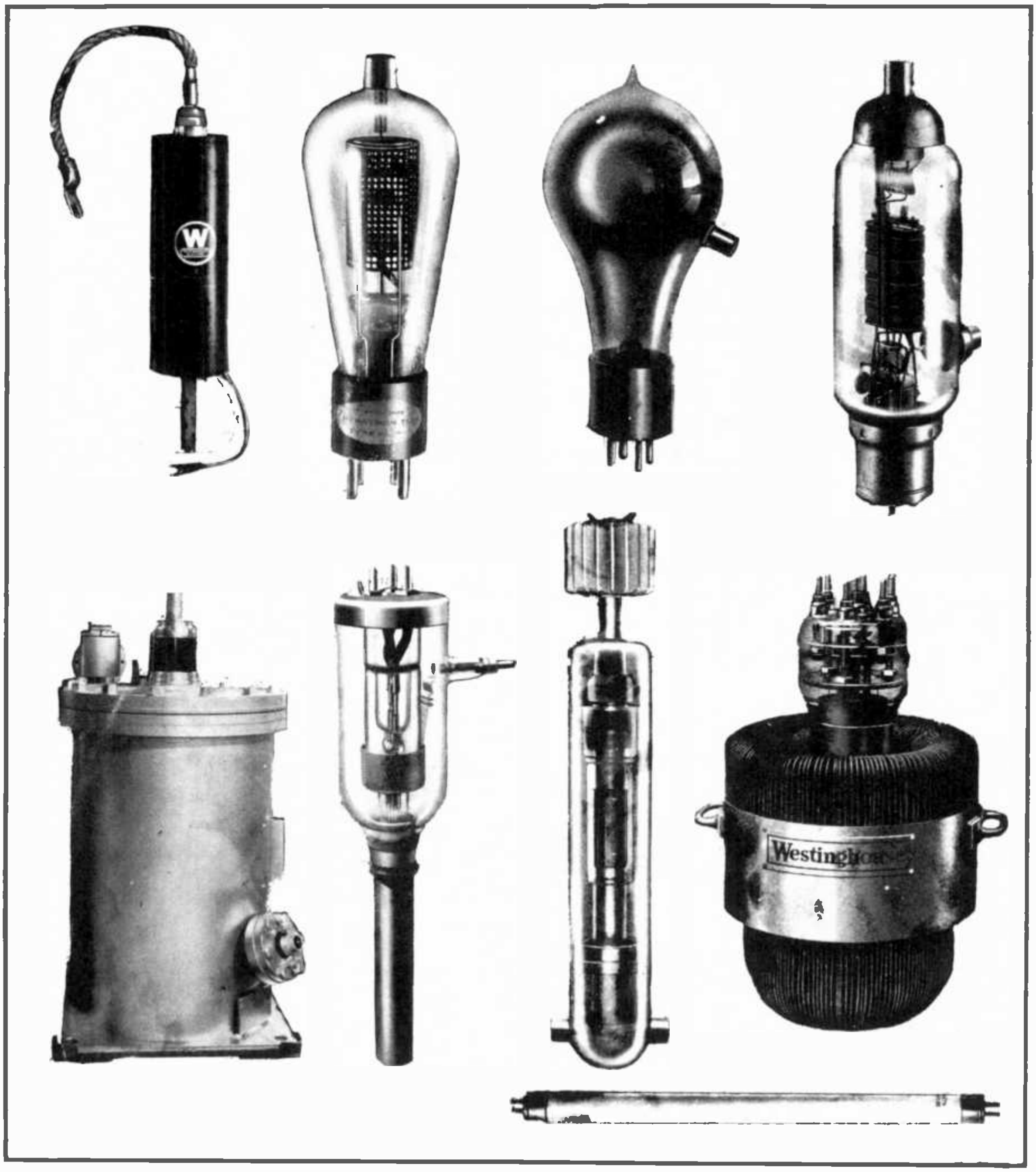


FIG. 11
TUBES OF MANY TYPES, SIZES AND SHAPES ARE USED IN FIELDS OF COMMUNICATION AND INDUSTRIAL ELECTRONICS

2. Generator of very high frequency oscillations.

GRID POOL TUBE:

1. High-voltage, high-current, controlled rectifier for large power applications.
2. Railway power supply.
3. Switching and commutation.
4. Current and power circuit.

GLOW TUBE:

1. Voltage regulator and stabilizer.
2. Visual indicator.
3. Light producer.
4. Circuit protector.

X-RAY TUBE:

1. Medical examinations.
2. Examination of industrial products.
3. Research.

CATHODE-RAY TUBE:

1. Television receivers.
2. Visual indicator of electrical measurements.
3. Application to industrial measurements.
4. Brain wave studies.

STROBOTRON:

1. Control tube for photographic uses.
2. Source of intermittent light flashes.
3. "Slowing action" of moving mechanisms.
4. Stroboscopic measurements.

PHOTOTUBE:

1. Measurement of light and color.
2. Picture transmission.
3. Measurement and control of temperature.
4. Measurement and control of light.
5. Measurement of density, opacity and glare.
6. Industrial control, counting, weighing, etc.

MOSAIC SCREEN TUBE:

1. Television camera and pick up tube.
2. Transmission of pictures over wires or radio circuits.

PHANATRON:

1. Voltage limiting or breakdown devices.
2. Pulse generators.
3. Trigger devices.
4. Relaxation oscillators.
5. Visual indicators.
6. Rectifiers.

THYRATRON:

1. Voltage or phase-controlled rectifier.
2. DC to AC inverter.
3. Electronic welding.
4. Commutation and switching.
5. Motor speed control.
6. Electrical timing.

PERMATRON:

1. Magnetically operated switch.
2. Control of large currents by external magnetic field.

IGNITRON:

1. Spot welding control.
2. Illumination control.
3. Motor commutation.
4. Frequency transformer.
5. High-current rectifier.
6. AC to DC inversion.

ELECTRON RAY TUBE:

1. Visual indicator of voltage, electrical balance, or resonance.
2. Measurement of voltage, current or power.

The operation of all of these tubes, and also the operation of the many different types of apparatus in which they are used, is completely dependent upon the powers of the tiny ELECTRON --- the smallest particle of any substance known to man. It is perfectly logical, therefore, that we begin our instruction in radionics and electronics by introducing you to the electron --- showing you how it may be liberated from its material "prison" and put to work in electronic tubes and circuits.

THE ELECTRON ---- A PARTICLE OF MATTER

The electron is found in all things that exist anywhere in the Universe. Scientists would say that electrons are found in all matter, the word matter being used by them to describe all things that have weight and occupy space. Thus, a chair, coal, salt, and thousands of other things are forms of matter.

Matter is considered to exist in three different forms or states:

1. Matter in the form of solids; such as iron, copper, wood, paper, rock, coal, etc.

2. Matter in the form of liquids; such as water, blood, gasoline, alcohol, sulphuric acid, etc.

3. Matter in the form of gases; such as air, helium, hydrogen, the fumes of evaporating gasoline, steam, etc.

While found in nature in one of the three states mentioned above, we often convert matter in one form into another form. A simple example of such conversion is where we change ice (a solid) into water (a liquid), and finally into steam(a gas), by the application of heat. As another example --- iron is a solid at ordinary temperatures; but when heated, it becomes a liquid.

THE WORLD OF THE MOLECULE AS SEEN THROUGH A MAGIC MICROSCOPE

Let us suppose that we have a microscope that will permit us to look at the structure of all the different forms of matter and see just how they are made. We will further suppose that our microscope can be adjusted so that it will magnify to any degree we wish. Of course, a microscope of such great power has never been built, but it is quite within the bounds of reason to expect that scientists will some day be able to see the things they have discovered and studied by indirect and more complicated methods. On the table with this microscope, we have several forms of matter --- a piece of iron; an ice cube; and some table salt.

Now, let us focus our microscope on the piece of iron, and adjust it so that it is magnifying one million times. When we peer through the microscope, we seem to be looking at a strange new world. Instead of the solid structure, as we usually think of a piece of iron as being, we see a cluster of thousands of small blobs, or chunks of matter, as shown in Fig. 12. These chunks or blobs look very much like a pile of coal would look to the unaided eye --- with the exception that they are all vibrating like so many microscopic "jitterbugs" standing on a dance floor. We also notice that most of their activity is confined to a limited area and that they do not move about over the "dance floor". Scientists call these small and active chunks of matter <u>molecules</u>.

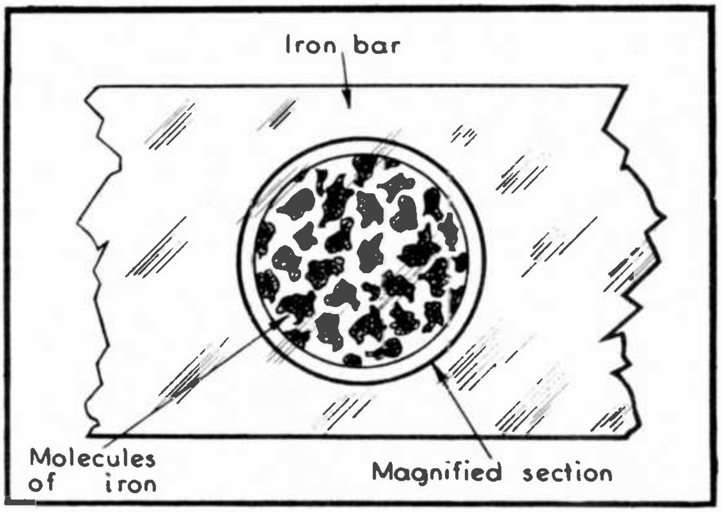


FIG. 12
HOW THE MOLECULES OF IRON WOULD LOOK IF SEEN THROUGH THE MAGIC MICROSCOPE

WHAT ARE MOLECULES? --- A molecule is the smallest piece of any particular material that it is possible to have. In fact, there are as many different kinds of molecules as there are different kinds of matter --- thousands of them. A tree, for instance, is made up of molecules of cellulose and molecules of water. An automobile is made up of molecules of iron, steel, brass, glass, rubber, copper, oil, and many others. Molecules are so small that billions of them are contained in one drop of ordinary water.

HOW THE ARRANGEMENT OF MOLECULES DIFFERS IN SOLIDS, LIQUIDS AND GASES

You have learned that all matter exists in one of these three forms (solid, liquid or gas); and that matter in one form can often be converted into matter in another form by a change in temperature. Let us see how this is done.

By placing the ice cube, which is matter in the form of a solid, in front of our microscope, we observe that the molecules of ice are packed rather closely together, somewhat as illustrated at (A) in Fig. 13 --- and which is true of all solids.

While continuing to look at the ice cube, let us apply heat to it. As the ice cube is heated, we see that the molecules vibrate much faster than originally, and that the more heat we apply, the more active they

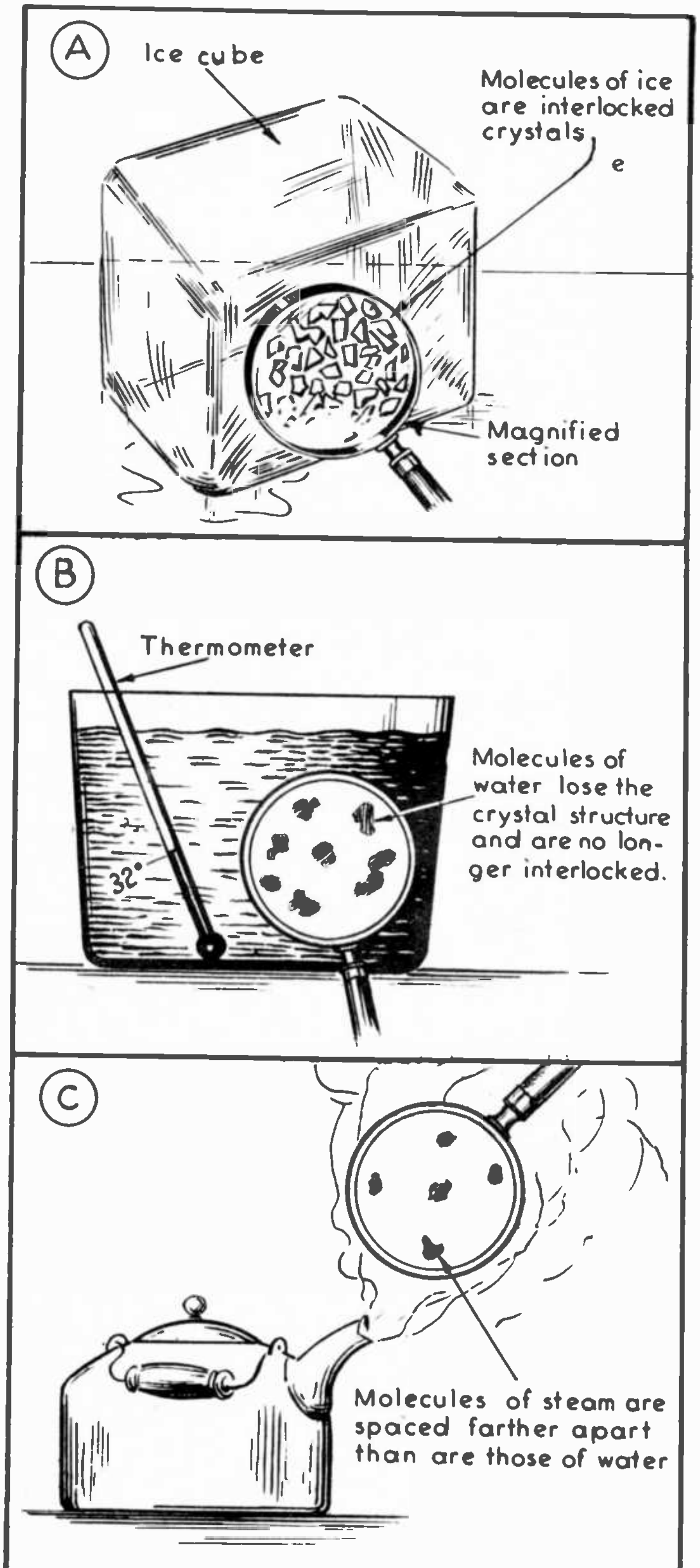


Fig. 13
Changes in Molecular Arrangement in Solid, Liquid and Gas

become. When the temperature of the ice is raised to 32 degrees Fahrenheit (the freezing point of water), the molecules suddenly jump away from each other. The jitterbugs have started to dance! That is,they no longer remain in an interlocked cluster, but arrange themselves in a loose cluster, free to move about somewhat as illustrated at (B) of Fig. 13. When this occurs, the molecules no longer form the solid, ice, --- but rather water, which is a liquid.

As we increase the temperature of the molecules of water beyond 32 degrees Fahrenheit, we see that they become even more active, until individual molecules begin to jump away from the rest and fly off into the surrounding atmosphere --- thus forming steam, which is a gas. (See Fig. 13-C). Molecules forming steam, or any other gas, are spaced at comparatively great distances from each other. This explains why matter in the form of a gas may be compressed, and why it is very light.

THE WORLD OF THE ATOM AS SEEN THROUGH A MAGIC MICROSCOPE

Now let us increase the magnification of our microscope so that we can examine a single molecule. Looking closely at this small vibrating chunk of matter, we see that it, too, is made up of parts or sections. A molecule of water, for example, is seen to contain three individual parts, two of them being alike, and one of them different from the other two. A molecule of table salt contains two parts, each different from the other. A molecule of iron contains only one part. These parts of the molecule are called atoms.

The atomic composition of molecules of water, salt, and iron, as they would appear through our magic microscope, is shown in Fig. 14.

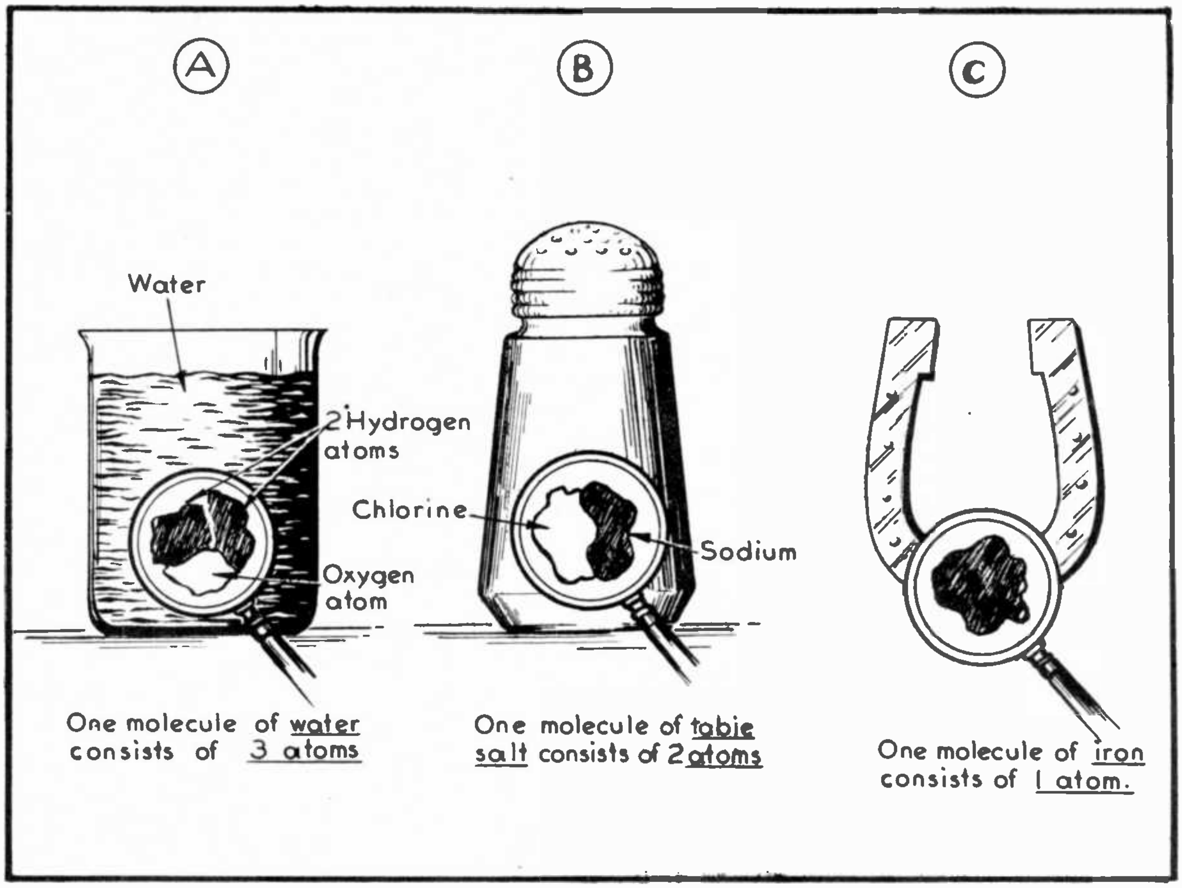


FIG. 14
COMPOSITION OF MOLECULES OF WATER, SALT, AND IRON

It is the number of atoms, and the kind of atoms in the molecule, which determines the nature of the molecule itself. Thus, a molecule of water differs from a molecule of iron, or from a molecule in any other form of matter, only in the number and type of atoms of which it is composed. Scientists have found that while there are thousands of different kinds of molecules, there are less than a hundred kinds of atoms. (At the present time, about 95 different kinds are known.)

THE ELEMENTS: Certain substances --- such as lead, copper, oxygen, chlorine, and sodium --- are found in nature, composed of only one kind of atom. Thus a molecule of lead, copper, or sodium, would each be composed of a single atom of that metal. These and other forms of matter where molecules contain only one kind of atom are known as elements.

Substances such as sodium chloride (ordinary table salt), air, and thousands of other things are made up of more than one kind of atom. A molecule of sodium chloride, for instance, is composed of one atom of sodium (a solid), and one atom of chlorine (a gas). This is shown in Fig. 14-B. It is interesting to note that while both sodium and chlorine are deadly poisons if taken into the human system alone, they are quite harmless when combined to form molecules of sodium chloride (table salt).

In Fig. 14-A, you are shown the structure of a molecule of water. You will note that it consists of 2 atoms of the element, hydrogen; and one atom of the element,oxygen. Both of these are normally in the form of a gas, but they combine at ordinary temperatures to form a liquid. Thus, the form in which an element is found in nature is not necessarily a true indication of the form and appearance it will have when compounded with other atoms to form a molecule of matter.

STRUCTURE OF THE ATOM: All atoms are very small. So small, in fact, that it is sometimes difficult for us to realize just what is meant by "smallness" when speaking of atoms and molecules. When we tell you that in a single glass of water there are more than a million, million, million, million, molecules --- and that an atom is many times smaller than a molecule --- you will get some idea of the size of these little "building blocks" of all matter.

It might be thought that scientists could not go any further in their investigations of the composition of matter, and would have to be content with the knowledge that all things are made up of molecules; and that molecules, in turn, are made up of atoms. Fortunately, however, such is not the case. For many years, workers in this field have recognized that the atom itself is made up of smaller parts or particles, just as the molecule is made up of atoms.

Only in the past few years has the composition of the atom been known with reasonable certainty. Today, it is believed that each atom is composed of at least two other different types of particles; one of these being that wonder-worker in which you are particularly interested --- THE ELECTRON.

THE WORLD OF THE ELECTRON AS SEEN THROUGH A MAGIC MICROSCOPE

Now, let us adjust our wondrous microscope until it is magnifying several million times more than it was when we examined the molecule. Looking at the atom, we see that it is not a solid particle, as scientists once thought, but really consists of many smaller particles; and we observe that most of these smaller particles are in continuous motion.

There is a central group of particles called the nucleus of the atom, around which the other particles are moving rapidly --- much like a swarm of flies would buzz around a piece of sugar. A diagrammatic picture of one atom, as it would probably appear if magnified many millions of times, is presented in Fig. 15.

The small particles which are in such rapid motion are the electrons, which are negative particles of electricity. The central portion, or nucleus, around which the electrons are whirling, is made up of positive particles called protons.

Again, looking through our microscope at the atom, we see that the center of the atom contains one or more surplus protons, and is therefore positively charged. The outer electrons fly in orbits about this positive nucleus. This is true of all atoms. An atom of iron would be seen to consist of orbital electrons and a central nucleus, just as would an atom of lead, or any other type of atom. But, there would be one important difference. Each type of atom contains an amount of electrons and protons that is different from any other type of atom.

WHY THERE ARE DIFFERENT KINDS OF ATOMS: The number of electrons and protons in an atom is what makes an atom of iron different from an atom of lead; or an atom of hydrogen different from an atom of helium.

Hydrogen is a very light, and highly inflammable gas, which is sometimes used to inflate dirigible balloons. Helium also is a very light gas, but it will not burn at all, so it is a much safer gas for use in dirigible balloons than is hydrogen. The only difference between an atom of hydrogen and an atom of helium is that the hydrogen atom contains only one unpaired proton in its central nucleus around which only one electron is revolving; while an atom of helium has two extra protons in its nucleus with two electrons rotating around it. This is illustrated in Fig. 16.

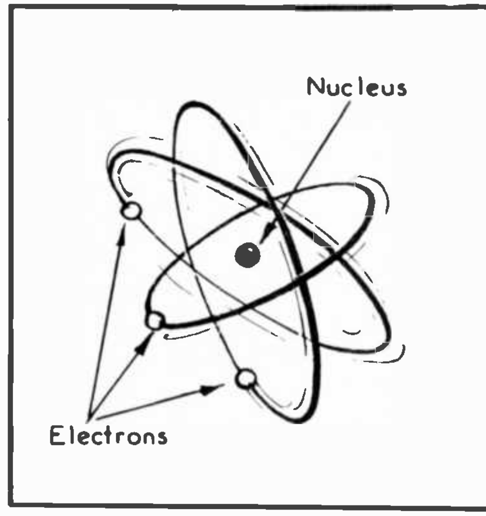


FIG. 15
THE ATOM CONSISTS OF ELECTRONS ROTATING AROUND A NUCLEUS

Atoms of some elements will have as high as 92 protons in their nucleus, with 92 electrons spinning around the outside of the nucleus.

HOW ELECTRONS AFFECT OTHER ELECTRONS:

Suppose it were possible for us to take two electrons and place them in an enclosure such as a microscope prize ring, and study their actions with our magic microscope. Let's see then, what would happen.

This situation is illustrated at (A) and (B) of Fig. 17, where we observe that the instant the electrons are placed in the center of the ring, and released, they will run away from each other and place as much distance between them as is possible; eventually winding up at opposite corners of the ring as shown in Fig. 17-B.

If four electrons were released in the center of the ring, as in Fig. 18, they would immediately dash to the corners --- each of them striving to get as far away from the others, as possible. The release of any number of electrons in the ring would see them all dashing madly away from each other. Thus, we can say that electrons repel other electrons; or that there is a force existing between all electrons which causes them to move away from each other.

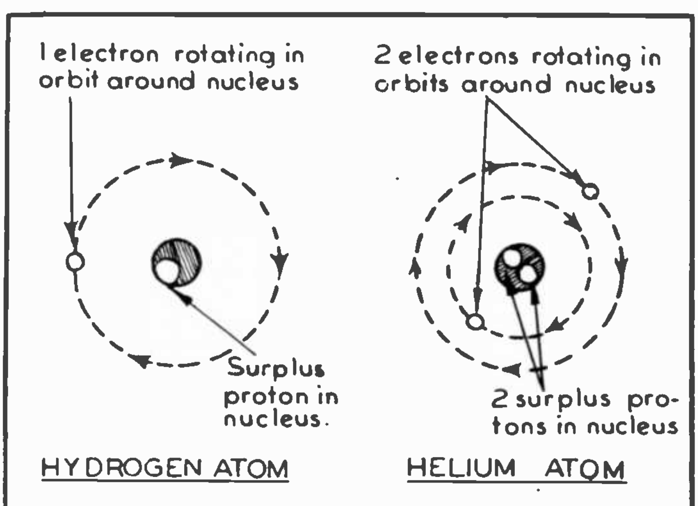


FIG. 16
COMPARISON BETWEEN HYDROGEN AND HELIUM ATOMS

HOW PROTONS AFFECT ELECTRONS:

Now, let us suppose that we have placed a proton in the center of our ring. An electron released anywhere in the ring, such as shown in Fig. 19-A, will immediately rush toward the proton in the center. When the electron gets close to the proton, it will start whirling around the proton in a circular motion as at (B) of Fig. 19. This action would be very much like that of a boxer rapidly circling around another boxer who is standing in one spot, in the center of the ring. The circular path that

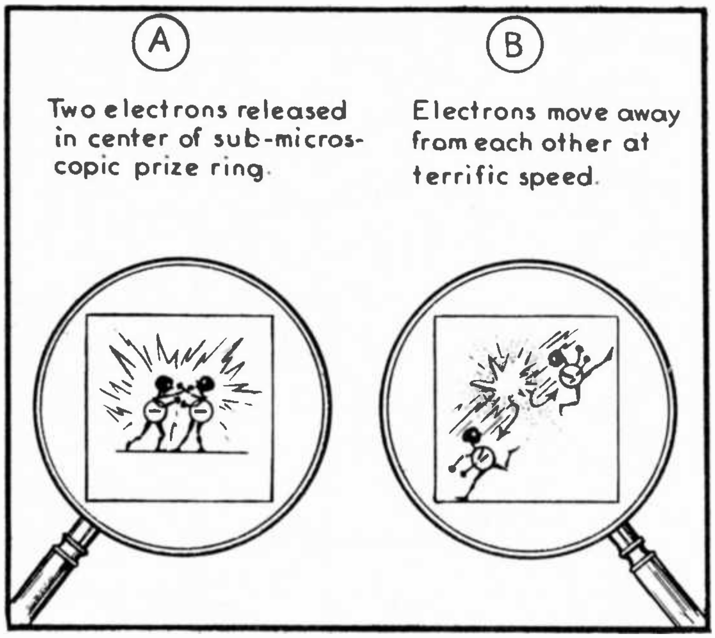


Fig. 17
How Electrons Repel Other Electrons

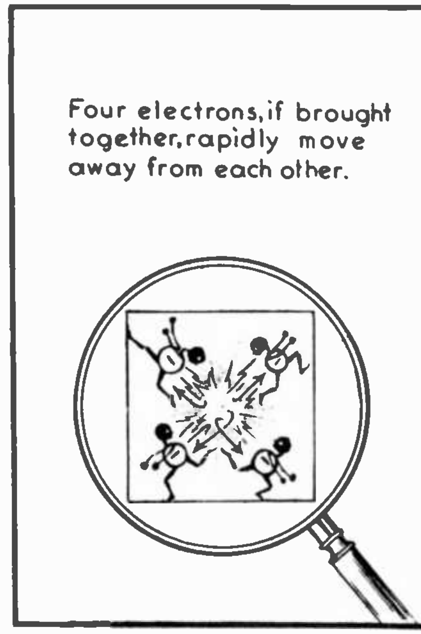


Fig. 18
Repulsion Between Electrons

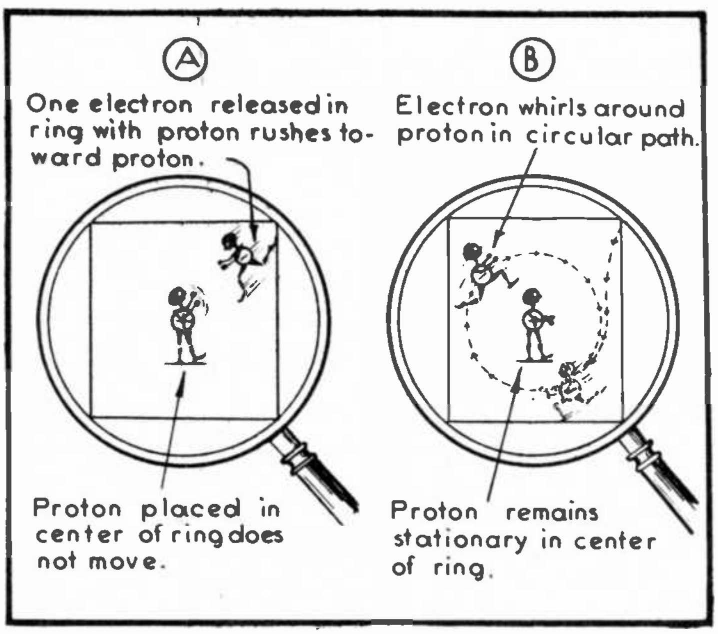


Fig. 19
How Protons Affect Electrons

is formed by the electron as it rotates around the nucleus is called the <u>orbit</u> of the electron.

In Fig. 20, you are shown what would happen if two electrons were in the ring with two protons. The two protons would cling together in the center of the ring, forming the nucleus around which the electrons would continually circle. If the two protons were to be removed from the ring, the electrons would immediately rush to opposite corners as they did in Fig. 17-B

Thus, you have seen that while one electron will be repelled by another electron, all electrons will be attracted by one or more protons. Simply, we can state that: ELECTRONS REPEL EACH OTHER; PROTONS ATTRACT ELECTRONS. You will note that it is the electron which does most of the moving about. The protons are bound within the nucleus, and capable of very little motion; but the orbital electrons are active, and capable of moving anywhere that forces of attraction or repulsion guide them.

In practical electrical work the above principles are simply stated:

LIKE CHARGES REPEL
UNLIKE CHARGES ATTRACT

A SIMPLE EXPERIMENT THAT YOU CAN PERFORM WITH ELECTRONS

By means of a few articles that are to be found in the home, it is possible for you to perform the following experiment that will demonstrate the force of attraction between electrons and protons.

Tear some dry paper into small bits. Then rub an ordinary, hard rubber or plastic comb vigorously with a piece of dry flannel or other wool cloth. Upon bringing the comb close to the bits of paper, you will find that the paper will cling to the comb.

It is interesting to note that this experiment is comparable to that made by Thales back in 600 B. C., your comb serving the same purpose as the amber used by him.

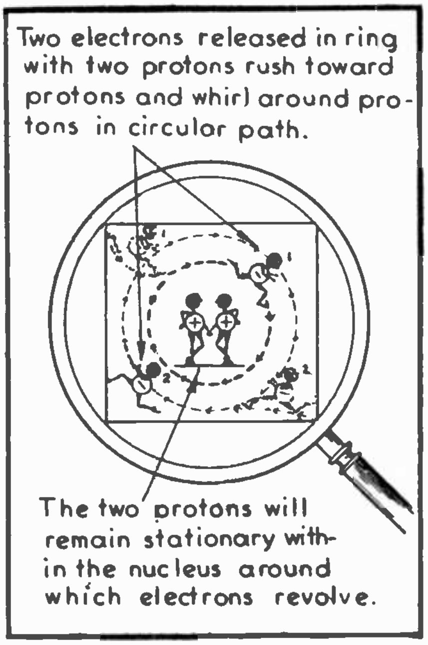


FIG. 20
HOW TWO ELECTRONS AND TWO PROTONS BEHAVE TOGETHER

WHY THE PAPER IS ATTRACTED TO THE COMB: When you rub the comb with the wool cloth, (Fig. 21-A), the friction dislodges some of the orbital electrons contained within the atoms on the surface of the cloth, and these electrons collect on the comb. This leaves the comb with an excess of electrons, or with more electrons than there are positive particles, (Fig. 21-B). We then say that the comb has a negative charge. Incidentally, when electrons were removed from the cloth, a surplus of protons remained and the cloth had therefore acquired a positive charge.

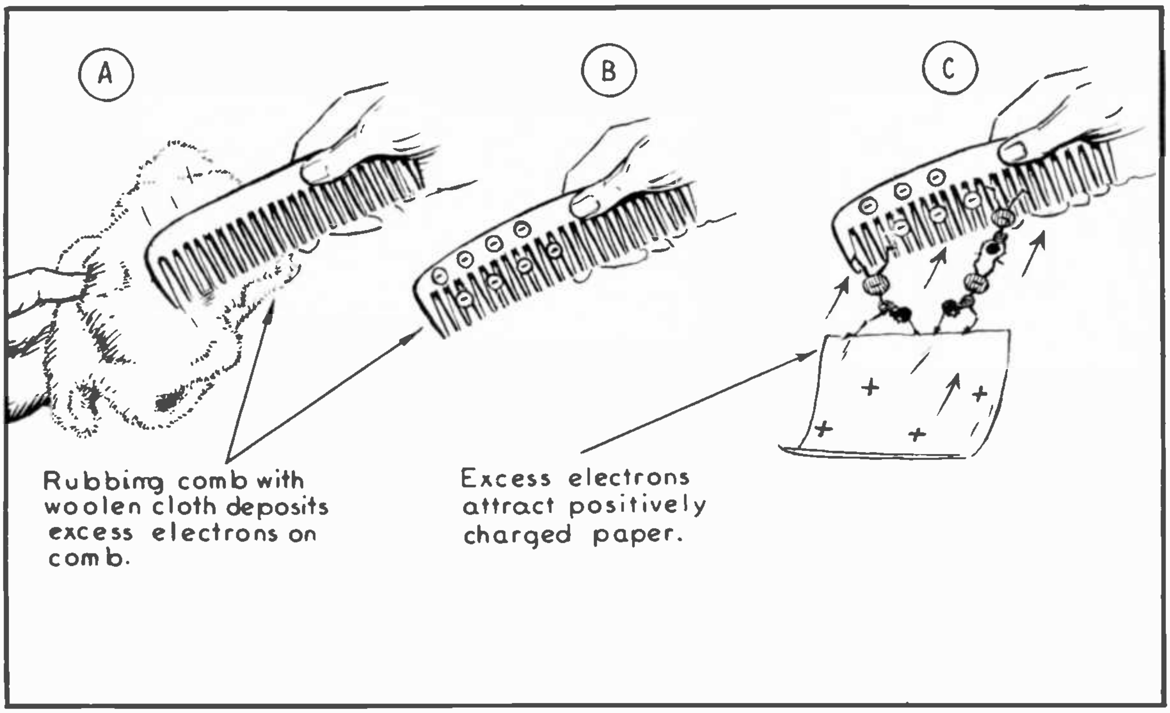


FIG. 21
GIVING THE COMB A NEGATIVE ELECTRICAL CHARGE

The bits of paper each contain their normal number of electrons and protons, but as the comb temporarily contains an excess of electrons, the comb is strongly negative, and the paper is positive with respect to the comb. Thus, the strong attraction between the positive particles of the paper and the excess electrons on the comb tends to draw the comb and the paper together, as illustrated in Fig. 21-C. As the paper is very light, the forces of attraction will be strong enough to make it cling to the comb.

STATIC ELECTRICITY

Remembering that electrons are actually particles of negative electricity, you can understand that when we have collected an excess of electrons on any substance --- such as the comb --- we have really deposited electricity on the comb, and the comb is said to be charged with electricity, or electrified. The charge of electrons on the electrified comb is usually called a "charge of static electricity" --- the word "static" meaning without motion. Thus, when anything is charged with electrical particles (free electrons), it is said to have a charge of static electricity.

AN EXPERIMENT WITH STATIC ELECTRICITY

Here is another experiment that you can perform, and which will teach you a great deal about the behavior of electrons and electric charges:

Suspend a piece of popcorn, or a kernel of one of the "shot-from-the-gun" breakfast foods, such as Puffed Wheat, by a dry thread. A simple way to do this is shown in Fig. 22, where the other end of the thread is fastened to a pencil which is supported by a few books.

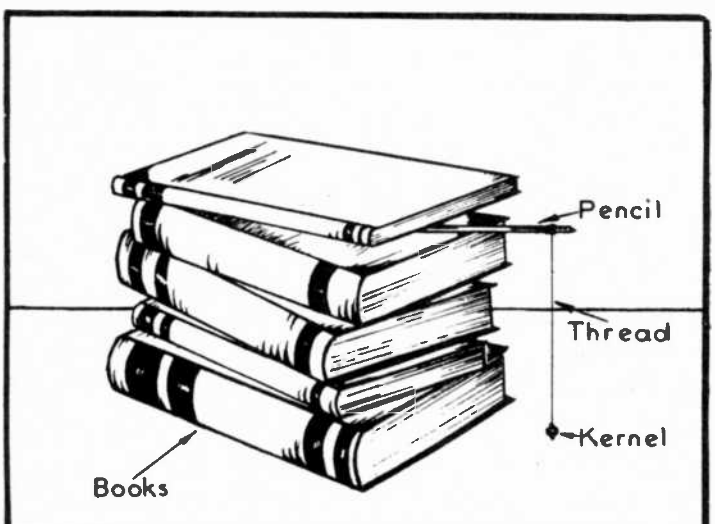


FIG. 22
SIMPLE WAY OF SUSPENDING KERNEL

GIVING THE KERNEL A NEGATIVE CHARGE: We will first give the kernel a negative charge. To do this, collect some free electrons on a comb by rubbing it with a wool cloth, such as was done in the experiment with the paper particles, and again demonstrated in Fig. 23-A. Now, let us bring the comb close to the kernel, as in Fig. 23-B, and we see the kernel swing toward the comb and cling to it for an instant. This is caused by the attraction of the excess electrons on the comb, upon the kernel which is positive with respect to the comb.

As the kernel clings to the comb, electrons will rush from the comb to the kernel, and the kernel will thus acquire a negative charge which is equal to that of the comb. As two like charges will always repel each other, the kernel will swing quickly away and it will be almost impossible to again touch it with the comb (Fig. 23-C).

GIVING THE KERNEL A POSITIVE CHARGE: Now, without touching the negatively-charged kernel, let us take a piece of glass, such as a glass towel rod, or even a drinking glass, and rub it vigorously with a piece of silk cloth, or an ordinary pocket handkerchief (Fig. 23-D). By rubbing the glass with the silk, we will remove some of the electrons from the glass; thus charging the glass positive.

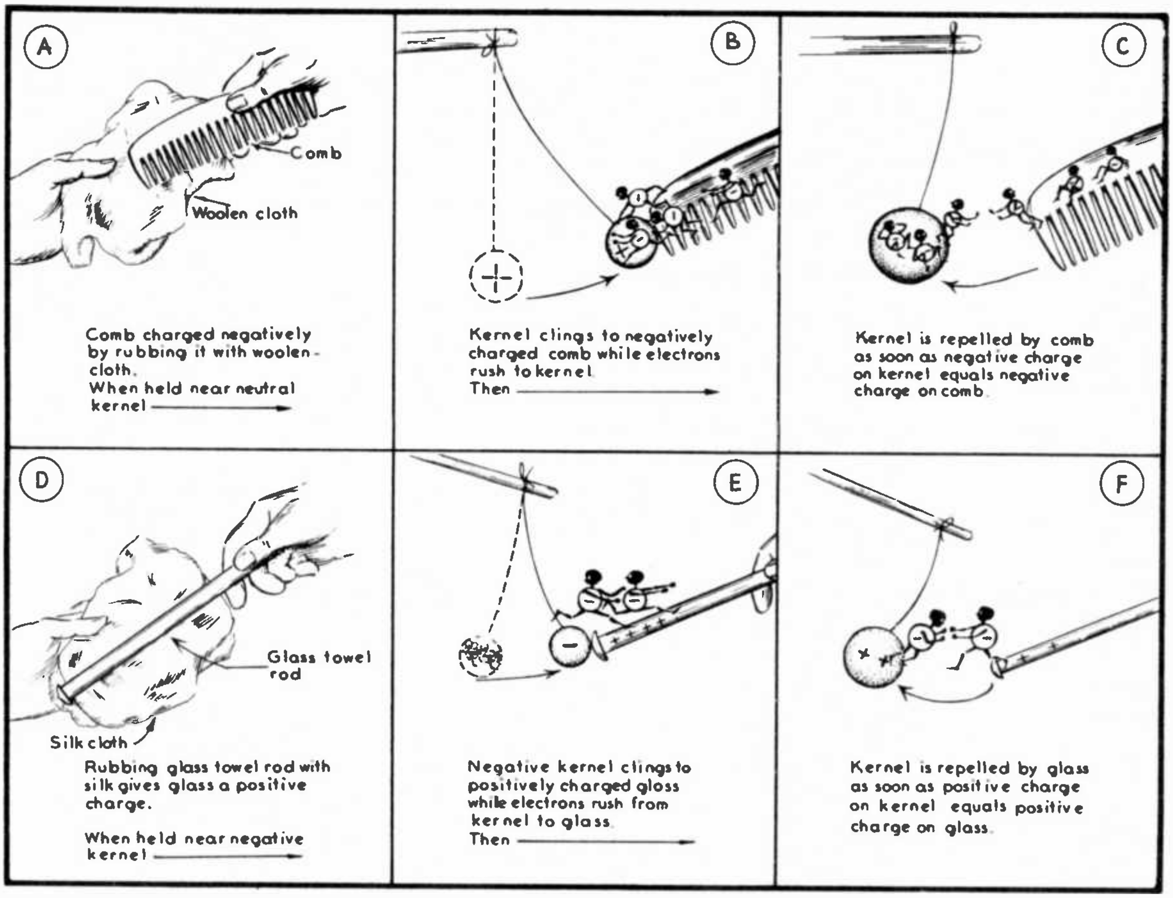


FIG. 23
SIMPLE HOME EXPERIMENT WITH ELECTRICAL CHARGES

With the kernel negative, and the glass rod positive, we now find that if we bring the rod close to the kernel, it will cling to the glass rod as in Fig. 23-E. While clinging to the positive glass rod for a brief instant, the free electrons on the kernel will move to the glass rod. This will leave both rod and kernel with like charges, so the electrons on the rod will repel the electrons on the kernel, (Fig. 23-F). This charging and discharging of the kernel may be repeated, although the comb will probably have to be recharged before it will again electrify the kernel.

OTHER MANIFESTATIONS OF STATIC ELECTRICITY

You have probably seen or heard of persons walking across a carpet on a cold winter day, and then having a small spark jump from their hand to a metallic object that they might touch. In this case, the friction of the shoes on the carpet has caused a quantity of free electrons to be scraped off and collected on that person's body. Then, when the metallic object is touched, this static charge of free electrons will rush from the body to the object in such a large quantity that they are visible as a spark. This happens only on a cold day, because it is necessary that the surrounding air be dry; otherwise, moisture in the air would carry off the charge as fast as it could accumulate.

LIGHTNING CAUSED BY STATIC ELECTRICITY: You are no doubt already somewhat familiar with Benjamin Franklin's experiment with lightning and his famous kite, in 1752. Franklin sent a kite up into a cloud during a thunder storm and fastened a door-key to the string. When he held a knuckle of his hand near the key, a spark was observed --- thus proving that lightning is an electrical phenomena. Let us now apply what you have learned about electrons and see why this is so.

When wind, or other air currents, pass close to, or through a cloud, they carry off a large number of the electrons which are normally in that cloud, (See Fig. 24-A). Then, when this cloud comes close to another cloud, or close to the earth, electrons jump to the

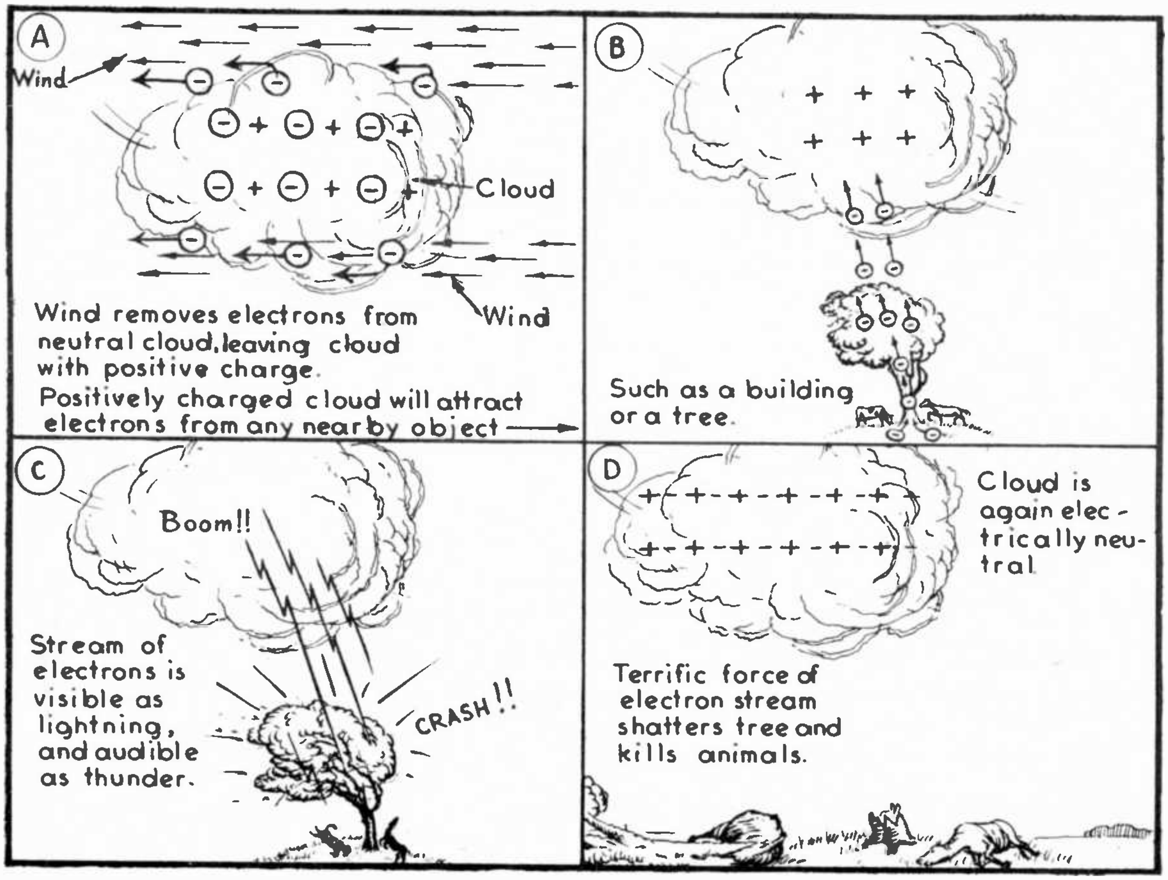


FIG. 24
ELECTRONS AND LIGHTNING

positively-charged cloud in great numbers, (Fig. 24-B). This passage is visible as a flash of lightning, and audible as thunder, (Fig. 24-C). Possible results of this mass movement of tiny electrons is illustrated in Fig. 24-D; and demonstrates what tremendous power can be developed by their united action.

CURRENT ELECTRICITY OR DYNAMIC ELECTRICITY

You have just learned of electricity in the form of static charges of electrons. Now, although electrostatic charges are used in heat treatment of plastics, in smoke precipitation, and in other ways, no one attempts to use these static charges to run electrical machinery, or to furnish light and heat for our homes. We use a current of electricity for that purpose. A current of electricity is a stream of moving electrons.

To fully explain the meaning of a current of electricity, let us go back to our experiment with the comb and the kernel of breakfast food, (Fig. 23). Here, the free electrons, which were placed on the comb by means of friction, formed a charge of static electricity. However, while the electrons on the comb were moving to the kernel, they were no longer static or motionless; rather, they were in motion. Whenever electrons thus move from one point to another, we have what is known as dynamic electricity, or what we more commonly call an electric current.

Lightning, for instance, while it is caused by the accumulation of a static charge in a cloud, becomes dynamic or current electricity during the time that the stream of electrons passes between the cloud and the ground.

Whenever electrons move, as just explained, they produce some reaction; this reaction may be noticeable in the form of heat, light, noise, chemical changes, or the production of a magnetic field.

HOW ELECTRONS ARE CAUSED TO MOVE

While a discharge of static electricity is one way of causing electrons to move, that method is seldom used outside of the laboratory. Today, we generally set electrons in motion by means of chemical action occurring in an electric battery; or by means of electromagnetic forces produced in an electric generator. Electrons may also be set in motion by means of heat, as is done in the case of the electronic tube.

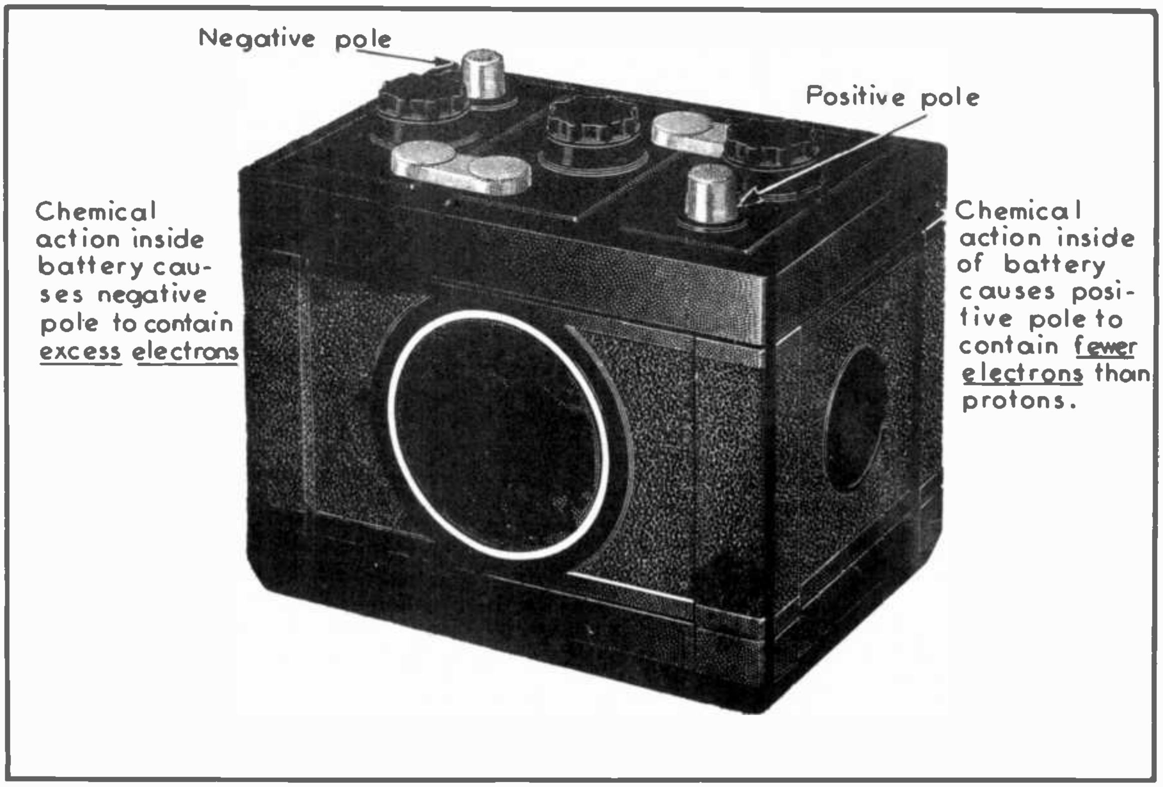


FIG. 25
STORAGE BATTERY

In Fig. 25, you are shown an electric battery. The chemical action inside this battery is such that one of the poles of the battery always contains an excess of free electrons; while the other pole (terminal) contains very few free electrons. Thus, one pole of the battery (called the negative pole) is always charged negative; and the other pole (called the positive pole) is always charged positive.

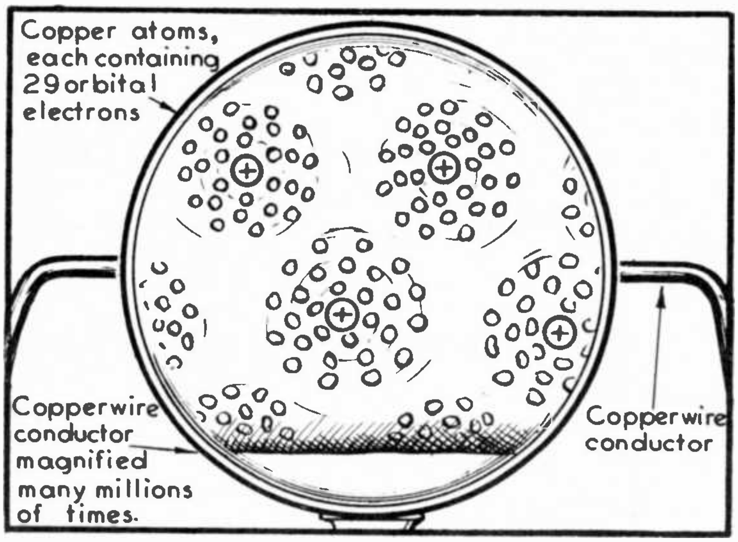


Fig. 26
Condition of Electrons in Conductor When NO Current Flows

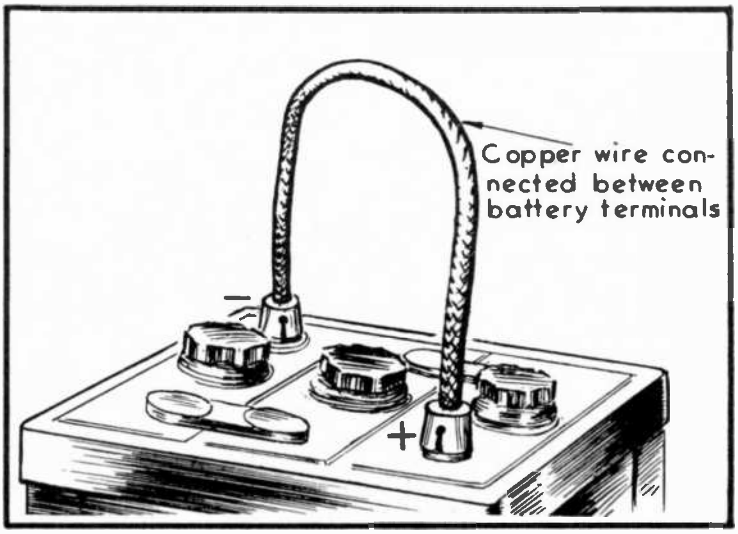


Fig. 27
Providing a Path for Current Flow

In Fig. 26, is shown a piece of copper wire as it might appear if viewed with the magic microscope used previously in this lesson. You will note that the copper wire is made up of millions of atoms, each of which contain a positive nucleus surrounded by electrons which are moving in their orbital paths around the nucleus. Therefore, we may say that the wire is "filled" with electrons.

In Fig. 27, the wire has been connected to the poles of the battery. Fig. 28, shows a greatly enlarged view of the action which takes place in the wire. Here, you will observe that at the instant the wire is connected to the poles of the battery, the positive pole attracts some of the electrons from the nearest copper atoms. At the same time, the free electrons on the negative pole attempt to crowd into the end of the wire which is connected to that pole, and join the electron groups in the atoms of the wire. The final and instantaneous result is shown in Fig. 28, where you see a steady stream of electrons drifting throughout the length of the copper wire. Thus, electrons are constantly entering the wire at the negative pole of the battery; flowing through the wire; and emerging from the end of the wire at the positive pole of the battery.

It is this movement of electrons which produces heat, light, and power. It is to be noted that the electrons themselves are not consumed, used up, nor changed in any way --- they only move.

DIRECTION OF CURRENT FLOW: Scientists are now in agreement that it is the negative particles of electricity (the electrons) which move when we have an electric current; and that these negative particles always leave the negative pole of a battery or generator and move toward the positive pole. However, this was not always realized, and so before adequate research in electronics had taken place, it was believed that an electric current flowed from the positive pole of a battery toward the negative pole. Workers in the fields of radionics and electronics base all of their circuit analyses on the modern theory of negative to positive movement, so don't permit yourself to become confused by the "positive to negative theory of current flow" which is still used by some old-timers in the field of industrial electricity.

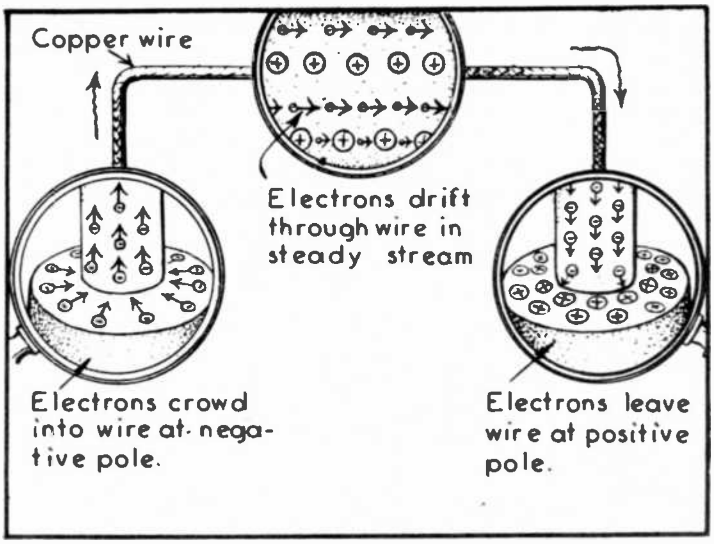


FIG. 28
ELECTRON DRIFT THROUGH CONDUCTOR

THE GENERATION OF ELECTRICITY

You often hear the expression, "to generate electricity," or "an electrical generator." Strictly speaking, it is incorrect to say that we can generate electricity. Electricity in the form of electrons and protons is found in all things that exist; therefore, it can not be generated or made. It can only be set in motion by a battery or a generator. Thus, you see that we do not actually generate electricity, nor does an electric generator manufacture electricity --- it merely causes a movement of electrons to take place.

CONDUCTORS AND INSULATORS: Materials which offer only slight opposition to the drift of electrons through their atomic structure are considered to be conductors of electricity. Materials which offer great opposition to the drift of electrons through their atomic structure are called non-conductors, or insulators. In general, metals are considered to be conductors; and non-metallic objects are considered to be poor conductors, or insulators.

FREE ELECTRONS IN SPACE

You have been taken on a trip through the once unknown world of the electron. You have seen how the electron behaves; and how the electron in its sub-microscopic world makes our own world a better place in which to live. So far, we have only considered the behavior of the electron in solids, liquids, or gases. Now, we come to the most valuable part of our study --- namely, that part which is generally considered to be ELECTRONICS, and which has to do with the action and behavior of electrons when they are removed from all matter, and are free in space. This happens in the electronic tube. This is electronics.

Have you ever watched the antics of some rare tropical fish in a glass bowl? The movements and gyrations of the little creatures provides an interesting show. An even more interesting spectacle would be available to us if we could see the millions and millions of electrons in one of these "electronic" fish bowls, the electronic tube.

With the aid of the mythical super-super-powered microscope that was spoken of earlier in this lesson, we can explain some of the things that scientists have found out about the free electron in space.

First let us focus our microscope on a piece of metal --- any hard metal will do. With several millions of magnifications, we would see the normal movement of electrons as they swing ceaslessly in their orbital path around their nuclei (Fig. 29-A).

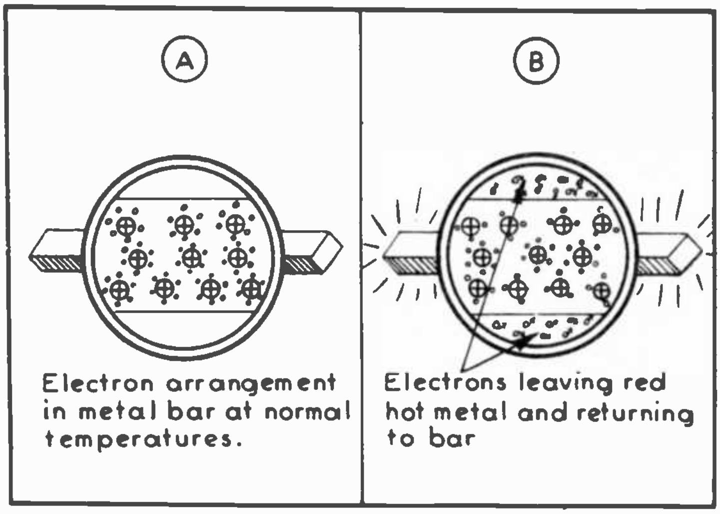


FIG. 29
THERMIONIC EMISSION FROM HEATED METAL

Now, let us apply heat to the piece of metal which we are studying. As the metal is heated, we see the movement of the electrons become ever more rapid and violent. In fact, this movement of the electrons in the heated metal becomes so violent that when a "red-hot" condition is reached, many of the electrons are set free and fly off the metal into the surrounding air as illustrated at (B) of Fig. 29. Since there is no place for the free electrons to go, they must of necessity return to the hot metal which they have just left. Thus, around any heated substance, there is a constant swarm of electrons; very much like a swarm of gnats. When electrons are thus leaving a heated substance, the substance is said to be emitting electrons, and the process of emitting electrons by the action of heat is known as thermionic emission.

THERMIONIC EMISSION IN A VACUUM

Let us now suppose that our piece of heated metal, which we are scrutinizing with our microscope of magical powers, has been placed within a glass enclosure from which all air has been removed. This is shown in Fig. 30.

We continue to heat the metal by means of a small electric heater which is placed directly under it; much as a skillet is heated on an electric stove. Looking at the metal, we see that many more electrons are now swirling about in the vacuum with which it is surrounded. As no air is present in the glass enclosure, very little opposition is being offered to the electrons emitted from the heated metal, and so they are found in all of the space adjacent to the cathode. We call this heated, electron-emitting metal the cathode.

Now, let us place a small metal plate in our electronic "fish bowl," a short distance from the cathode. By comparison with the cathode, this plate is cool. Our next step is to connect the positive terminal of a battery to the plate (which we now call the anode), and the negative terminal to the cathode --- as shown in Fig. 31. This connection of the battery will cause the plate to be charged positively and thereby exert a force of attraction upon the negative electrons that have been emitted by the cathode.

Studying the action of the electrons, we see that many of them which leave the hot cathode attempt to join the "electron family groups" of the atoms in the plate. In fact, so hard do they try to do this that they are constantly striking the plate with great force. This is also shown in Fig. 31.

Many of the emitted electrons join the atoms of the plate; other electrons leave the plate through the connecting wire, and flow through the battery, toward the cathode, where they are re-emitted. Thus, there is now a continuous drift of electrons through the conductor outside of the glass enclosure, as illustrated in Fig. 31, where you are shown an enlarged sectional view of the connecting wire.

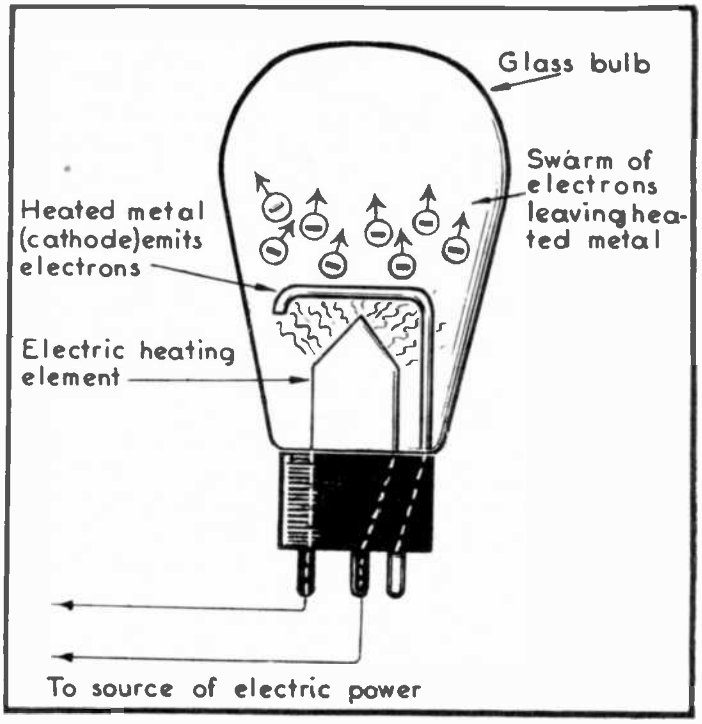


FIG. 30
CATHODE EMITTING ELECTRONS IN A VACUUM

THE ELECTRONIC TUBE

You have probably guessed by this time, that the evacuated glass enclosure, with its cathode and anode, is in reality a simple form of electronic vacuum tube --- and so it is. The vacuum tube is the very heart of the world of electronics. It is the place where the electron is set free in space, and travels through a vacuum between two electrodes (cathode and anode) instead of through some form of matter.

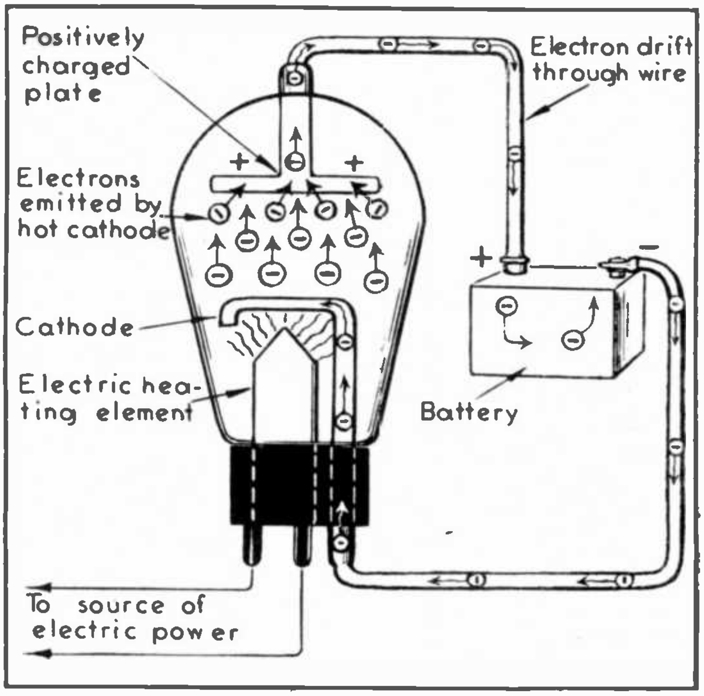


FIG. 31
POSITIVELY-CHARGED PLATE ATTRACTS ELECTRONS

By placing additional electrical equipment in the path of the electrons as they drift through the conductor outside of the tube, we may use this stream of electrons to operate amplifiers, television receivers, welding control devices, electric door openers, loudspeakers, electro-therapy apparatus, and hundreds of other types of electronic equipment.

By placing additional electrodes within the glass enclosure, we can achieve perfect control over the stream of electrons between the cathode and plate. Through the use of tubes in various sizes, as well as with varying combinations of electrodes, modern science has made electronics the miracle worker of our time. And, because of the action of the electron as it moves through space, as well as when it moves through matter employed in various parts of electrical or electronic equipment, electronics is now being applied to thousands of uses which make our world a better place in which to live.

——— ★ ———

From the study of this first lesson, you have in a few hours learned many things about the electron which it required early experimenters and scientists years to learn. Yet, in spite of the knowledge you acquired in such a short time, you have found the study of this lesson to be comparatively simple.

The lessons that follow are just as interesting and easy to understand as this one. This is made possible by the fact that all subjects are covered in the best learning order so that you progress systematically from lesson to lesson in simple, logical steps.

Now that you are familiar with the electron, itself, you are ready to learn how electrons are put to use in order to accomplish useful work. The next lesson will show you how this is done in basic electrical circuits.

Practical Technical Training In
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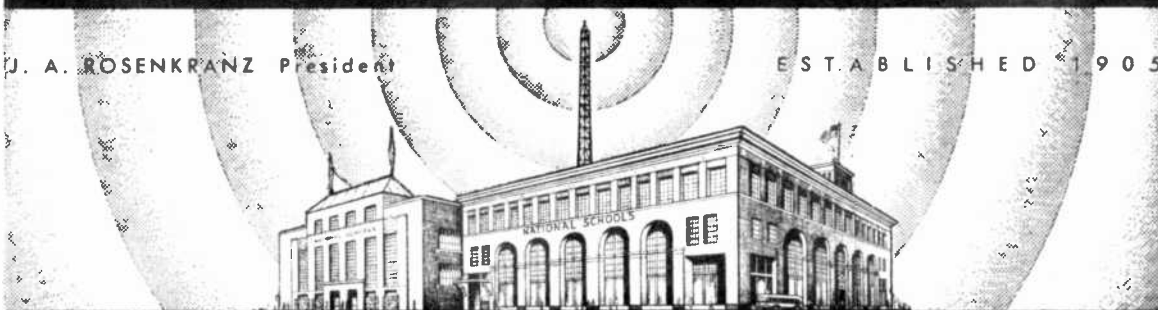

NATIONAL SCHOOLS ★ LOS ANGELES 37, CALIF.

LESSON NO. 2

DIRECT-CURRENT ELECTRICITY

Radio is a highly specialized field, based on the fundamental principles of electricity. Therefore, before we enter into a discussion of the construction and operation of radio equipment, it is of great importance that you first become familiar with the basic electrical terms and principles which it will be necessary for you to apply in your study of Radio, Television and Electronics.

We realize fully that you are very anxious to get right into the heart of your radio and electronic studies as soon as possible. With this thought in mind, we have prepared this preliminary instruction on basic electrical principles in such a manner that you can cover this work quickly; and yet, at the same time, be sure that you have acquired a sufficient knowledge of these important subjects so that you will be able to master with ease the many types of radio and electronic circuits that are explained in succeeding lessons.

DYNAMIC ELECTRICITY

In the first lesson of this course you learned of the discovery of electricity by the ancients; and how they experimented with it by rubbing amber with a woolen cloth. You also learned how Benjamin Franklin, much later, succeeded in extracting static electricity from lightning by means of a kite. And, you were shown how you, yourself, could perform simple experiments in order to become better acquainted with the methods for producing static electricity; and at the same time study its behavior under different conditions.

FIG. 1
DRY CELL

Now, the word "static" pertains to something that is at rest, or motionless. Therefore, when we speak of <u>static electricity</u> we mean electricity that is <u>not</u> in motion, or electricity at rest. Static electricity, as such, is of no use to us in the transmission of energy, but electricity in motion is useful.

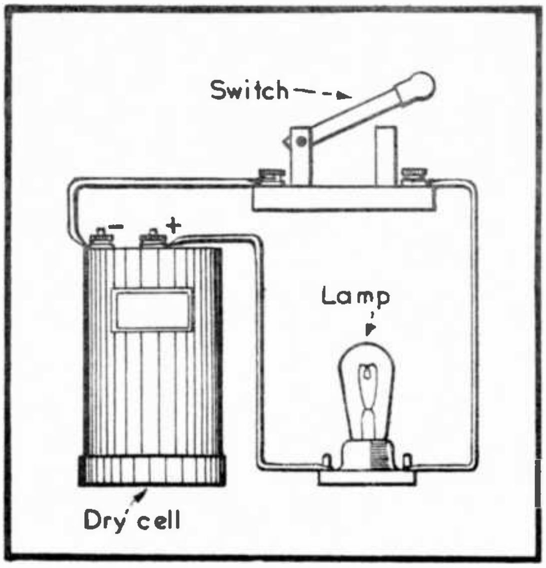

FIG. 2
SIMPLE ELECTRIC CIRCUIT

We sometimes call electricity that is moving dynamic electricity; but more often, current electricity. Dynamic, or current electricity, is the power or energy that we use for so many thousands of applications in everyday life; to run motors, light lamps, work our telephones, operate electronic and radionic devices, etc.

In this lesson, therefore, you are going to study current electricity, and circuits that enable us to put this form of energy to useful work.

HOW ELECTRICITY MAY BE SET IN MOTION

Electricity may be set in motion in any one of several different ways. For example, when a wire is moved across a magnetic field, or a magnetic field is swept across a wire or coil, electrical forces are set up which cause a current to flow. Generators, which operate on this principle, are used in power houses and on ships where rather large amounts of currents are desired.

Another method is through the use of a chemical reaction as occurs in the well-known dry cell and the storage battery. This is the simplest source of current electricity, and is widely used in applications where but a small amount of power is required. A dry cell is shown in Fig. 1.

THE ELECTRIC CURRENT

The dry cell in Fig. 1 produces by chemical means the "electro-motive force" or electrical pressure which sets electricity, or electrons, in motion. However, in order for this cell to set electricity in motion, we must first have a circuit through which current can flow. And, if we wish to have the electrical energy supplied by the cell do useful work, we must provide an appropriate electrical apparatus or "load" in the circuit; and so arrange the circuit that the current will flow through this apparatus.

In Fig. 2, we have such a circuit and load (a lamp in this case). Copper wire is used as the means of connection (path) between the dry cell and lamp, over which the current can travel. Copper wire is employed for this purpose because it conducts a flow of electric current readily.

Notice, also, that a switch is included in this circuit. When the switch is in the open position, as here shown, no current will flow through the circuit.

In Fig. 3, the switch has been closed. Therefore, the circuit is now complete and current will flow through it, with electrons traveling in the direction of the arrows, which you will observe to be from the negative (-) cell terminal toward the positive (+) cell terminal; and, since this current flows through the circuit continuously in one direction only, when the switch is closed, we logically call it a direct current.

HEATING EFFECT IN A CIRCUIT

When current flows through the filament of the lamp in Fig. 3, part of the electrical energy is converted (changed) into thermal energy, or heat. If sufficient current passes through the lamp filament, the latter will become so hot that it will appear red or white-hot to the eye. We then have light.

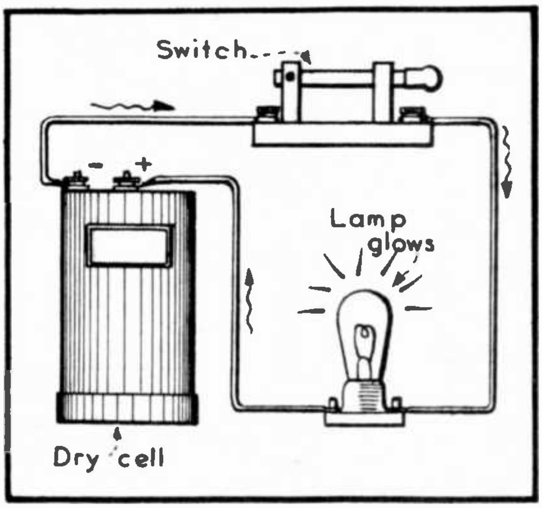

FIG. 3
CLOSING SWITCH COMPLETES CIRCUIT

In the case of the circuit just described, heating of the lamp filament is desirable, and necessary, in order to produce light. However, in many other types of circuits heat is not desirable, and special means must then be provided to prevent the wires and other parts of the circuit from becoming heated beyond a safe operating temperature. In our lamp circuit, the heating effect has been concentrated at the lamp filament to the extent that it has become visible to the eye. However, it is also true that the conductors used to connect the lamp to the dry cell will experience a slight increase in temperature due to the flow of electricity through them.

We repeat, electricity in motion always produces a certain amount of heat.

MAGNETIC EFFECT IN A CIRCUIT

In Fig. 4, is shown a pocket compass. We know that one end of the compass needle always attempts to point to the magnetic North pole of the earth because of the magnetic attraction exerted upon it. We also know that the compass needle will always line itself up in a North-and-South direction if it is free to turn on its bearing, and if there are no objects in the immediate vicinity of the compass which will provide greater attraction for the needle than will the earth's magnetic poles.

FIG. 4
POCKET COMPASS

A piece of iron or steel, or a small magnet, held close to the compass will attract the needle of the compass even more than will the earth's magnetic poles; and one end of the needle will then attempt to point to the piece of iron, or to the magnet, rather than to one of the earth's magnetic poles. It should be noted, however, that among the metals, only iron or steel will affect the compass needle in this way; so we can place the compass quite close to a copper wire conductor without causing the needle to be deflected from its normal North-and-South position.

Now, let us place the compass beneath one of the conductors of our simple electric circuit, as is being demonstrated in Fig. 5. Here, the switch is open, no current is flowing through the circuit, the lamp does not light, and the compass needle points in its normal North-and-South direction. In other words, the compass is not affected by the circuit when no current is flowing through it.

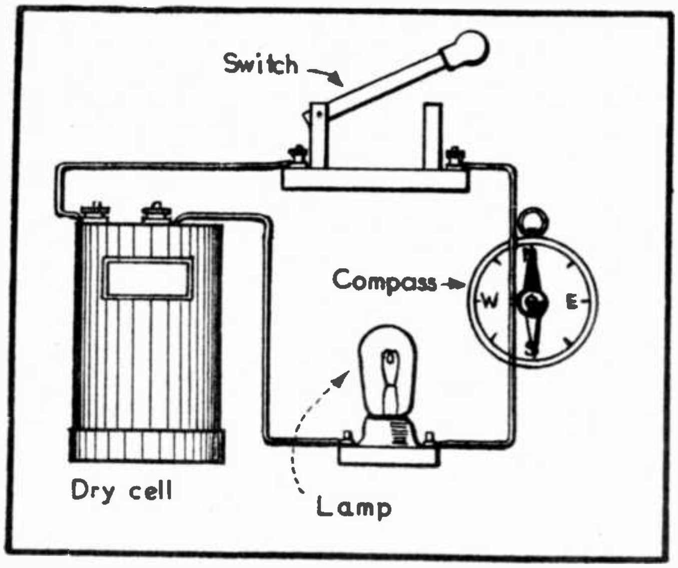

FIG. 5
NO MAGNETIC EFFECT WHEN CIRCUIT IS OPEN

If the switch is now closed, as in Fig. 6, the lamp will glow, indicating that electricity is flowing through the circuit. Furthermore, when current is flowing in the circuit, the compass needle will be deflected from its normal position and will now, instead of pointing parallel to the conductor as in Fig. 5, take a position at an angle to the conductor. Or, we could say that the compass needle now points "across" the conductor (see Fig. 6). If we open the switch, the needle of the compass will swing back to its original position, indicating North and South.

Therefore, if the compass needle is not affected by the copper wire itself, but only when electricity is flowing through it, isn't it logical to assume that the electricity in the wire produced the force which influenced the needle of the compass in this way? Such is exactly what happened.

Whenever electricity moves in a metallic circuit, part of the electrical energy is converted into magnetism, as demonstrated by the deflection of the compass needle.

REMEMBER THIS!

The important principles brought out in our discussion up to this point are:

1. When an electromotive force or an electrical pressure is applied to a complete circuit, a current of electricity will flow.

2. This flow of current tends to heat the circuit.

3. This flow of current tends to set up a magnetic field about the circuit which will deflect a compass needle.

Another way of stating this is to say:

1. You cannot have a current of electricity unless an electromotive force or pressure, such as is produced by a generator, battery or imilar device, is present to cause that flow.

2. You cannot have a flow of electricity without producing heat.

3. You cannot have a flow of electricity without producing magnetism.

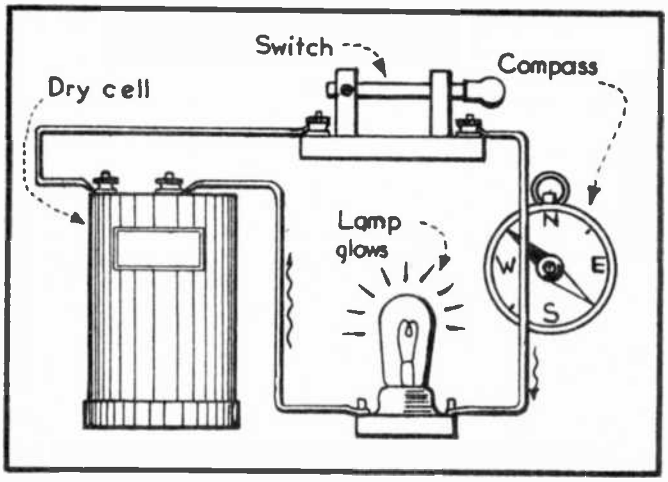

FIG. 6
MAGNETIC EFFECT WHEN CURRENT FLOWS

PRACTICAL APPLICATIONS OF THESE PRINCIPLES

It is true that we can often arrange our circuits so that one of these effects can be accentuated, or be made greater than the other; but we can never, even if we should desire to do so, absolutely prevent the production of magnetism or heat in an electrical circuit. For instance, in an electric toaster, our chief desire is that the electricity in the circuit be converted into heat because we have no use for the magnetism that is produced. Nevertheless, magnetism is present around the heating coils of the toaster as well as around the conducting wires leading to the toaster.

In a motor, we want the current that flows through the winding of the motor to produce as much magnetism as possible; heat being very undesirable. But even though motors are designed so that magnetism is present in greater quantities than is heat, we know that if we place our hand on a motor which has been in operation for several minutes it will be very warm to the touch. This shows that the motor is being heated by the electricity flowing through it.

In electronic devices we constantly utilize the magnetism and heat produced by the flow of electricity through such circuits. Therefore, it is essential that you become acquainted with these principles at the very beginning of this course.

INCREASING THE ELECTRICAL PRESSURE

Now let us revise our circuit so that it takes the form illustrated in Fig. 7. A glance at this drawing, and we readily see that fundamentally, the arrangement is the same as that of Fig. 6 -- with the exception that we now have two dry cells connected to our conducting wires. You should also note that the positive (+) terminal of one cell is connected to the negative (-) terminal of the second cell.

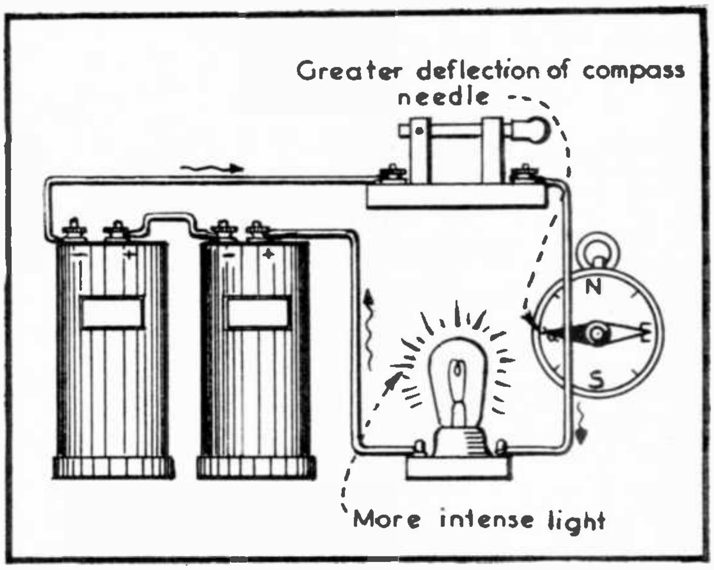

FIG. 7
EFFECT OF INCREASE IN ELECTROMOTIVE FORCE

When two or more cells are connected in this manner, they are said to be connected in series; and the combination of cells is called a battery of cells, or simple a "battery." (Note: it is never correct to call just one cell a "battery." A battery must always consist of two or more cells; otherwise, it is not a battery in the proper sense of the word.)

Let us see just what will happen in the circuit of Fig. 7, now that we have two cells connected in series. First, we have doubled the amount of electrical pressure applied to our circuit. This being true, and with no other changes having been made in our circuit, twice as much electric current will flow in the circuit as was the case when we used only one cell. Second, if twice as much current is now moving through our circuit, a greater amount of heat will be produced in the circuit. The latter will be readily apparent in a circuit containing a lamp, as the lamp will then glow with increased brilliancy.

Also -- and this is very important -- the needle of the compass will now move farther from its normal North-South position, and will be pointing more nearly in an East-West direction; or, the needle will take an approximate right-angle position with respect to the wire conductor,as shown in Fig. 7. Thus, we see that the magnetism produced by the current flow through the wire has also been increased by the addition of the second cell because of the greater current flow.

If we were to continue adding more series-connected cells to our battery, we would eventually increase the current to a value which would cause the filament of the lamp to become so hot that it would melt or "burn out" due to the high temperature at which it would then be operating. If this should happen, the circuit would be "open" and current could no longer flow. The compass needle would then return to its former North-South position, because magnetism would no longer be generated around the conductor.

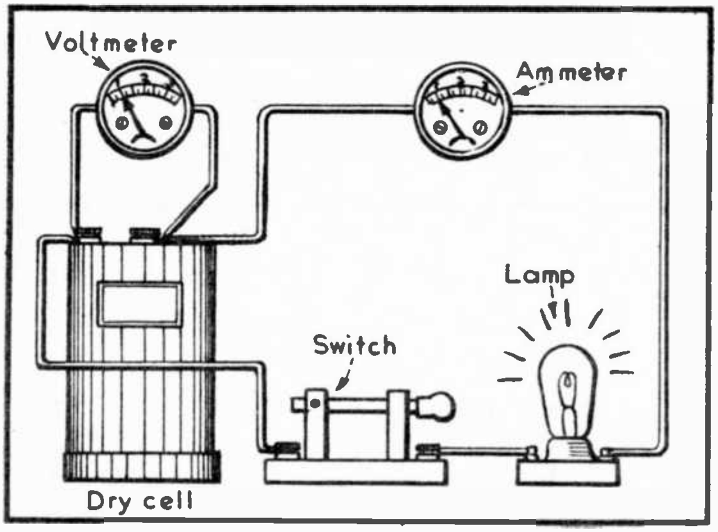

FIG. 8
VOLTMETER AND AMMETER CONNECTED IN CIRCUIT

For the present, we are mainly concerned with the fact that these things happen in a circuit through which a current is flowing. In later lessons,you will learn why they happen

THE AMPERE, UNIT OF ELECTRICAL CURRENT

Obviously, it would be of great value to have some word or term, by which we can indicate, or speak of the amount of current flowing in an electrical circuit. We have such a term. The unit of current is called the "ampere", named after Andre Marie Ampere, the experimenter who first made exact measurements of electric current. The word "ampere"is often abbreviated to "amp."

The ampere is an indication of the quantity of electricity moving in a conductor. It can be compared to gallons-per-second which is the unit by which we would measure the quantity of water moving in a river or a pipe. By inserting an instrument known as an ammeter into the circuit, as shown in Fig. 8, we can measure the number of amperes flowing in a circuit and thus get an indication of how much work may be done by it. (In passing, we might say that the needle of the ammeter is deflected by the magnetic effect of the current passing through the meter).

When the single dry cell was first connected to our circuit containing the lamp, it caused a certain number of amperes of current to flow. When we added the second cell to our circuit, we merely doubled the pressure applied to the circuit, thus causing twice the amount of current (amps) to flow.

It will also no doubt be of interest to you to know that there is a definite relation between the number of amperes flowing through a circuit and the number of electrons drifting through the circuit in a given length of time. This relation is that a current flow of one ampere represents one coulomb per second --- and a coulomb, in turn, represents a quantity of electricity that is equal to over six million, million, million electrons. Thus, when we say that the current flow through a certain circuit is one ampere, the electron drift through that same circuit will amount to somewhat over six million, million, million electrons per second. Because of the tremendous number of electrons involved, the ampere is obviously the more practical unit for expressing current flow.

THE VOLT, UNIT OF ELECTROMOTIVE FORCE

You have learned that we can measure the amount of electricity flowing in a circuit in terms of amperes. It is also important that we be able to indicate or measure the amount of electromotive force, or electrical pressure applied to a circuit. This is done by using a unit known as the "volt."

The volt (unit of electromotive force) is named after Volta, one of the early experimenters with batteries. The volt is just as much a unit of electrical pressure as the term "pounds per square inch" is a unit of steam pressure, or water pressure; or the amount of air pressure in an automobile tire. Just as steam, water or air pressure can be measured by means of a suitable pressure gauge, so also can electrical pressure be measured by means of a suitable instrument, known as voltmeter. By connecting a voltmeter across the source of electromotive force as shown in Fig. 8, we can measure the number of volts applied to a circuit.

At this time it is well to emphasize two points:

1. The ampere is the unit which expresses the rate of flow in an electric circuit.
2. The volt is the unit which expresses the electromotive force.

Remember that a volt never flowed through any circuit. It is the amperes which flow. The voltage is the electromotive or "electricity-moving" force which causes the current to flow.

RESISTANCE

A third property or characteristic,which is present in all things through which electricity flows,is the resistance or the opposition that they offer to the flow of electricity. This opposition is often undesirable, but is, nevertheless, always present.

On many occasions resistance, or opposition, is of value to us; and we then deliberately introduce additional resistance into the circuit in order to control the flow of electricity. In fact, it is the resistance offered to the flow of current by the lamp filament which causes the filament to heat to such a high temperature as to produce light. Here, then, is a good example of how electrical resistance is used to good advantage.

You understand how friction will oppose the movement of a sled you are dragging along the ground, or how the friction of a dry bearing will oppose the turning of a wagon wheel upon its axle. Now, just as overcoming mechanical friction will produce heat, so forcing a current of electricity through a circuit having resistance will produce heat. Indeed, we can think of resistance as being the internal friction encountered by the electric current as it flows through a conducting circuit. It can also be compared to the opposition offered by the rough walls of a water pipe to a flow of water through that pipe.

THE OHM, UNIT OF ELECTRICAL RESISTANCE

Resistance to the flow of electricity is measured in terms of a unit known as the "ohm." Thus, if we say that a circuit or some electrical apparatus has a certain number of ohms resistance, or that it offers resistance to the flow of current equal to a certain number of ohms, we are stating in definite terms the opposition to the flow of electric current offered by that circuit or apparatus.

To make very clear the meaning of resistance (ohms) -- and the relationship between volts, amperes, and ohms -- we can say in non-technical language that the volts are attempting to push the amperes through the circuit, and that this attempt to push the amperes through the circuit is opposed by the ohms of resistance present in the circuit. Two ohms of resistance in a circuit will offer twice the resistance to a flow of current as will one ohm, and one-half the resistance that four ohms would offer.

RELATIONSHIP BETWEEN VOLTS, AMPS, OHMS

We can see from this discussion, that the current in a circuit will have a value which depends not only upon the electromotive force applied to the circuit, but also upon the resistance residing in the circuit. In other words, an increase in volts will cause an increase in amperes; or, the higher the voltage, the greater the current. However, an increase in ohms will cause a decrease in current. This basic principle is called OHM'S LAW.

In setting up Ohm's Law, our three fundamental electrical units of measurement have been so chosen that if ONE VOLT OF ELECTROMOTIVE FORCE IS APPLIED TO A CIRCUIT HAVING ONE OHM OF RESISTANCE, THEN ONE AMPERE OF CURRENT WILL FLOW.

For instance, if our simple circuit of Fig. 8 had a resistance of one ohm, and the dry cell were applying one volt of electromotive force, then one ampere of current would flow through the circuit. Thus, we see that the voltmeter which is connected across the dry cell in Fig. 8 indicates that the cell is applying a pressure of one volt to the circuit. The pointer on the ammeter has moved across the scale to indicate that a current of one ampere is flowing through the circuit. (Note: A new dry cell generates an electromotive force of approximately 1 1/2 volts, but we are assuming an electromotive force of 1 volt in this particular discussion merely to simplify the mathematical values).

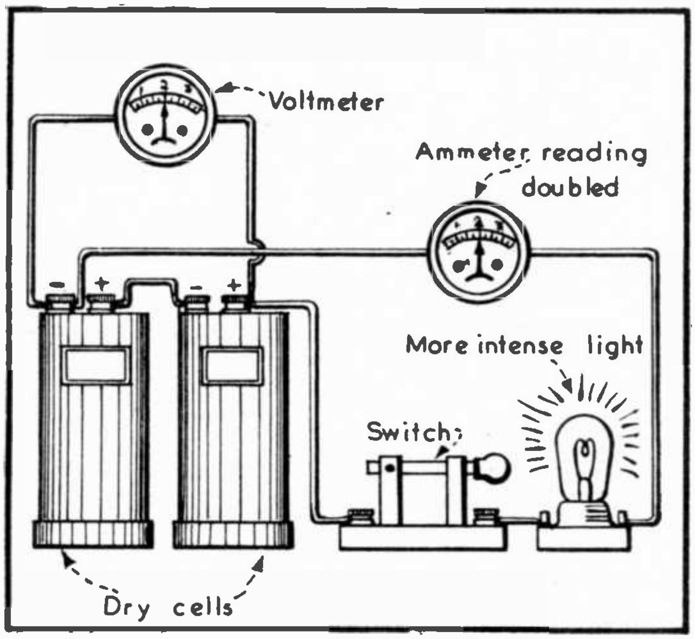

FIG. 9
DOUBLING THE VOLTAGE DOUBLES THE CURRENT

EFFECT OF INCREASED VOLTAGE:

Now, if we connect two dry cells in series to form a battery, as in Fig. 9, the addition of this second cell will double the voltage and thus cause the voltmeter to indicate that two volts of electrical pressure are being applied to the circuit. In accordance with Ohm's Law, the ammeter pointer will now indicate that two amperes of electric current are flowing through the conductors and the lamp. Thus, we can say: IF THE VOLTAGE APPLIED TO A CIRCUIT IS INCREASED, AND THE RESISTANCE OF THE CIRCUIT REMAINS UNCHANGED, THE CURRENT WILL INCREASE. THIS RELATIONSHIP IS ALWAYS TRUE.

EFFECT OF INCREASED RESISTANCE: Now, let us look at the circuit in Fig. 10. Here, we have added another lamp, which has increased the electrical resistance of the circuit. We see now that the voltmeter which is connected across the two-cell battery indicates that two volts of electrical pressure are still being applied to the circuit; but the ammeter shows that the current flowing through the circuit has decreased to one ampere.

This demonstrates that adding the second lamp has so increased the resistance of the circuit that two volts of electrical pressure can force only one ampere of current through it. This means that the number of ohms of resistance has now been exactly doubled. It also means that the second lamp offers the same resistance as does the first. And, now that they are connected so that current must flow through both lamps in succession, the current is opposed by the resistance presented by both of them. We can also say that if each lamp has a resistance of one ohm, we now have a total resistance of two ohms in this circuit.

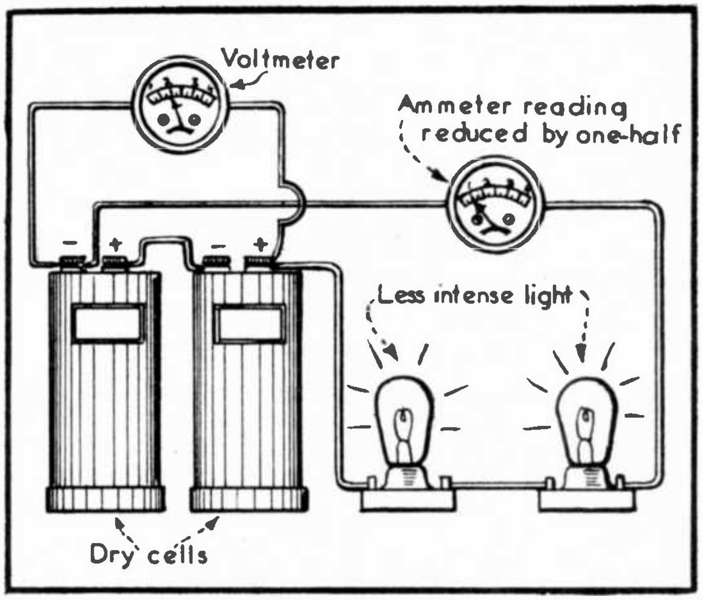

FIG. 10
DOUBLING THE RESISTANCE REDUCES THE CURRENT BY ONE-HALF

From this, we learn that: INCREASING THE RESISTANCE IN A CIRCUIT CAUSES A CORRESPONDING DECREASE IN THE AMOUNT OF CURRENT (AMPS) THAT WILL FLOW THROUGH THE CIRCUIT, WITH A GIVEN APPLIED VOLTAGE. THIS RELATIONSHIP IS ALWAYS TRUE.

We also observe that during the conditions illustrated in Fig. 10, each lamp will glow with only one-half the brilliance than was the case when only one lamp was connected in the circuit. This decrease in the brilliance of the lamps is due to the decrease in current flow through the circuit. We could, of course, connect additional cells in series with our battery and thereby increase the electromotive force to four volts so that a current of two amperes would again flow through the circuit, and thus permit both lamps to glow at the same brilliance as before.

OHM'S LAW EXPRESSED AS A FORMULA

Ohm's Law, expressed as a formula, is a most valuable tool to the radionic technician, as through its use he can conveniently and accurately calculate either volts, amperes or ohms, in relation to the other values. It is not at all hard to do this, and a proper understanding of it will greatly aid you in mastering the principles of electricity as applied to radionics. To put it briefly, and in non-technical language, Ohm's Law can be set-up in three basic forms, as shown on the following page:

1. To find the number of amperes, divide the number of volts by the number of ohms.

2. To find the number of volts, multiply the number of amperes by the number of ohms.

3. To find the number of ohms, divide the number of volts by the number of amperes.

APPLICATIONS OF OHM'S LAW

Let us now see how we would use Ohm's Law for computing the voltage, current or resistance in a simple circuit.

HOW TO CALCULATE CURRENT: In Fig. 11, we have a circuit for operating an ordinary door bell. As a source of electromotive force (abbreviated "emf"), we are using a storage battery. The push button (switch) is designed so that it will cause the circuit to be "open" except when it is depressed with the finger. Upon pressing the button, the circuit is closed; and current is then permitted to flow through the circuit, causing the bell to ring.

In this diagram the door bell has a total resistance of 2 ohms, and the storage battery is applying an electromotive force of 6 volts. The resistance of the copper wire (conductors) is so small as to be negligible in this particular problem.

In this example, then, we know the electromotive force or number of volts which is applied to the circuit, and the number of ohms of resistance present in the circuit. So, now let us determine, by means of Ohm's Law, how many amperes of current are flowing in the circuit. Referring to form #1 of Ohm's Law, as previously given, we note that:

"To find the number of amperes, divide the number of volts by the number of ohms."

Since the number of volts is 6, and the number of ohms is 2, we simply divide 6 by 2 and find that two will go into six exactly three times: $(6 \div 2 = 3)$. Therefore, there must be 3 amperes of current flowing through the circuit when the push-button (switch) in Fig. 11 is closed.

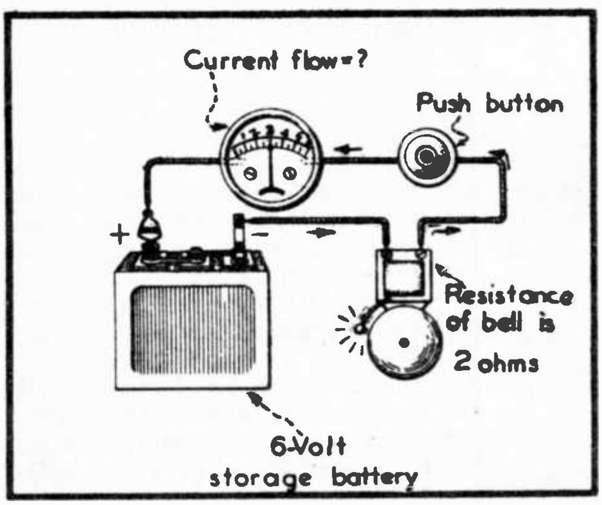

FIG. 11
PROBLEM: TO CALCULATE CURRENT

HOW TO CALCULATE VOLTAGE: In Fig. 12, we have another circuit. Here, the lamp bulb requires that two amperes of current flow through it in order to heat the filament to the proper temperature to produce the required light. The lamp has a resistance of 3 ohms. We wish to know how many volts will have to be applied to the circuit in order to force the required 2 amperes through it. Referring now to form #2 of Ohm's Law, we have that:

"To find the number of volts, multiply the number of amperes by the number of ohms."

Our diagram in Fig. 12 tells us that the number of amperes is 2, and that the number of ohms is 3. Therefore, we multiply 2 by 3 and obtain 6, (2 x 3 = 6), which is the number of volts required. Thus, we now know that if we connect a battery of six volts to our circuit, two amperes of current will flow through the lamp.

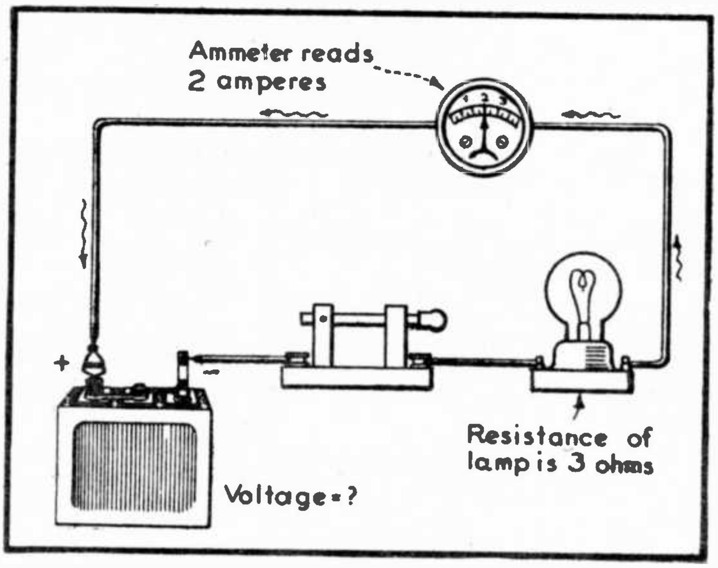

FIG. 12
PROBLEM: TO CALCULATE VOLTAGE

HOW TO CALCULATE RESISTANCE: In Fig. 13, is shown a circuit for operating a small motor. With the motor running, we measure the applied electromotive force and find it to be 12 volts. The ammeter informs us that 6 amperes are flowing in the circuit. We wish to know how many ohms of resistance the motor has Referring now to form #3 of Ohm's Law, we have that:

"To find the number of ohms, divide the number of volts by the number of amperes."

In this problem, the number of volts equals 12 and the number of amperes is 6. Therefore, we divide 12 by 6 which gives us 2 as the number of ohms resistance of the motor.

Ohm's Law will be covered at greater length in future lessons. However, it is very desirable that you acquire a basic understanding of its purpose and application at this time.

CIRCUIT COMPONENTS

CONDUCTORS: Certain metals as well as some other materials offer comparatively little resistance to a flow of current, or drift of electrons. A material of this type is called a conductor. For example: iron, silver, copper, carbon, and aluminum are conductors of electricity.

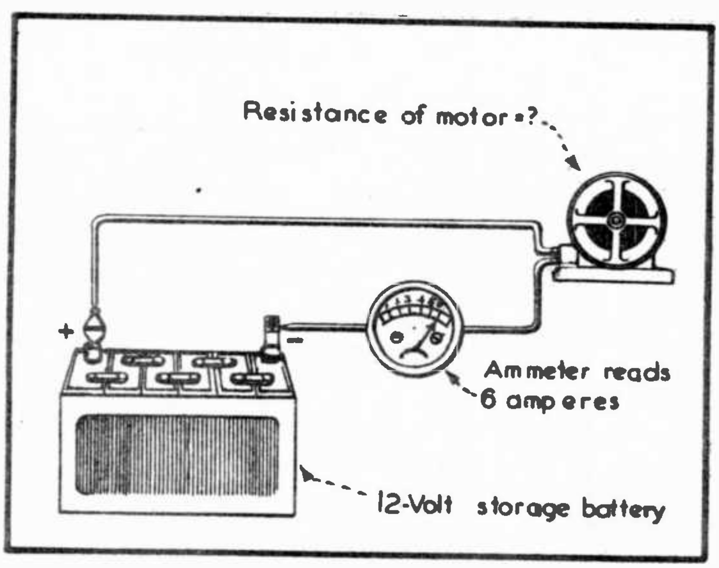

FIG. 13
PROBLEM: TO CALCULATE RESISTANCE

Not all of the metals just mentioned are good conductors. For instance, we say that iron is a conductor of electricity, but that copper is a better conductor. What we actually mean by this is that iron will offer more resistance to a current of electricity than will copper. Therefore, a copper wire of a certain diameter and length will offer less resistance to the flow of current than will an iron wire of like dimensions. A silver wire

TABLE I
ELECTRICAL CONDUCTORS (IN THE ORDER OF THEIR CONDUCTIVITY)
SILVER
PURE COPPER
GOLD
ALUMINUM
ZINC
BRASS
IRON
TIN
NICKEL
LEAD
HARD STEEL

TABLE II
INSULATING MATERIALS
DRY AIR
SHELLAC
PARAFFIN
PARAFFIN PAPER
RUBBER
BAKELITE
PORCELAIN
GLASS
MICA
SILK
VARNISH
DRY PAPER
CELLULOID
DRY WOOD
DISTILLED WATER

would have a slightly lower resistance than would the copper wire, and a much lower resistance than iron wire.

In Table I, you have a list of many commonly known materials which are considered to be conductors. They are listed in the order of their ability to carry an electric current. Notice that silver heads the list, with copper a close second.

INSULATORS: It is often desirable that electricity be prevented from flowing, or that some substance be inserted between two conductors to prevent current passing from one to the other. Materials that have this ability are called insulators. A typical example of an insulator is the rubber which is used as a covering for electric wires. Other examples of insulators in everyday use are the glass insulators on power line poles, the bakelite panels used in electronic equipment, and the porcelain knobs to support house wiring. The things we call "insulators" are really just very poor conductors of electricity, because they are made of materials which offer a very high resistance to current flow. Table II, lists a number of familiar substances which are used as insulators in electricity and radionics.

PERFECT INSULATORS AND PERFECT CONDUCTORS: It should be noted that there is no such thing as a perfect conductor nor a perfect insulator. All materials through which electricity moves offer some resistance to this movement. All materials will permit electricity to flow through them; but those which we call "insulators" permit so little current to pass through them, even though a

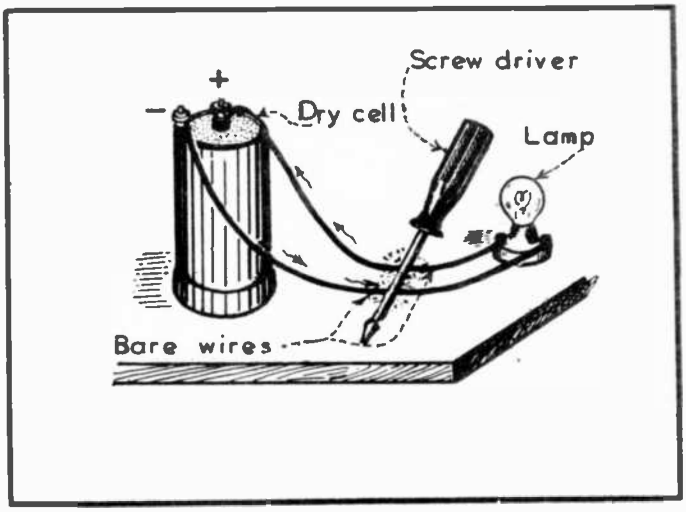

FIG. 14
SHORT CIRCUIT

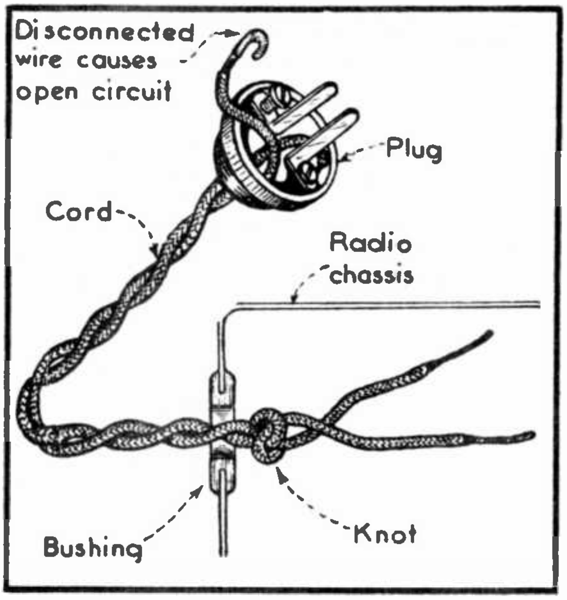

FIG. 15
OPEN CIRCUIT DUE TO DEFECT

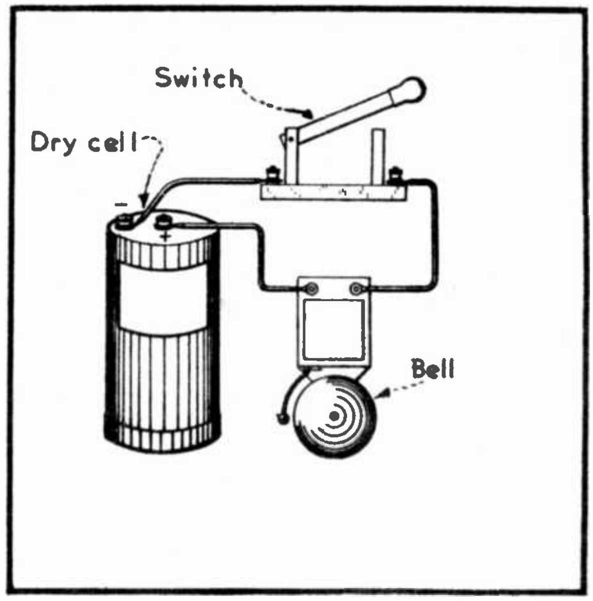

FIG. 16
INTENTIONAL OPEN CIRCUIT

high voltage be applied, that we consider them as insulators in practical applications.

USE OF INSULATORS AND CONDUCTORS IN ELECTRIC CIRCUITS:: An electric circuit consists of a conductor, or conductors, which are so connected to a source of electromotive force that current will move through it. Insulators are installed wherever it is necessary to prevent current leaving the desired path through the circuit and taking some other, and undesired, path.

TYPES OF CIRCUITS

SHORT CIRCUITS: In Fig. 14, we show a dry cell connected to a lamp by means of two copper wire conductors. These wires are bare or uninsulated. The metal blade of the screw driver which is laying on the bare wires has "shorted out" the circuit, and the current will, therefore, now follow the shorter and more direct low-resistance route which is through the screw driver, rather than passing through the lamp filament which is of higher resistance. This demonstrates, also, that current has a natural tendency to flow more easily through a circuit of lesser resistance than through one of greater resistance.

By using rubber-covered (insulated) wires for our conductors in Fig. 14, laying the blade of the screw driver across the conductors will not cause a short circuit; and our lamp will, therefore, light in a normal manner.

OPEN CIRCUITS: Now refer to Fig. 15. This shows a line cord for connecting a radio to the house lighting circuit. One of the wires of the cord has become disconnected at the plug. If the wire is disconnected at this point, or broken anywhere along its length, there is no longer a con-

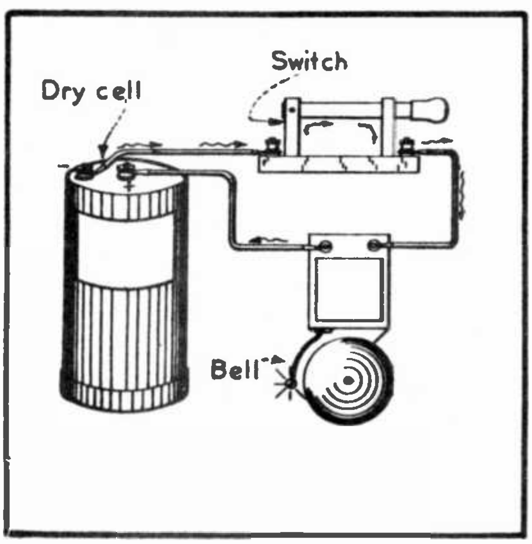

FIG. 17
CLOSED CIRCUIT

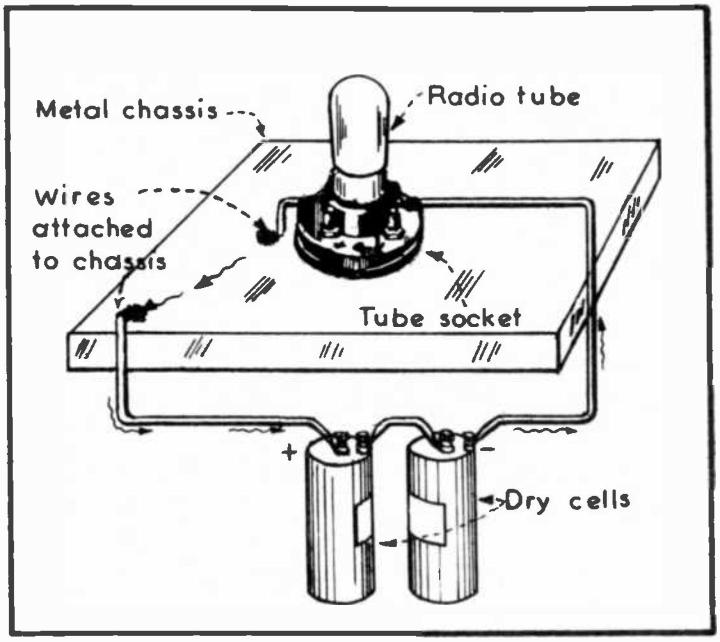

FIG. 18
GROUNDED CIRCUIT

tinuous circuit over which current may flow. Therefore, we say that the circuit is "open," or that we have an open circuit, which condition will prevent current from flowing. Open circuits are often caused by the breakage of a wire, or by a poorly soldered joint, and must be found and repaired before current will again flow.

In Fig. 16, we show a simple circuit in which a switch is incorporated. When the switch is pulled to the "off" position, we also have an open circuit. This, however, is an intentional open circuit -- meaning that we deliberately opened the circuit in order to stop the flow of current and prevent the bell from ringing.

CLOSED CIRCUITS: When a circuit is continuous throughout, and has no breaks or other interruptions of any kind in it, current will flow through it if an emf is applied. A circuit in this condition is said to be a closed circuit, (see Fig. 17). If we wish current to flow, we must always have a closed circuit; and if we wish to stop the flow of current, we must open the circuit.

Here is a good rule to remember about open and closed electric circuits: "If the current can't get back, it will not start".

GROUNDED CIRCUITS: In Fig. 18, we show a vacuum tube mounted on the metal chassis or base of a radio receiver or other electronic instrument. Current must flow through its filament in order for the tube to "light" and function. We could run two wires from our battery to the tube filament, but it is much simpler to run only a single wire from one terminal of the battery to one of the filament connections on the tube. The other battery terminal can then be connected directly to the metal chassis of the radio. And, if the other filament terminal of the vacuum tube is also connected directly to the chassis at a point close to the tube, we will have a closed circuit as far as the flow of battery current is concerned.

Current will now flow through the connecting wire between the battery and one side of the filament, through

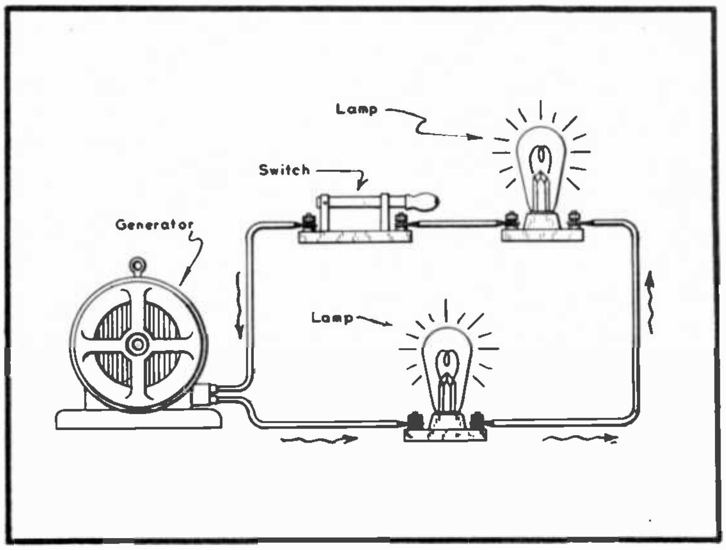

FIG. 19
SERIES ELECTRICAL CIRCUIT

the filament and into the chassis, and through the chassis to the other battery terminal. By connecting our circuit in this manner so as to utilize the metal chassis as a conductor, we economize on wire and simplify our design. Circuits of this type which use a metallic mass (other than a wire conductor) as one side of the circuit are known as grounded circuits.

The actual ground or earth can also be used to ground a circuit. This is done in many telegraph, telephone, fire alarm, police alarm and electronic burglar alarm systems; as well as in the well-known "electric fence" which prevents livestock from straying.

SERIES CIRCUITS: In Fig. 19, we have what is known as a series circuit. Here, a source of emf (generator), switch and two lamps are connected together in such a manner that current leaving the lower terminal of the generator must flow through every part of the circuit in succession before returning to the generator. The course over which current is moving is shown by the arrows.

Notice, particularly, that the same current flows through all parts of a series circuit. Therefore, if the filament of one lamp were to burn out, the circuit would thereby be opened, and no current would flow through any part of it. This would cause the other lamp to stop giving light.

Christmas tree lighting systems, where many bulbs are connected in series, are typical of series circuits as just described. If one bulb in such a system burns out, none of the others will light until the defective bulb is found and replaced with a good one.

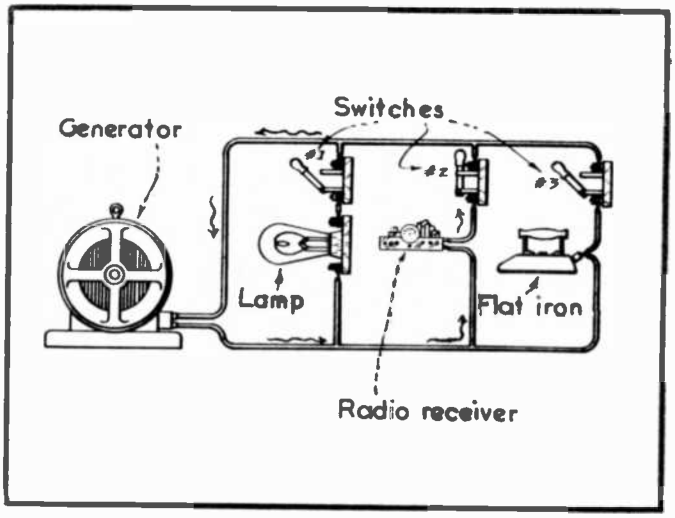

FIG. 20
PARALLEL ELECTRICAL CIRCUIT

PARALLEL CIRCUITS: A parallel electrical circuit appears in Fig. 20. In this case, a lamp, radio receiver, and a flat iron are all connected across the generator terminals. This arrangement of the circuit is such that switch #1 controls the lamp, switch #2 controls the radio, and switch #3 controls the flat iron. In the event that either the lamp, radio, or flat iron branch circuit should be interrupted, this will not prevent the correct operation of the remaining units or appliances. Thus, by comparing a series and a parallel circuit, we can state that in a series circuit all appliances in the circuit are dependent upon each other; whereas in the parallel circuit, the appliances are all independent of each other.

In Fig. 20, current flows through the radio circuit only, because switch #2 is the only one of the three switches which is closed at this time.

* * * * *

The fundamental principles of electricity that have been brought to your attention in this lesson are going to serve as the very foundation for all of your studies in radio and electronics that follow. You will also find it necessary to apply this knowledge to your practical work later on when you are active in the industry.

Difficulties are insurmountable mountains to those who fearfully run from them, but they will prove to be mere molehills if you courageously go after them.

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AND ALLIED ELECTRONICS
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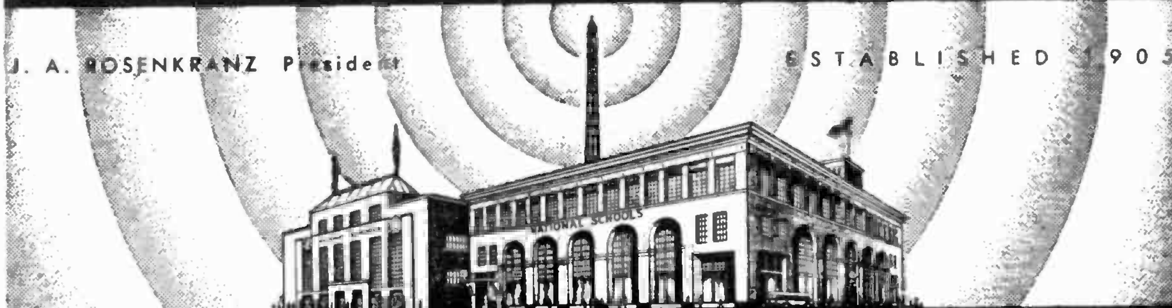

NATIONAL SCHOOLS ★ LOS ANGELES 37, CALIF.

LESSON NO. 3

MAGNETISM and ELECTROMAGNETISM

In this lesson, we are going to learn the basic principles of magnetism and electromagnetism, which we will apply in our radio studies time after time from now on.

Electrical meters, coils, transformers, loudspeakers, relays and many other devices used throughout the entire field of radio and electronics depend upon magnetic effects for their operation. This being true, you will realize that the study of this subject is a very important part of our training program.

NATURAL MAGNETS

As a child you were no doubt impressed with the manner in which a magnet attracted pieces of iron and steel, but at that time you probably gave little thought to the natural forces which made this possible.

This same observation

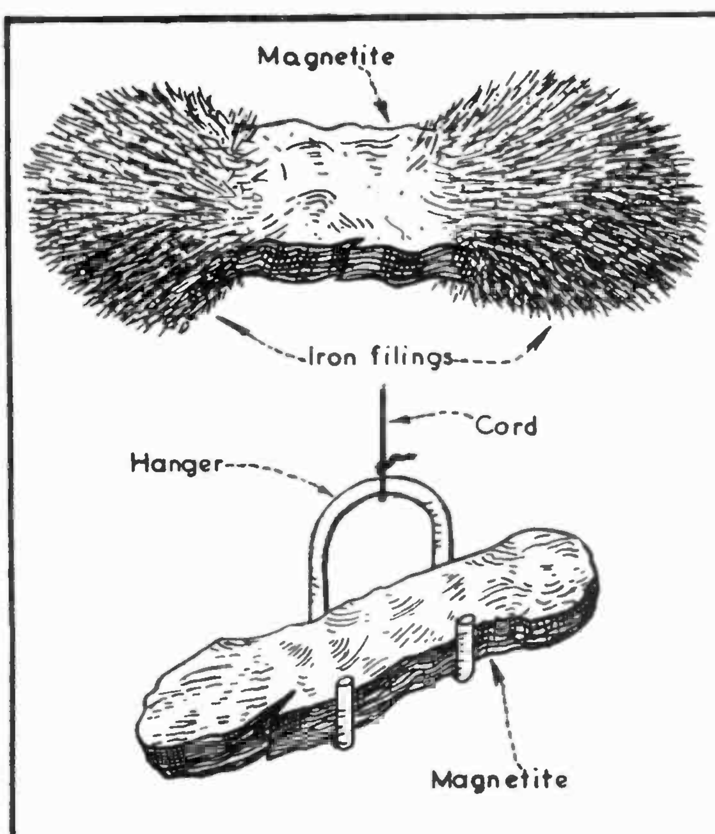

FIG. 1
A LODESTONE MAGNET AND COMPASS

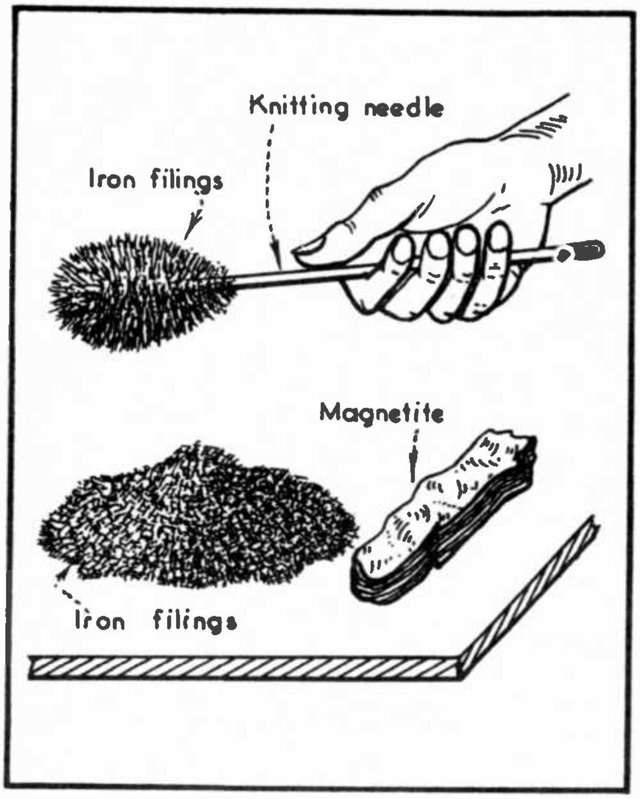

FIG. 2
MAKING AN ARTIFICIAL MAGNET

of magnetic attraction was made centuries ago by the inhabitants of the province of Magnesia in Asia Minor. These people discovered that an iron ore, today known as magnetite, possessed a power of attracting iron and steel. By inserting the ends of a piece of magnetite into a pile of iron filings, it will be found that the iron filings will be attracted and firmly held to the ends of the magnetite, as shown at the top of Fig. 1.

Another important discovery made by ancient mariners was that when a piece of magnetite was freely suspended as illustrated at the bottom of Fig. 1, the ore had a tendency always to seek a position so that one of its ends (and always the same end) pointed north, and the other end south. Because of this valuable property, these early mariners used a piece of magnetite for a compass; and since it thus served as a direction indicator, they called this ore loadstone, meaning "leading-stone".

The ore, magnetite, is also found in quantity in Sweden, Spain, and in the state of Arkansas here in the United States. There are also possibilities of its being found in other parts throughout the world.

Since magnetite possesses magnetic properties when in its natural state and does not depend upon any man-made processes to acquire this property, it is classified as a natural magnet.

ARTIFICIAL MAGNETS

"Artificial magnets" are those substances which have acquired their magnetic properties by means of some external assistance. For example, if a knitting needle or other piece of steel be stroked with a piece of magnetite, the steel will also acquire magnetic properties. This can be demonstrated by dipping the magnetized needle into some iron filings, at which time filings will cling to its extremities as shown in Fig. 2. The knitting needle in Fig. 2 would then be said to be an artificial magnet.

In the upper section of Fig. 3 is shown a bar magnet, while two popular types of horseshoe magnets are shown in the lower section of this same illustration.

Magnets that retain their magnetism for a long period of time are called per-

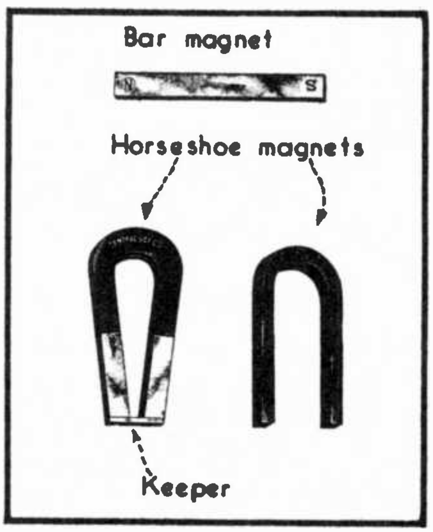

FIG. 3
COMMON ARTIFICIAL MAGNETS

manent magnets. Magnets of this type are generally made of hardened steel. The permanency of an artificial magnet is greatly increased by placing a piece of soft iron across the free ends, as is the case with the horseshoe magnet shown at the lower left of Fig. 3. When used for this purpose, such a small piece of iron is called a keeper or armature.

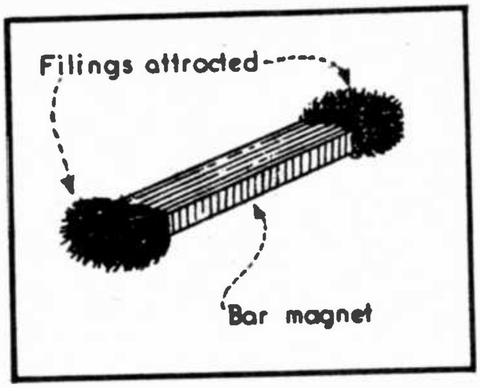

FIG. 4
THE MAGNETIC POLES

MAGNETIC AND NON-MAGNETIC SUBSTANCES

A magentic substance is one that is forcibly attracted by a magnet or else capable of being temporarily magnetized. Among the magnetic substances are iron, steel, nickel, cobalt, alloys of these metals, as well as salts of iron and the other metals mentioned. It is interesting to note that a very few substances are pronouncedly magnetic, and that most of these are not magnetizable.

A magnetizable substance, on the other hand, is one that will retain magnetism. Among these substances we find only a very few--namely, magnetite, steel, impure iron, and nickel.

Nearly all other metals are classified as being non-magnetic substances because they do not behave or act like iron when brought near a magnet. The most important of the non-magnetic metals are copper, aluminun and brass. Many other substances such as air, wood, paper and liquids are classified as non-magnetic substances because they are not acted upon or attracted by magnets.

Besides magnetic and non-magnetic substances, we also have what are known as diamagnetic substances. Such substances are actually repelled when placed under the influence of a magnet, rather than being attracted. The best known of these diamagnetic materials are bismuth and antimony, but the effect is very small. This property is not being put to any practical use because the substances in which it is found are scarce and expensive, and the effect is not strong enough to be of any practical value.

THE POLES OF A MAGNET

If a bar magnet of the type shown in Fig. 4 is suspended freely at its center by a cord, then one of its ends will always point towards the north and the other end towards the south magnetic pole of the earth. We call the north-seeking end of the magnet the north pole; and the other end, the south pole.

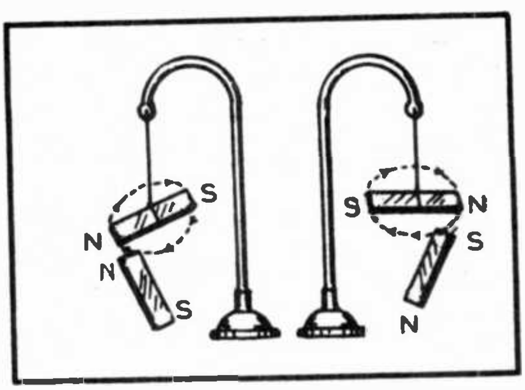

FIG. 5
LIKE POLES REPEL
UNLIKE POLES ATTRACT

The power of attraction of a magnet is always concentrated at certain points and not throughout its entire length. You can prove this for yourself by dipping a bar magnet in some iron filings. When you withdraw the magnet, you will find that the iron filings are all bunched at the two ends of the magnet as shown in Fig. 4. It is at these two ends that the magnetic

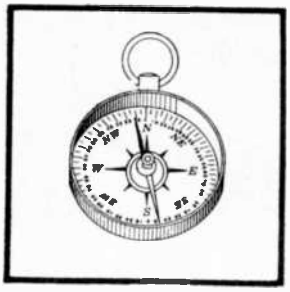

FIG. 6
POCKET COMPASS

strength is concentrated, and the poles of a magnet may therefore be defined as those regions where the magnetic attraction is greatest.

REACTION BETWEEN MAGNETIC POLES

Let us proceed and see how the poles of two separate magnets affect each other. An interesting experiment showing this action is illustrated in Fig. 5, where the north and south poles are respectively marked as "N" and "S".

Note that when two <u>like</u> poles are brought near each other as shown at the left of Fig. 5, the suspended magnet will be repelled. That is, it will swing away from the other magnet. However, if two <u>unlike</u> poles are brought together, as shown at the right of Fig. 5, you will find that the swinging magnet will be attracted towards the other magnet.

From these two simple experiments you can readily see that <u>like</u> magnetic poles <u>repel</u> each other, whereas <u>unlike</u> magnet poles <u>attract</u> each other. This is one of the most important basic laws of magnetism, and it is of great importance that you remember it.

The force of this attraction and repelling effect between magnet poles varies inversely as the square of the distance between the poles. That is, by separating the two poles to twice their original distance, the force acting between them will be reduced to one-fourth its original value. Similarly, by separating them to three times their original distance, the force between them will be reduced to one-ninth its original value, etc.

THE COMPASS

The compass, as used for navigation and other direction-determining purposes, is nothing more than an accurately balanced and pivoted magnet; housed in a glass-covered case so as to exclude drafts of air, afford protection for the movement, and so that a suitable scale can be provided. A typical pocket compass is illustrated in Fig. 6.

With the scale of this compass placed in such a position that a line drawn through the N and S markings of the scale lies in a direct path with the north and south magnetic poles of the earth, the compass needle will also point along this same line. In other words, one end of the compass needle always points towards the north magnetic pole of the earth, while the other end of the needle always points towards the south magnetic pole of the earth--provided, of course, that the compass is not being influenced by the magnetic effects of any nearby objects.

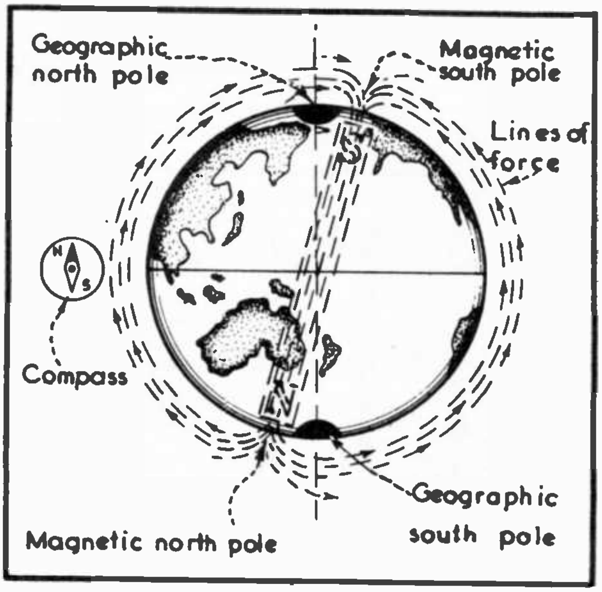

FIG. 7
THE EARTH ACTING AS A MAGNET

THE EARTH'S MAGNETISM

By considering the fact that

like magnetic poles repel while unlike magnetic poles attract, and that a compass needle always points in a given direction as just explained, it is perfectly logical to believe that the earth itself is a great magnet. Such is actually the case--the earth having a south magnetic pole near the geographical north pole and a north magnetic pole near the geographical south pole.

FIG. 8
THE MAGNETIC FIELD

A point which sometimes causes confusion in the mind of a student is the relation between the compass needle and the earth's magnetic poles. That is to say, does the north end of the compass needle point towards the north or south magnetic pole of the earth? This question can be answered in the following manner: The north pole of the compass needle points to the south magnetic pole of the earth (unlike poles attract) which is now located on Boothia Peninsula in the Arctic region north of Canada, a few hundred miles from the north geographic pole. Thus the "north seeking pole" of a compass is a north magnetic pole, but the north geographic pole of the earth is really near the earth's south magnetic pole. This, then, is in keeping with the laws governing polar attraction and repulsion between magnets. (Refer to Fig. 7).

It is to be noted that the needle of a compass does not point exactly north. The reason for this is that the magnetic poles of the earth do not coincide exactly with the geographic poles of the earth, and which fact is illustrated in Fig. 7.

THE MAGNETIC FIELD OF FORCE

From what has so far been explained to you regarding magnets, it is obvious that some definite force exists around a magnet which makes the various magnetic phenomenae possible. The simplest method of illustrating the nature of this force is to place a sheet of paper over an ordinary horseshoe magnet, sprinkle some finely divided particles of iron on the paper and then gently tap the edge of the paper. Upon doing so, you will find the particles of iron to arrange themselves into a definite pattern similar to that shown you in Fig. 8. This simple experiment serves to show that the magnet must possess a force of some kind that affects the particles of iron in this way.

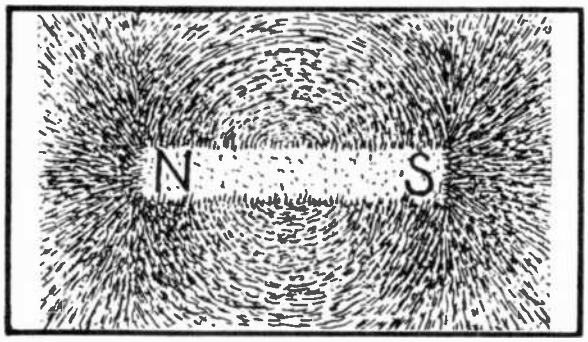

FIG. 9
MAGNETIC FIELD OF A BAR MAGNET
(SIDE VIEW)

If the same experiment should be repeated, the pattern formed by the iron particles would be a duplicate of that obtained with the previous experiment, thereby proving that the magnetic force surrounding a certain magnet always exerts itself along definite lines, and we call these lines of force. The entire space in which these lines of force exist around a magnet is called the magnetic field of force, or simply the magnetic field. The expression "magnetic spectrum" is also frequently associated with this pattern formed by the lines of force.

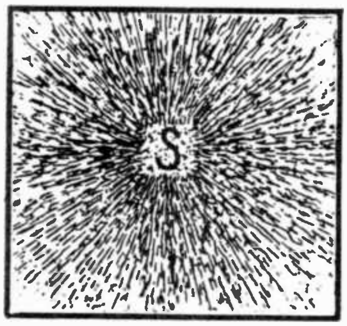

FIG. 10
MAGNETIC FIELD OF A
BAR MAGNET (END VIEW)

Fig. 9 illustrates how lines of force arrange themselves around a bar magnet. Here, the bar magnet is shown in a horizontal position, with the observer looking down upon it from above. In Fig. 10 is shown the field pattern as it appears at one end of the bar magnet.

CHARACTERISTICS OF THE LINES OF FORCE

Another interesting and important feature is that the lines of force are unbroken lines, leaving the magnet by way of the north pole, passing through the space surrounding the magnet and returning to the magnet through the south pole.

To determine the direction of the lines of force around a magnet, you can place a small magnetic compass in the magnetic field. The north end of the compass needle will then point in the direction of the magnetic lines of force. This is illustrated in Fig. 11.

No matter whether the magnet is of the horseshoe or the bar type, the lines of force will always pass out of the magnet at the north pole and return to the magnet through the south pole. Thousands of lines of force make up the magnetic field. Sometimes this field is called the magnetic flux.

Also notice in Fig. 11 that the south end of the compass needle points towards the north pole of the magnet, while the north end of the compass needle points towards the south pole of the magnet. In this way, the poles of a magnet can be identified quickly.

The lines of force map out the lines of magnetic strain. Each of these lines of force completes an unbroken, continuous path or circuit; and the complete course or loop taken by the lines of force comprises the magnetic circuit.

It is a natural characteristic of the lines of force to assume a definite path as shown. Each line exerts a sidewise push in all directions, tending to crowd adjacent lines away from it. If for any reason, these lines are distorted from their normal path, they tend to recover from the distortion or to react against it.

FIELD PATTERN SURROUNDING ATTRACTING POLES

Now that you are familiar with the magnetic field and the lines of force or flux, let us continue and see how two such magnetic fields react when brought near each other. In Fig. 12 you will notice that two bar magnets are laid near each other in such a way that unlike poles are opposite.

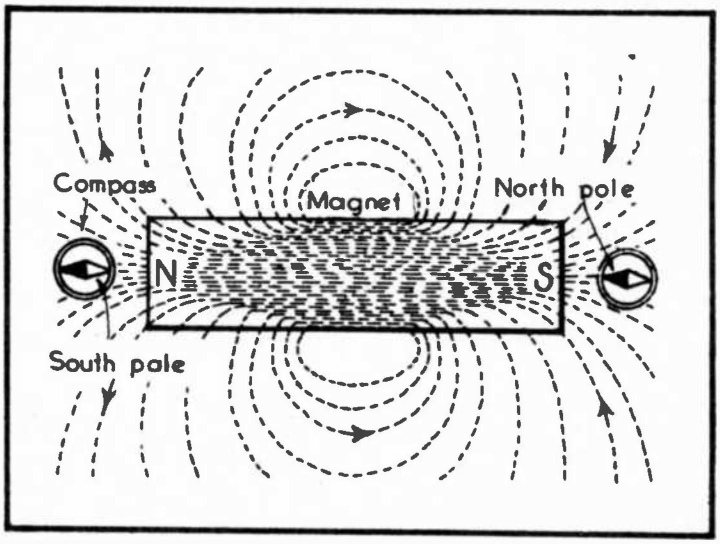

FIG. 11
DETERMINING POLARITY OF A MAGNET
WITH A COMPASS

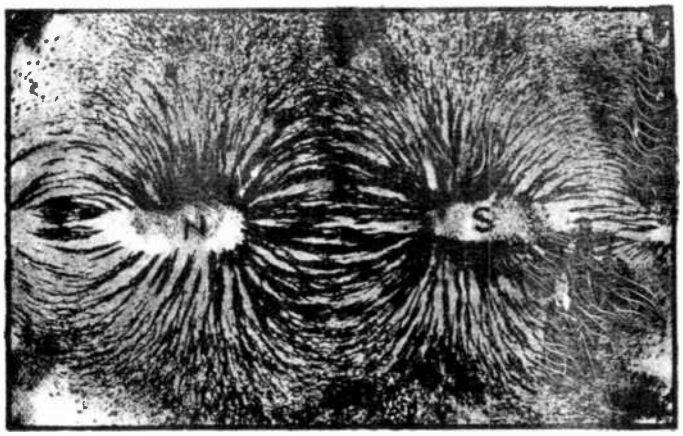

FIG. 12
FIELD PATTERN OF ATTRACTING POLES

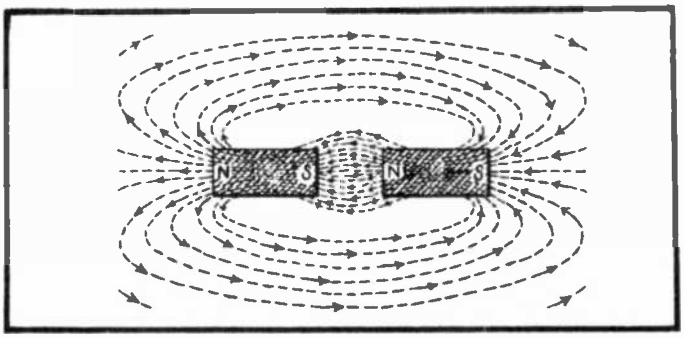

FIG. 13
DIAGRAM OF FIELD PATTERN OF ATTRACTING POLES

If you should place a piece of stiff paper over the top of these two magnets and then sprinkle some iron filings on the paper, you would find that when the paper is tapped lightly, the filings will arrange themselves in a pattern as shown in Fig. 12. Notice that at this time the lines of force are harmonized, and they pass freely from the north pole of one to the south pole of the other. In Fig. 13 you are shown diagrammatically the condition which exists at this time between the two magnets.

Under these conditions, a band-like tension exists along the lines of force; and since the lines produced by both magnets are now acting together, or are harmonized, the tension in the lines creates a strain across the air gap tending to pull the two magnets together.

FIELD PATTERN SURROUNDING REPELLING POLES

Since you have now seen how the field arranges itself between unlike poles, let us next turn over one of the magnets so that like poles of the two magnets will be opposite. With the paper covered with iron filings, again tap the paper lightly and you will see that the field will arrange itself in a different pattern, as shown in Fig. 14.

When these like poles are placed opposite each other, the lines of force no longer pass freely from one magnet to the other. Instead, the two fields oppose each other. In other words, the lines from one magnet repel those from the other and the sidewise pushing tendency, which is a property of the lines of force, creates a tendency for the magnets to push away from each other.

This field reaction between opposing poles is illustrated diagrammatically in Fig. 15.

SALIENT AND CONSEQUENT POLES

If a piece of steel is irregularly magnetized by touching it with a strong magnet at several points along its length, we have what is known as an anomalous magnet. A magnet of this type, together with its field pattern, is illustrated in Fig. 16.

Here you will observe that such a magnet has the customary poles located at its ends, but in addition has several more poles along its length. This piece of steel thus amounts to nothing more than several smaller magnets all placed end to end; but in a reversed order, with like poles adjacent to each other.

The poles at the ends of such an anomalous magnet are called the salient poles, while the intermediate poles of the same piece of steel are called the consequent poles.

NEUTRALIZING EFFECT OF UNLIKE POLES

An interesting experiment is illustrated in Fig. 17. At the left of this illustration you are shown two bar magnets placed side by side in such a manner that the two north poles are together, and the two south poles together.

Upon dipping either end of this combined magnet into a pile of iron filings, the filings will be attracted by the magnet with considerable force. In fact, if both these magnets are of the same strength, the two together will have practically twice the attracting power of either one alone.

By reversing the position of one of the magnets so that two unlike poles coincide, as illustrated at the right of Fig. 17, and again dipping one end of the combined magnet into the iron filings, practically no iron filings at all will be attracted. What really happens in this latter case is that if the two magnets each have the same strength, and are placed together in the manner illustrated, then the unlike poles will neutralize one another and the combination will have practically no external magnetic flux or field. As a result, the magnetic strength of the combination is reduced practically to zero.

RING MAGNETS

At the left of Fig. 18 two horseshoe magnets have been placed end-to-end in such a manner that the north and south poles of the pair coincide. Under these conditions, the magnetic circuit is confined to the metal structure, and it is not necessary for the lines of force to pass through an air-space at any point to complete this circuit. Although the two magnets may be strongly magnetized, yet under these circumstances no appreciable external magnetic field exists.

A similar condition appears at the center of Fig. 18, where we are illustrating a steel ring which has been magnetized. In spite of the fact that this ring is strongly magnetized it has no poles, because its lines of force nowhere leave the metal of which its magnetic circuit is composed. Magnetic circuits of this type are used extensively in transformers and will be explained more fully in later lessons.

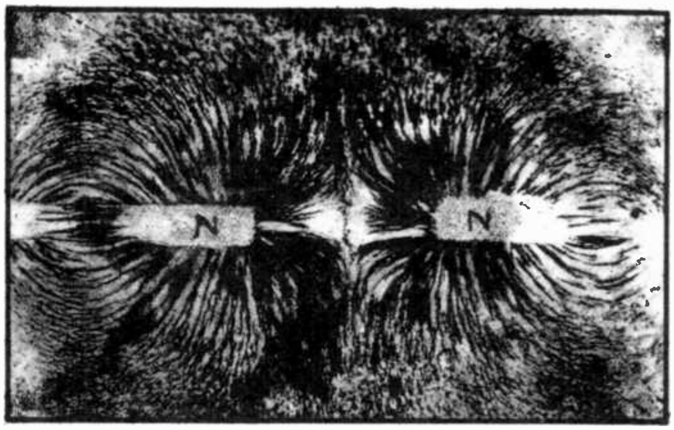

FIG. 14
FIELD PATTERN OF REPELLING POLES

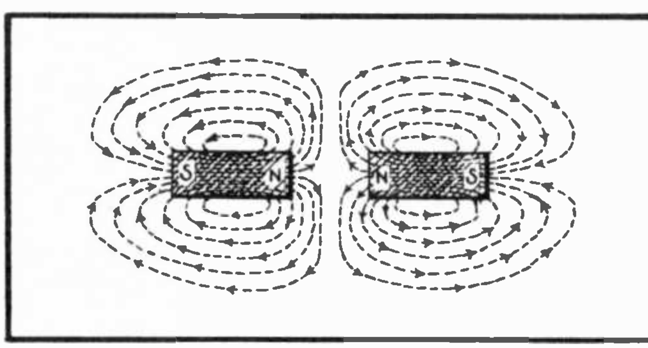

FIG. 15
DIAGRAM OF FIELD PATTERN
OF REPELLING POLES

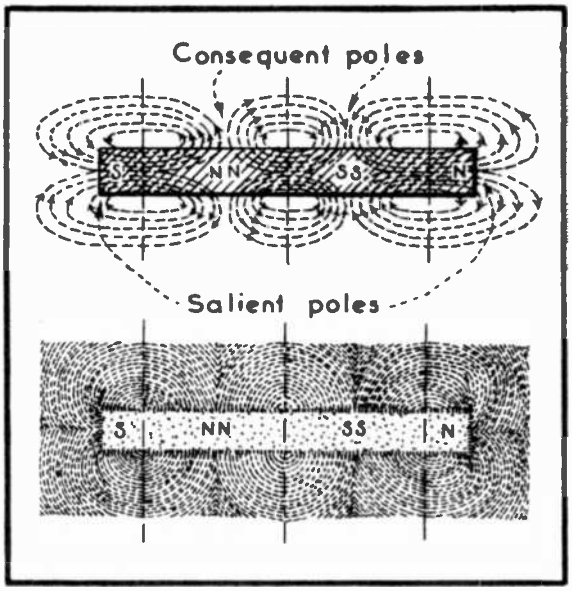

FIG. 16
SALIENT AND CONSEQUENT POLES

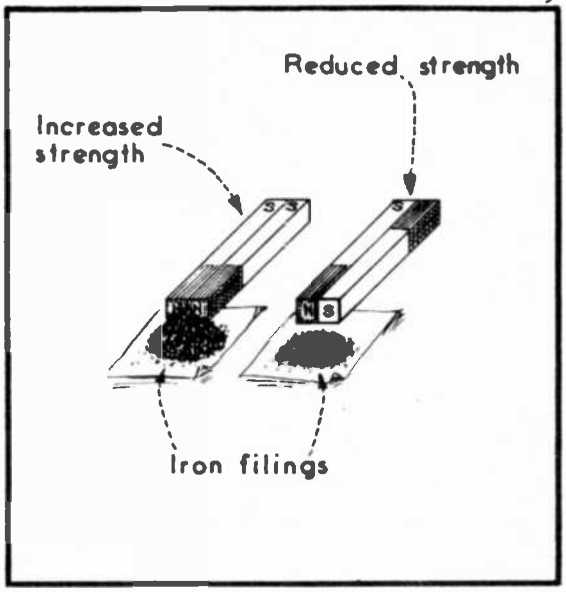

FIG. 17
THE NEUTRALIZING EFFECTS

By removing a small section from the ring magnet, as shown at the right of Fig. 18, two powerful poles will be formed at the cut. The air-space between these ends is generally referred to as the "air gap." This form of magnet is widely used throughout the radionic industry, as you shall soon learn.

MAGNETIC INDUCTION

If an unmagnetized piece of iron or soft steel (a nail, for example) be brought in contact with a strong magnet as shown in Fig. 19, then a north and south magnetic pole will appear at the ends of the nail. In other words, the nail itself has also now become a magnet.

By bringing the free end of the nail near to another unmagnetized body, such as another nail, for example, it will be found that the second nail will be attracted to the first nail. In fact, even before the two nails actually come into physical contact with each other, the power of attraction between them will be apparent.

It is possible to suspend several such nails, one from the other--each acting as a small magnet--but the instant that the magnet is withdrawn from the first nail, the others will all drop off. This experiment demonstrates that the magnet itself was the sole source of energy, and only imparted some of its properties to the other bodies temporarily. We then say that the nails were magnetized by the original magnet through the process known as <u>magnetic induction</u>.

In Fig. 20 another interesting experiment is illustrated that also demonstrates the principle of magnetic induction.

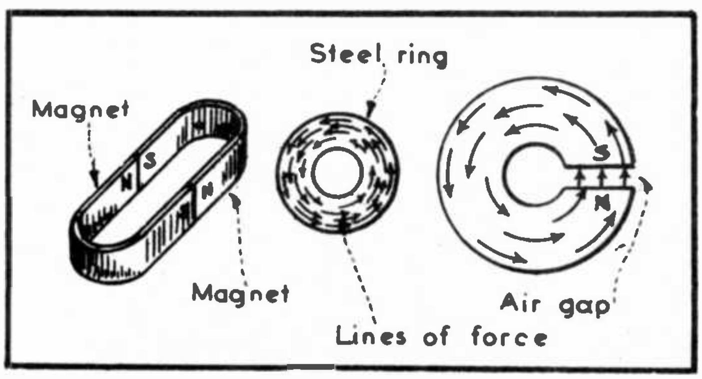

FIG. 18
RING MAGNETIC CIRCUITS

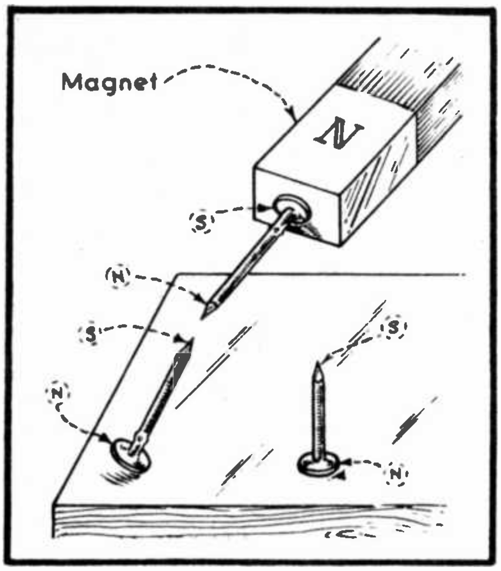

FIG. 19
MAGNETIC INDUCTION

Here, an unmagnetized soft iron bar is held in contact with a small pile of iron filings. No power of attraction for the iron filings will be noted.

One end of a strong bar magnet is then brought near the end of the iron bar, as also shown in Fig. 20, but the magnet is not permitted actually to touch the bar. As this is done, it will be noted that the iron bar has acquired the ability to attract the iron filings just as though it were a real magnet; but as soon as the magnet is withdrawn to a certain distance, the filings will suddenly drop off the soft iron bar.

In this case, the iron bar has been temporarily converted into a magnet by the original bar magnet, through the process of magnetic induction. When this occurs, the body into which magnetism is induced assumes a pair of poles as pointed out in Figs. 19 and 20, so that the end of the body nearest the magnet assumes a polarity which is opposite to that end of the magnet which is nearest. This is also in accordance with the rule that unlike poles attract.

The principle of magnetic induction is illustrated in Fig. 21. Here, you will observe how the lines of force, as produced by the magnet, use the soft iron bar as a part of the path to complete their magnetic circuit. Since soft iron "conducts" lines of force more readily than does air, the presence of the iron bar in Fig. 21 will keep the magnetic field in a more concentrated or dense condition.

VARIOUS TERMS PERTAING TO MAGNETISM

PERMEANCE: The ease or readiness with which any material "conducts" lines of force is called permeance.

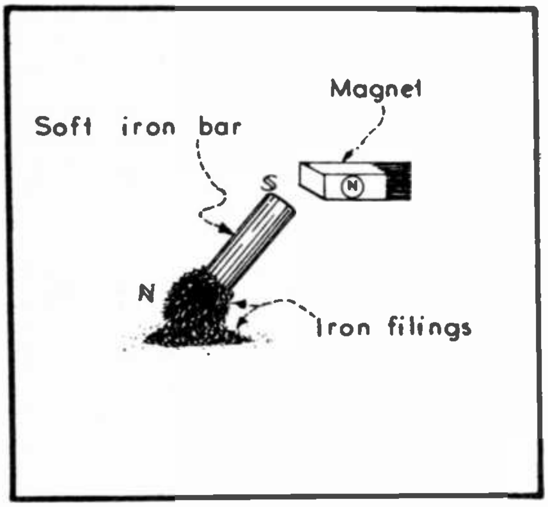

FIG. 20
MAGNETIC INDUCTION

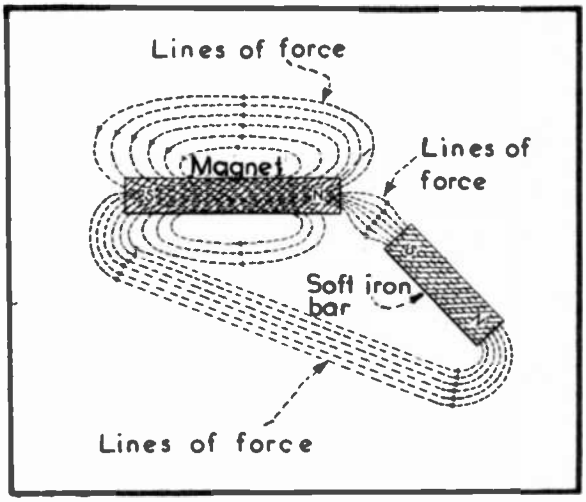

FIG. 21
PRINCIPLE OF MAGNETIC INDUCTION

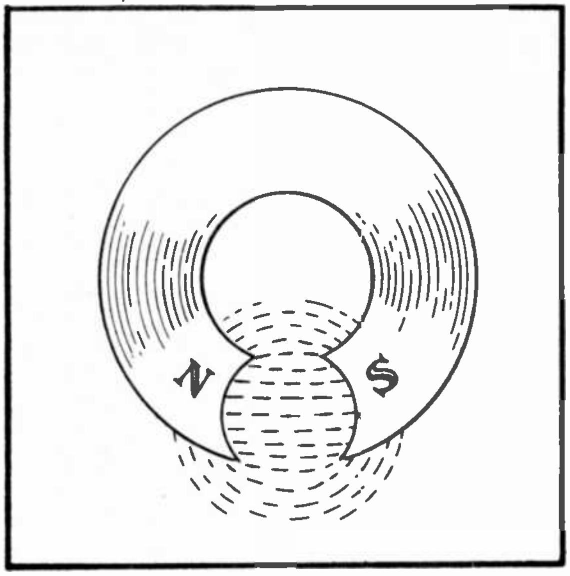

FIG. 22
HIGH-RELUCTANCE MAGNETIC CIRCUIT

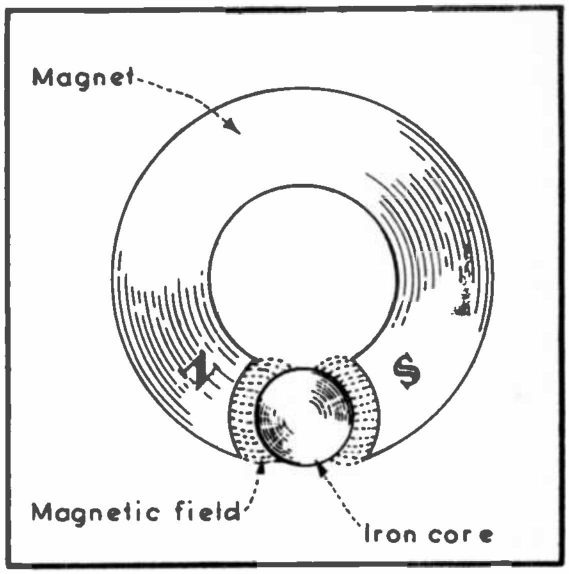

FIG. 23
LOW-RELUCTANCE MAGNETIC CIRCUIT

PERMEABILITY: The degree of magnetization resulting in a substance from a given strength of inducing pole is called its permeability. That is, how much magnetism can be retained by a given substance when brought under the influence of a magnet.

RELUCTANCE: The resistance or opposition which any material offers towards the passage of magnetic lines of force (flux) is called reluctance. This property of reluctance in a magnetic circuit is thus comparable to resistance in an electric circuit.

RETENTIVITY: The power of resistance which any material offers toward either magnetization or demagnetization is called retentivity.

FLUX DENSITY: By flux density we mean the number of magnetic lines of force passing through a plane at right angles to the lines of force, and which plane has an area of one square inch. Thus, the flux density is often spoken of in terms of a certain number of lines of force per square inch. Obviously, the flux density will increase when the reluctance of the magnetic circuit is decreased, just as current flow increases as the resistance of an electric circuit is decreased.

In Fig. 22, for example, we have a magnet with an air gap between its poles. Air, being a non-magnetic material, offers considerable reluctance and therefore the flux between the poles is not very dense. We then say that the flux density is low.

In Fig. 23, on the other hand, an iron core has been placed in the air gap between the poles. And, since iron is a good conductor of magnetic lines of force, the reluctance of this magnetic circuit is reduced appreciably and therefore more lines of force pass through the space between the poles. We then say that the flux density in Fig. 23 is greater than that in Fig. 22.

THE MOLECULAR THEORY OF MAGNETISM

So far in this lesson, we have considered the behavior of magnets quite thoroughly, but we haven't as yet mentioned a great deal regarding the nature of magnetism. This then, will be our next step.

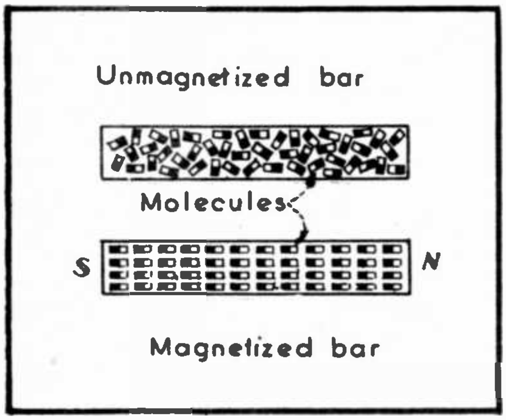

FIG. 24
MOLECULAR ARRANGEMENT OF A MAGNETIZED AND UNMAGNETIZED BAR

Scientists tell us that the difference between a piece of metal which is magnetized, and one which is not, is the arrangement of the molecules in the metal.

The molecules within a bar of iron or steel, which is not magnetized, are arranged in a disorderly manner as shown in the upper illustration of Fig. 24. When this same bar is magnetized, these molecules re-arrange themselves and straighten out in an orderly manner as shown in the lower illustration of Fig. 24.

This theory offers an explanation as to why a piece of soft iron is more readily magnetized than a piece of steel, but yet is not capable of retaining its magnetism for so great a length of time as steel. In other words, the molecules in a piece of soft iron straighten themselves out much easier and quicker than those of hardened steel; but the molecules in the steel will remain in an orderly manner longer than those in the soft iron, because it is harder for them to change their arrangement.

DIVISION OF A MAGNET

Another interesting fact is illustrated in Fig. 25, where a bar magnet is shown in the upper section of the illustration in its complete form. Should this same magnet be cut or broken into several smaller parts, then each of the parts thus formed will become an individual magnet, and with polarities in the same relative order as illustrated in Fig. 25.

Another point for you to bear in mind is that the lines of force as produced by a magnet do not flow through the magnet in the same sense that an electric current flows through a conductor. The lines of force are simply imaginary lines along which the attractive or repulsive force of a magnet acts; and as has been mentioned previously in this lesson, they map out the lines of magnetic strain. We simply use the expression "flow" in connection with magnetic lines of force as a matter of convenience.

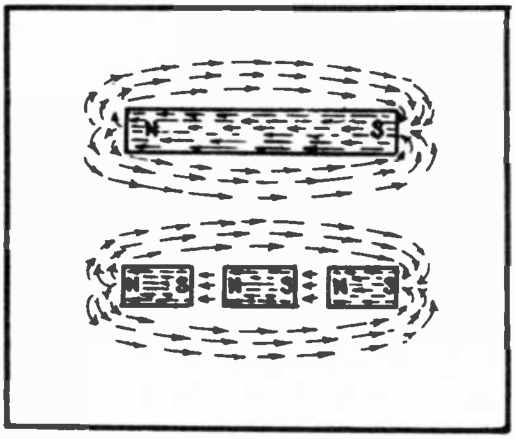

FIG. 25
DIVISION OF A MAGNET

MAGNETIC SCREENS

In Fig. 26 a magnetized needle has been inserted through a cork and the arrangement floated in a glass of water. In effect, this is a simple magnetic compass; and the needle will therefore assume a north-and-south position.

Now, if a magnet is placed near the glass, it will attract one end of the needle. By placing any non-magnetic body such as a piece of glass, cardboard, rubber, wood, non-magnetic metal, etc., between the magnet and the magnetized needle, no noticeable change

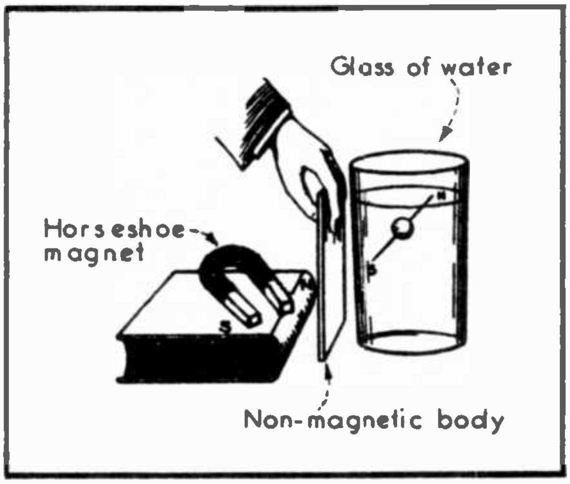

FIG. 26
A LACK OF MAGNETIC INSULATION

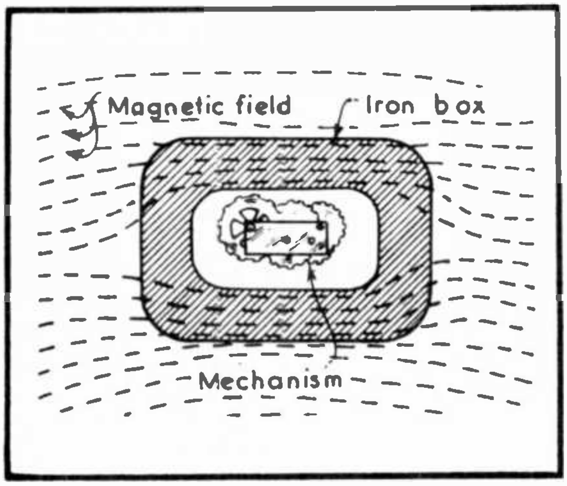

FIG. 27
APPLICATION OF A MAGNETIC SHIELD

will be apparent. If, however, a magnetic substance such as a sheet of soft iron be placed between the magnet and the needle, the deflection of the needle will be reduced materially. The iron sheet conducts lines of force readily and thus serves as a portion of the magnetic circuit, thereby deflecting its course away from the needle. The sheet of iron is then said to act as a screen or shield, but not as a magnetic insulator.

If the mechanism of a watch were placed in the center of a box made of soft iron, and the box placed in a magnetic field as shown in Fig. 27, then the lines of force would confine themselves to the iron body of the box, and the watch mechanism would not be affected. This principle of shielding is much used to protect watches and other delicate instrument movements from strong magnetic fields which might otherwise impair their proper operation due to magnetization.

From this explanation you will see that we have magnetic screens or shields, but that there is no such thing as an insulator for magnetism.

ELECTROMAGNETISM

In the preceding lesson you observed that magnetism is produced whenever an electric current flows through a conductor, by placing a pocket compass near the conductor. This effect can also be demonstrated in the manner illustrated in Figs. 28 and 29 in this lesson.

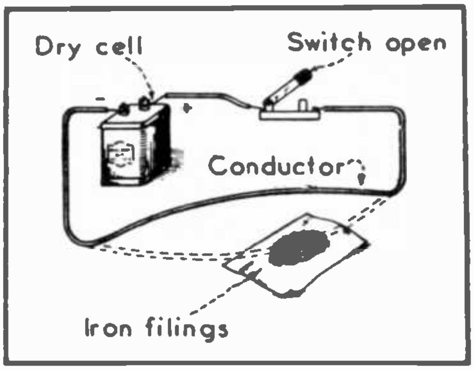

FIG. 28
NO MAGNETIC ATTRACTION
WHEN NO CURRENT FLOWS

In Fig. 28, the switch is open and no current flows through the circuit. If the conductor is now dipped into the pile of iron filings, and then raised, none of the filings will cling to the conductor. This proves that the conductor possesses no magnetic properties at this time.

But, if we close the switch so that current flows through the circuit as in Fig. 29, we find that by dipping the conductor into the iron filings and then raising it, filings will now cling to it as here shown. Therefore, we know that magnetism exists around a conductor that is carrying an electric current.

HOW THE MAGNETIC FIELD SURROUNDS A CURRENT-CARRYING CONDUCTOR

In Fig. 30 you are shown how the magnetic lines of force arrange themselves around a conductor that is carrying an electric current. Here, you are looking at the conductor from one end, and the electron drift through this conductor is in such direction as to be moving away from your eye, or into the paper. Notice, particularly, that when the electron drift is in this direction, the magnetic lines of force encircle the conductor in a counter-clockwise direction as illustrated by the arrows in the illustration.

When the electron drift is in the opposite direction to that in Fig. 30--that is, toward your eye, or out of the paper--the magnetic lines of force will encircle the conductor in a clockwise direction. In other words, reversing the direction of electron movement (or direction of current flow) through the conductor will reverse the direction of the encircling magnetic lines of force that are produced by this current flow.

Fig. 30 also illustrates why the compass behaved as it did in your last lesson. In Fig. 30 you are looking at the compass from the side so that you can see clearly how the needle points from right to left, or in the same direction as the magnetic lines of force, in the region where the compass is placed. If the compass were placed below the conductor in Fig. 30, its needle would point from left to right; thus showing that the magnetic lines of force below the conductor are acting in an opposite direction to those above it. However, the magnetic field, as a whole, follows only one direction around the conductor (either clockwise or counter-clockwise), and reverses only when the direction of current flow in the conductor is reversed.

It is to be noted further that the magnetic field is most intense nearest the conductor, and becomes weaker as the distance from the conductor is increased. Also, the greater the current flow through the conductor, the more intense will be the resulting magnetic field.

From what you have thus far learned from a study of Fig. 30, you will realize that the compass provides a convenient means for determining the direction of the magnetic field surrounding a conductor that is carrying an electric current. That is, since the compass needle always points in the same direction as the magnetic lines of force, we need only to place the compass near the conductor and note the position of its needle.

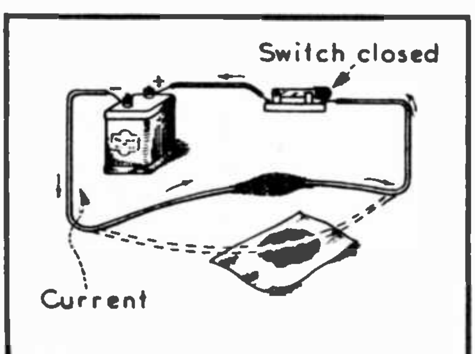

FIG. 29
MAGENTIC ATTRACTION WHEN CURRENT FLOWS

THE THUMB RULE FOR STRAIGHT WIRE

Another simple method of determining the direction of the magnetic field surrounding a conductor carrying an electric current is illustrated in Fig. 31.

In the application of this rule, we grasp the wire with our right hand in such a manner that the thumb points in the direction of the negative terminal of the battery or generator. The remaining four fingers will then point in the direction in

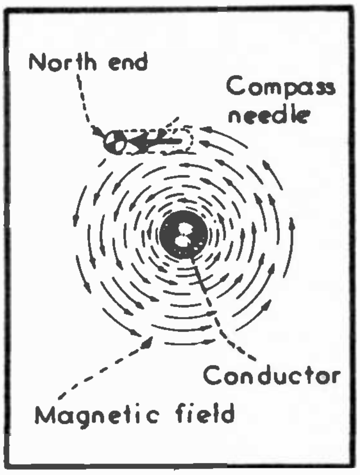

FIG. 30
MAGNETIC FIELD SURROUNDING CURRENT-CARRYING CONDUCTOR

which the lines of force encircle the conductor.

Similarly, if we know the direction of the magnetic field, we can by the application of this same rule find the direction of the current or of the electron drift through the wire. To do this, we place the four fingers of the right hand around the conductor so that they point in the direction in which the lines of force encircle the conductor. The extended thumb will then point in the direction of the negative source of electromotive force. The positive terminal will then, of course, be found at the other end of the circuit.

In determining the direction of current, when applying this rule, remember that the direction of current from the practical electrician's standpoint is from positive to negative outside the battery or generator, while the actual movement of electrons is from negative to positive in the external circuit.

In applying all of the practical electrician's "hand rules" as presented in this lesson, it is very important not to become confused between the direction of the so-called "current flow" and electron drift. Also note in Fig. 31 that reversing the polarity of the emf will reverse the direction in which the magnetic lines of force encircle the conductor.

MAGNETIC FIELD SURROUNDING A LOOP

Now that we know that a magnetic field surrounds a conductor that is carrying an electric current, let us wrap such a conductor around a wooden cylinder so as to form it into the shape of a loop as in Fig. 32.

Assuming the electron drift through this looped conductor to be in the direction of the arrows drawn in the conductor, the magnetic lines of force will encircle the conductor as indicated by the other set of arrows. The relation between the direction of the electron drift and the encircling magnetic field is still the same as pointed out in Fig. 30; but because of the shape of the loop, the magnetic lines of force all travel "in" toward the center of the loop at the right, and "out" from the center of the loop at the left.

Then, since magnetic lines of force always leave a magnet at its north pole and re-enter at its south pole, it is apparent that by looping the conductor in the manner done in Fig. 32, a south magnetic pole will be produced at the right and a north magnetic pole at the left. Furthermore, so looping the conductor has concentrated or "lumped" the magnetic field into a smaller space than would be the case if the same conductor were stretched out straight. The latter results in a stronger magnetic field within a limited area.

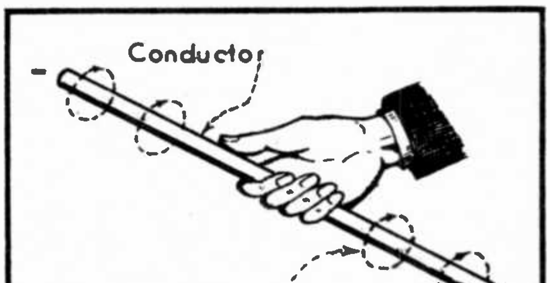

FIG. 31
THUMB RULE FOR STRAIGHT WIRE

Now, if instead of only one loop, we form the conductor into two loops, conditions will become as illustrated in Fig. 33. Here, you will observe that each loop establishes its own magnetic field in accordance with the principles thus far outlined; however, since the lines of force of loop #1 travel downward in the

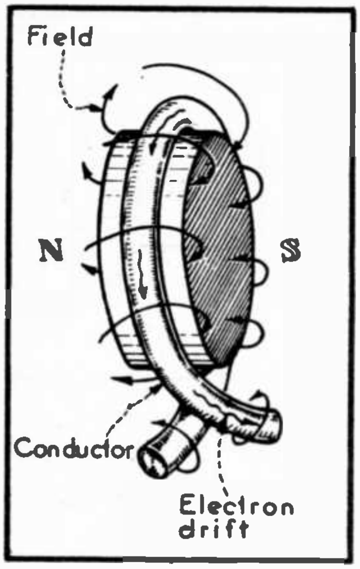

FIG. 32
MAGNETIC FIELD
AROUND LOOP

region marked "X" while those of loop #2 travel upward in this same region, it is clear that opposition between the two fields occurs here. However, instead of the magnetic lines of force of these two individual fields continuing to oppose each other in this region, they take the path of least resistance and "fall into line", so to speak, and establish a combined or resultant field that encircles the entire winding as illustrated by the larger arrows.

When several turns of wire are applied in this manner, we refer to the arrangement as a helix. Also observe in Fig. 33 that the combined field leaves the center of the helix at the left end; and after completing its external circuit, returns to the center of the helix at the right end. According to the rules of magnetism, a north magnetic pole will thus be established at the left end of the helix and a south pole at the right end. The same effect will be had if the wood cylinder is removed from the helix, provided that the wire is stiff enough in order for the helix to be self-supporting.

In Fig. 33 the helix is said to have a wooden core; whereas if the wooden core is removed and the helix is self-supporting, we say that it has an air core. In the latter case, only air acts as a conductor of magnetic lines of force, while in Fig. 33 the wooden cylinder and air serve as conductors of magnetic lines of force.

MAGNETIC FIELD SURROUNDING A SOLENOID

In Fig. 34 you will see a winding with the coils wound side by side, but insulated from each other. If a current should be passed through this winding, and if the "turns" are all wound in the correct relation to each other so that they will work together, as just described, then the lines of force will encircle the entire coil in the manner shown by the dotted lines. Thus, a north pole will be produced at one end and a south pole at the other end.

A coil such as here illustrated, whether or not it is supported on a non-magnetic form, may be called a "helix" or a "solenoid". As a general rule, a solenoid is considered as being a helix which is rather long in comparison to its diameter and consisting of a large number of turns, usually wound close together. Frequently, more than one layer of winding is used on a solenoid. Cardboard or bakelite tubing are often used as forms for solenoids.

THE ELECTROMAGNET

In the case of the helix or solenoid, air is the conducting medium for the magnetic lines of force. However, since iron is a far better conductor of the lines of force, we find that the magnetic strength can be increased by filling the space within the coil with an iron core, offering a much easier path for the lines of force. In other words, the iron core will attract any "stray" lines of force, keeping them

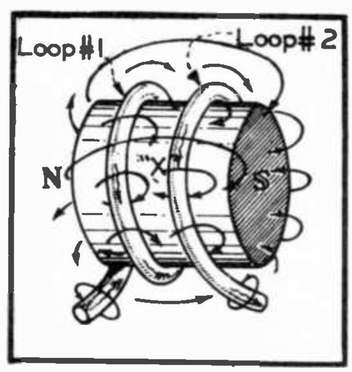

FIG. 33
MAGNETIC FIELD
AROUND HELIX

more concentrated. This new arrangement forms what we call an electromagnet, and is illustrated in Fig. 35.

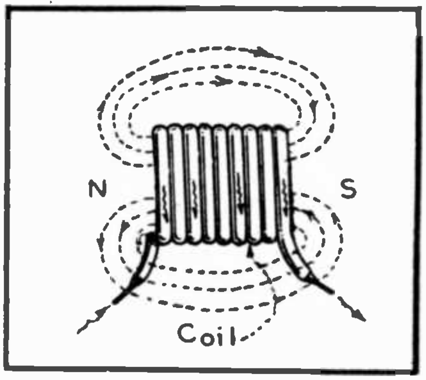

Fig. 34
Solenoid

Observe closely how the insulated wire is wrapped around the iron core. The electrons are drifting through the wire in the direction indicated by the arrows, and the field encircles the unit as shown by the dotted lines and arrows. Such electromagnets are used extensively in the many branches of radionics.

A north pole will be established at the left end and a south pole at the right end of the electromagnet appearing in Fig. 35, for the same reason as such poles are established at the ends of a helix or solenoid. Reversing the direction of current flow through either a helix, solenoid or electromagnet, will reverse the direction of the magnetic lines of force in the resulting magnetic field; and, consequently, the polarity.

THE RIGHT-HAND COIL RULE

The polarity of an electromagnet can be determined in the following manner:

With your right hand, grasp the electromagnet so that your fingers are pointing in the direction of the negative terminal of battery or generator through the winding, as in Fig. 36. The extended thumb will then point to the north pole of the electromagnet, as also here shown. This rule can be applied equally well to a helix, solenoid or electromagnet.

MAGNETOMOTIVE FORCE

Just as a difference of electrical pressure (voltage or electromotive force) causes a current to flow through an electric circuit, so a difference in magnetic pressure which exists between the poles of a magnet causes lines of force to be produced. This difference in magnetic pressure is called magnetomotive force, and it is usually abbreviated to m.m.f.

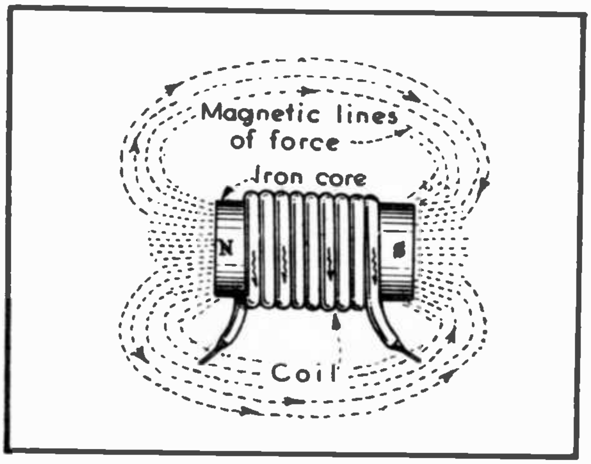

Fig. 35
Electromagnet

In the case of electromagnets, we speak of this quantity in terms of the number of ampere-turns which establish the magnetomotive force and the resulting magnetic flux.

The magnetomotive force in ampere-turns of any magnetic winding is equal to the product of the current flowing through the winding and the number of turns employed.

In the upper illustration of Fig. 37, a current of 5 amperes is flowing through a winding consisting of 2 turns. Therefore, the magnetomotive force in this case is 5 times 2 or 10 ampere-turns. In the lower illustration of Fig. 37 a current

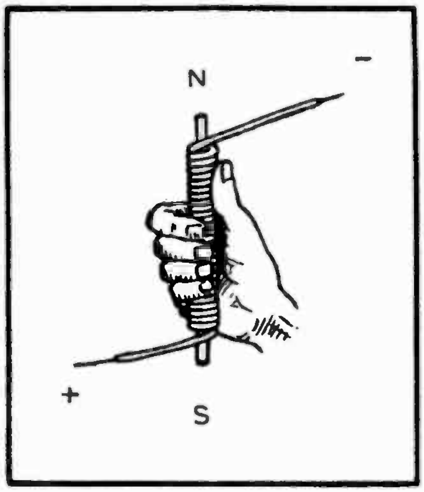

FIG. 36
RIGHT-HAND COIL RULE

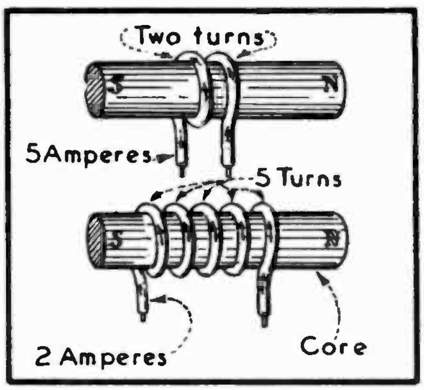

FIG. 37
AMPERE-TURNS RELATION

of 2 amperes is flowing through a winding consisting of 5 turns, and therefore the magnetomotive force in this case is 2 times 5 or 10 ampere-turns.

In the event that 10 amperes should flow through a winding consisting of 100 turns, then 10 times 100 or 1000 ampere-turns would be realized; 2 amperes through 600 turns would furnish 1200 ampere-turns, etc., and the strength of the magnetic field would be increased correspondingly.

Thus it is seen that the magnetomotive force can be increased by increasing either the current flow through the winding, the number of turns on the winding, or both. And, the intensity of the magnetic field can be increased by reducing the reluctance of the magnetic circuit through the use of a core made of iron or special types of steel that conduct magnetic lines of force more readily than do air or other non-magnetic materials.

COMPARISON OF CIRCUITS

In Table I you are given in handy reference form a comparison between a hydraulic, electric and magnetic circuit--showing how the quantity, flow, pressure, friction (opposition) and ease of flow are expressed in each system. The names of the units of measurement are also given where they apply.

Some of these units of measurement have been defined in lessons that you have already studied. The others will be explained in later lessons that require their use.

TABLE I

COMPARISON OF CIRCUITS

HYDRAULIC CIRCUIT	ELECTRIC CIRCUIT	MAGNETIC CIRCUIT
QUANTITY IN GALLONS. A GALLON OF WATER CONTAINS MANY MOLECULES.	QUANTITY IN COULOMBS. A COULOMB OF ELECTRICITY CONTAINS OVER SIX MILLION MILLION MILLION ELECTRONS.	NONE
FLOW IN GALLONS PER SECOND.	CURRENT IN COULOMBS PER SECOND OR AMPERES.	FLUX IN LINES OF FORCE
PRESSURE IN POUNDS PER SQUARE INCH.	ELECTROMOTIVE FORCE IN VOLTS.	MAGNETOMOTIVE FORCE IN AMPERE-TURNS.
PIPE FRICTION (NO UNIT)	RESISTANCE IN OHMS.	RELUCTANCE IN OERSTEDS OR RELS.
EASE OF FLOW (NO UNIT)	CONDUCTANCE IN MHOS.	PERMEANCE IN PERMS.

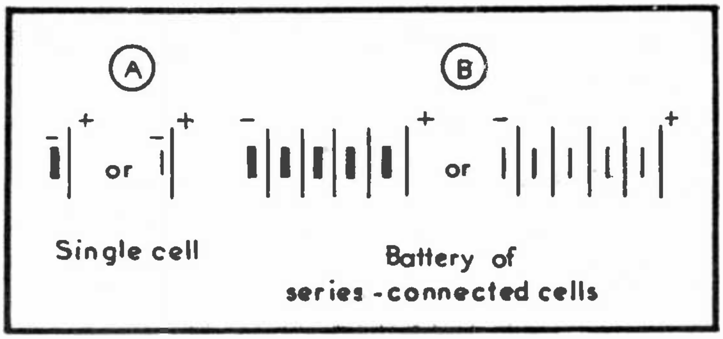

FIG. 38
CELL AND BATTERY SYMBOLS

SCHEMATIC SYMBOLS AND DIAGRAMS

In electronics and radio it is often necessary that we illustrate a circuit in such manner as to show all connections clearly. We could, of course, draw each piece of equipment that is connected in the circuit so that it resembles the actual part; and then show the wiring between the various parts pictorially. However, this would require too much time even if we possessed the necessary artistic ability. So, instead, we use a form of engineering "short-hand" which enables us to quickly and accurately draw a simplified diagram (called a "schematic diagram") of any complete radionic system. To make such a schematic diagram, we employ standard electronic symbols which it is necessary for you to learn.

At (A) of Fig. 38 you are shown two symbols that are used to represent a single cell in a circuit diagram; while (B) of the same illustration shows how a series connection of cells, or battery, may be drawn symbolically. Notice how polarity is indicated. The number of short and long lines in the symbol of a battery does not necessarily indicate the exact number of cells that are connected in the series group. Usually, as many lines are used as is convenient, and a notation of the battery-voltage is then placed near the symbol.

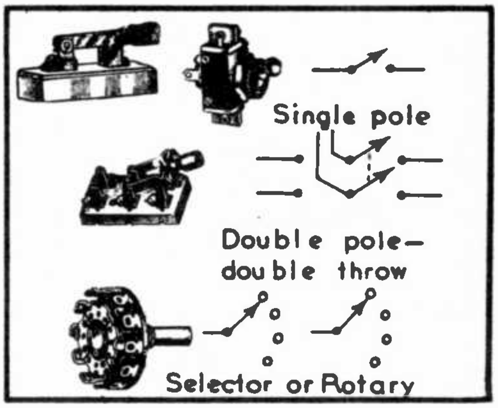

FIG. 39
SWITCHES

Several types of switches appear in Fig. 39, together with their symbols. Observe that a single-pole, single-throw (S.P.S.T.) switch interrupts only one side of the circuit, and can be used only for opening and closing the circuit. The double pole-double throw (D.P.D.T.) switch opens and closes both sides of the circuit simultaneously, and also permits the switch arms to be connected to or disconnected from either one of two different circuits. The selector or rotary switch provides the means for connecting one side of one circuit to any one of several contacts to which other circuits may be wired.

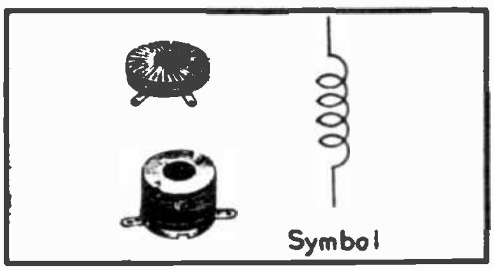

FIG. 40
AIR-CORE COIL

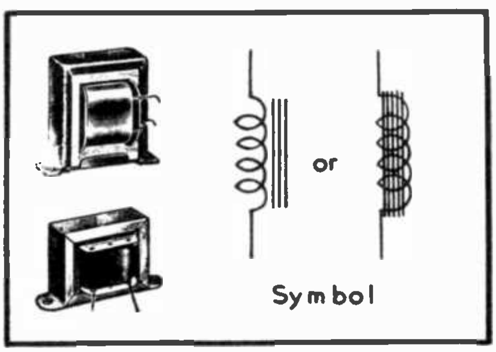

FIG. 41
IRON-CORE COIL

By comparing Figs. 40 and 41 you will note that the symbol for an air-core coil or winding differs from that of an iron-core coil only in the fact that several straight lines are drawn either alongside of or through the latter to denote the presence of the iron core.

The meter symbols in Fig. 42 are self-explanatory. Here, the letter "V" is placed in the center of the symbol to denote a voltmeter, "A" for an ammeter and "M.A." for a milliammeter. (The latter instrument is calibrated to register thousandths of an ampere).

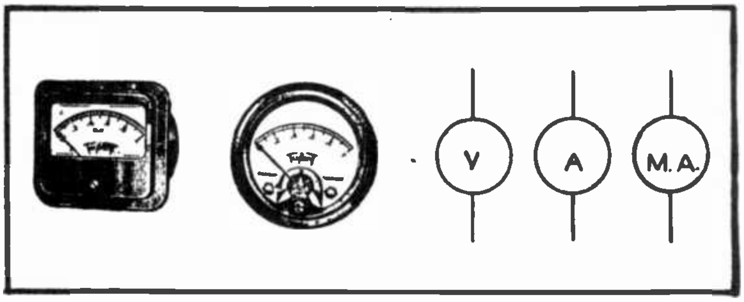

FIG. 42
METERS

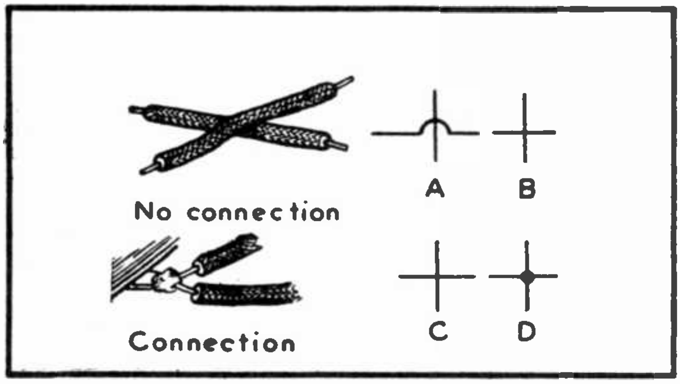

FIG. 43
CROSS-OVER AND CIRCUIT CONNECTION

Whenever the arrangement of a wiring diagram is such that two lines representing wires must cross each other, we use the methods shown at (A) and (B) of Fig. 43. This condition is shown pictorially at the upper left of Fig. 43.

The symbols at (C) and (D) of Fig. 43 signify that two wires of the circuit are connected together electrically as at the lower left of the illustration. Although the symbols at (B) and (C) of Fig. 43 are alike, it is to be noted that, usually, when symbol (A) is used in wiring diagrams to denote a cross-over (no connection) symbol (C) is employed to indicate a connection; and that when symbol (B) is used to denote a cross-over, symbol (D) is employed to indicate a connection. You will find this system to be fairly well standardized in commercial practice; but to avoid any possibility of confusion in this respect, we have adopted in our course the plan of using symbol (A) for cross-overs and (D) for connections, as we believe this method to be more positive in its meaning to the student. However, if any variations are found, simply remember that these distinct systems exist and are used.

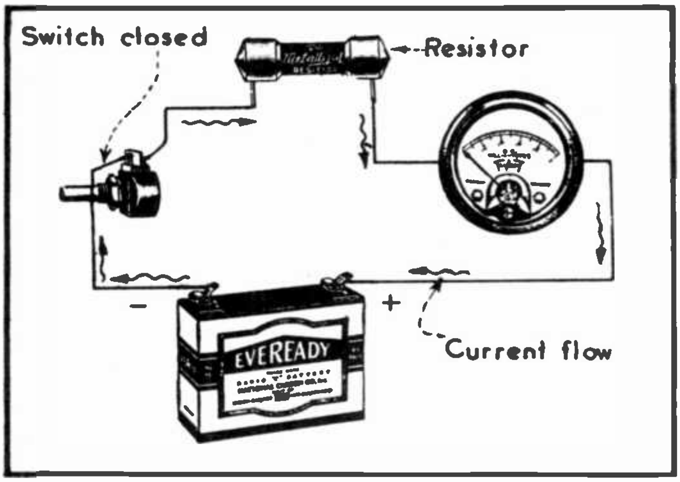

FIG. 44
ELECTRIC CIRCUIT

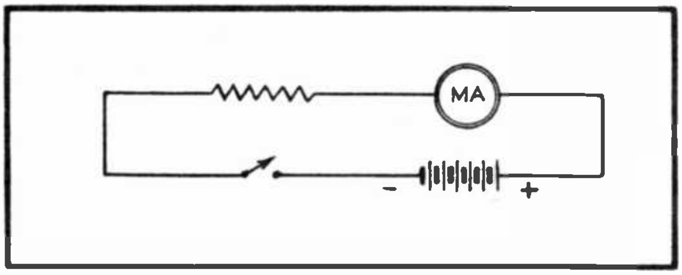

FIG. 45
DIAGRAM OF CIRCUIT

In Fig. 44 you are shown a series circuit comprising a battery, switch, resistor and milliammeter illustrated pictorially. The same circuit appears as a schematic diagram in Fig. 45. Notice, especially, the simplicity of the diagram.

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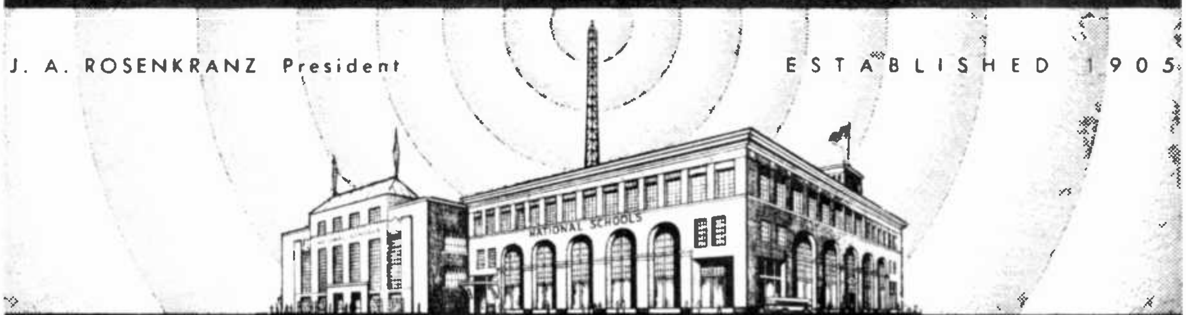

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LESSON NO. 4

PULSATING AND ALTERNATING CURRENT

Up to this point we have concerned ourselves with the behavior of direct current (d-c) in electrical circuits. You learned that a d-c emf may be generated by means of an electro-chemical device called a "battery," or by means of an electro-magnetic device called a "generator;" and that the d-c emf will force current to flow through a circuit from the negative terminal to the positive terminal of the voltage source. You will also remember that this current continues to flow through the circuit at a constant amperage, and in an unchanging direction, until the circuit is interrupted.

In nearly all radio and electronic devices, two other forms of electrical current must be accounted for--namely: pulsating direct current and alternating current. A proper understanding of the action and behavior of these currents is essential if you are to thoroughly master the functioning of radionic equipment.

PULSATING CURRENT

Pulsating current is a form of direct current which always moves or flows through a circuit in one direction, but which is of a varying intensity.

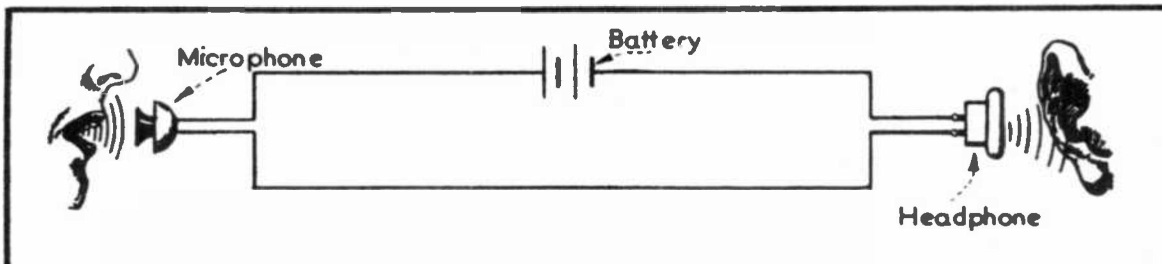

FIG. 1
SIMPLE TELEPHONE CIRCUIT

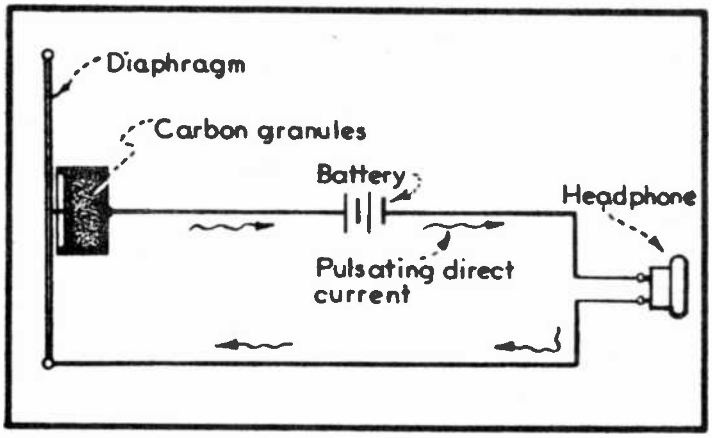

FIG. 2
PRINCIPLE OF CARBON MICROPHONE

Pulsating current may be generated by any one of several different ways. For example, a carbon microphone and a battery connected in series serves as a very common and simple type of pulsating-current generating circuit that we will describe at this time. Other circuits of this type employ electro-magnetic circuit breakers, vacuum tubes, etc., and about which you will hear more later in the course.

<u>THE MICROPHONE CIRCUIT</u>: In Fig. 1, you are shown a simple telephone circuit comprising a carbon microphone, headphone (sometimes called an "earphone") and a battery--all connected in series. Let us now analyze the action of the microphone and see how it changes direct current into pulsating current.

The same circuit appears in Fig. 2, only that the microphone is here shown in section, viewed from the side so that your eye is in line with the edge of the diaphragm. This diaphragm is constructed in the form of a thin metallic disk that has a certain amount of flexibility, and which is rigidly supported around its rim.

A small piston-like unit is fastened to the center of the diaphragm. Whenever the center point of the diaphragm is forced to bend inward and outward, this piston moves in and out of a small cup which contains finely ground carbon granules. The piston does not move through a great distance, but it does produce a definite effect upon the system.

In Fig. 3, you are shown the position of the diaphragm in the "mouthpiece" or "microphone" of an ordinary telephone. Normally, the diaphragm maintains the relatively straight position shown at the left of Fig. 3. However, if we speak into the microphone, the sound of our voice sets up a varying air pressure that causes the diaphragm to vibrate, or to alternately bend inward and outward. This is illustrated in the center and right illustrations of Fig. 3, which are labeled "inward" and "outward," respectively.

By again referring to Fig. 2, you will observe that a battery is connected in this circuit. Therefore, when the diaphragm is at rest, a certain amount of current will flow through the carbon granules, diaphragm, headphone, and battery. This is a pure direct current--often called the <u>average current</u>, or the "carrier current", of the microphone circuit.

Whenever the diaphragm bends <u>inward</u>, the piston will move farther into the cup of carbon granules and thereby compress these granules closer together. This <u>reduces</u> the electrical resistance of the circuit so that <u>more</u> current will flow through the system than when the diaphragm is in its normal position.

On the other hand, whenever the diaphragm moves <u>outward</u>, the pressure upon the carbon granules will be <u>less</u> than normal. Therefore, the carbon granules will now be free to move farther apart and thereby <u>increase</u> the electrical resistance of the circuit. This causes the flow of battery current through the system to be less than normal.

Summing up these actions, it is apparent that as a sound acts upon the microphone and causes its diaphragm to undergo a vibrating motion, the current flow through the microphone will vary correspondingly; but, it never reverses its direction of flow. We call a current of this nature a PULSATING DIRECT CURRENT, or simply a PULSATING CURRENT.

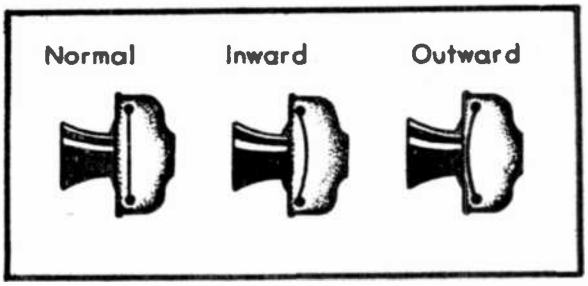

FIG. 3
DIAPHRAGM VIBRATIONS

Notice in Fig. 4, how this pulsating current is illustrated graphically, by means of what engineers call a "curve." The straight, horizontal portion of the curve represents the uniform (normal) flow of current through this circuit when no sound is acting upon the microphone, and at which time the diaphragm of the latter is stationary. The wavy portion of the curve represents variations of current flow above and below the normal value, as caused by vibrations of the microphone diaphragm when sound is acting upon it. Since this curve is above the zero (no current) reference line throughout its entire length, it shows that the current increases and decreases with respect to some normal value (the average or carrier current), but at <u>no time</u> reverses its direction of flow.

UTILIZATION OF PULSATING CURRENT IN A SIMPLE TELEPHONE CIRCUIT

Now, before we show you how this pulsating current is utilized in the circuit of Figs. 1 and 2, it is necessary that we first acquaint you with the structural features of the headphone that is employed in this system.

The "receiver" or headphone, in both a telephone and a radio system, performs a task that is just the opposite to that of the microphone. That is, it converts pulsating electric current back into sound.

In Fig. 5, is shown the principle of construction as found in the ordinary headphone. This unit consists of a small permanent magnet, the poles of which are spaced only a slight distance from the central portion of the diaphragm. The diaphragm in this case is also a disc-shaped unit, made from thin metal that possesses a certain amount of flexibility; and which is pivoted around its rim to the shell or housing of the assembly. In addition, coils of very small insulated wire are placed over the poles of the permanent magnet. Under normal conditions, the central portion of the diaphragm is attracted or pulled downward by the permanent magnet.

The varying, or pulsating microphone current flows through the headphone winding as in Fig. 6, causing a magnetic field of varying intensity to be set up around the electromagnet of the headphone. This varying field results in a magnetic reaction that causes the headphone diaphragm to move or vibrate in direct step with the movement of the microphone's diaphragm and corresponding current variation in the circuit. This action of the headphone diaphragm, in turn, sets up vibrations in the air which is in contact with it. And, if the ear be placed close to the headphone, these vibrations of air cause a corresponding vibration of the ear drum which the brain interprets as the same sound produced in front of the microphone.

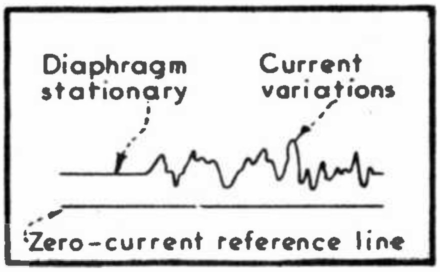

FIG. 4
MICROPHONE CURRENT
(PULSATING D-C)

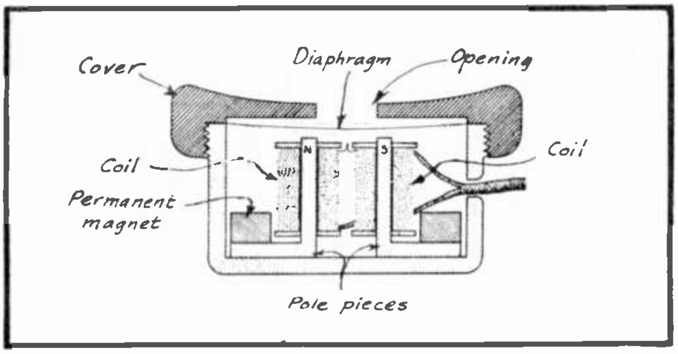

FIG. 5
CONSTRUCTION OF THE HEADPHONE

PULSATING CURRENT PRODUCED BY OPENING AND CLOSING THE CIRCUIT: There is yet another way in which pulsating current may be generated. This is shown in Fig. 7, where a circuit is being opened and closed in rapid succession by means of a switch. It is obvious that whenever the switch is in the closed position, current will flow through the circuit; and that whenever the switch is in the open position, no current will flow. Thus, if the switch be opened and closed rapidly, the current will flow through the circuit in surges, or in "spurts," as shown by the graph directly above the five pictures of the same circuit and the different positions of the switch.

Since in the circuit of Fig. 7 no current whatever flows when the switch is open, the horizontal line of zero current is used as the reference level. Thus, the gaps between the curved lines that represent periodic surges of current in the graph of Fig. 7 denote intervals of no current flow.

The generation of pulsating current by means of a hand-operated switch would, of course, not be practical in a radionic circuit. Therefore, whenever we desire such action in actual practice, we use small electro-magnetically operated switches which open and close the circuit automatically, many times each second, as does the vibrator on an electrical door bell or buzzer. These "switches," usually called vibrators are found in the power supply unit of most present-day automobile receivers and in many farm radios. They were once used to a great extent on the ignition coils of Model-T Ford automobiles, and in early "wireless" transmitters.

SUMMATION ON PULSATING CURRENT: Pulsating current may be:

1. - A current that flows through a circuit in one direction only; but which varies constantly in intensity with respect to some normal value. An example of this is the flow of current through a microphone circuit.

2. - A current which flows through a circuit intermittently. In this case, it has a definite value at one instant, and drops to zero at the next instant. This type of current is generated by an automatic switch--often called a vibrator, which rapidly opens and closes the circuit.

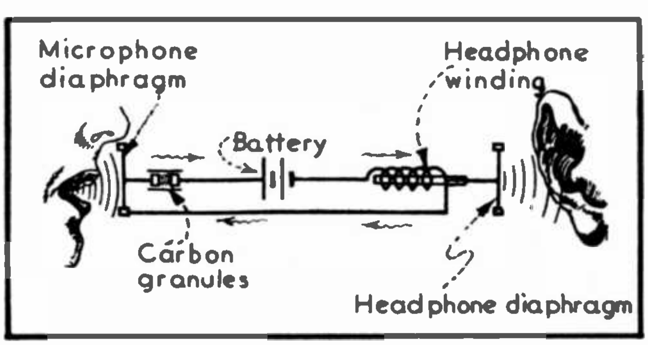

FIG. 6
DETAILS OF COMPLETE CIRCUIT

ALTERNATING CURRENT

Alternating current, commonly abbreviated as "a-c," differs from direct current (d-c) in that it constantly reverses its direction of flow. That is, it first flows through a circuit

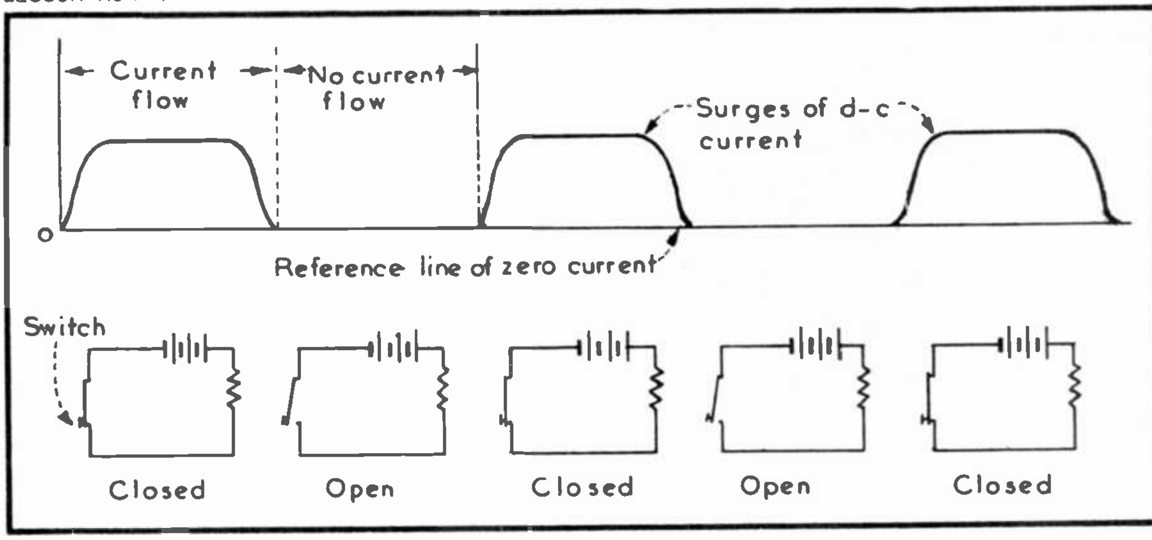

FIG. 7
PRODUCING PULSATING D-C BY PERIODICALLY OPENING AND CLOSING CIRCUIT

in one direction for an instant, stops for an instant, and then flows through the circuit in the reverse direction for an instant. These reversals in the direction of current occur repeatedly, many times per second.

HYDRAULIC ANALOGY OF A-C: The reversal action of a-c will be further clarified by comparing it with that existing in the hydraulic (water) system shown in Fig. 8. Upon examining Fig. 8, very carefully, you will observe that we have here a piston which is caused to move back and forth in the cylinder of a pump. An inlet and an outlet are provided in the cylinder, and they are interconnected by a continuous section of pipe. The system is completely filled with water.

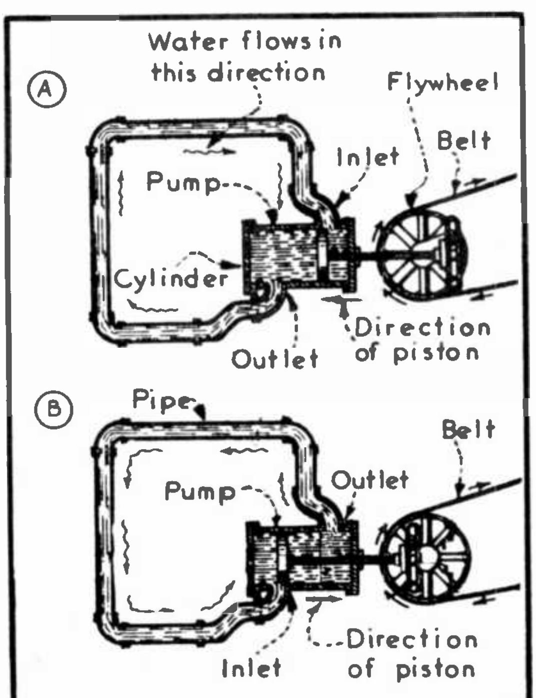

FIG. 8
HYDRAULIC ANALOGY OF A-C

When the motion of the crank arm on the flywheel at any one instant is such as to cause the piston to travel from the right towards the left, as at (A) of Fig. 8, it will force water through the pipe in one direction until the piston reaches the end of its stroke. The flow of water will then stop for an instant.

As the crank arm causes the piston to move through the cylinder from the left towards the right, as at (B) of Fig. 8, the water will flow through the pipe in the opposite direction until the piston reaches the end of its stroke. The circulation of water will then stop and again reverse its direction of travel as the piston commences its stroke towards the left. Thus, the water will continually reverse its direction of flow through the pipe as long as the piston moves back and forth in the cylinder; thereby providing us with an alternating current of water.

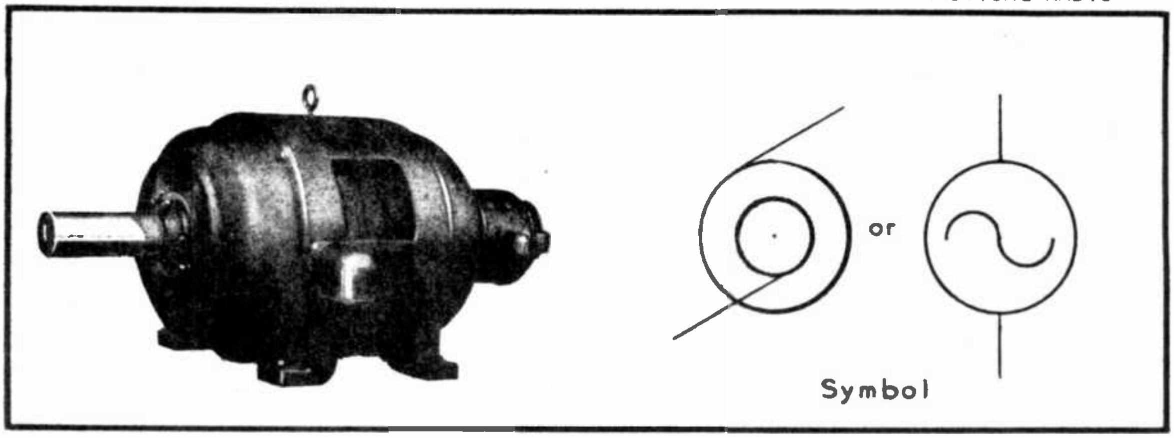

FIG. 9
A-C GENERATOR AND SYMBOLS

An alternating electrical current behaves in a similar manner. In this case, the "pump," or alternating-current generator, produces a voltage of such nature as to cause the current to reverse its direction of flow through the circuit periodically. In the following paragraphs you will be shown how this is done.

A-C GENERATOR

An a-c generator is a device which produces an alternating emf. This a-c emf, in turn, causes an a-c current to flow in the circuit to which the generator is connected. All a-c generators are electromagnetic devices, having a rotating element which must be revolved by an external force, such as water power, wind power, a steam engine, a gasoline engine, or an electric motor. In Fig.9, is shown a picture of an a-c generator, and also its schematic symbols.

ANALYSIS OF A-C GENERATOR ACTION: In Fig. 10 we have an analysis of the flow of current in an a-c circuit. Here, the same circuit is repeated five times. The heavy line below the drawings represents time, and is calibrated to indicate fractions of a second. Above the drawings, appears the curve of a graph that illustrates the flow of alternating current in the circuit below. A curve of this type which shows the action of a-c voltage or current in a simple circuit is called a SINE CURVE.

At (A) of Fig. 10, no emf is being supplied by the generator, and therefore zero current is indicated on the meter and on the graph at this instant. At 1/4 second later, the generator is forcing current through the circuit in the direction indicated at (B). As the electron theory of current flow has taught us that electrons always drift in a circuit from the negative toward the positive source of emf, it is obvious that one of the generator terminals must be (-) and the other (+), as noted on the drawing. Notice particularly in Fig. 10, how the current has gradually increased in value from starting point "A" (zero current) until the maximum or peak value of current is attained at position (B), 1/4 second later.

Once this maximum value has been attained, the current flow in this direction decreases gradually until at (C), the 1/2 second point, there is again no current in the circuit. The curve, therefore, returns to the zero reference line at this point. Obviously, no emf is being produced by the generator at this instant and so the generator terminals have no polarity at this time.

At (D), the 3/4 second point, current is once more flowing in the circuit at maximum intensity; but, in a direction opposite to that at (B). Therefore, the polarity of the generator terminals and the meter reading at (D) are the reverse of that at (B). Having attained a maximum value in this direction, the current flow then decreases gradually until at (E) it has again returned to zero value; and therefore no generator polarity is shown at this position. It should be noted that according to the markings on the "time line" in Fig. 10, the five conditions illustrated all take place during one second.

SINE WAVE CURVE

As has been previously mentioned, the curved line drawn in graph form above the circuits in Fig. 10 is called a SINE WAVE CURVE. Radio and electronic technicians use such curves extensively for the purpose of illustrating the action of a-c currents or voltages which are applied to radionic circuits. Remember that the heavy horizontal line at the center of this curve is the reference or "zero line," and represents a current of zero value; and that as the generator forces current through the circuit, a curve is drawn from this zero line to indicate the value of the current (amperes) at different periods of time. Units of current are indicated along the vertical line at the extreme left.

When the sine wave curve appears above the zero line, it shows that current is flowing through the circuit in the direction as is illustrated at (B) of Fig. 10. When current in the circuit has reversed, as at (D), the sine wave curve is drawn below the zero line to show this reversal of current flow.

ALTERNATION: That part of the sine wave curve which is shown above the zero line we call a POSITIVE ALTERNATION. That part of the curve which is shown below the zero line is known as the NEGATIVE ALTERNATION. Thus,

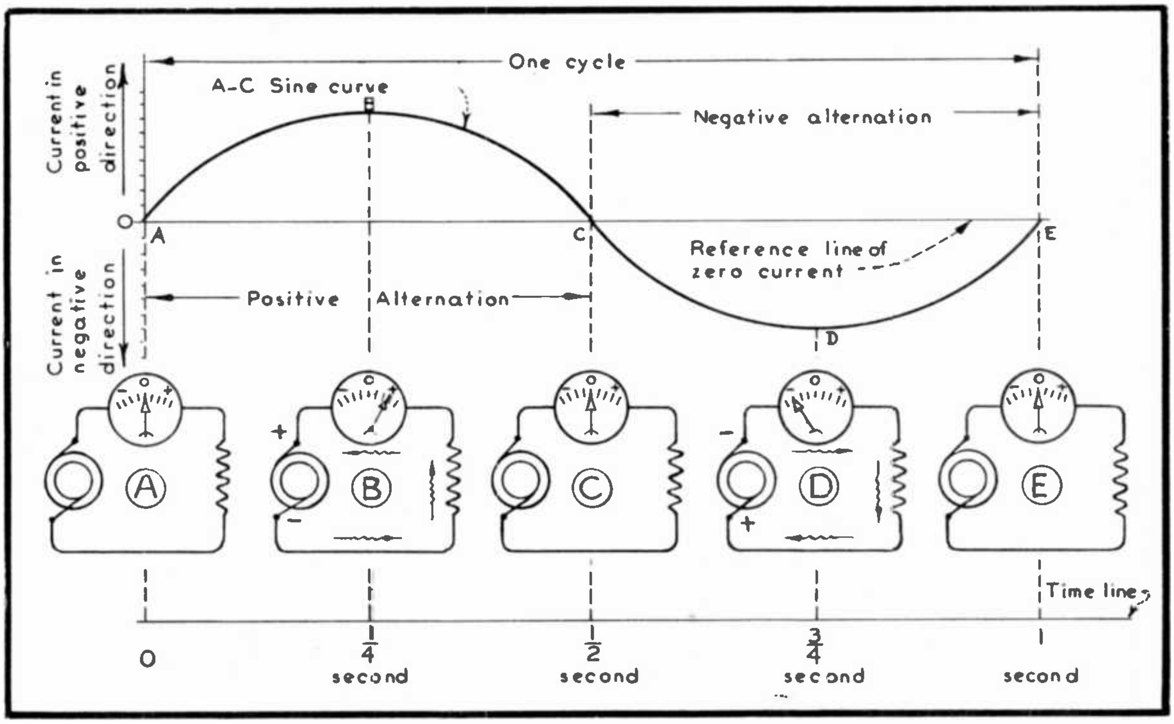

FIG. 10
GENERATION OF A SINE-WAVE CURVE

a positive alternation represents current flowing in one direction, while the negative alternation represents current flowing in the opposite direction.

CYCLE: Whenever two dissimilar alternations (one positive and one negative) of current or voltage follow one another in a circuit in succession, or are shown together as a sine wave as in Fig. 10, we call the combination of the two a CYCLE.

Thus, a cycle of a-c is composed of two alternations; one of them being positive, and the other negative. Or, to put it another way: A cycle can be said to represent the action which takes place from (A) to (E) of Fig. 10. During one complete cycle of a-c, current will increase from zero to a maximum value in one direction--decrease from maximum to zero in this same direction -- increase from zero to maximum in an opposite direction -- and then again decrease to zero.

FREQUENCY: "Frequency" is a word which we use in connection with a-c to indicate how many complete cycles of a-c are being produced or generated in a given length of time. This length of time is nearly always one second. In Fig. 10, for example, where we have shown the development of one complete cycle of a-c current during one second of time, we could say that the generator is producing cycles of a-c at the rate of one each second; or, that it is producing a-c at a frequency of one cycle per second. In practical radio and electronic circuits we seldom encounter frequencies as low as one cycle per second, but we have used this frequency in our illustration for the sake of simplicity. We usually abbreviate cycles per second as "cps."

FREQUENCIES COMMONLY ENCOUNTERED IN POWER AND LIGHT CIRCUITS: Most electric light companies which sell power for the lighting of homes, offices, and factories--as well as for the operation of motors and other power-operated devices--supply this electrical energy at a frequency of 60 cps, and at a voltage of 110 volts. A higher voltage (220 volts) is often supplied at the same frequency (60 cps) for heavy-duty, power-operated machinery.

A-C IN RADIONICS

While low frequencies of a-c (60 cps) are used for heating the filaments of vacuum tubes in most radio and electronic equipment, such as the ordinary home radio receiver, many radionic circuits carry a-c of frequencies much higher than this. In fact, frequencies of several thousand, or even several million cycles per second, are common in this field. These very high frequencies of a-c are not generated by means of the electro-magnetic generator previously described in this lesson; but, rather by means of a device called an oscillator; which consists of a circuit in which is incorporated one or more electronic vacuum tubes. These circuits are described fully later in the course.

KILOCYCLE: If we wish to speak of a frequency higher than a few thousand cycles per second, we usually express it in terms of kilocycles per second--the prefix "kilo" meaning thousand. Thus, we would call a frequency of one million, five-hundred thousand cycles per second (1,500,000 cps) "fifteen hundred kilocycles per second," or 1500 kc--where kc is the abbreviation for kilocycles. Obviously, the latter method is much more convenient.

MEGACYCLE: If we are dealing with frequencies as high as several million cycles per second, we express them in terms of megacycles per second--the prefix "mega" meaning million. Thus, a frequency of ten million cycles per second (10,000,000 cps) is equal to "10 megacycles," or, 10 mc--where mc is the abbreviation for megacycles.

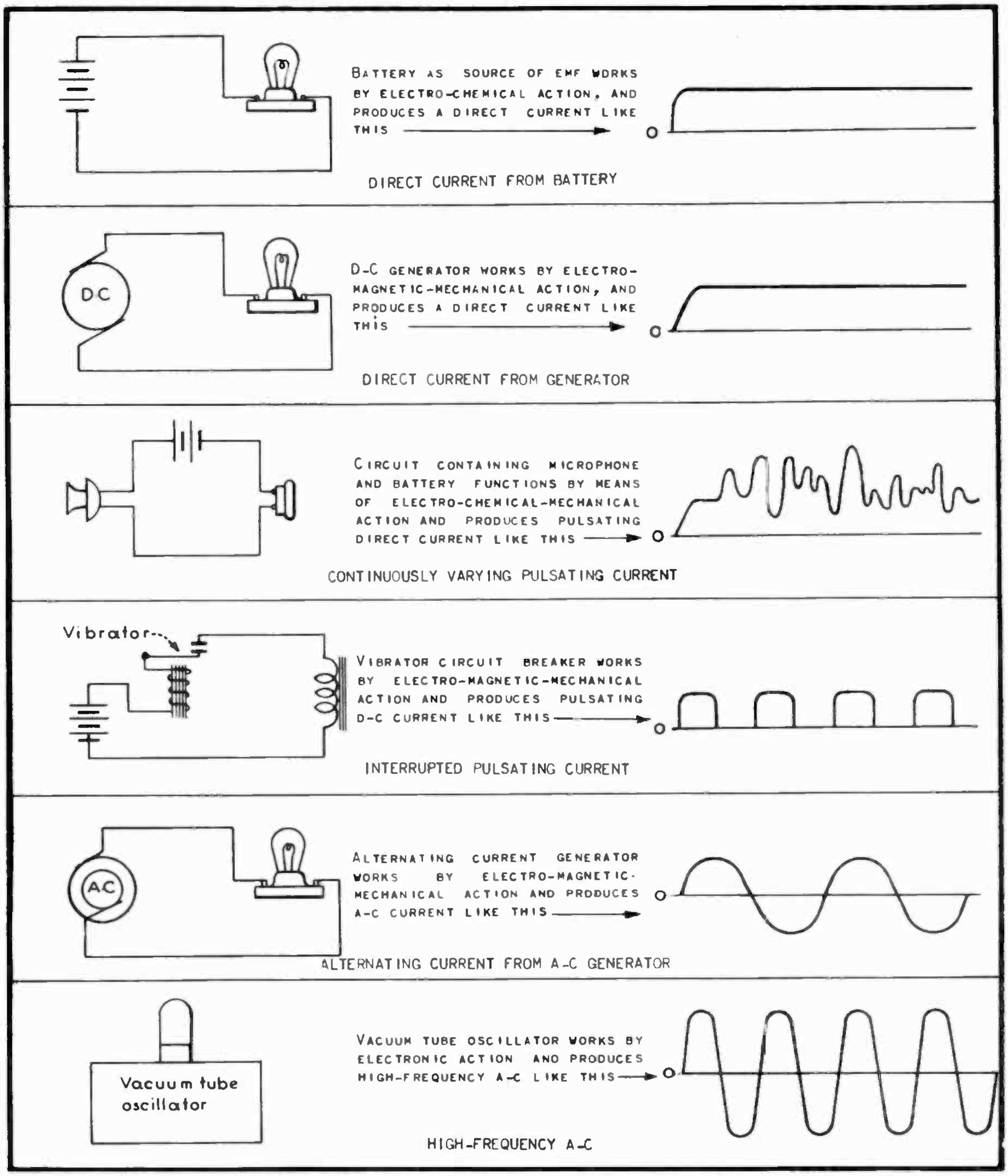

FIG. 11
COMPARISON OF D-C, PULSATING AND ALTERNATING CURRENT

SUMMATION: Fig. 11 shows in an easy-to-compare form, the three fundamental types of current--namely direct current, pulsating current, and alternating current--together with some of the means by which they may be produced. The accompanying curves illustrate the action of each type of current. Study this illustration carefully, as it is self-explanatory.

PEAK AND EFFECTIVE VALUES OF A-C

In our analysis of Fig. 10, you learned that the value of an alternating current varies constantly from minimum to maximum and back to minimum, in both a positive and negative direction. Point B in the sine curve of Fig. 10, represents the maximum positive current and voltage; and point D on the same curve represents the maximum negative current and voltage. These maximum values are often called peak values.

That value of alternating current which is equivalent to a direct current that produces the same heating effect, under exactly similar conditions, is called the effective value of the alternating current; and is measured in amperes. Actually, the effective value of an alternating current is equal to 0.707 of the maximum value when the current has a sine wave form. Similarly, the effective emf of an a-c voltage is equal to 0.707 of the maximum voltage.

For example, the effective voltage of an a-c emf, having a maximum or peak voltage of 150 volts, is 0.707 times 150 or 106.05 volts. And, the effective current corresponding to an alternating current having a maximum value of 75 amperes is 0.707 times 75 or 53.025 amperes. In other words, an alternating current having a maximum value of 75 amperes would have the same heating effect as a direct current of 53.025 amperes.

Radionic technicians often speak of effective voltage and current as RMS values. It is to be noted, also, that ordinary a-c voltmeters and ammeters indicate effective (RMS) values when connected to a-c circuits.

For the present, this is all you need to know about maximum and effective voltage and current. Later in the course, you will receive more advanced instruction on this subject.

UTILIZATION OF PULSATING AND A-C CURRENTS

Pulsating and alternating current may be used, as is direct current, for the production of heat, light and power. The higher frequencies of a-c make it possible for us to transfer energy through space in the form of radio and television programs. The field of medicine employs exceedingly high frequencies of a-c in the treatment of the sick and injured by means of radio-therapy. The great war weapon, Radar, makes use of very high frequencies of a-c in detecting objects, many miles distant.

MUTUAL INDUCTION

One of the most valuable features of alternating current is that by its use we can:

1. - Transfer electrical energy from one circuit to another nearby circuit without the need for any direct electrical connection between the two circuits.

2. - Step-up or step-down voltages by means of simple electromagnetic devices known as transformers.

In preceding lessons of this course you learned that whenever a current of electricity is moving in a circuit, a magnetic field is built up around the conductor; and that this field will be maintained at a constant intensity as long as the flow of current remains steady or uniform in value. When the supporting current ceases to flow, due to the opening of the circuit, or the removal of the applied emf, the lines of force collapse or recede back into the conductor of the circuit.

When a magnetic field is produced by a current of electricity, energy in the form of electricity is actually being converted into energy in the form of magnetism. It stands to reason, therefore, that if we can convert electrical energy to magnetic energy, we should also be able to convert magnetic energy back into electrical energy. And, this is exactly what we do in the case of mutual induction.

"Mutual induction" can probably best be defined as the action or method whereby current is caused to flow in a circuit by means of a magnetic field which is produced by current flowing in another nearby circuit.

TRANSFER OF ELECTRICAL ENERGY BY MUTUAL INDUCTION

In Fig. 12, you are shown how electrical energy can be transferred from one circuit to another nearby circuit by means of mutual induction. One of these circuits consists of a battery, a switch, and wire conductors--and is known as the PRIMARY CIRCUIT. The other consists of a galvanometer (a sensitive, current-indicating instrument), and a conductor shaped in the form of a continuous rectangular loop. The latter circuit is called the SECONDARY CIRCUIT.

At (A) of Fig. 12, the switch in the primary circuit has been suddenly closed. As current commences to flow and increase in value from zero to maximum in the primary circuit, as shown by the graph to the left of the circuit at (A), magnetic lines of force will form around the conductor of this circuit. As these lines of force are being built up from zero to maximum intensity, in accordance with the increasing current flow, they will extend outward from the conductor of the primary circuit and in so doing sweep across the nearby conductor of the secondary circuit. In sweeping across the secondary circuit, they will induce an emf in it. Proof of this is shown by a "kick" or deflection of the pointer in the galvanometer which is connected in the secondary circuit. The flow of current resulting from an induced voltage is called an induced current.

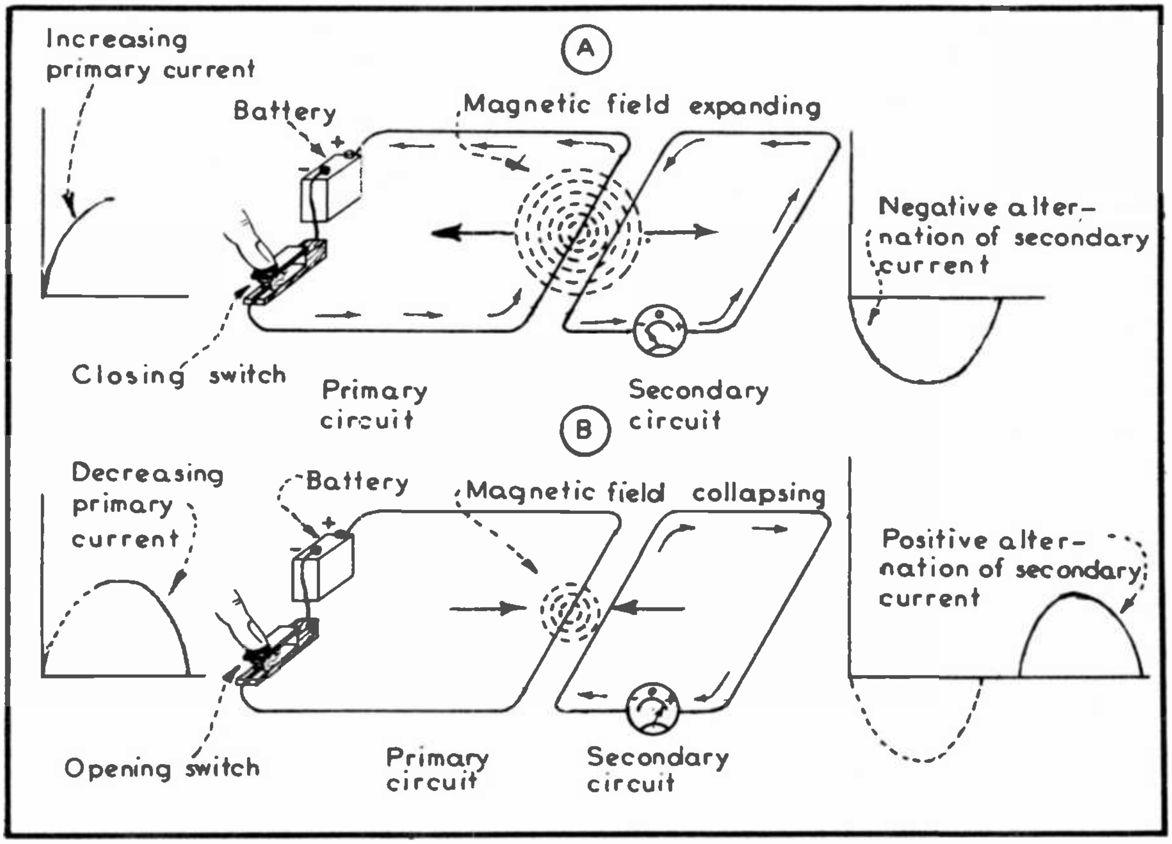

FIG. 12
PRINCIPLE OF MUTUAL INDUCTION

An important point to notice in illustration (A) of Fig. 12, is that the induced current in the secondary circuit flows in the opposite direction to that of the primary current. This is in accordance with a basic law of electricity known as Lenz's Law, which is:

> The direction of the induced emf is such that it tends to set up a current the magnetic field of which always opposes any change in the existing field.

The small graph appearing directly to the right of the circuit in illustration (A) of Fig. 12 shows how an impulse of induced current flows through the secondary circuit at the time the switch in the primary circuit is first closed. Notice how this induced current increases from zero to a maximum value and returns to zero again during the time that the primary current and corresponding magnetic field increase from zero to their maximum value.

At (B) of Fig. 12, the switch in the primary circuit has been suddenly opened. Therefore, current stops flowing in the primary circuit, and the magnetic lines of force recede or "collapse" back into the conductor of the primary circuit as the current decreases to a zero value. However, in collapsing, these lines of force again sweep across the conductor of the secondary, and induce an emf in the secondary circuit. This is also indicated by a deflection of the galvanometer pointer.

It is of particular interest to note that as the magnetic field collapses at (B), the induced current flows through the secondary circuit in a direction opposite to that at (A). This is shown by the graph at the right of Fig. 12-B, where the secondary impulse of (A) has been repeated as a dotted line. The reason for this current reversal is that during the collapse of the magnetic field, the lines of force sweep across the secondary circuit in a reverse direction to that when the field is building up. Thus, as the switch is closed and opened in rapid succession, we have a pulsating current in the primary circuit and an alternating current in the secondary circuit. Observe, also, how Lenz's Law applies during the collapse of the primary's magnetic field as well as during the building up of this field.

It should be noted that if the switch in the primary circuit be allowed to remain closed, a steady direct current will flow in the primary circuit, and a magnetic field of unvarying strength or intensity will be maintained around the conductor of the primary circuit. But, as long as the current and field of the primary circuit are steady, or non-varying in intensity, no voltage or current will be induced in the secondary circuit.

It is only when the magnetic field of the primary circuit is building up, or when it is collapsing, that an emf is induced in the secondary circuit. It follows then, that an emf is induced in the secondary circuit only at the instant the switch is closed, and again at the instant when the switch is opened, but not during a period while the switch is permitted to remain closed or open.

We could also say that an emf will be induced in the secondary circuit only at the time that the current in the primary circuit changes in value.

ELECTROMAGNETIC COUPLING

When two circuits are operating by mutual induction as in Fig. 12, we say that they are coupled magnetically, or that magnetic coupling exists between them. This is actually true, as the varying magnetic field is the means by which we transfer energy from the primary to the secondary circuit. Because this principle is known as "mutual induction," we often say that when two circuits are thus magnetically coupled, they are in inductive relationship, one with the other. Also, the phrase, "inductive coupling" is sometimes used in place of "magnetic coupling."

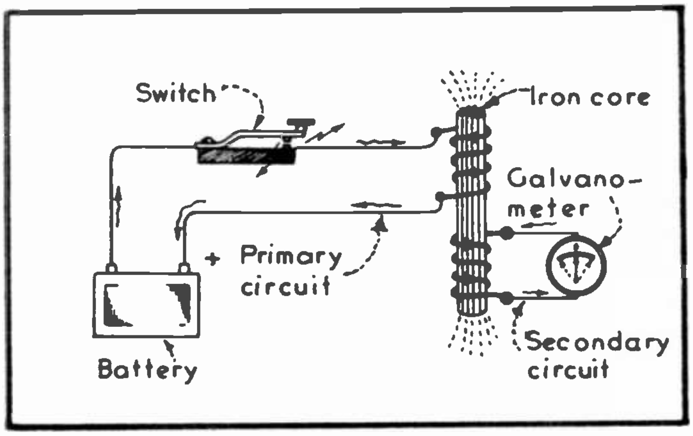

FIG. 13
INDUCTIVELY-COUPLED COILS

INDUCTIVE COUPLING BETWEEN TWO COILS: By inserting a coil of wire in each of the two circuits, we can concentrate the action of the magnetic field, which provides the means of coupling, within a smaller space and thus transfer a greater amount of energy from the primary circuit to the secondary circuit. Then, by placing an iron core through the centers of the two coils, so as to increase the number of lines of force surrounding the coils, we can increase still further the amount of electrical energy induced in the secondary circuit. This is shown in Fig. 13.

By checking the direction of the current flow in both the primary and secondary windings in Fig. 13, you will see how Lenz's Law applies to inductively-coupled coils. Here, the direction of current flow through the primary winding is such that this winding tends to set up a north magnetic pole at its upper end and a south magnetic pole at its lower end. However, the induced current in the secondary winding tends to set up a south pole at the upper end and a north pole at the lower end of this winding. Thus, the polarity of the secondary winding opposes the polarity of the primary winding whenever the current flow through the primary winding increases in value.

When the switch in Fig. 13, is opened, the induced current flows through the secondary winding in a direction opposite to that indicated by the arrows in the illustration. This condition tends to maintain a magnetic field of the same polarity as that originally established by the primary winding. Thus, we see that the polarity of the secondary winding is of like polarity as that of the primary whenever the current flow through the primary winding decreases in value.

PULSATING CURRENT AND MUTUAL INDUCTION

You will, no doubt, realize that if we substitute a source of continuously pulsating current for the hand-operated switch of Fig. 13, there will then be a constantly varying current in the primary circuit; and a constantly varying magnetic field around the coil connected in this circuit. Therefore, an emf will be induced continuously in the secondary circuit.

Such an arrangement is shown in Fig. 14, where a microphone, battery, coil, and a current-measuring instrument are connected in the primary circuit; and a headphone and current-measuring instrument in the secondary circuit. The two coils are inductively coupled, being placed on the same iron core.

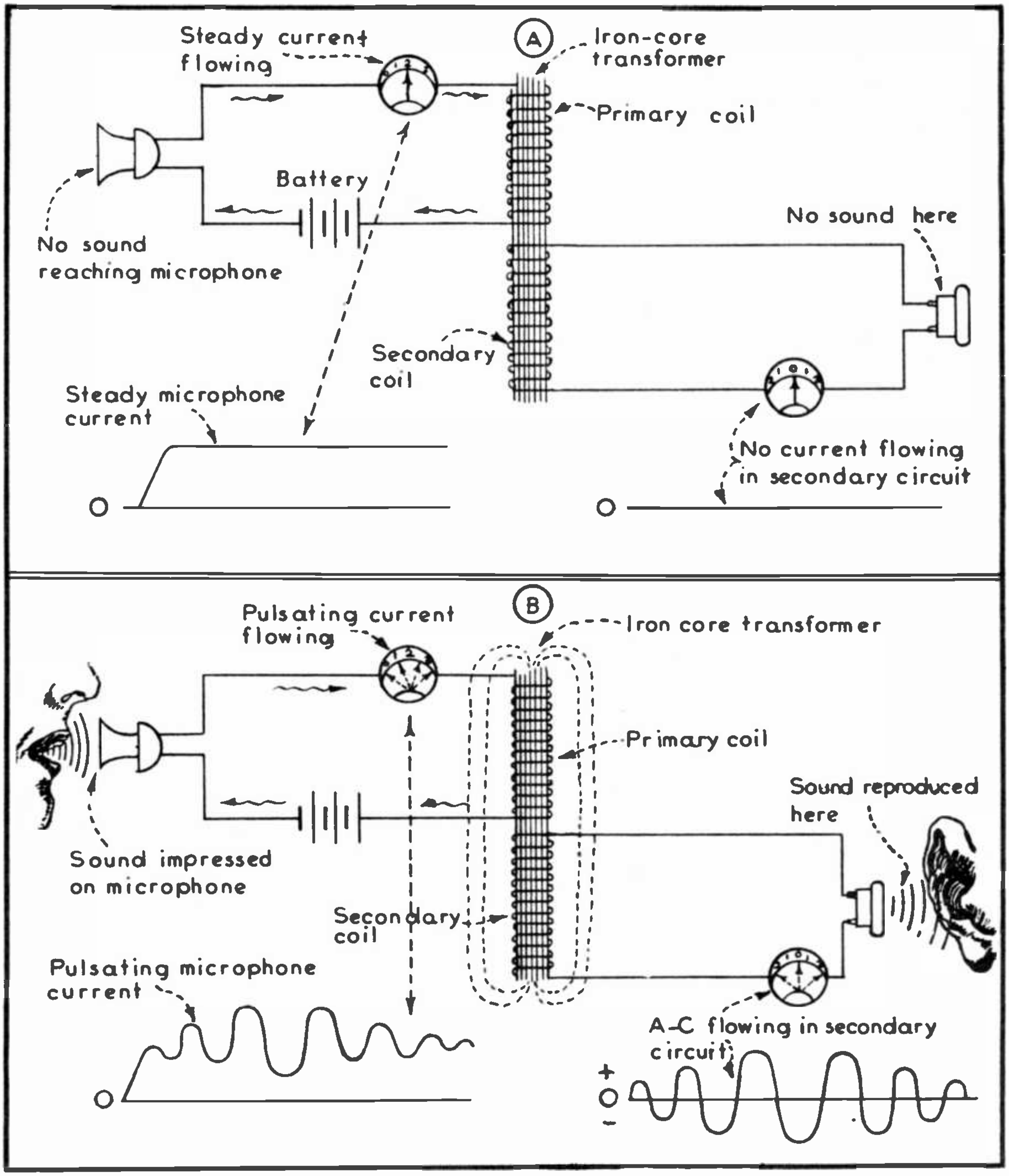

FIG. 14
MICROPHONE CIRCUIT EMPLOYING TRANSFORMER

At the time no sound is impressed on the diaphragm of the microphone, a steady flow of battery current will pass through the primary winding, as indicated by the steady deflection of the meter needle in this circuit, and also as shown by the graph in the lower left-hand corner of illustration (A). Under these conditions, the resulting magnetic field will be stationary, and therefore no voltage or current will be induced in the secondary circuit. Consequently, the meter in the secondary circuit reads zero, no indication of current appears in the graph for the secondary circuit at the lower right of the illustration, and no sound is reproduced by the headphone.

However, when sound is impressed upon the microphone, the current flow through the microphone circuit will vary in intensity for reasons previously given, and thereby produce a corresponding fluctuation in the magnetic field. The variation in current flow at this time will be indicated by oscillation of the meter needle in the primary circuit, and is also illustrated graphically at the lower left of illustration (B) in Fig. 14. The resulting varying magnetic field induces an alternating voltage in the secondary circuit, which voltage is illustrated graphically at the lower right of (B). Under such conditions, the sounds that originally actuated the microphone will be reproduced by the headphone. Here, again, we have pulsating direct current in the primary circuit and alternating current in the secondary circuit.

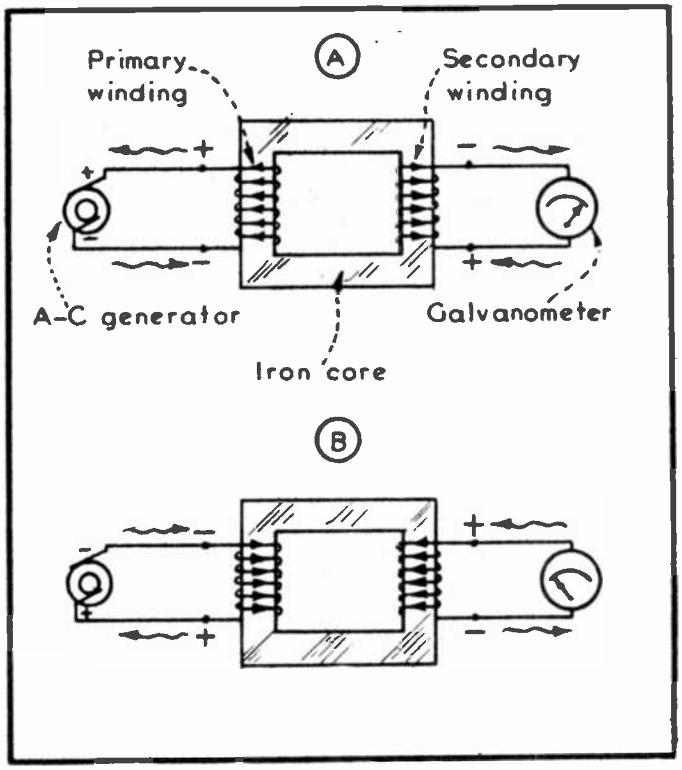

FIG. 15
A-C APPLIED TO PRIMARY

A-C AND MUTUAL INDUCTION

If a source of a-c emf be applied to the primary, an a-c emf will be induced in the secondary just as when pulsating current flows through the primary; except that the two circuits will operate with somewhat greater efficiency. That is, a greater voltage and current will be induced in the secondary circuit when a-c is supplied to the primary.

In Fig. 15, we have a set-up similar to that appearing in Fig. 13, with the exception that the two inductively-coupled coils (windings) are placed on a closed-type iron core, and a-c instead of interrupted d-c is now being applied to the primary winding. Under such conditions, the current flow through the primary winding will vary continuously in both intensity and direction. At (A) of this illustration you are shown conditions as they exist while the current through the primary winding is increasing in value in one direction, while illustration (B) shows what takes place as the current through the primary winding is increasing in value in the opposite direction. Notice, also, how the secondary voltage reverses in step with the reversals of primary current, and how the polarity of the secondary winding is opposite to that of the primary winding at such times.

Whenever the primary current decreases in value in any one direction, the induced current in the secondary winding, caused by the collapse of the magnetic field, will reverse its direction of flow; and will then tend to maintain a magnetic field of the same polarity as that originally established by the primary winding during the same alternation of the a-c cycle. All of these actions conform with Lenz's Law which was previously given.

TRANSFORMERS

The primary and secondary coils of Fig. 15, together with the core, constitute a device which is known as a <u>transformer</u>. Transformers of many different types and forms are used in radionic equipment. For example, the average home radio receiver, which is one of the most common radionic devices in use today, contains transformers of several different types.

A typical iron-core transformer, designed for use in a radio receiver, is shown in Fig. 16, together with the standard transformer symbol.

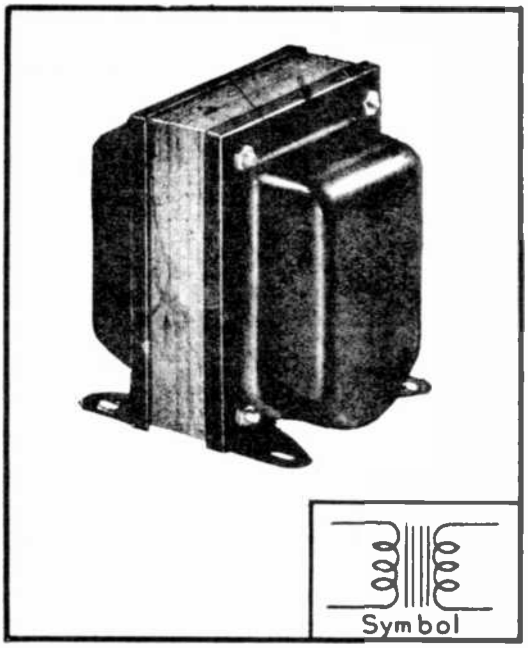

FIG. 16
IRON-CORE TRANSFORMER

A transformer will function only if pulsating current, or alternating current is flowing in its primary winding. No transfer of electrical energy will take place in a transformer, or in any other inductively coupled circuit, if only pure direct current is flowing through the primary circuit.

The frequency of the emf applied to the primary circuit has a great deal to do with the action and efficiency of transformers. Briefly, the higher the frequency of the applied emf, the greater will be the amount of electrical energy transferred from the primary to the secondary--provided, of course, that the construction of the transformer is such that the unit is capable of operating efficiently at the higher frequencies. If the construction of the transformer is not suited to operation at higher frequencies, applying a high frequency to it will cause it to overheat.

<u>IRON-CORE AND AIR-CORE TRANSFORMERS</u>: It is to be noted that although we generally speak of "iron" as being used for transformer cores; actually, special types of steel are employed for the purpose. Such steel (often called "transformer steel") is ideally suited to this use because it conducts magnetic lines of force readily and also permits the lines of force to reverse their direction without too much opposition when the current flow through the windings reverses its direction.

These cores are "built-up" of thin sheets or strands of steel, called <u>laminations</u>, that are insulated from each other by insulating varnish. Such <u>laminated cores</u> (Figs. 18 and 19) enable the transformer to operate with less generation of heat than would a solid steel core.

If the frequency of the applied pulsating or alternating emf be high enough, the iron core may be dispensed with (see Fig. 17). The particular transformer in Fig. 17 is known as a "solenoid-type r-f transformer," and is employed extensively in radio receivers. Air,

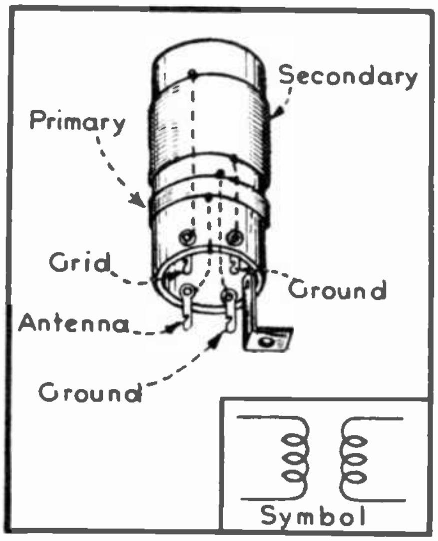

FIG. 17
R-F TRANSFORMER

which serves as a "core" in this case, does not retain magnetism to the extent as does transformer steel; therefore the reversals of the magnetic field can "keep up" more easily with the high-frequency alternating current that is flowing through the windings.

The core material does not affect the basic theory of transformer operation. All transformers function according to the same theory, and all behave according to a few simple rules or principles.

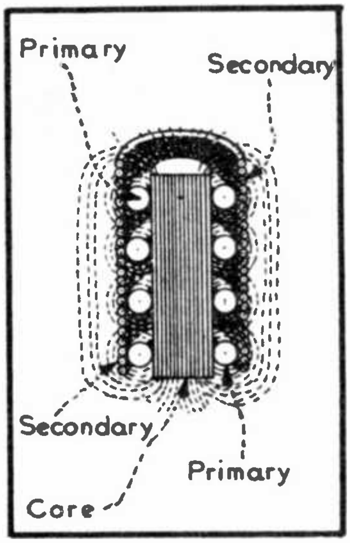

FIG. 18
OPEN-CORE TRANSFORMER

OPEN-CORE TRANSFORMERS: Open-core transformers have straight cores which are in the form of a "bundle" of soft iron or mild steel wires. These cores are less efficient, but more economical to build, than are the closed-type cores. Their use is confined to small transformers where efficiency is not as important as economy. Typical examples of open-core transformers are the step-up transformers as used in some automobile ignition systems (usually called "ignition coils").

The principle of construction as found in open-core transformers is illustrated in Fig. 18. The secondary winding in this case consists of many more turns of wire than are on the primary. And, the secondary is here wound on top of, though insulated from, the primary.

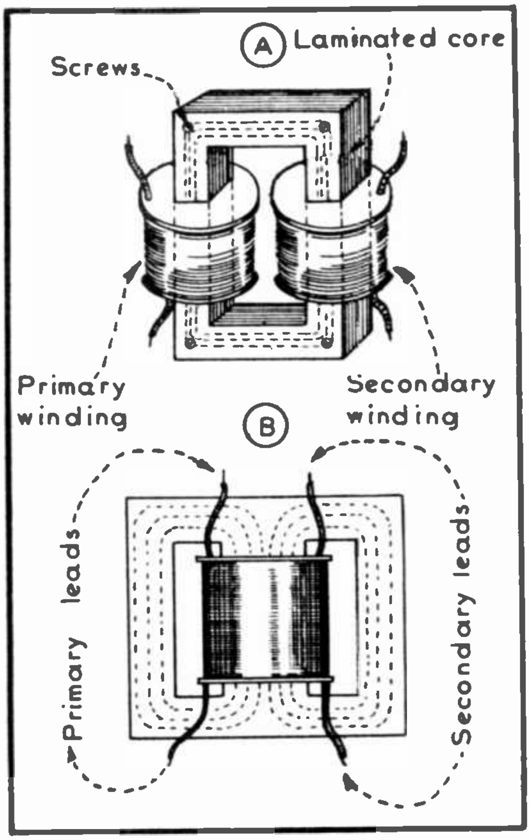

FIG. 19
CLOSED-CORE TRANSFORMER

CLOSED-CORE TRANSFORMERS: Closed-core transformers are much more efficient in operation than are the open-core types, and are used more in practice. The fact that the cores are designed so that they are "closed" provides a continuous path through iron, for the magnetic lines of force--thus enabling a given current in the primary winding to build up a greater number of lines of force, with which to induce voltage in the secondary.

In Fig. 19 are shown two varieties of closed-core transformers. On some transformers of the type appearing at (A) of Fig. 19, the primary winding is placed on one leg of the core, and the secondary winding on the other leg, as here shown. However, in other cases, the secondary winding is wound on top of the primary, and the entire coil assembly placed on one leg of the core. The other leg will then not have any winding on it. It should be noted that in transformer (B) of Fig. 19, the primary and secondary windings are both wound on the central section or "leg". The paths followed by the magnetic lines of force are indicated by means of dotted lines at both (A) and (B).

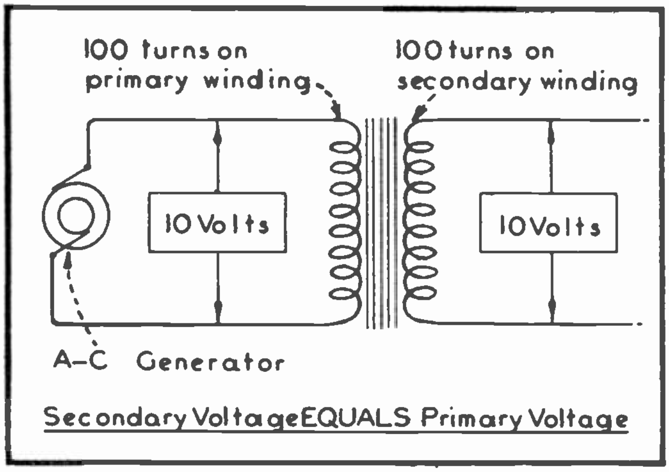

FIG. 20
ONE-TO-ONE TRANSFORMER

TRANSFORMER VOLTAGES

As was mentioned in a previous paragraph, it is possible by means of transformers to:

1.- Step-up the secondary voltage so that it is greater than that of the voltage applied to the primary.

2.- Step-down the secondary voltage so that it is less than that of the voltage applied to the primary.

3.- Have the voltage developed across the secondary exactly equal to the voltage applied to the primary.

ONE-TO-ONE TRANSFORMERS

In Fig. 20, we have a simple iron-core transformer with an a-c emf of 10 volts applied to the primary The primary and secondary windings each consist of 100 turns of wire. An a-c voltmeter, connected across the secondary winding, would indicate that an emf of 10 volts appears across the secondary winding.

The arrangement in Fig. 20 thus demonstrates that if the number of turns of wire on the secondary winding of a transformer is exactly equal to the number of turns on the primary winding, the voltage developed across the secondary winding will be equal to the voltage applied to the primary. We call such a transformer a "one-to-one" transformer, meaning that it has a 1-to-1 voltage ratio; or, that for every volt applied to the primary, 1 volt is developed across the secondary.

USES FOR ONE-TO-ONE TRANSFORMERS: One-to-one transformers are used chiefly when it is desired to operate an electrical apparatus at line voltage, but where it is not desirable to connect the apparatus directly to the line (main lighting or power circuit). The transformer thus serves as a means for electrically isolating the line from the load circuit so that an accidental short in the latter will not directly short circuit the line as well.

STEP-UP TRANSFORMERS

Another simple iron-core transformer is shown in Fig. 21. This transformer has more turns of wire in the secondary winding than it has in the primary winding. To be exact, there are 100 turns on the primary and 300 turns on the secondary. In this case, we find that with the same 10 volts applied to the primary, 30 volts will now appear across the secondary. This is a "three-time" increase, or step-up in voltage.

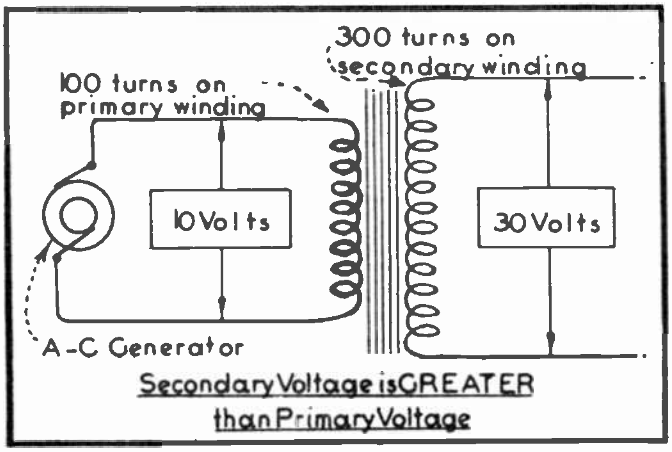

FIG. 21
STEP-UP TRANSFORMER

From this demonstration, we learn that if there are more turns of wire on the secondary than there are on the primary, the voltage across the secondary will be greater than that across the primary winding. A transformer of this type is said to be a step-up transformer.

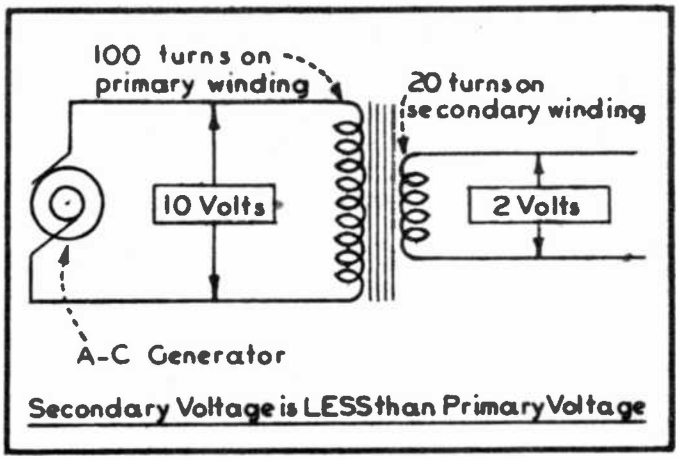

FIG. 22
STEP-DOWN TRANSFORMER

Since in the above example, there are 100 turns on the primary and 300 turns on the secondary winding, or three turns of wire on the secondary for every turn on the primary, this transformer is said to have a turns-ratio of 3 to 1. And, since in this same example the voltage across the secondary winding is three times that across the primary winding, we also have a voltage-ratio of 3 to 1. This latter, also, is a three-time increase--that is, for each volt applied to the primary, three volts are developed across the secondary.

RULE: The voltage across the secondary of a transformer, which is functioning under normal conditions, will always compare to the voltage across the primary as the number of turns on the secondary winding compare to the number of turns on the primary.

CURRENT VALUES IN STEP-UP TRANSFORMERS: Always, and unavoidably, when voltage is stepped up by means of a transformer, the current (amps) in the secondary is less than that in the primary. It is never possible to step-up both voltage and current, by means of a transformer.

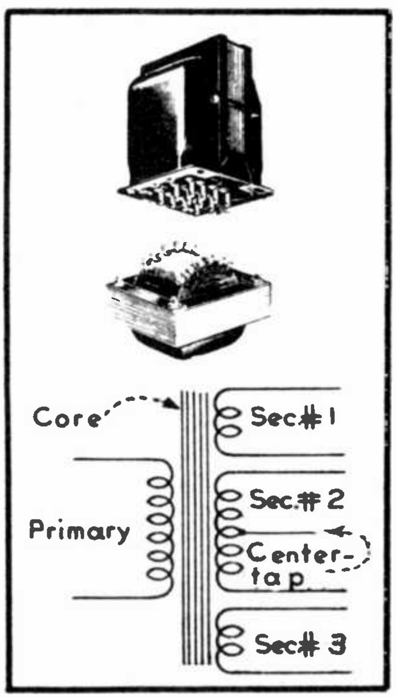

FIG. 23
RADIO POWER TRANSFORMER

USES FOR STEP-UP TRANSFORMERS: Step-up transformers may be used anywhere that it is desired to increase an alternating or pulsating voltage. Typical applications of this are the power transformers used in radio sets, and the transformers--often called "ignition coils"--that are employed to supply high-voltage electricity (the "spark") in automobile ignition systems.

STEP-DOWN TRANSFORMERS

The transformer in Fig. 22 will step-down the secondary emf to a value below that of the primary emf. In this case, there are 100 turns on the primary winding and 20 turns on the secondary. Ten volts are applied across the primary; and a voltmeter would show that an emf of 2 volts is developed across the secondary. Thus, with less turns on the secondary winding than there are on the primary, we have caused the voltage across the secondary winding to be of a lower value than that across the primary. This, then, is a step-down transformer.

From this example, we learn that whenever a transformer contains fewer secondary turns than it does primary turns, the secondary voltage will be lower than the primary voltage. And, since in this particular example there are 100 turns on the primary winding and 20 turns on the secondary, or one turn on the secondary for each 5 turns on the primary, the turns ratio is 1-to-5; but, in this case it is a step-down ratio. Again, we see that the voltage across the secondary compares to the voltage applied to the primary as the number of turns on the secondary compares to the number of turns on the primary.

CURRENT IN STEP-DOWN TRANSFORMERS: Voltage step-down transformers differ from voltage step-up transformers in that it is often possible to have a greater current (amperes) in the secondary circuit than there is in the primary circuit. That is, as the secondary voltage decreases, the permissible secondary current drain increases.

USES FOR STEP-DOWN TRANSFORMERS: Voltage step-down transformers are used just as extensively as are voltage step-up transformers. Transformers which supply power for electron tube filaments are step-down transformers, as also are ordinary door bell transformers.

TRANSFORMERS WITH MORE THAN ONE SECONDARY WINDING

In Fig. 23 are shown pictures of two styles of radio power transformers and also a schematic diagrar of such a transformer that has three secondary windings. In multi-secondary transformers, just as in the simple two-winding transformers that we have described up to this point, the voltage across each secondary winding will compare to the voltage applied across the primary winding as the number of turns in each secondary compares to the number of turns in the primary.

In the transformer illustrated by the diagram in Fig. 23, secondary winding #1 consists of a few turns of rather heavy wire, and furnishes an emf of 6.3 volts.

Secondary winding #2 (called the "high-voltage winding") is composed of a great many turns of fine wire. A lead for connection to the external circuit is attached to it so that the number of turns between this connection and one end of the winding is equal to the number of turns between this same connection and the other end of the winding. We therefore logically call this connection a "center tap". An emf of 350 volts is available between the center tap and each end of the winding, and 700 volts between the two ends.

Secondary winding #3 in this case consists of a few turns of heavy wire, and furnishes an emf of 5 volts.

Obviously, the voltages available from the secondary windings of transformers as just described will vary with the requirements of the receiver in which the particular transformer is to be used.

The principles just covered are basic in nature and will be applied repeatedly in electronic circuits throughout this course. It is therefore imperative that you master this lesson in its entirety, and that you remember all of the important facts presented herein.

At first, some of the theories concerning a-c may appear to be somewhat complex, but they will all gradually become clearer as you progress with your studies. In fact, in a very short time you will think of them in terms of nothing more than common, natural laws that must be complied with in order for any piece of radio or electronic equipment to operate.

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LESSON NO. 5

RESISTORS-CONDENSERS-COILS

As you progress farther into the interesting field of radio and electronics, you will find that the greater part of your work and studies has to do with circuits containing RESISTORS, CONDENSERS, and COILS.

The effect of resistors (resistance) in an electrical circuit has already been mentioned in this course. In this lesson, we will give you some additional information on resistors, as well as an introduction to, and an explanation of, the action of condensers and coils in d-c, a-c and pulsating-current circuits. You will then be ready to apply this knowledge to the radio and electronic equipment discussed in the following lessons.

RESISTORS

A resistor is an electrical device which is placed in a circuit for the purpose of reducing, or limiting, the current flow in the circuit. Resistors, as used in radio and electronics in general, are classified into two basic types -- fixed resistors and variable resistors.

FIXED RESISTORS: In Fig. 1 you are shown what are known as wire-wound, fixed resistors. These resistors comprise a coil of special high-resistance wire wound on a porcelain tube or on a strip of mica. The standard symbol for fixed resistors appears at the bottom of Fig. 1.

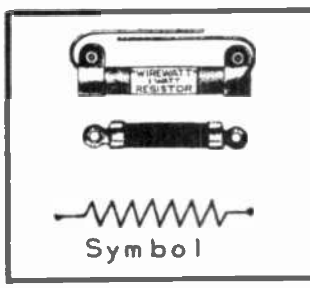


FIG. 1
WIRE-WOUND
FIXED RESISTOR

Examples of carbon resistors are presented in Fig. 2. Carbon resistors are made of a carbon rod, with a connector affixed to each end; and are generally painted in colors, arranged in the form of a code to indicate their value in ohms. (Note: complete details concerning this code are given later in the course). The same symbol is employed for carbon resistors as for wire-wound resistors. Commercial fixed resistors are manufactured in a great many different values, ranging from fractions of an ohm to several million ohms (megohms).

VARIABLE RESISTORS: Variable resistors --- as their name suggests --- are so constructed that their value in ohms can be varied at will.

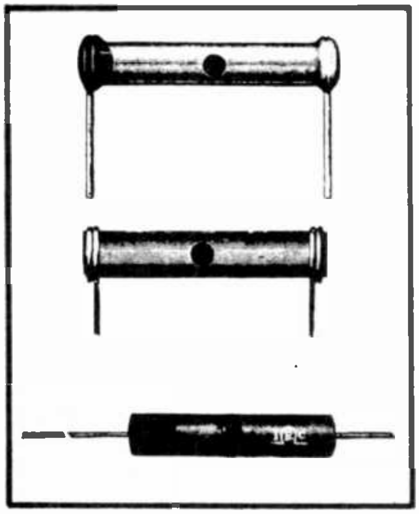


FIG. 2
CARBON FIXED RESISTORS

One form of variable resistor, together with its symbols, is shown in Fig. 3. This resistor consists of a special resistance wire wound on a porcelain tube, and provided with terminals at each end. A metal clip contacts the bare, exposed portion of the resistance wire, and can be slid along the length of the tube and locked in any position desired. Thus, the amount of resistance included between either one of the end-terminals and the slider terminal can be varied.

Other forms of variable resistors, known as potentiometers, (pronounced po-ten-chee-ah-meters), appear in Fig. 4. In this case, the resistance element (wire or carbon) is shaped to conform with the circumference of a circle, and is provided with a terminal at each end. A slider, operated by a shaft, contacts different points on the resistance element when the shaft is rotated by hand.

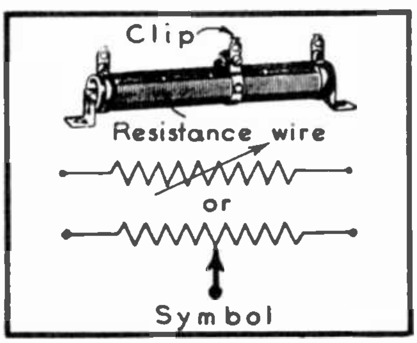


FIG. 3
VARIABLE RESISTOR

The symbol for a potentiometer is also included in Fig. 4. The arrow of the symbol represents the slider.

One of the potentiometers in Fig. 4 has a switch incorporated in it. This switch is electrically independent of the resistance element of the assembly, but is operated by the same shaft that regulates the resistance of the potentiometer.

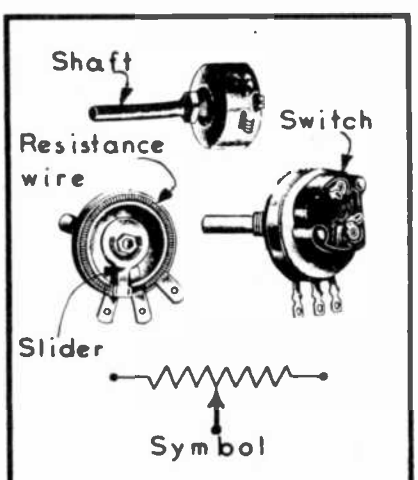


FIG. 4
POTENTIOMETERS

PRINCIPLE OF THE RHEOSTAT: In Fig. 5 is shown a typical application of a potentiometer as a rheostat. Here, you will observe that as a rheostat, only two terminals are utilized -- the slider (center) terminal and one of the end-terminals of the resistance element.

In the particular example illustrated in Fig. 5, the rheostat is being employed for the purpose of controlling the amount of current flow through the filament of a radio tube. Notice how the circuit connections are such that only that portion of the resistance element between terminals #1 and #2 is included in the circuit; and that the farther the slider is moved toward the right, the greater will be the amount of resistance included in the tube's circuit. Consequently, the filament current is reduced as the slider is moved toward the right, and is increased as the slider is moved toward the left.

PRINCIPLE OF POTENTIOMETERS: The principle of the potentiometer is demonstrated in Fig. 6,

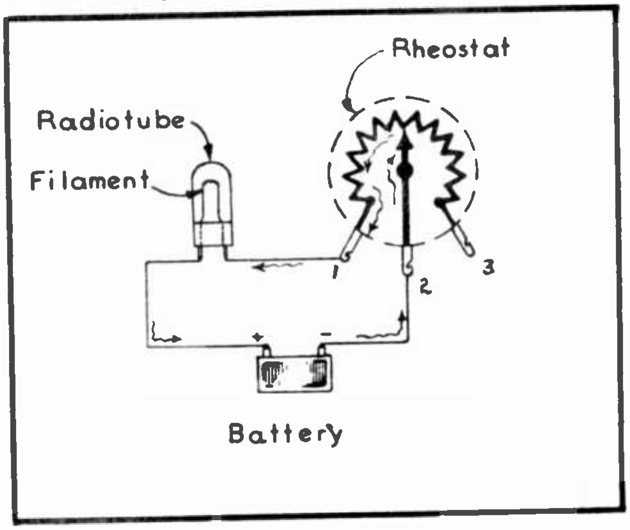


FIG. 5
PRINCIPLE OF RHEOSTAT

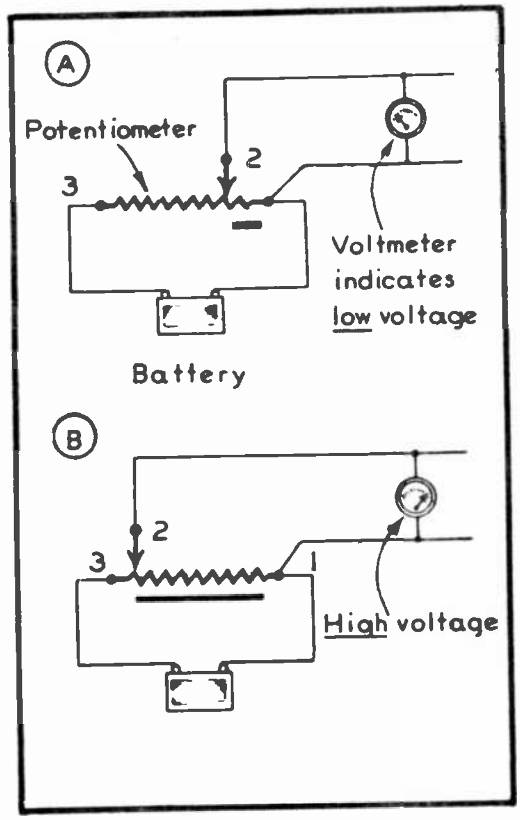


FIG. 6
PRINCIPLE OF POTENTIOMETER

where the end-terminals of the potentiometer (terminals #1 and #3) are connected across the terminals of the battery.

When the slider of the potentiometer (2) is rather close to end #1 of the resistor element as at "A", only a very small part of the resistor element is included between these two points as indicated by the short, heavy line below the resistor element. You will also notice in this illustration that an appreciable amount of resistance is included between points #2 and #3, and which is now effectively connected in series with the voltmeter and the scurce of voltage. Under such conditions, a low voltage will be indicated by the voltmeter that is connected between points #1 and #2.

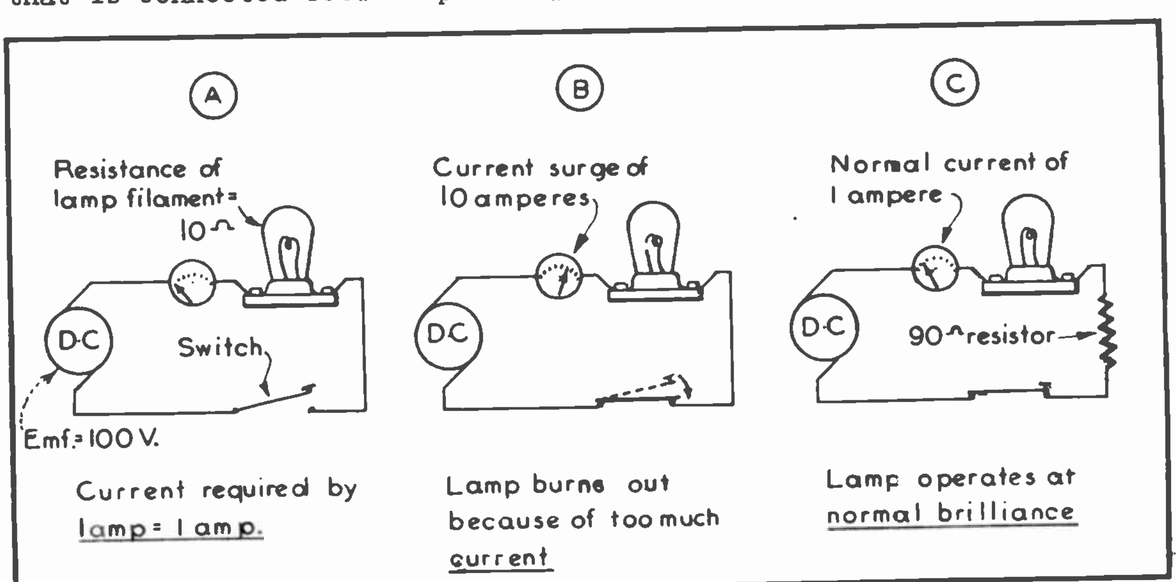


FIG. 7
HOW A RESISTOR ACTS IN A D-C CIRCUIT

As the slider is moved farther toward the left (see "B" of Fig. 6) more resistance will be included between terminals #1 and #2, as indicated by the increased length of the heavy line directly below the resistance element in this illustration. At the same time, the resistance between points #2 and #3 is reduced, and the meter is more nearly connected directly across the source of voltage. Therefore, a greater voltage will now appear between terminals #1 and #2.

Thus, it is apparent that by slowly rotating the shaft of the potentiometer, the voltage available between terminals #1 and #2 can be varied in a gradual manner.

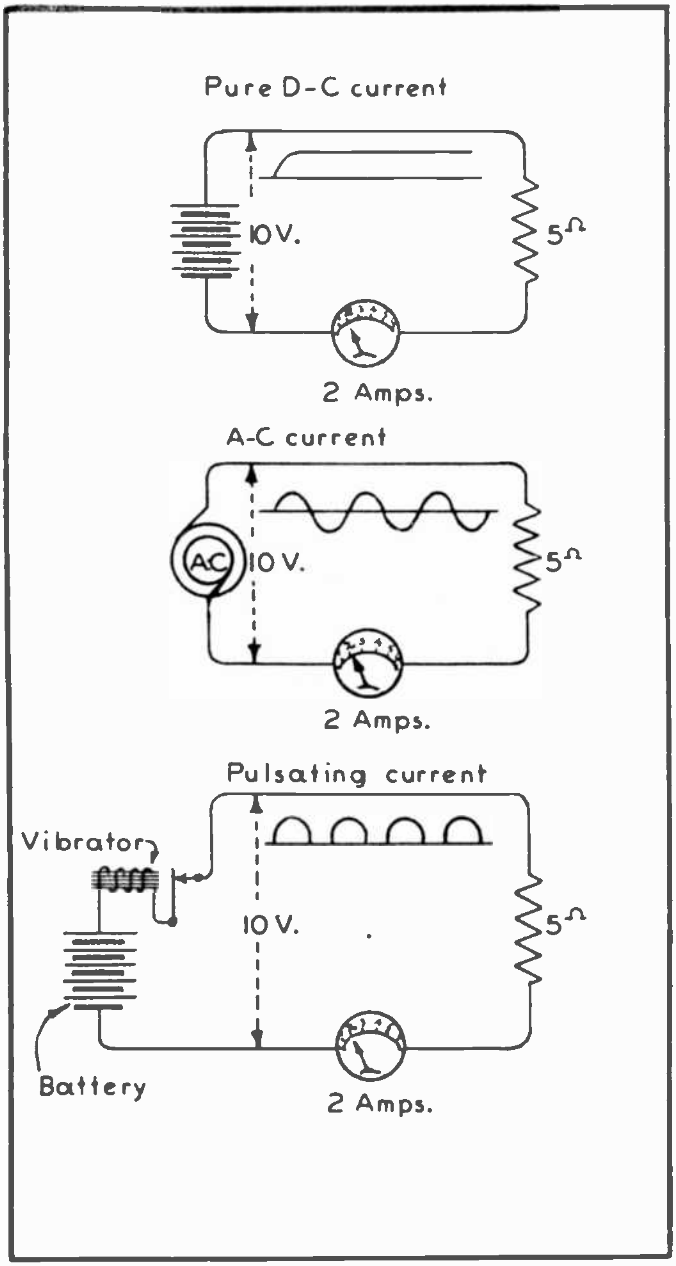


FIG. 8
EFFECT OF RESISTANCE IN D-C, PULSATING OR A-C CIRCUIT

APPLICATION OF RESISTORS

One of the simplest and most common uses of a resistor is illustrated in Fig. 7. At "A" you are shown a circuit in which a lamp is connected to a d-c generator through a switch and ammeter. The filament of this lamp has a resistance of 10 ohms and the normal current required by the lamp is 1 ampere.

Now, if we were to connect the lamp directly to the generator which is developing an emf of 100 volts, we know -- by Ohm's Law -- that 10 amperes of current will surge through the lamp. (Note: 100 divided by 10 equals 10.) This momentary surge of current exceeds the normal lamp current sufficiently to burn out the filament, as at "B". At "C", we have the same basic circuit, with the exception that a current-limiting resistor of 90 ohms has been connected in series with it. The total resistance of the circuit is now 90 ohms (the resistor value) plus 10 ohms (the lamp resistance), or 100 ohms. We find by applying Ohm's Law that 100 volts divided by 100 ohms, or 1 ampere, will flow through the circuit.

Notice, particularly, how the addition of the 90-ohm resistor in this circuit controls the current flow so that it will not exceed the normal value for the circuit, when a given voltage is applied.

ACTION OF RESISTORS IN D-C, PULSATING CURRENT AND A-C CIRCUITS

All types of current are affected by a resistor of a given value in the same manner, or to the same extent. This is true whether the circuit is carrying pure direct current, pulsating current, or alternating current. Thus, if a resistor of 90 ohms will reduce the direct current in circuit "C" of Fig. 7 by 9 amperes when 100 volts d-c is applied, it would have the same effect if an alternating or a pulsating voltage were involved. This is illustrated in Fig. 8, where a comparison is shown of resistor action in circuits carrying these three types of current. Notice that the current flow in all three of these circuits is exactly alike.

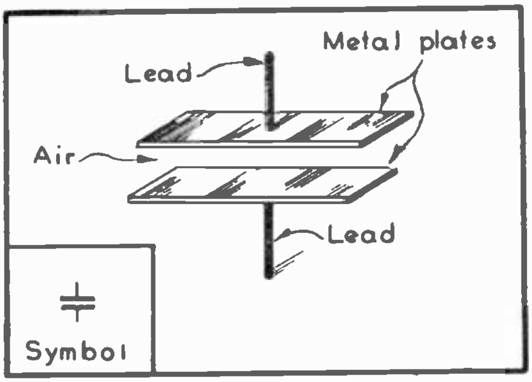


FIG. 9
SIMPLE CONDENSER

CONDENSERS

Almost all electronic or radionic equipment contains a number of condensers. In fact, the average home radio contains as many as from ten to twenty condensers of different types. It is also of interest to note that almost 50% of all servicing of modern radio receivers consists of locating and replacing defective condensers.

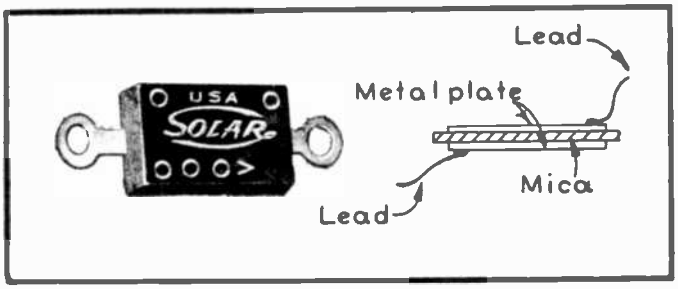


FIG. 10
MICA CONDENSER

Basically, a condenser is a storage device for electrical energy. That is, a condenser may have electrical energy applied to it from some external source of emf -- accumulate a charge -- hold this charge for an appreciable length of time after the source of emf has been removed -- and then discharge this energy at a later time.

A condenser in its simplest form consists of two or more conducting plates separated from each other by good insulating material such as sheet mica, waxed paper, a non-conducting gas, or air. A condenser of this type, employing air as the insulating material, is shown in Fig. 9, together with the standard condenser symbol.

The condenser shown in Fig. 10 is known as a "mica

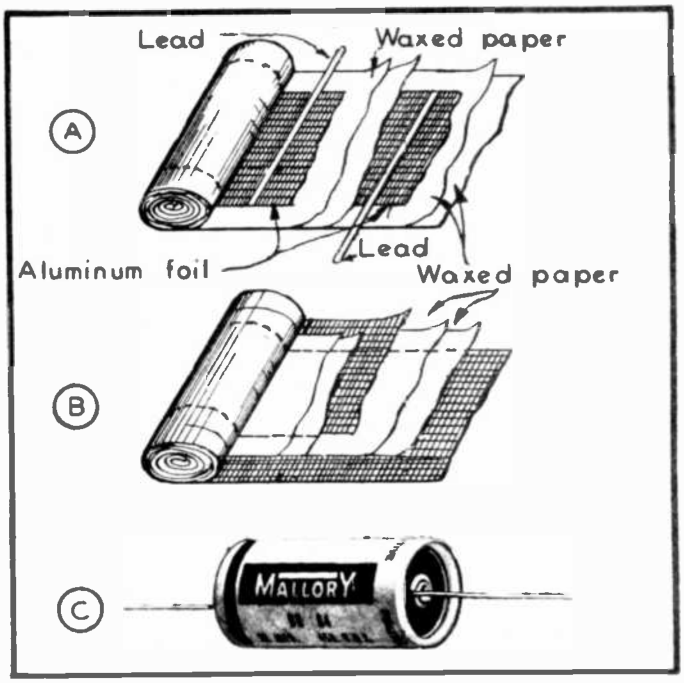


FIG. 11
CARTRIDGE-TYPE (PAPER) CONDENSER

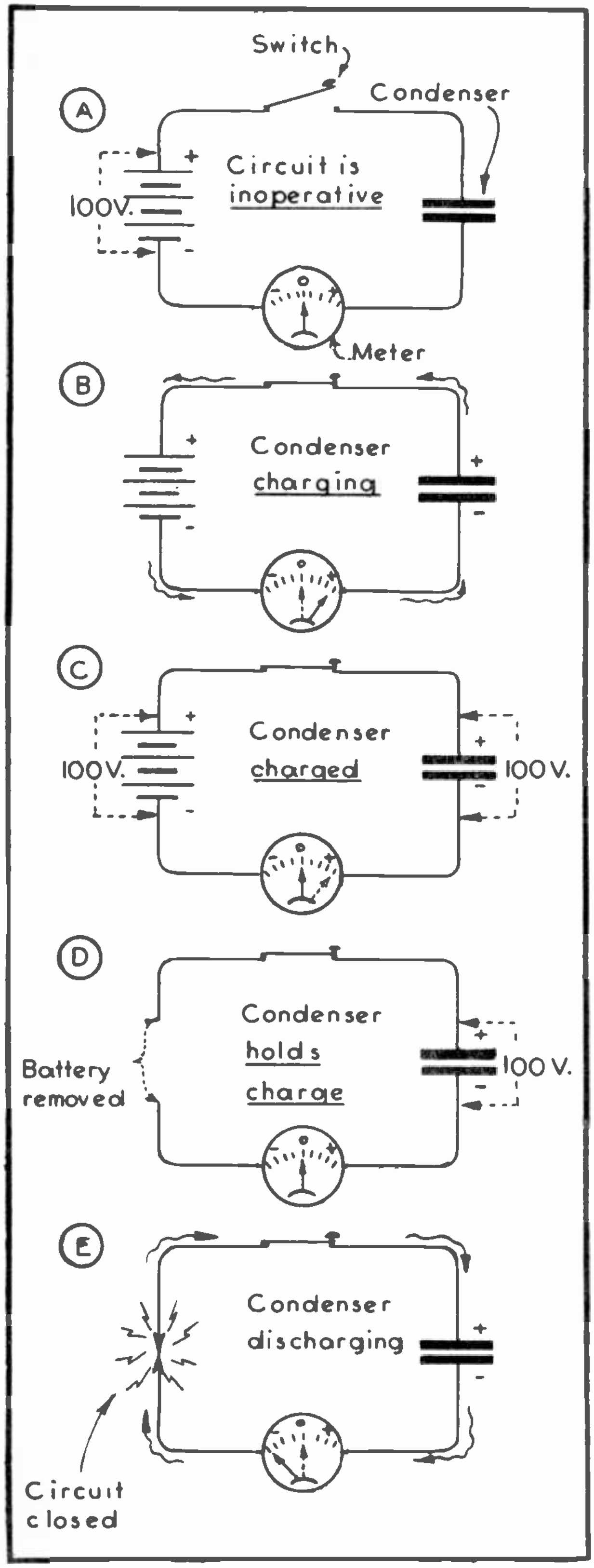


FIG. 12
CHARGING AND DISCHARGING A CONDENSER

condenser" because mica is used as the insulating material (dielectric) between the two metal plates, as illustrated at the right in Fig. 10. The entire assembly is usually housed in a molded bakelite case, with terminal lugs or leads provided at each end so that the condenser can be connected to the radio circuit conveniently.

Another common form of condenser construction is shown in Fig. 11. This condenser consists of two pieces of thin aluminum foil, separated from each other by waxed paper or cellophane as at "A" of Fig. 11. This whole sandwich of foil and paper is rolled up to form a compact cartridge-shaped condenser, as at "B" of Fig. 11; and since paper is used as the dielectric, such condensers are often classed as "paper condensers". Quite often, instead of bringing out both connectors at the same end of the condenser, they are brought out at opposite ends, as at "C" of Fig. 11, where the rolled element has been placed in a cylindrical cardboard container.

Since the capacity value of the condensers shown in Figs. 9, 10 and 11 cannot be altered after manufacture, they are called fixed condensers. Later in the course, you will learn about other forms of condensers. Those already illustrated will serve adequately to illustrate the principles involved, and with which we are most concerned at this time.

CHARGING A CONDENSER

The charging action of a condenser is illustrated in Fig. 12. At "A" you are shown the condenser connected in series with a current-indicating meter, switch, and a source of d-c emf of 100 volts.

At "B", the switch has been closed, thus connecting the meter and condenser to the battery. At the instant the switch is closed, the pointer on the meter will be deflected -- thus showing that current is flowing from the battery to the condenser.

If the switch is permitted to remain closed, the pointer of the meter will, after a short time, gradually return to the zero mark on the scale; thus indicating that current flow between the battery and condenser has stopped. When this happens, the condenser is said to be completely charged. That is, the condenser has built up a charge of electrical energy, the voltage of which is exactly equal to the applied battery voltage. And, since the two voltages are now exactly equal in value, but opposing in polarity, no more current will flow in the circuit. This is shown at "C" of Fig. 12.

At "D", the battery has been removed from the circuit. The condenser is now in a "charged" condition, and is applying an emf to the remaining portion of the circuit. This charge in the condenser may be retained for several minutes to several hours, depending upon the quality of the condenser.

DISCHARGING A CONDENSER

At "E" of Fig. 12, the wires which formerly connected the condenser to the battery have been touched together (shorted) -- thus, again forming a complete circuit through the switch, meter, and condenser. At the instant the two wires are touched together, the pointer of the meter will be deflected; thus showing that current is now flowing through the circuit from the condenser. As this discharge action continues, the meter reading will gradually approach zero. When the meter pointer returns to zero, we know that the condenser has discharged all of its stored energy through the circuit. The condenser is then said to be discharged.

When a condenser is discharging through a circuit, as at "E" of Fig. 12, the discharge current will flow in the circuit until the condenser is completely discharged. This current may be used to perform useful work, such as lighting a lamp or energizing an electromagnet, just as any other d-c current; but, of course, for a limited time, because it is discharged very rapidly under such conditions.

ELECTRON THEORY OF CONDENSER ACTION

Fig. 13 shows exactly what happens while a condenser is being charged and discharged. Here, we have at "A" an illustration of the condenser when in its normal or discharged state. When in this condition, an equal number of free electrons fill the two plates of the condenser.

CHARGING ACTION: Now, when the source of emf (battery) is connected to the circuit, the negative terminal of the battery repels free electrons, and the positive terminal attracts them. Therefore, electrons move through the circuit away from the negative terminal and toward the positive terminal of the voltage source, as indicated by the arrows at "B".

The electrons cannot flow through the insulation which separates the plates of the condenser. But the repelling effect of the negative battery terminal attempts to force them through it. So we have, then, a heavy charge of electrons accumulating on one of the plates of the condenser. The excess of electrons (negative electrical charges) on this plate cause it to become highly negative in character and to repel the electrons in the other plate of the condenser. Electrons which are thus forced away from this other condenser plate drift through the circuit toward the positive battery terminal. This is also shown at "B".

This condition leaves the condenser with a heavy accumulation of electrons on one of its plates, and very few electrons on the other plate. Or, we could say that the one plate now has a high negative charge impressed upon it, while the other plate is highly positive due to an absence of electrons. The plate which has the high negative charge is called the negative plate; and that which has the high positive charge is called the positive plate. Notice that the negative plate of the condenser is always the one which is connected to the negative terminal of the source of emf, and that the positive plate is always the one which is connected to the positive terminal of the source of emf.

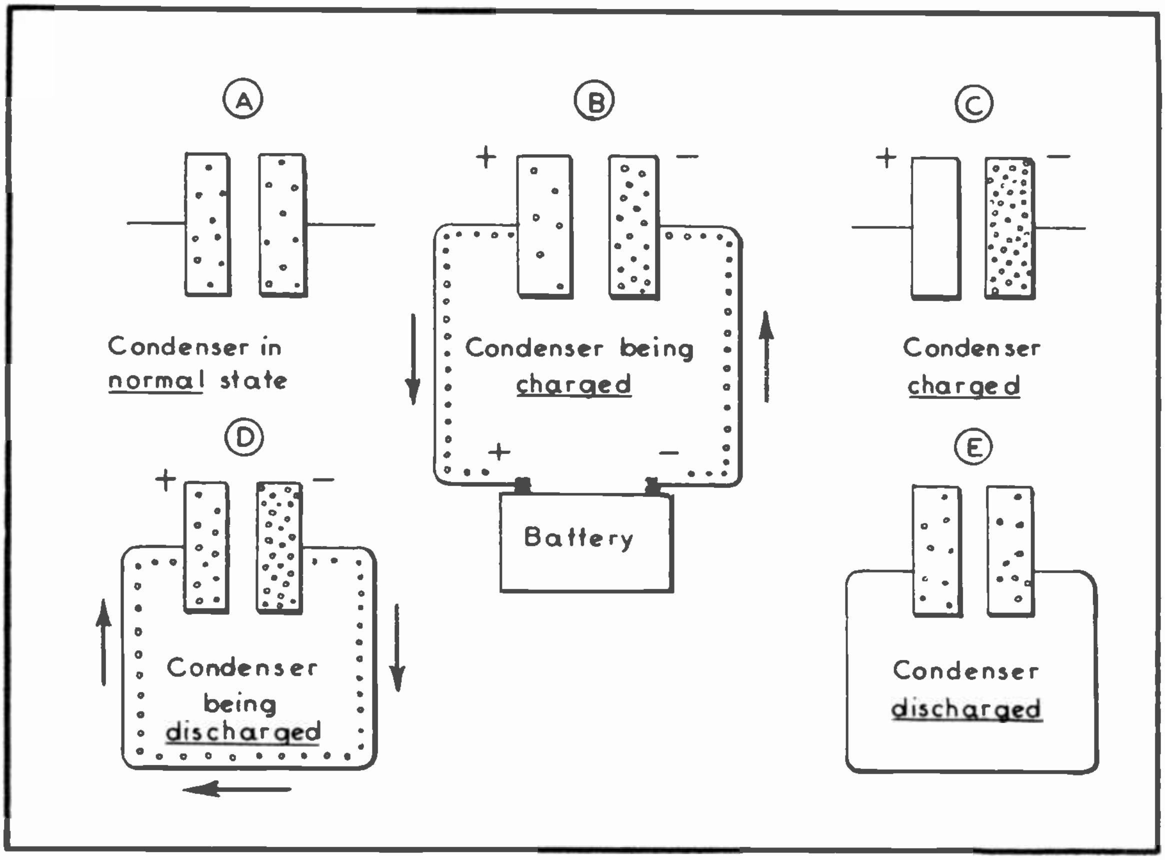


FIG. 13
CHARGING AND DISCHARGING ACTION OF CONDENSER

When the charging source of emf is disconnected as at "C", the condenser is left in a state of electronic unbalance; that is, with one plate highly negative and the other highly positive. There is then a constant attempt being made by the electrons on the negative plate to return to the positive plate from whence they came. However, they are prevented from doing this because of their inability to pass through the insulator which is placed between the plates. A condenser in this condition is said to be charged, or to possess an electrostatic charge. And, since the charge on the condenser opposes the voltage applied by the source, we say that a charged condenser offers a counter electromotive force (counter-emf, or C.E.M.F.).

DISCHARGING ACTION: The instant that an electrical connection is made between the plates, as at "D" of Fig. 13, the excess electrons on the negative plate will return to the positive plate. They do this by moving through the circuit in the form of an electric current. When a sufficient number of electrons have traveled through the circuit to the positive plate so that the charges on the two plates are again in exact electronic balance, there will be no further flow of current (electrons), and the entire circuit will then be electrically "dead" as at "E".

OSCILLATORY NATURE OF CONDENSER DISCHARGE

It is interesting to note that when a condenser discharges, as just described, the discharge action is oscillatory in nature. By oscillatory, we mean that a condenser while discharging does not reach a state of zero charge instantly.

Actually, when the discharge begins, electrons leave the negative plate at such speed that more electrons travel to the positive plate than are needed to neutralize the positive charge at that point. These excess electrons then surge back and forth through the circuit, between the negative and positive plates, in ever-diminishing numbers over a brief but appreciable period of time, until a state of perfect electronic balance is finally attained, and at which time all electron movement stops. It is this oscillatory nature of a condenser discharge that makes it possible for the simplest of radio transmitters to function.

CONDENSER TERMS

DIELECTRIC: The insulating material which separates the plates of a condenser is known as the dielectric. Typical condenser dielectrics are listed in Table I. You will note that several different materials are employed for this purpose, their selection being dependent upon the use to which the condenser is to be put.

TABLE I
COMMON CONDENSER DIELECTRICS
WAXED PAPER
CELLOPHANE
MICA
GLASS
OIL
AIR
NON-CONDUCTING GASES

CAPACITY: The capacity of a condenser is an indication as to the quantity of electrical energy that the condenser will store when a certain value of emf (voltage) is applied to it. Capacity is dependent upon: (1) Dielectric material; (2) Thickness of dielectric -- which also determines the distance between the plates; (3) Area of plates. In the case of some condensers which have more than one positive and one negative plate, the total number of plates also influences the effective plate area.

Briefly, we can say that the better the insulating quality of the dielectric, the thinner the dielectric (the less the separation between plates), or the larger the plate area, the greater will be the capacity of the condenser.

Poor insulating quality of the dielectric, unduly thick dielectric (greater separation between plates) and small plate area tend to reduce the capacity of a condenser.

UNIT OF CAPACITY: The capacity, or ability of a condenser to store electrical energy is measurable, and is expressed by a unit called the FARAD. If the voltage across a condenser is raised one volt by a charging current of one ampere flowing into the condenser for one second, the condenser has a capacity of one farad. Thus, a condenser which is so built as to be rated at two farads will have a greater capacity than would a condenser rated at one farad.

As the farad is a rather large unit which would seldom be encountered in practical radio and electronic circuits, a smaller unit, the microfarad is more commonly used. One microfarad is equal to 1/1,000,000 or the one-millionth part of one farad. In radionics, we often employ condensers, the capacities of which are expressed in terms of micromicrofarads. One micromicrofarad is equal to 1/1,000,000 or the one-millionth part of one microfarad. The unit "microfarad" is often abbreviated to "mfd" or "mf", and the unit "micromicrofarad" to "mmfd" or "mmf". The symbol for capacity or capacitance is the capital letter "C".

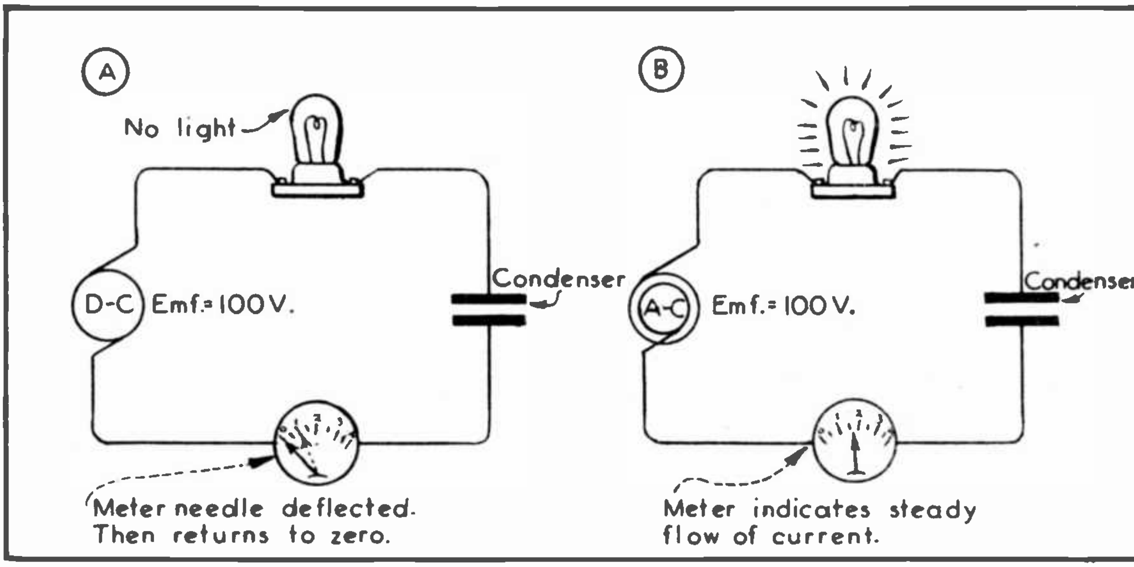


FIG. 14
EFFECT OF CONDENSER IN D-C AND A-C CIRCUIT

EFFECT OF CONDENSER ON DIRECT CURRENT

At "A" of Fig. 14, we have a simple circuit much like those described in the resistor section of this lesson. Here, the d-c generator is applying 100 volts to the circuit, the lamp does not glow, and the ammeter reads zero. Thus, we see that current will not flow in a series circuit containing a condenser, when a d-c emf is applied. Therefore, we can say that a condenser will block the passage of direct current through a circuit.

Of course, there will be a very brief surge of current in this circuit, when the emf is first applied. But this surge of current will stop as soon as the condenser has acquired a charge in the manner described previously. However, if the dielectric of the condenser happened to be deficient in its insulating qualities, there would be a steady leakage of current through the condenser and circuit.

EFFECT OF CONDENSER ON ALTERNATING CURRENT

The same basic circuit is shown at "B" of Fig. 14, as at "A", with the exception that an a-c generator is now applying 100 volts to the circuit. In this case, the lamp is glowing brilliantly and the ammeter indicates that current is flowing.

This shows that while a condenser will block the passage of a direct current, it will, with some opposition, permit the passage of alternating current. Or, we could say that a condenser connected in series with an a-c circuit will function very much in the manner of a resistor, permitting current to flow in controlled amounts. Condensers are often used in a-c circuits for this purpose.

You might well ask at this point, "Does the alternating current actually pass through the condenser?" The answer is No! No current of any kind ever flows through a condenser unless the condenser is defective. It is the alternate charging and discharging action of the condenser that permits a continuous series of current surges to flow through the circuit in which it is connected. This is illustrated in Fig. 15, where an a-c generator is shown as being connected across the plates of the condenser. The solid portion of the sine curve directly above each of the circuits in Fig. 15 illustrates the portion of the a-c cycle being considered at the time.

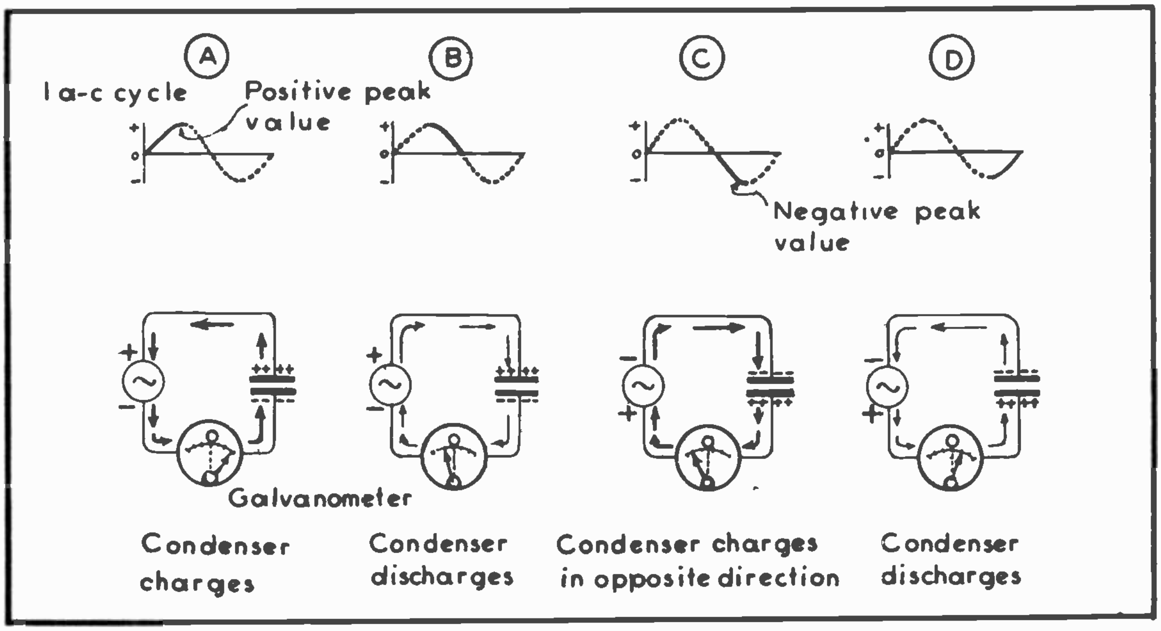


FIG. 15
ACTION OF CONDENSER IN A-C CIRCUIT

At the instant pictured at "A" of Fig. 15, we find the polarity of the generator to be such that electrons are caused to flow in the direction indicated, thereby charging the condenser so that its upper plate becomes positive; and the lower plate negative. When the voltage across the condenser plates becomes equal to the generator voltage, this charging current will stop due to the opposing effect of the condenser voltage toward the generator voltage.

Then, as the generator voltage diminishes, the condenser will commence to discharge through the generator winding, as at "B" of Fig. 15. As soon as the generator voltage reaches zero value, the condenser will discharge at a rapid rate.

The generator will now commence to build up a voltage of opposite polarity and thus charge the condenser in the opposite direction, as at "C". When the condenser is fully charged in this direction, it will again oppose the generator voltage; and will discharge through the generator as the latter's voltage once more approaches a value of zero (see "D" of Fig. 15). Thus, the charging and discharging of the condenser during one a-c cycle is pictorially illustrated in Fig. 15. This sequence will repeat itself in successive order as long as the a-c voltage is applied across the condenser plates.

From this explanation you can see that a condenser permits a flow of alternating current, but that this current does not actually flow through the dielectric of the condenser. In other words, the alternating current simply flows back and forth through the circuit from one condenser plate to the other as the condenser undergoes a charge and discharge when subjected to a-c voltage. Because of the fact that an alternating current flows in a circuit in which a condenser is connected, it is quite common to say that a condenser permits an alternating current to flow "through" it. However, what we really mean is that the condenser permits an alternating current to flow through the circuit in which it is installed, rather than through the condenser itself.

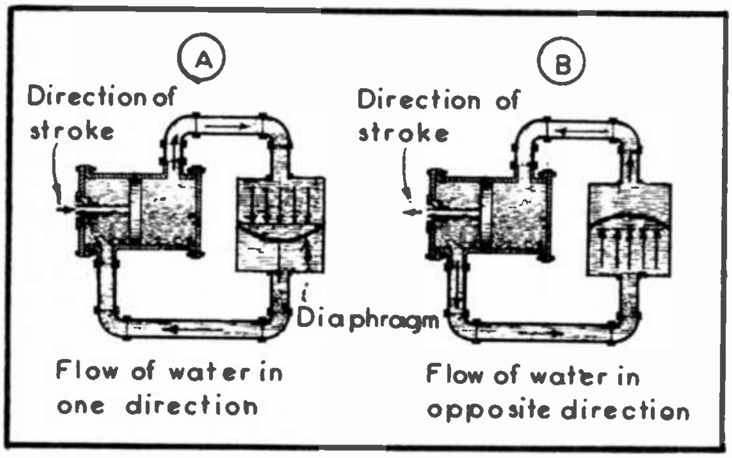


FIG. 16
HYDRAULIC ANOLOGY OF ALTERNATING CURRENT FLOW IN A CIRCUIT CONTAINING A CONDENSER

This action of the condenser permitting a flow of alternating current in a circuit, in which it is connected, can be compared with the water system illustrated in Fig. 16. Here, we have a closed circuit of pipes, completely filled with water; and also containing a piston-pump and a flexible diaphragm. As the piston moves towards the right at "A" of Fig. 16, it forces water through the upper passage of the pump and causes the diaphragm to bend downward. At the same time, the water displaced by this downward movement of the diaphragm is drawn into the pump housing through the lower passage.

When the piston moves toward the left, as at "B" of Fig. 16, water is forced out of the pump housing through the lower passage and causes the diaphragm to bend upward. The water displaced by this upward movement of the diaphragm flows into the pump housing through the upper passage. Notice, especially, that as the piston moves back and forth repeatedly, there will be a continuous reversal of water flowing through the system, but that at no time does the water ever flow through the diaphragm.

The pump in this system can be compared to the generator in an a-c electrical circuit; the diaphragm can be compared to the dielectric of a condenser; and the reversing flow of water can be compared to alternating current. Thus, just as an alternating current of water can flow through this system of pipes without actually flowing through the diaphragm, so also can an alternating current of electricity flow through a circuit containing a condenser without actually flowing through the dielectric of the condenser.

EFFECT OF CONDENSER ON PULSATING CURRENT

Fig. 17 shows a simple telephone circuit. At the time the diaphragm is not being acted upon by sound waves, a normal current of constant intensity will flow through the circuit and no sound will be emitted by the headphones. But, as soon as sound waves are impressed upon the microphone's diaphragm, the current will increase and decrease with respect to its normal value---resulting in a pulsating current somewhat as illustrated in the upper section of Fig. 17. This pulsating current will actuate the headphone diaphragms and so reproduce the sound accepted by the microphone.

If we were now to install a condenser in this circuit (indicated by the dotted condenser symbol) sound acting upon the microphone would not be reproduced. The reason for this is that a condenser will block the flow of d-c, regardless of whether it be non-varying or pulsating in nature.

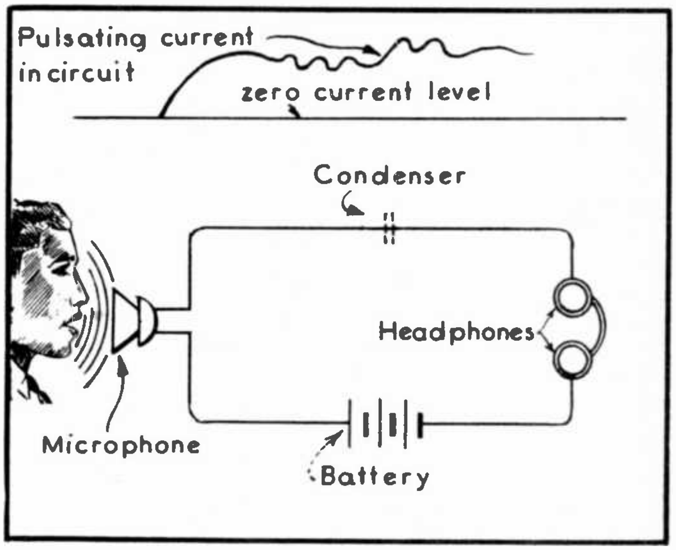


FIG. 17
EFFECT OF CONDENSER IN PULSATING D-C CIRCUIT

CAPACITIVE REACTANCE

You have been shown that a condenser in an a-c circuit will function as a current-limiting device. The amount of opposition offered to the flow of alternating current by a condenser is expressed in units of capacitive reactance. We use the term "capacitive reactance" rather than "resistance" so that there can be no confusion between the opposition offered to alternating current flow by a condenser, and that offered by a resistor. The opposing effect of the latter is called pure ohmic resistance. The symbol for capacitive reactance is "X_C".

The reactance or opposition which is offered to a flow of alternating current by a condenser is expressed in ohms. Thus, the "ohm" is used as a unit of capacitive reactance as well as a unit of resistance.

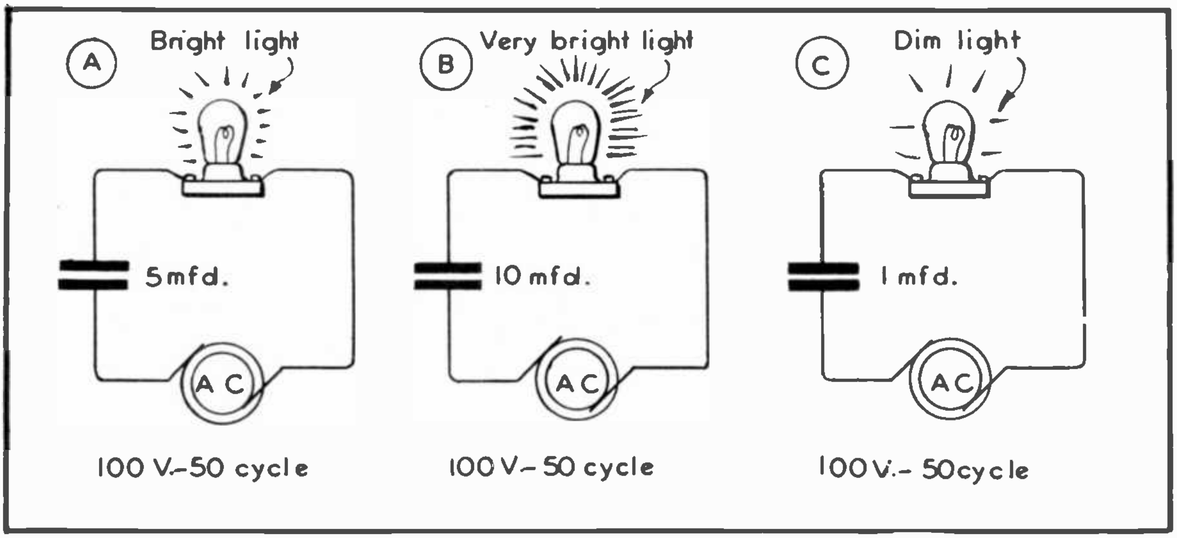


FIG. 18
HOW CAPACITY AFFECTS CAPACITIVE REACTANCE

EFFECT OF CAPACITY VALUE UPON CAPACITIVE REACTANCE: In Fig. 18, you are shown three circuits; each consisting of an a-c generator, a condenser, and a lamp connected in series. A 50-cycle a-c emf of 100 volts is being impressed upon each of the circuits by the a-c generator. The condenser in circuit "A" has a capacity of 5 mfd; that in circuit "B" has a capacity of 10 mfd; and that in circuit "C" has a capacity of 1 mfd.

The lamp in circuit "A" is glowing with fair brilliance. The lamp in circuit "B" is producing much more light than that in circuit "A". The lamp in circuit "C" is operating at such reduced brilliance that its glow is barely visible.

This shows that the greater the capacity of a condenser, the less will be its capacitive reactance. And, the less the capacitive reactance of a condenser, the greater will be the flow of alternating current in a circuit in which the condenser is included. Thus, condensers of larger capacity will permit the flow of more alternating current than will condensers of small capacity.

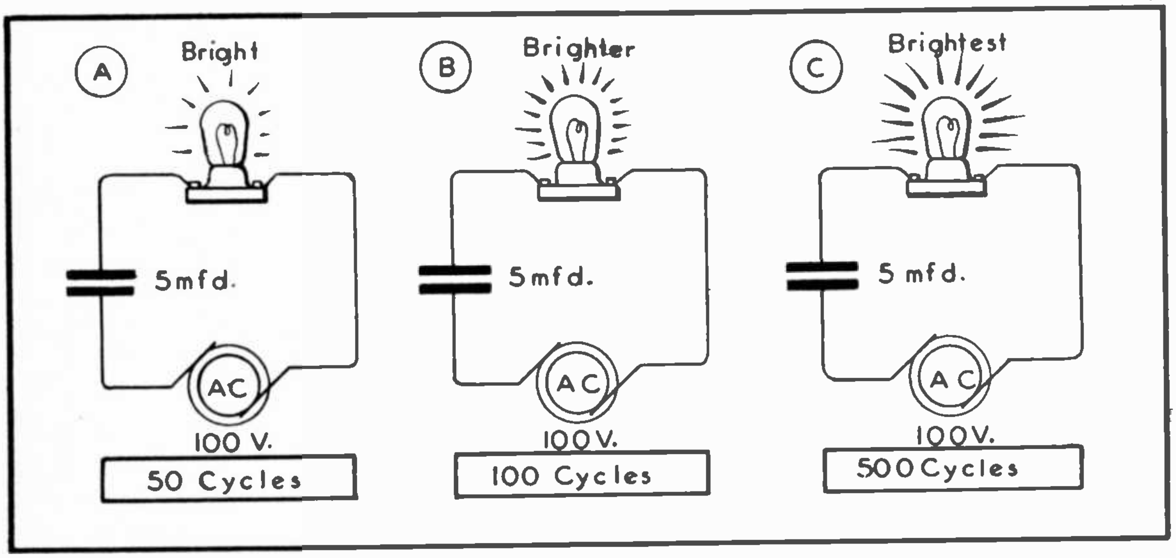


FIG. 19
HOW FREQUENCY AFFECTS CAPACITIVE REACTANCE

EFFECT OF FREQUENCY UPON CAPACITIVE REACTANCE: In Fig. 19, you are shown three other a-c circuits which contain condensers and lamps. Again, the generators are applying 100 volts to each circuit. But this time, they are supplying this voltage at different frequencies. That is, the generator in circuit "A" is furnishing 100 volts at 50 cycles per second; the generator in circuit "B" is furnishing 100 volts at 100 cycles per second; and the generator in circuit "C" is furnishing 100 volts at 500 cycles per second. The condenser in each case has a capacity of 5 mfd.

You should note that the lamp in circuit "B" is glowing with greater brilliance than is the lamp in circuit "A", and that the lamp in circuit "C" is glowing with greater brilliance than are the lamps in either circuit "A" or "B". This shows that the frequency of the applied alternating emf has a great deal to do with the amount of capacitive reactance that a condenser offers to a flow of alternating current.

The rule in this case is: The higher the frequency, the greater will be the current flow in an a-c circuit which contains a condenser. Or, at high frequencies, a condenser of a certain capacity will offer relatively little opposition (capacitive reactance) to current flow; at low frequencies, a condenser of the same capacity will offer greater opposition (capacitive reactance) to current flow.

TABLE II

CAPACITIVE REACTANCE (X_C) OF A FEW COMMON VALUES OF CAPACITY AT VARIOUS COMMERCIAL POWER, AUDIO AND RADIO FREQUENCIES

MFDS. OF CAPACITY	COMMERCIAL POWER FREQUENCIES			AUDIO FREQUENCIES		LOW RADIO FREQUENCIES
	50 CPS.	60 CPS.	100 CPS.	1000 CPS.	10,000 CPS.	100,000 CPS.
.00025	12,640,000	10,640,000	6,320,000	632,000	63,200	6,320
.0005	6,320,000	5,308,000	3,160,000	316,000	31,600	3,160
.001	3,160,000	2,640,000	1,580,000	158,000	15,800	1,580
.005	632,000	530,800	316,000	31,600	3,160	316
.01	316,000	264,000	158,000	15,800	1,580	158
.05	63,200	53,080	31,600	3,160	316	31.6
.1	31,600	26,400	15,800	1,580	158	15.8
.5	6,320	5,308	3,160	316	31.6	3.16
1.0	3,160	2,640	1,580	158	15.8	1.58
2.0	1,580	1,320	790	70.0	7.0	.70
4.0	792	660	396	39.6	3.9	.39
8.0	396	330	188	18.8	1.8	.18
10.0	316	264	158	15.8	1.5	.15
15.0	212	177	106	10.6	1.0	.10

The capacitive reactance of a number of commonly used condenser capacities appears in Table II. Here, you will note that the capacitive reactance of each condenser is given for several frequencies of alternating current, the frequencies being indicated across the top of the table.

Example: Suppose that you wished to determine the capacitive reactance of an 8 mfd condenser, when employed in a circuit to which an a-c emf of 60 cps is applied. To do this, first look for the number "8" in the "Mfds. of Capacity" column at the extreme left of the table. Then, glance straight across to the "60" column, and you will find that the capacitive reactance (X_c) of this 8 mfd condenser to a 60 cycle current is 330 ohms.

COILS

When wire is wound in the form of a coil, such as when several turns of wire are wrapped around a cardboard salt box, the complete arrangement is called an inductance coil, or simply a "coil".

COMMERCIALLY MANUFACTURED COILS: Coils of many different sizes and shapes, as well as with varying electrical characteristics, are produced in great quantities for use in today's radio and electronic circuits. While literally hundreds of different designs are available to the radionic tech-

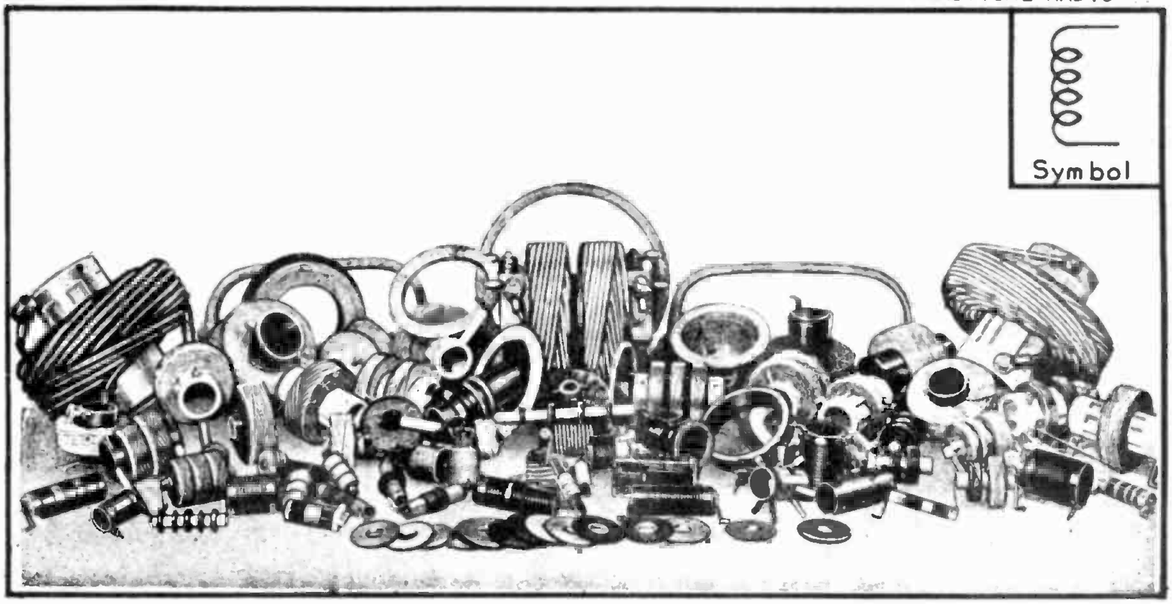


FIG. 20
VARIOUS FORMS OF AIR-CORE COILS AS USED IN RADIONICS

nician, we can classify all of them into two general groups -- Namely, as air-core coils and iron-core coils.

AIR-CORE COILS: An air-core coil is a coil of wire which does not have an iron or other metallic core. While most air-core coils are wound on tubes made of cardboard, bakelite, ceramic, or other insulative material, such tubing is used only to furnish a physical support for the turns of wire, and serves no electrical purpose in the circuit in which the coil might be connected. A group of air-core coils is shown in Fig. 20, together with the symbol for an air-core coil.

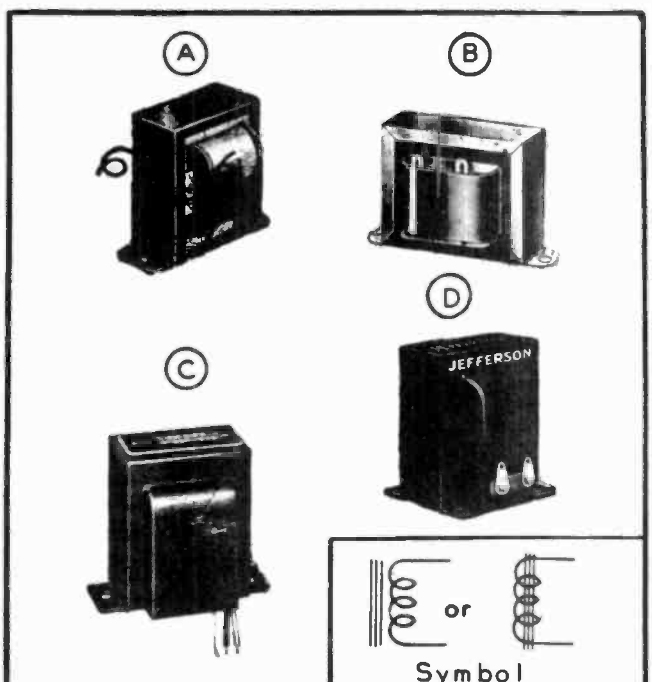


FIG. 21
IRON-CORE COILS AS USED IN RADIONICS

IRON-CORE COILS: Several iron-core coils and the standard symbols for such coils appear in Fig. 21. Notice how straight lines represent the presence of an iron-core.

EFFECT OF COILS ON CURRENT FLOW

Whenever a coil is inserted in a circuit, it will always influence the flow of current in that circuit. However, it will affect the flow of alternating or pulsating current differently than it will direct current. The following paragraphs will clarify this.

EFFECT OF A COIL ON DIRECT CURRENT: In Fig. 22-A, you are shown a circuit which contains a lamp, an ammeter, and a d-c emf of 120 volts. The ammeter indicates that a current of 4 amperes is flowing through the circuit. The lamp is glowing at normal brilliance.

According to Ohm's Law, resistance is equal to the number of volts divided by the number of amperes. Thus, we can divide the 120 volts being applied to the circuit by the 4 amperes of current flowing, and so determine the total resistance of the circuit.

Since 120 divided by 4 equals 30, the total resistance of the circuit is 30 ohms. And, as the lamp is the only object in the circuit which offers appreciable resistance to current flow, we conclude that the circuit resistance of 30 ohms is concentrated in the filament of the lamp.

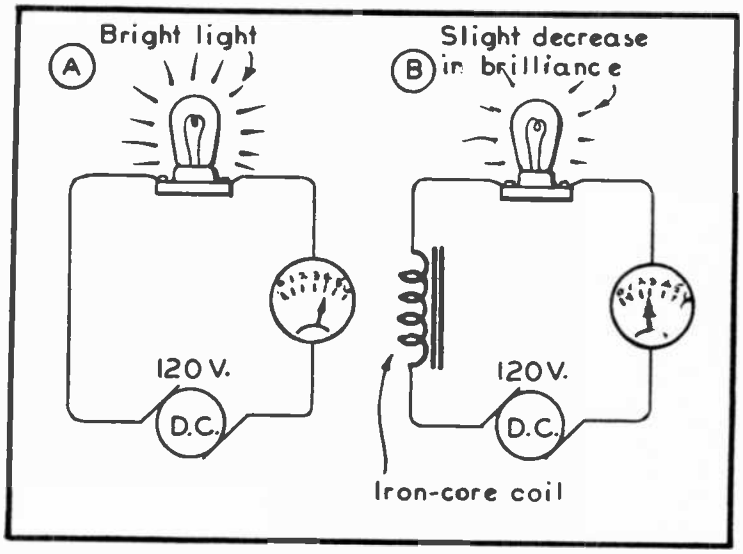


FIG. 22
INDUCTANCE (COIL) OFFERS LITTLE OPPOSITION TO D-C

The circuit illustrated at "B" of Fig. 22 differs from that at "A" of the same illustration only in the fact that a small iron-core coil has been connected in series with it. The lamp is now glowing at slightly reduced brilliance, and the ammeter indicates that a current of only 3 amperes is flowing through the circuit. This is 1 ampere less than is the case in Fig. 22-A.

Since the current value is now 3 amperes, we find by dividing 120 by 3 that the total resistance of circuit "B" is 40 ohms, instead of 30 ohms as in circuit "A". Then, knowing that the resistance of the lamp is only 30 ohms, we conclude that the additional 10 ohms of resistance is offered by the wire of which the coil is wound. Thus, we have the rule that: A coil which is connected in a circuit that is carrying pure direct current will always reduce the flow of that current in accordance with the pure ohmic resistance of the wire of which it is wound. Thus, the effect of a coil in a d-c circuit is identical to that of a resistor which has a resistance value equal to the resistance of the wire in the coil. This is true of both air and iron-core coils.

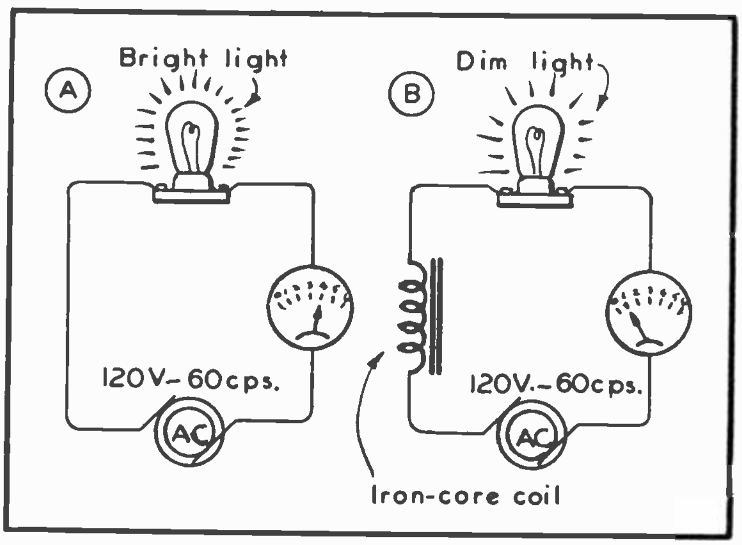


FIG. 23
INDUCTANCE (COIL) OFFERS APPRECIABLE OPPOSITION TO A-C

EFFECT OF A COIL ON ALTERNATING CURRENT: Having seen the effect of a coil in a d-c circuit, let us now turn our attention to the action of a coil in an a-c circuit. We show you such a circuit in Fig. 23.

Observe at "A" that this circuit is the same as that of Fig. 22-A, with the exception that we are now using an a-c generator which is delivering 120 volts at a frequency of 60 cps. Again, the ammeter indicates that 4 amperes of current is flowing through the circuit. This is quite correct because, you will remember, that the opposition offered by pure ohmic resistance affects all types of current in the same manner. Therefore, if the lamp offers a resistance of 30 ohms to direct current, it will offer the same resistance to alternating current of any frequency.

Now, if the same coil as used in Fig. 22-B be inserted in this a-c circuit, as in Fig. 23-B, the effect upon current flow will be different from that which occurred in the d-c circuit. For instance, at "B" of Fig. 23, you will note that the ammeter now indicates but 1 ampere of current. This means that the total opposition to the flow of alternating current has been greatly increased by the addition of the coil.

Again referring to Ohm's Law, we find that by dividing 120 by 1 we get 120 as the number of ohms of resistance present in the circuit of Fig. 23-B. Subtracting the known 30 ohms resistance of the lamp from the total of 120 ohms, we find that the coil is offering an opposition equal to 90 ohms of resistance. This is a much greater opposition than offered by the same coil to a direct current in the circuit of Fig. 22-B; in fact, greater by 80 ohms. Thus, we see that a coil always offers more opposition to alternating current than it does to direct current.

EFFECT OF A COIL ON PULSATING CURRENT: If we were to change the source of emf in circuit "B" of Fig. 23, so that pulsating current were to flow

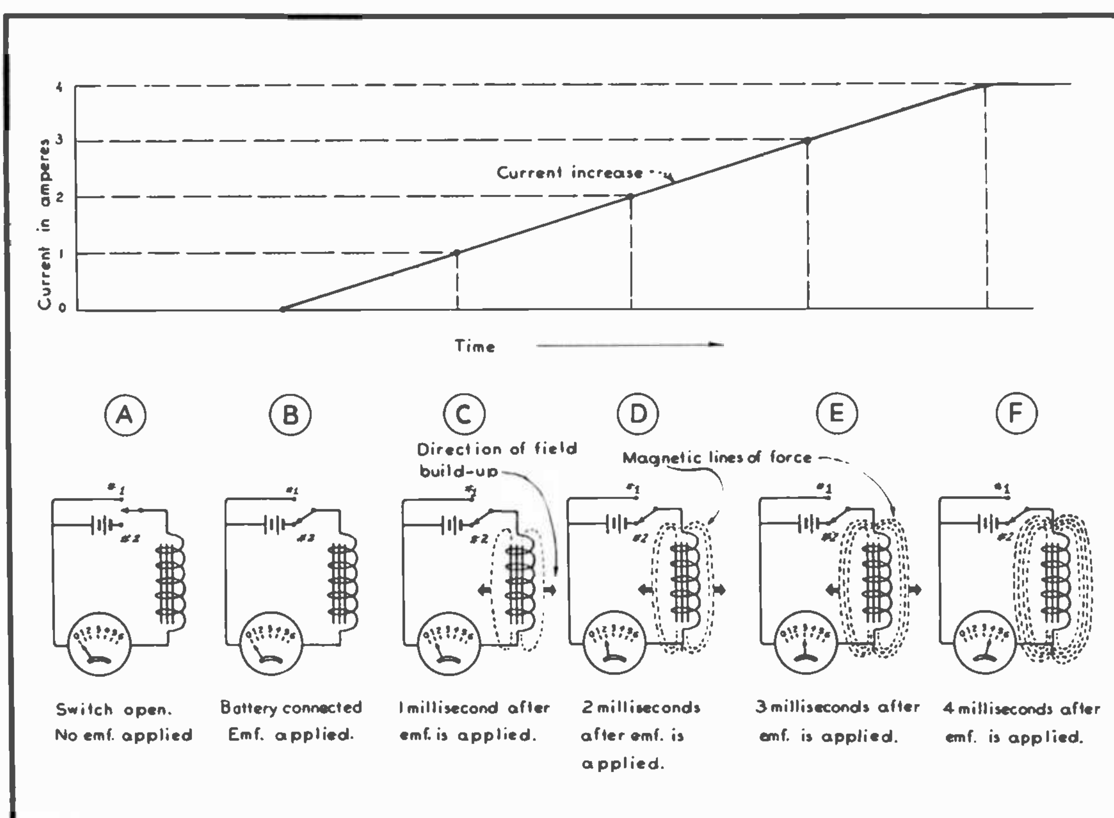


Fig. 24
EFFECT OF SELF-INDUCTION WHEN CURRENT INCREASES

through the circuit, we would find that the same coil also offers more opposition to the flow of pulsating current than it does to direct current.

Now, let us see why a coil behaves in different types of circuits in the manner just described. While it is true that it is not necessary that you have a complete understanding of the theory of the operation of coils in order to be able to test and replace defective coils in simple radionic circuits, yet a clear understanding of these principles gained at this time will make it easier for you to master the more advanced circuits which will be presented later in the course.

SELF-INDUCTION

In previous lessons, you learned that when current flows through a coil of wire, a magnetic field builds up around the coil. This magnetic field represents energy; and to build up this field from zero to maximum intensity requires time. That is, a brief but definite period of time lapses from the instant that the emf is first applied to the circuit until the current has built up the field to the extent that it contains a maximum number of lines of force. Full current will not flow through the circuit until the field has been fully built up. This is illustrated in the drawing of Fig. 24, where you are shown the building up of current in a d-c circuit, and the resultant magnetic field. Notice in Fig. 24 how the current flow gradually increases from "B" to "F"; how the magnetic field becomes more intense, until the maximum current flow and field intensity are finally attained. (Note: The current and time values in Fig. 24 were selected arbitrarily merely to illustrate the principle involved, and are therefore not intended to infer exact values for any particular circuit.)

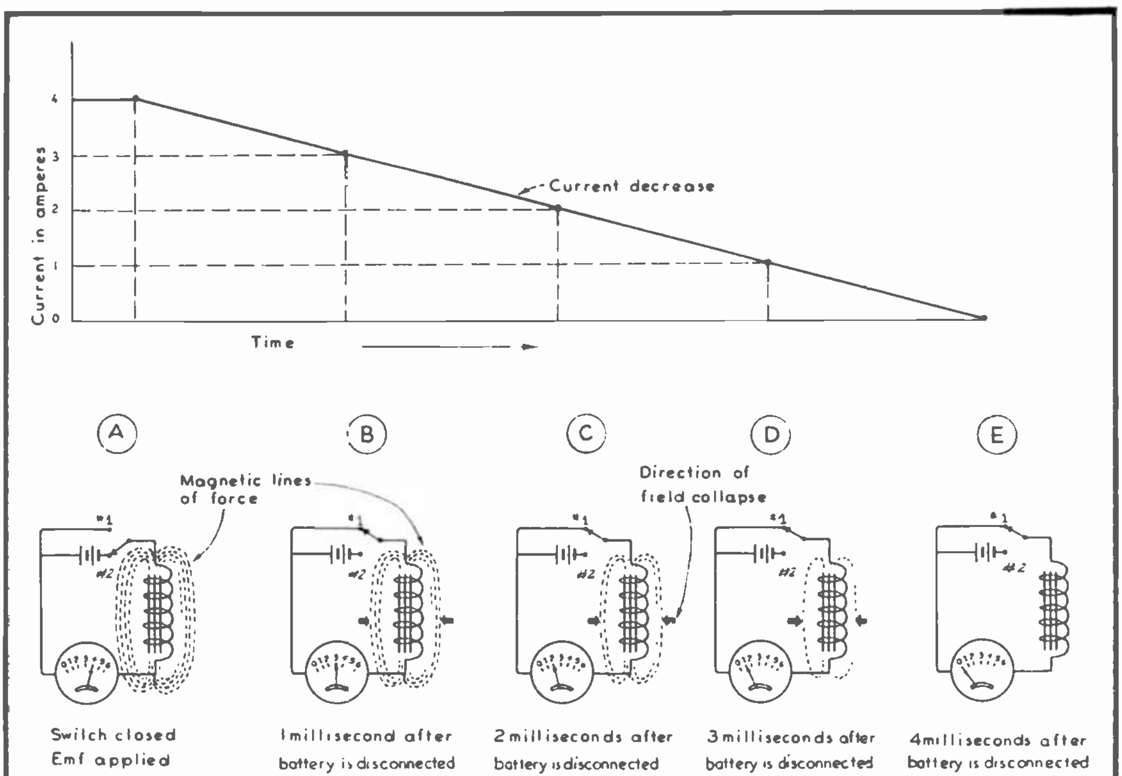


FIG. 25
EFFECT OF SELF-INDUCTION WHEN CURRENT DECREASES

This delay in current build-up is due to the fact that the expanding lines of force "cut" the turns of the coil's winding in such manner that a voltage is induced in the winding. And, the polarity of this induced voltage is such as to oppose the applied voltage. We call this opposing voltage counter-electromotive force or C.E.M.F., the same as we do the opposing voltage offered by a charged condenser toward the applied voltage.

Since the counter-electromotive force, in the case of a coil, is induced in the same winding that produced the magnetic lines of force in the first place, we logically call this action self-induction -- and the voltage so produced is often referred to as a self-induced voltage. This is in contrast to mutual-induction, about which you studied earlier, and in which case the voltage is induced in a secondary winding that takes no part in establishing the magnetic field that makes induction possible. The current flow resulting from the self-induced voltage is called the self-induced current.

Self-induction also takes place every time that the flow of current through a coil decreases in value, or is stopped entirely. For instance, at "A" of Fig. 25, you are shown a coil through which a steady value of direct current is flowing -- 4 amperes to be exact. Under such conditions, the magnetic field built up around the coil is of constant intensity.

Now, in Fig. 25-B, the source of d-c emf (battery) has been disconnected from the circuit by moving the switch to contact #1, so current from the battery stops flowing through the circuit. When this happens, the magnetic field collapses or recedes into the iron-core; and as it does so, the lines of force "cut" the turns of the coil's winding in a direction opposite to that experienced during the build-up of the magnetic field. Therefore, the resulting self-induced voltage in the coil will now be of opposite polarity to that which existed during the build-up of the field, or of the same polarity as the voltage which was originally applied. Thus, the voltage which is induced in the coil during the collapse of the magnetic field will, for a brief interval of time after the original source of emf (the battery) has been disconnected from the circuit, tend to keep the current flowing through the closed circuit in the same direction as the applied voltage caused it to flow. This is shown in steps "B", "C", "D", and "E" of Fig. 25, where we see that it requires four milliseconds (four thousandths of a second) of time, after the original source of emf has been disconnected, for the current to stop flowing entirely in this circuit. Here again, the values have only been arbitrarily selected.

(Note: In the above, we assume that the switch is moved instantaneously from contact #2 to contact #1, with no time consumed in switching. The slight amount of time required is neglected so that the principle of self-induction may be clearly demonstrated).

WHY A COIL OPPOSES A-C MORE THAN D-C

Since a coil opposes an increase in current flow when a d-c voltage is applied to the circuit, it stands to reason that the same coil will oppose a flow of alternating current even more; because, in the latter case, the current increases either in a positive or negative direction, during each alternation; or twice per cycle, throughout the entire time that the a-c emf is applied to the circuit. Similarly, if a coil is included in a circuit carrying pulsating direct current, it will oppose the increases in current value that are continually ocurring in circuits of this type.

It is to be noted, also, that whenever the current in either an alternating or pulsating current circuit decreases in value, the direction of the field collapse is such that the self-induced current at this time tends to flow in the same direction as the flow of current due to the applied emf. This is just the reverse to what happens when the current due to the applied emf increases in value.

INDUCTANCE

Obviously, we must have a term by which we can technically speak of the electromagnetic characteristics of a coil. We do, by saying that the action of a coil in a d-c, a-c or pulsating current circuit, as just described, is due to the property of inductance possessed by the coil. Quite often, the coil itself is spoken of as being an "inductance". The capital letter "L" is used as the standard symbol to denote inductance. The HENRY is the unit of inductance, and is abbreviated to "H".

When a circuit or coil has sufficient inductance so that an emf of 1 volt is generated when the current is changed at the rate of 1 ampere per second, we say that the circuit or coil has an inductance of ONE HENRY. One millihenry is equal to the one-thousandth part $\left(\frac{1}{1000}\right)$ of a henry. One microhenry is equal to the one-millionth part $\left(\frac{1}{1,000,000}\right)$ of a henry. The millihenry is abbreviated to "mh", and the microhenry to "uh".

The amount of inductance in terms of henries, present in a coil, is determined by the number of turns of wire in the coil; by the physical shape of the coil and by the type of core. Many turns of wire; a large coil diameter; and an iron core; are factors which make for a comparatively large amount of inductance (henries) in a coil.

Small diameter; few turns of wire; and an air core (absence of an iron core); are factors which tend to reduce inductance.

HOW AMOUNT OF INDUCTANCE AFFECTS A-C CURRENT FLOW: The amount of inductance (henries) possessed by a coil has a great deal to do with the amount of opposition that the coil will offer to alternating current. This is illustrated in Fig. 26.

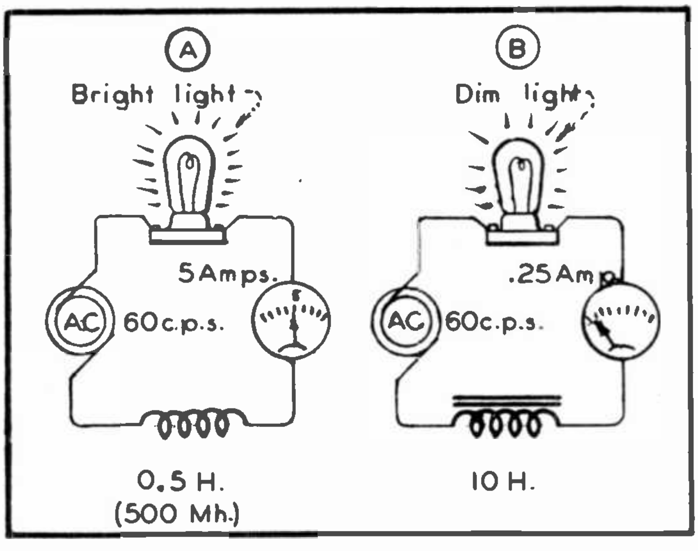


FIG. 26
GREATER INDUCTANCE OFFERS MORE OPPOSITION TO A-C

The circuit at "A" contains an air-core coil of 500 millihenries (0.5 H.) inductance inserted between the lamp and 60-cycle generator. The lamp is glowing at full brilliance, and the ammeter indicates that 5 amperes are flowing; thus showing that the 500 millihenry coil reduces the current flow only slightly.

The circuit at "B" has an iron-core coil of 10 henries inserted between the lamp and generator. Here, the lamp glows at considerably reduced brilliance and the ammeter indicates a reading of only 0.25 ampere, even though the same voltage and frequency be supplied by the generator as at "A". This shows that the greater the value of inductance (henries), the greater is the opposition offered by the coil to alternating current.

INDUCTANCE AND FREQUENCY: Just as is the case with a condenser, the frequency of the applied a-c, in terms of cycles per second, has a great deal to do with the amount of opposition that a coil of given inductance offers to a flow of pulsating or alternating current.

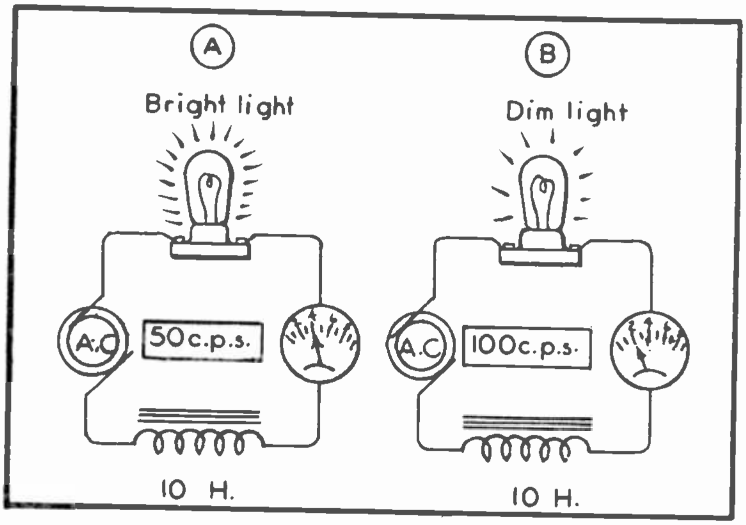


FIG. 27
AN INCREASE IN FREQUENCY PRODUCES A DECREASE IN CURRENT IN AN INDUCTIVE CIRCUIT

In Fig. 27-A, you are shown a coil of 10 henries inductance connected in an a-c circuit. You will note that the applied a-c emf has a frequency of 50 cycles per second. The current flow in the circuit is 4 amperes.

In Fig. 27-B, you are shown a circuit exactly like that of "A", except that the frequency of the applied emf has been increased to 100 cycles per second. The ammeter now shows that only 2 amperes are flowing through the circuit containing the 10 henry inductance.

Thus, we have established the following rules: The higher the frequency of the applied emf, the greater is the opposition offered to alternating current by an inductance of any given value. The lower the frequency of the applied emf, the less is the opposition offered to alternating current flow. The same applies to a circuit carrying pulsating current, and which has a coil or inductance in it. You should note that this is the opposite of the effect of frequency upon an a-c circuit which contains a condenser.

INDUCTIVE REACTANCE

Just as we use the expression "capacitive reactance" to indicate the opposition offered by a condenser to alternating or pulsating current flow, so do we use the term inductive reactance to express the opposition offered by an inductance (coil) to a varying current flow. The symbol for inductive reactance is "X_L". (You will remember the symbol for capacitive reactance as being "X_C".) Like the opposition of a resistor or a condenser, we express the amount of opposition offered by inductive reactance to alternating or pulsating current in terms of ohms.

In Table III is given the inductive reactance of several common values of inductance at a number of common commercial frequencies. Reference to this table will aid you in solving for current flow in circuits which contain inductive reactance.

Example: Suppose you wished to determine the inductive reactance "X_L" of a coil having an inductance value of 20 henries, when used in a circuit to which an a-c emf of 100 cps, is being applied. To do this, look for the number "20" in the column at the extreme left of the table titled "Henries of Inductance." Then, glancing straight across to the "100" column, you will see that the inductive reactance of a 20-henry inductance is equal to 12,640 ohms at 100 cps.

Later in the course, you will learn how to calculate both capacitive reactance and inductive reactance without the assistance of tables. The tables are being used at this time solely to simplify matters for you at this early stage of your training, and are sufficiently accurate for our present use.

TABLE III

INDUCTIVE REACTANCES (X_L) OF A FEW COMMON VALUES OF INDUCTANCE AT VARIOUS COMMERCIAL POWER, AUDIO AND RADIO FREQUENCIES

HENRIES OF INDUCTANCE	COMMERCIAL POWER FREQUENCIES		AUDIO FREQUENCIES				LOW RADIO FREQUENCIES
	50 CPS	60 CPS	100 CPS	500 CPS	1000 CPS	10,000 CPS	100,000 CPS
0.01	3.2	3.7	6.4	32	64	640	6,400
0.05	15.8	18.8	31.6	156	316	3,160	31,600
0.1	31.6	37.6	64.0	316	640	6,400	64,000
0.5	158.0	188.4	316.0	1,580	3,160	31,600	316,000
1.0	316.0	376.8	632.0	3,160	6,320	63,200	632,000
2.0	632.0	753.6	1,264.0	6,320	12,640	126,400	1,264,000
5.0	1,580.0	1,884.0	3,060.0	15,800	30,600	306,000	3,060,000
10.0	3,160.0	3,768.0	6,320.0	31,600	63,200	632,000	6,320,000
20.0	6,320.0	7,536.0	12,640.0	63,200	126,400	1,264,000	12,640,000
30.0	9,480.0	11,304.0	18,960.0	94,800	189,600	1,896,000	18,960,000
40.0	12,640.0	15,072.0	25,280.0	126,400	252,800	2,528,000	25,280,000
50.0	15,800.0	18,840.0	31,600.0	158,000	316,000	3,160,000	31,600,000
100.0	31,600.0	37,680.0	63,200.0	316,000	632,000	6,320,000	63,200,000

EFFECT OF INDUCTIVE REACTANCE COMBINED WITH CAPACITIVE REACTANCE

At first thought, you might expect that since inductive reactance and capacitive reactance both offer opposition to a flow of alternating current, that the total reactance or opposition to current flow would be greater when a condenser and coil are combined in a circuit, than if only either one of them were present in the circuit alone. This, however, is not true; because in an a-c circuit, the behavior of inductive reactance is exactly opposite to that of capacitive reactance, and therefore, the total effective reactance of the inductance - capacitance combination will always be less than if only one of them were present. Let us see how this works out in practice.

At "A" of Fig. 28, we have a circuit which contains a 10 mfd condenser connected in series with an ammeter and an a-c generator that is supplying 1000 volts at a frequency of 60 cps. Referring to Table II, we see that the capacitive reactance of a 10 mfd condenser at 60 cycles is 264 ohms.

Applying Ohm's Law, we find the number of amperes of current flow in the circuit by dividing the applied voltage of 1000 by the capacitive reactance of 264 ohms, thus: 1000 divided by 264 equals 3.78 amperes. In other words, a 10 mfd condenser furnishes a capacitive reactance of 264 ohms toward a 60 cycle current and permits 3.78 amperes of such current to flow through the circuit. This current flow of 3.78 amperes will be indicated on the ammeter in Fig. 28-A.

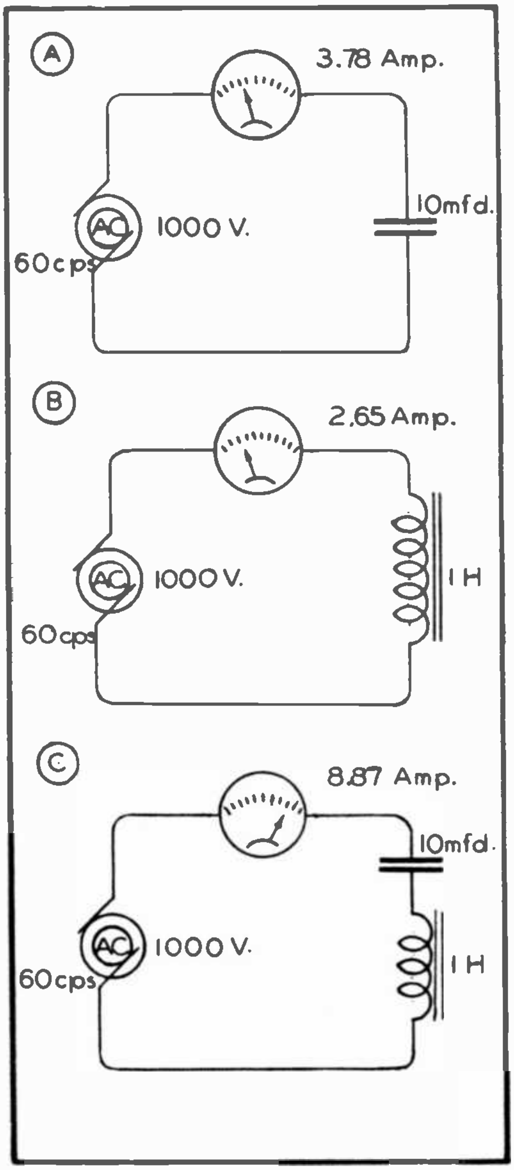


FIG. 28
EFFECT OF BOTH INDUCTANCE AND CAPACITY IN CIRCUIT

By substituting an inductance of 1 henry for the condenser, as at "B" of Fig. 28, we find that 1 henry of inductance, when used in a circuit to which an a-c emf of 60 cps is applied, will offer an inductive reactance "X_L" of 376.8 ohms. Then, by again applying Ohm's Law to determine current value, dividing the 1000 volts of applied emf by 376.8 ohms of inductive reactance, equals 2.65 amperes, which is the value of the current in this circuit. This current value will therefore be indicated on the ammeter at "B".

Now, by combining the 10 mfd condenser in the same circuit with the 1 henry coil, as at "C" of Fig. 28, we have a circuit containing a capacitive reactance "X_C" of 264 ohms and an inductive reactance "X_L" of 376.8. But, by referring to the ammeter, we observe that more current is now flowing than was the case when either one of the two reactances was used separately in the circuit. To be exact, the ammeter at "C" is indicating a current flow of 8.87 amperes. This shows that capacitive reactance "X_C" and inductive reactance "X_L", when present together in a circuit, combine to produce a total reactance which is <u>less</u> than that of either of them alone.

<u>RULE</u>: When inductive reactance and capacitive reactance are both present in a circuit, we determine the total or effective reactance by subtracting the lesser of the two reactance values from the larger one. For instance, working out our example in Fig. 28-C, we subtract 264 from 376.8 to obtain 112.8, which is the value of the effective reactance expressed in ohms. So, by dividing the applied emf (1000 volts) by the effective reactance (112.8 ohms), the current in the circuit should be 8.87 amperes, which you will observe to be the value actually indicated on the ammeter in this illustration. Usually, this effective reactance is called the <u>net reactance</u>.

You should note that the values used in the circuits just described apply only to these particular examples. In any other problem in which it is necessary to determine the current flowing in an a-c circuit containing X_C and X_L, other values of inductance, capacity, frequency and voltage will probably be encountered. But the principles governing the behavior of X_C and X_L in a-c and pulsating-current circuits are <u>always</u> as just explained.

EFFECT OF FREQUENCY ON COMBINED X_C AND X_L

In the preceding example, you have seen that with 1 henry of inductance and 10 mfd of capacity combined in an a-c circuit to which a 60 cps emf is applied, we will have a net reactance of 112.8 ohms. Now, let us see how a change in frequency will affect the operation of this circuit.

In Fig. 29, we have changed a-c generators, substituting one which is producing an emf of 50 cps for the one of 60 cps. This change of frequency will change the capacitive reactance of the condenser and the inductive reactance of the coil.

Again referring to Tables II and III, we find that with a 50 cps emf applied to the circuit, the capacitive reactance of a 10 mfd condenser is 316 ohms; and that the inductive reactance of a 1 henry coil is also 316 ohms. In other words, the two reactances are exactly equal; and as they are of equal value, we may subtract either one from the other to obtain the net reactance. Then, since 316 minus 316 equals zero, we know that the combination of the frequency, capacity and inductance values in this particular circuit are such that the net reactance of the circuit is zero.

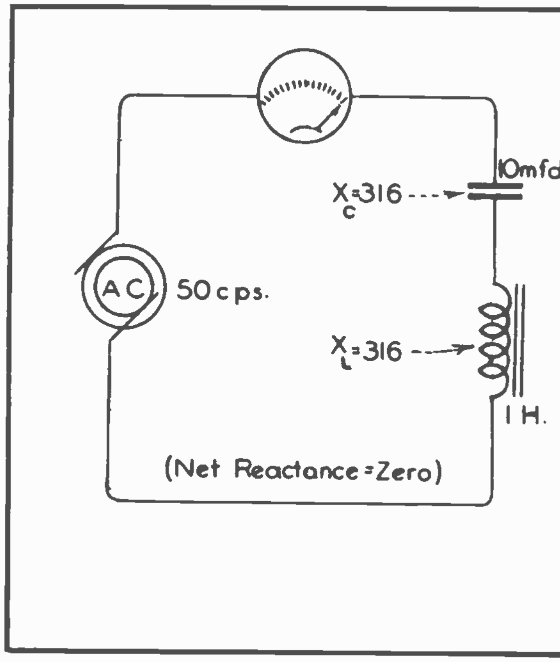


FIG. 29
MAXIMUM CURRENT FLOWS
AT RESONANCE

With zero reactance in the circuit, the condenser and coil would in no way oppose the flow of current in the circuit of Fig. 29. This leaves only the negligible resistance of the conductors and the wire of the coil to offer opposition to current flow.

RESONANCE

When the values of capacity, inductance and frequency are such that zero reactance exists in a circuit, we say that the circuit is in RESONANCE at that particular frequency. A circuit which is in resonance at a certain frequency offers no opposition in the form of inductive or capacitive reactance to current flow of that frequency. Of course, if resistance were to be included in the circuit -- and resistance is always present in the windings of a coil -- this resistance would still oppose current flow in this case just as it would in a d-c circuit. Resistive opposition is separate and apart from capacitive reactance and inductive reactance, and is in no way affected by either of them.

You should note that a circuit containing a certain amount of capacitance and inductance is resonant to only one frequency. If it is desired to have the circuit resonate at any other frequency, it is necessary to change either the inductance or capacitance values, or both. Glancing down the 50 cycle column of Tables II and III, you will see that a capacity of .5 mfd and an inductance of 20 henries each have a reactance of 6,320 ohms; and that the net reactance would therefore be zero if they were together connected in series with a 50 cps circuit. In other words, this combination would be resonant at a frequency of 50 cps. Similarly, a capacity of .1 mfd and an inductance of 100 henries would cause the circuit to resonate at 50 cps.

ALL CIRCUITS CONTAIN SOME RESISTANCE, CAPACITANCE AND INDUCTANCE

Any circuit through which electric current will flow, always has some resistance, capacitance and inductance. Theoretically, it is impossible to have a circuit in which absolutely none of these factors exist. For instance, resistance is present in small amounts in even the best conducting materials; capacity is present in small amounts wherever there is a potential difference (voltage-difference) between two conductors; inductance is present in small amounts wherever electrical energy is generating or supporting energy in the form of magnetism. Yes, even in a straight wire.

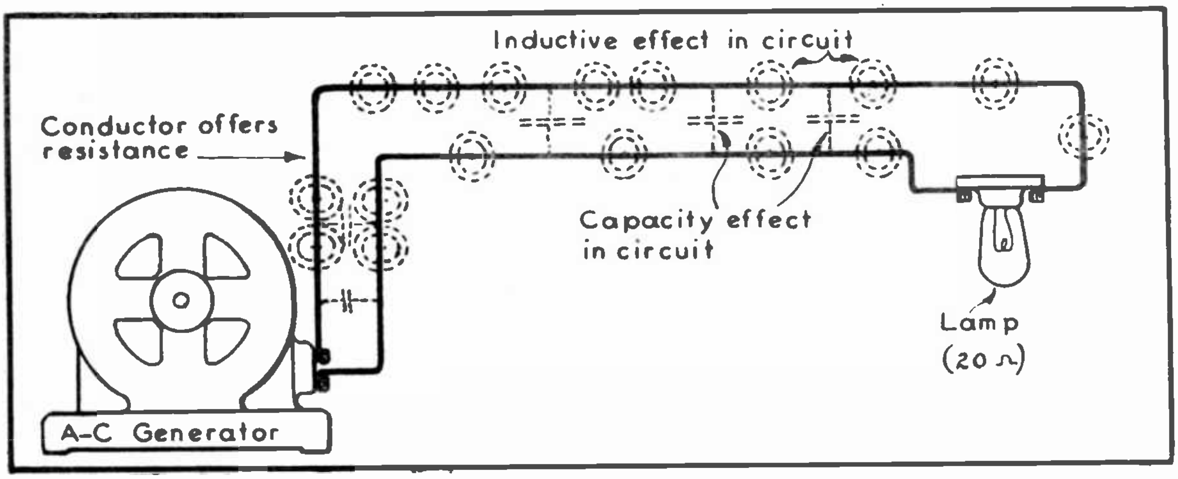
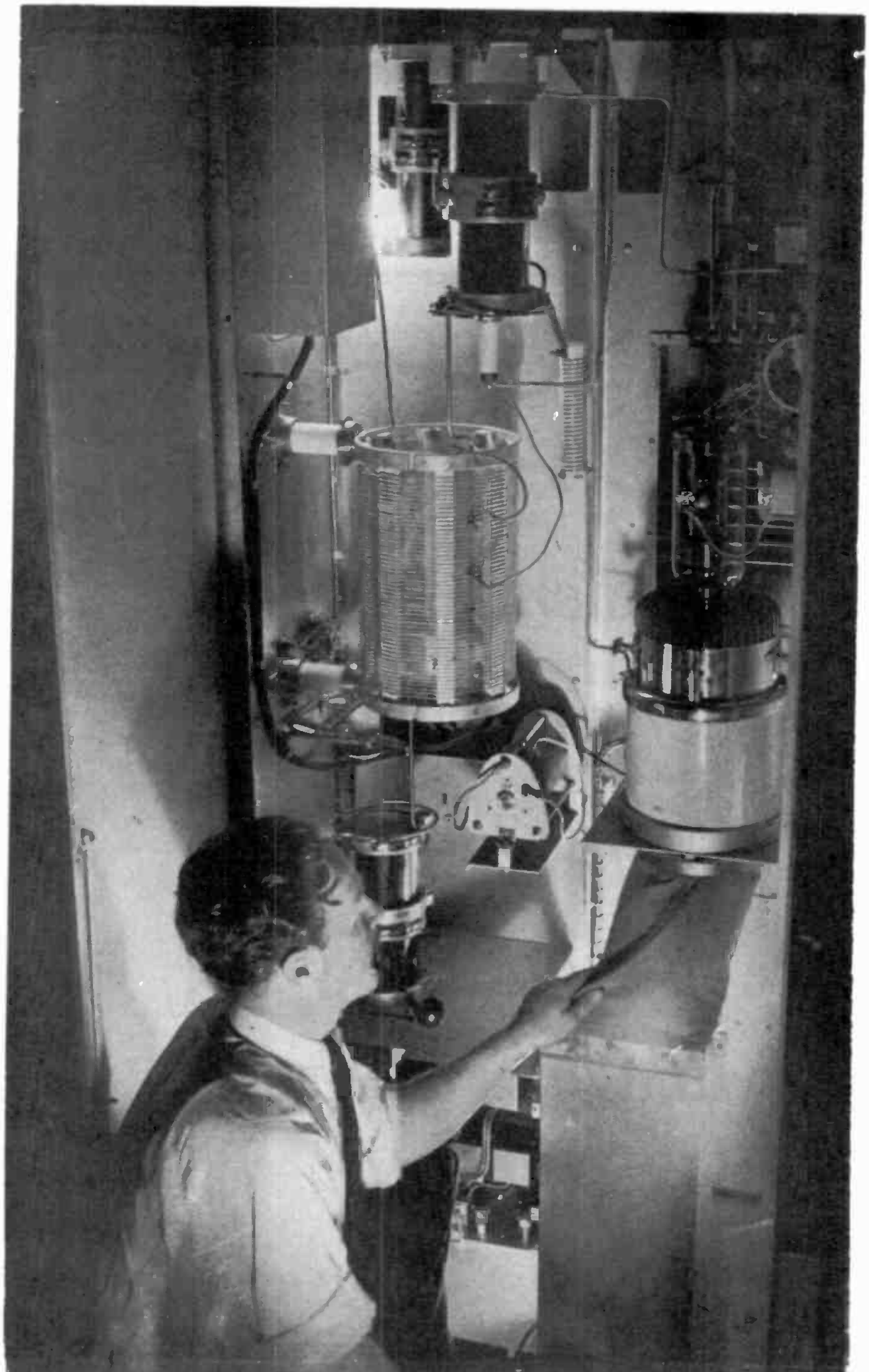


FIG. 30
ALL CIRCUITS CONTAIN SOME RESISTANCE, CAPACITANCE AND INDUCTANCE

This is illustrated in Fig. 30, where current is shown flowing through a circuit which contains only an incandescent lamp. The lamp, of course, is offering resistance equal to 20 ohms. There is a resistance of perhaps 1/100 ohm (one, one-hundredth of an ohm) in the two wires connecting the lamp to the battery. The capacity between the two conducting wires is perhaps equal to one or two micromicrofarads (shown by the phantom condenser). The magnetic field which is set up around the conductors throughout their length causes these conductors to offer an inductance of perhaps one or two millihenries.

As you will note in the above example, these values are usually so slight as to be of little or no importance to us in most practical work; but there are circuits in which every bit of resistance, capacitance, and inductance will have to be given consideration. Examples of this are common when dealing with certain precision radio equipment which operates at very high frequencies. Another example is a telephone line which, if it is of great length, possesses considerable resistance, capacitance and inductance.

Throughout this course, and as long as you are engaged in work involving radionic and electronic circuits, you will apply what you have learned in this lesson concerning resistance, capacitance, inductance and resonance. Every effort which you make to thoroughly master these basic principles will be worthwhile, as it will greatly simplify your understanding the equipment described in later lessons and the operation of which is dependent upon these very same principles.



THIS RADIO-FREQUENCY GENERATOR IS ONLY ONE EXAMPLE OF A GREAT MANY DIFFERENT TYPES OF ELECTRONIC EQUIPMENT IN WHICH RESISTORS, CONDENSERS AND COILS ARE USED. OBVIOUSLY, YOU MUST BE THOROUGHLY FAMILIAR WITH THESE PARTS IN ORDER TO FULLY UNDERSTAND THE OPERATION OF APPARATUS SUCH AS ILLUSTRATED ABOVE.

MAKE it your mission... to render service to others, & you shall find that you are rendering the greatest service to yourself.

J. A. ROSENKRANZ

Practical Technical Training In
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LESSON NO. 6

WAVE MOTION --- SOUND

In your study of radio and electronics you will work extensively with sound, radio, heat and light waves--most of all with sound and radio waves. It is, therefore, necessary that you learn how these various types of waves differ from each other, how they are produced and how they are transmitted through space. And, also, that you become familiar with the basic technical terms that are used in connection with wave motion in general.

At the very beginning of this discussion, it is important for you to know that sound, radio, heat and light are all different forms of energy having different characteristics and producing different effects. But, that they also have one thing in common; and that is that they all travel through space as vibrations, or waves. It is this latter relation between them that enables us to convert radio energy into sound, heat into light, light into sound, etc. This will become quite apparent as you progress through this lesson, and will be explained even more fully in succeeding lessons.

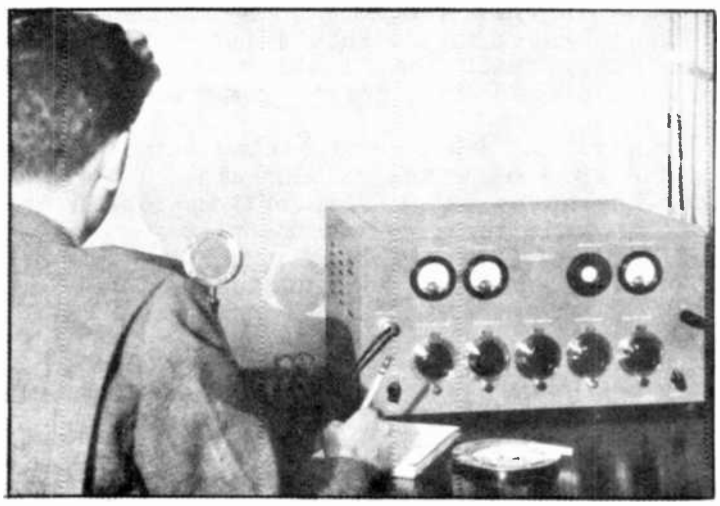

FIG. 1
COMBINATION RADIOTELEPHONE AND RADIOTELEGRAPH TRANSMITTER

With these fundamental facts in mind, let us now continue with a detailed study of this wave motion.

WAVE MOTION

Since sound, light, heat and radio waves are

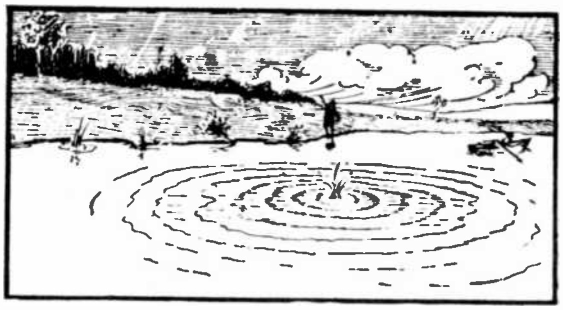

FIG. 2
WAVE MOTION ON THE SURFACE OF A LAKE

not visible as they pass through space, we can analyze their nature and behavior more easily by comparing them with other types of wave motion that are visible, and with whose action we are already familiar. For example, everyone is familiar with the wave motion of water--and since water waves have something in common with those waves in which we are now interested, we can study the behavior of the water waves, and then apply our findings to these other types of waves.

WAVES IN WATER

Assume for the moment, that we are standing on the bank of a pond in which the water is absolutely calm. Now let us suppose that we pick up a stone and drop it into the pond, as shown in Fig. 2. When we do this, we observe that waves will be set in motion due to the disturbance of the water caused by the stone; and that these waves will travel or radiate outward in all directions from the point at which the stone penetrated the surface of the water. The waves will continue to travel over the surface of the pond in ever widening circles until they finally reach the outermost edges of the body of water.

Several things should be noted regarding these waves. FIRST: The waves are set in motion at the instant the stone disturbs the surface of the water. SECOND: The waves begin to travel toward the outermost boundaries of the pond at the instant they are set in motion. THIRD: The height of the waves, or the amount they disturb the surface of the water, decreases as the distance over which they have traveled increases. In fact, if the pond were large enough, it is probable that the waves would finally travel so far that the disturbance produced by them would eventually be reduced to the extent that they would no longer be visible.

Now, let us place a block of wood, or other floating object on the surface of the calm body of water. If the pond were large enough, a small row boat would serve this purpose. Again, let us drop a stone into the water, thereby ruffling its surface and setting waves in motion. By watching for a brief period of time, we shall see that the waves, as they travel or radiate outward from the point of disturbance, will eventually reach the floating object and cause it to rise and fall in an up and down or undulating motion.

Here, we are demonstrating that it is possible to transmit energy in the form of waves in a fluid. Of special importance, is the fact that the waves which were set in motion by tossing the stone into the pond have, in turn, caused the rise and fall of the floating object which is located at some distance from the point where the stone struck the surface of the water.

TRANSFER OF ENERGY BY WAVE MOTION: The stone striking the water represents energy. Energy cannot be destroyed, but can only be converted into some other form of energy. Thus, the energy expended by the stone striking the water is transformed, or converted, into energy

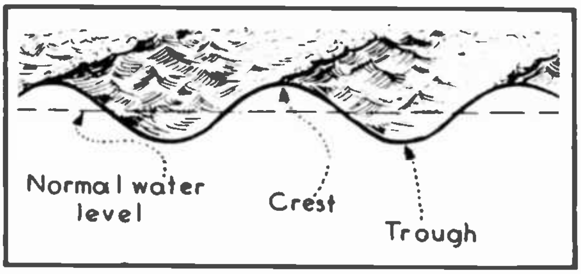

FIG. 3
PICTURING WATER WAVES AS A "CURVE"

in the form of vibrating waves. The vibrating waves, when they reach the floating object, apply energy to it, causing it to move up and down.

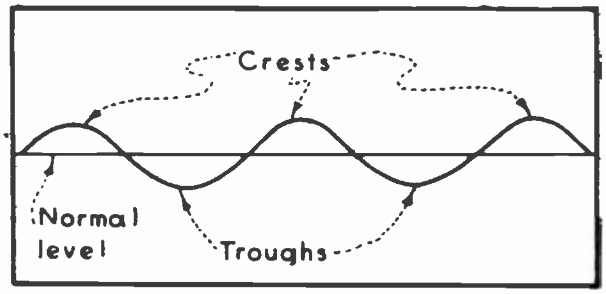

FIG. 4
"DRAWING A WAVE" FOR RADIO PURPOSES

A STUDY OF THE INDIVIDUAL WAVES

Now, let us analyze the waves in greater detail as they travel through their conducting fluid (water in this case).

Upon studying this wave-motion more closely, you will note that it consists of a series of "peaks" and "valleys", or crests and troughs, as pictured in Fig. 3. This is emphasized in Fig. 3 by the heavy, black "wavy" line. Notice how these crests and troughs rise and fall alternately with respect to the normal water level.

By removing the artistic representation of water from this drawing, we have left the simple wave-form in Fig. 4. This is how we represent radio waves, sound waves, and other types of wave-forms that are used in the study of electricity and radionics.

THE ROPE ANALOGY OF WAVES

The experiment illustrated in Fig. 5 will also assist you in acquiring a clear understanding of wave motion. Here, one end of a long rope is fastened to a rigid support, while the other end is shaken up and down briskly. Such motion, imparted to the rope, will cause a series of "waves" to travel along its entire length.

If the free end of the rope is shaken twice, two waves will start from that end and travel to the other end, and they will maintain the same distance between them throughout their entire distance of travel. Such a shaking motion, repeated rhythmically, will cause a continuous wave motion to be set up, and the energy imparted by the movement of the hand will be transmitted by wave-motion to the other end of the rope.

Notice how the wave-motion of the rope closely resembles the diagrammatic representation of wave-motion appearing in Fig. 4. Also observe in Fig. 5 that only the wave-motion travels from one end of the rope to the other, while the two ends of the rope maintain their respective positions. The rope serves only as the conducting medium through which the wave-motion travels. A careful study of Fig. 5 will give you a clear understanding of these points.

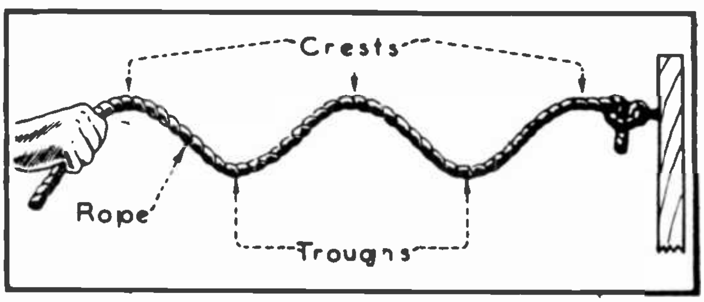

FIG. 5
USING A ROPE TO SHOW WAVE-MOTION

TERMS RELATED TO WAVE-MOTION

Several important terms are used relative to waves, the first of which is WAVE LENGTH. It is quite necessary that you learn these terms well, because they will be used throughout your course, as well as being applied constantly in the industry.

WAVE LENGTH: By referring to Fig. 6 you will observe

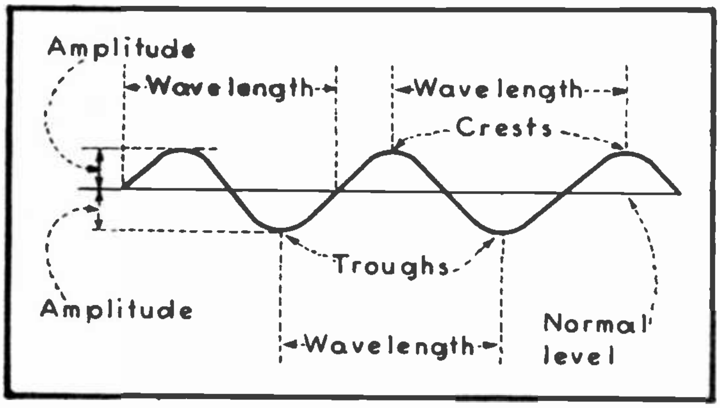

FIG. 6
AMPLITUDE AND WAVE-LENGTH ILLUSTRATED

that wave length is the distance between any point of one wave to the corresponding point of the next wave. That is, it is the distance between two successive crests of the wave, between two successive troughs of the wave, or between corresponding points of any two successive waves.

It is common practice to express the wave length of waves in terms of meters. The "meter" is the standard unit of length as used in the Metric System of measurement. (One meter is equal to 39.37 inches or approximately 3.28 feet). Thus, if we say that a certain radio wave has a wave length of 200 meters, we mean that the distance between corresponding points of two successive waves is 200 meters or approximately 656 ft. (200 x 3.28 = 656).

AMPLITUDE: The term AMPLITUDE is also indicated in Fig. 6. This value indicates the distance of a wave's crest above the normal value, and also the distance between the trough and the normal value. The amplitude can also be considered as representing the VIOLENCE or INTENSITY of the wave-motion--that is, the greater the amplitude of the wave-motion, the more violent or the more intense will be this action.

CYCLE: All types of waves occur in CYCLES. That is, the wave starts at its normal or zero value, rises to a maximum value and falls to zero. This sequence of events is called an ALTERNATION, and is pictured by the shaded area above the zero level in Fig. 7.

The wave-motion then continues by dropping to a maximum value below normal, after which it again returns to a normal or zero value. The latter series of events is also called an alternation, and is illustrated in Fig. 7 by the shaded area below the zero level. The two alternations, together, constitute a CYCLE.

The part of the wave above the normal or zero level is generally referred to as the POSITIVE ALTERNATION, while that below the zero level is called the NEGATIVE ALTERNATION. The expressions "positive" and "negative", as used in this case, are employed solely to designate opposite directions, and bear no relation to the same expressions as applied to the polarity of an electrical circuit.

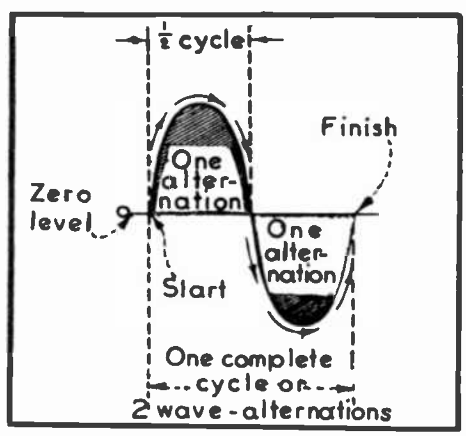

FIG. 7
ONE COMPLETE CYCLE

FREQUENCY: The term FREQUENCY can best be described as being the number of complete cycles that will pass a given point in a certain period.

Fig. 8 illustrates this. Here, you will observe that we have a platform erected above the surface of a body of water. An indicating rod is passed through a hole that is drilled in the top of the platform. The lower end of this rod is attached to a float, such as a block of wood or cork, and the float is permitted to rest upon the water's surface.

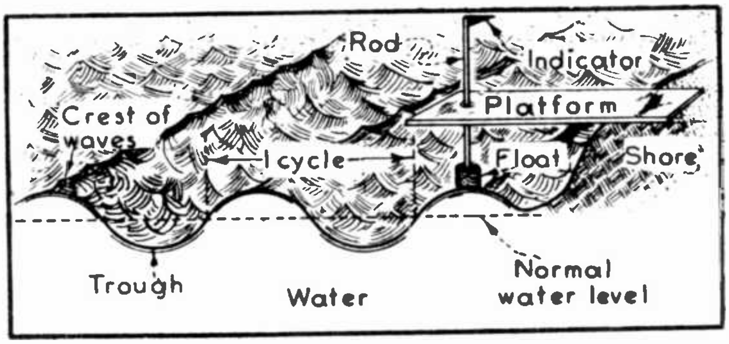

FIG. 8
SIMPLE ARRANGEMENT FOR ILLUSTRATING NUMBER OF CYCLES PASSING A GIVEN POINT

The rod, protruding through the hole in the platform, will rise to its highest level whenever a wave crest passes this point, and will drop to its lowest level whenever a wave trough passes this same point. Two such alternations of the wave-motion constitute one complete cycle. The tempo of the rising and lowering action of the rod thus indicates the "frequency" of the passing wave-motion. For instance, should this simple arrangement show that four consecutive cycles of wave motion pass this point during one minute of time, we would then say that the FREQUENCY of this wave motion is <u>four cycles per minute</u>. This condition is illustrated in Fig. 9, where the horizontal distance represents one minute of time.

The waves dealt with in radio, sound and electricity in general are of a higher frequency than used in our water analogy. Therefore, it is the practice in such cases to express the frequency in terms of a time interval of <u>one second</u>. For example, an ordinary alternating current house lighting supply is rated as having a frequency of 60 cycles per second, while a certain sound wave may have a frequency of 256 cycles per second, etc. The expression "cycles per second" is often abbreviated to cps.

<u>KILOCYCLES AND MEGACYCLES</u>: The frequencies of radio waves are so high that the basic term CYCLE is not convenient for their designation. Therefore, larger units of measurement are used for this purpose.

The KILOCYCLE, for example, is equivalent to 1000 cycles. Therefore, if the waves radiated by a certain radio transmitter have a frequency of 600,000 cycles per second, we find it more convenient to express this value as 600 KILOCYCLES per second.

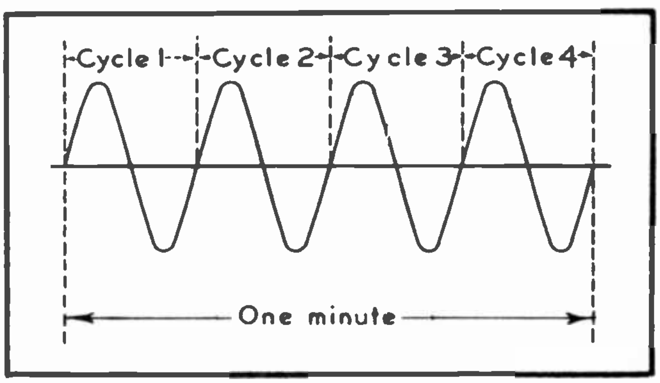

FIG. 9
REPRESENTATION OF THE FREQUENCY OF A WAVE-MOTION OF 4 CYCLES PER MINUTE

It has also become common practice to omit the phrase "per second"--this being understood. Thus, we often speak of a transmitter as operating at 600 kilocycles, or simply 600 kc--where kc is the abbreviation for kilocycles.

For the very high frequencies, the unit MEGACYCLES is often employed. <u>One megacycle is equal to one million</u>

cycles. Thus 60,000,000 cycles is equal to 60,000 kc or 60 megacycles. The abbreviation "mc" is used almost exclusively to designate megacycles. Notice, particularly, how the terms "KILOCYCLE" and "MEGACYCLE" enable us to avoid the use of too many ciphers where the higher frequencies are involved.

Be sure that the terms WAVE LENGTH, AMPLITUDE, FREQUENCY, CYCLE, ALTERNATION, KILOCYCLE, and MEGACYCLE are well fixed in your mind, as you will have occasion to use them many times in future lessons. If necessary, study the last few paragraphs again very carefully, so that there will be no doubt in your mind as to what each of these extensively-used terms means.

ESSENTIAL DIFFERENCES OF THE VARIOUS TYPES OF WAVES

The transformation of energy from one wave form to another will be more clearly understood if we make it clear at this point that all of them are of a vibratory nature, and that the only essential difference between them is in their frequency, the medium by which they are conducted and the speed at which they travel.

FREQUENCY DIFFERENCES: Frequency is perhaps the greatest distinguishing characteristic of a wave. For instance, the human ear will respond only to vibrations having a frequency between approximately 15 cycles per second and 15,000 cycles per second. Thus, we say that a mechanical wave which is vibrating at any frequency within those limits (15 to 15,000 cps) is a SOUND WAVE, and could be heard or detected by the average human ear. RADIO WAVES have frequencies higher than 15,000 cps, extending as high as 1,000,000,000,000 cps. HEAT WAVES vibrate at the incredibly high frequencies of from 1,000,000,000,000 cps to 400,000,000,000,000 cps. LIGHT WAVES have frequencies which are even higher; 400,000,000,000,000 cps., to 750,000,000,000,000 cps. It should be noted that the frequencies of heat and light waves are millions of times higher than any sound wave frequencies, as well as being much higher than any of radio signal wave frequencies.

WAVE LENGTH DIFFERENCES: Since wave length in meters is directly related to frequency, it follows that any difference in the frequency of a wave will cause a corresponding difference in wave length. Thus, the length of a wave is also a distinguishing characteristic.

VELOCITY DIFFERENCES: The velocity, or speed of travel of a wave, is another distinguishing characteristic. For instance, sound waves travel at varying speeds. This velocity of sound waves is dependent on the density of the materials through which the sound waves are traveling, and it never exceeds about 20,000 feet per second, or about 6,097.56 meters per second. Light, heat and radio waves, all travel at the uniform velocity of 186,000 miles per second, or 300,000,000 meters per second.

DIFFERENCES IN MEDIA OF TRAVEL: The medium through which a wave will travel, or be conducted, is another important factor which must be considered. As an example, sound waves will be conducted only through air, or some other physical substance--such as water, wood, earth, etc. Thus, all sound waves which travel through space are dependent on air for their conducting medium.

Light, heat, and radio waves will travel through space even though no air be present. They are said to be conducted by ETHER.

Ether (according to most scientists) is a substance which is assumed to fill all space and to permeate, or penetrate through, all substances.

In fact, even a perfect vacuum is assumed to contain ether. Ether is believed to be invisible, odorless, and tasteless; and it is not disturbed by wind, the movement of air, nor the motion of most physical objects. Temperature, apparently, has no affect upon it; and it behaves in the cold regions of the Arctic or Antarctic just as it does in the hot climate near the equator.

If ether is disturbed, by means described later, it is capable of transmitting or carrying these disturbances in the form of waves throughout the entire universe. In this respect, ether will react just as did the water in the pond which we described previously, where disturbances in the fluid (water) were transmitted or carried through the entire body of water. This is why we often call ether a "fluid-like" substance because, like a fluid, it is capable of conveying energy in wave form.

It should be noted at this point that all of our present day scientists are not in complete agreement as to the existance of ether, and its characteristics. However, slight descrepancies in scientific theories will in no way affect the practical application of the basic principles described in this lesson.

DIFFERENCES IN MEANS OF GENERATION: The means by which a wave may be set in motion is another important item which must be considered when analyzing waves. Sound waves are always set in motion by the mechanical vibration of some physical substance--such as a bell, human vocal chords, air, etc. Heat waves are set in motion by means of any heated body--such as a stove, electric toaster, burning gases, etc. Light waves are generated by any incandescent substance--such as a "red hot" stove, electric light bulb, burning gases as in an oil lamp, etc. Radio signals in wave form are electromagnetic waves generated by means of an electronic device known as a "radio frequency oscillator", which is described in the next lesson.

RELATION BETWEEN SPEED, WAVE LENGTH AND FREQUENCY

The relation between the speed, frequency and wave length of radio, light and heat waves can be arranged into convenient and practical formulas, in the following manner:

$$\text{Wave length in meters} = \frac{\text{speed in meters per second}}{\text{frequency in cycles per second}}$$

This relation between wave length, frequency and speed is illustrated in Fig. 10, where we have a graphic representation of a radio wave having a wave length of one meter, and notations to the effect that this wave has traveled a distance of 300,000,000 meters during a time interval of one second. In other words, the speed of this radio wave is 300,000,000 meters per second.

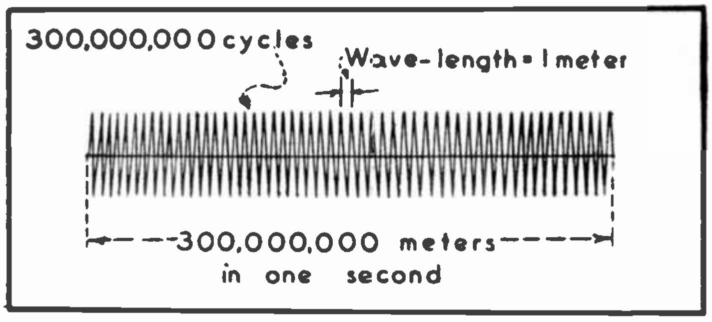

FIG. 10
RELATION BETWEEN SPEED, WAVELENGTH AND FREQUENCY

Since all of these waves are conducted by ether, and have identical speeds of 300,000,000 meters per second, this same formula can be written in the form:

$$\text{Wave length in meters} = \frac{300{,}000{,}000}{\text{frequency in cycles per second}}$$

Or, if we desire to determine the frequency in terms of the other factors:

$$\text{Frequency in cycles per second} = \frac{300{,}000{,}000}{\text{wave length in meters}}$$

These formulas are frequently written in abbreviated form as follows:

$$\lambda = \frac{300{,}000{,}000}{f}; \quad \text{and } f = \frac{300{,}000{,}000}{\lambda}$$

Here, you will observe that the Greek letter lambda (λ) is used to designate wave length; and the letter "f", frequency. These abbreviations have become standardized in Radionics. When used in these formulas, the wave length must always be expressed in meters and the frequency in cycles per second.

From an examination of these formulas, we learn that in case we know the wave length but not the frequency, we can very easily determine the frequency by simply dividing the speed of 300,000,000 meters per second by the wave length expressed in meters. Thus, if the wave length is known to be 500 meters, the corresponding frequency will be equal to 300,000,000 divided by 500, or 600,000 cycles per second. This is equal to 600 kc per second, because one kilocycle is equal to 1000 cycles.

On the other hand, if the frequency is known to be 1500 Kc, we find the wave length by dividing 300,000,000 by 1,500,000 cycles per second (Note: 1500 Kc = 1,500,000 cycles). Or, 300,000,000 divided by 1,500,000 equals 200 meters.

The velocity of sound in air is about 1130 feet per second. The wave length of a sound wave would therefore be expressed thus:

$$\text{Wave length in feet} = \frac{1130}{\text{frequency in cycles per second}}$$

DESCRIPTION OF INDIVIDUAL TYPES OF WAVES

Now that we have clarified the essential differences between the various waves, it is pertinent that we direct our attention toward the individual types of waves. The first of these forms of waves which we will study is sound waves.

SOUND WAVES

Of course, you already have somewhat of an idea as to what SOUND is, because it is such an important part of your daily life. Nevertheless, there are many characteristics associated with it that you probably never realized before. For example, the last time that you listened to a radio program, did you stop to think why it is that you are actually able to hear sounds? Do you know what happens when you strike a drum, so that a sensation is produced that we call "sound"? Do you know why some sounds appear to be louder than others, and why some sounds are high in pitch while others are low or so-called "deep" tones? These things are so common that most people simply take them for granted--never stopping to consider the wonders of the thing we call "sound".

GENERATING SOUND WAVES

To start with something easy, let us consider a simple experiment with an electric bell. Its arrangement is illustrated in Fig. 11.

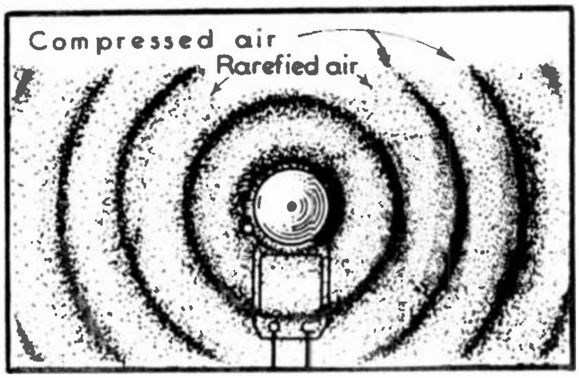

FIG. 11
RADIATION OF SOUND WAVES
FROM AN ELECTRIC BELL

When this bell rings, our eyes tell us that the little hammer strikes the bell many times in rapid succession, and at the same time we hear the characteristic sound of the electric bell. The question now is--What causes this sound?

To begin with, let us touch the bell with one of our fingers during the time that it is ringing. We find that the bell is vibrating at a rapid rate, and that it is the rapid succession of blows by the little hammer which causes this vibration. This is the first important point to remember.

The bell is surrounded completely by an "envelope" of air or atmosphere, the same as we are. Since air is a gaseous combination having an elastic nature, it can be set in motion by applying force to it.

Now, as the bell's shape is "rounded" or bowl-shaped, its natural tendency, when struck, is to vibrate from its center outward--equally in all directions, as though it were expanding and contracting from its center.

Each time that the vibrating bell makes an outward impulse, it compresses, to a certain extent, the air that presses on it from all sides. That is, it crowds the surrounding air particles together, pushing them outward in all directions. Then, during the following contracting impulse, it reduces the pressure on the surrounding air--in fact, it tends to draw away from the air, and the surrounding air particles are then no longer crowded together so that the air is less dense than normal. We then say that at this instant there is a "rarefaction of the air."

This successive series of compressions and rarefactions radiates outward from the bell equally in all directions, or in the form of expanding spheres. This is illustrated in a simplified manner in Fig. 11, where the dark rings represent air compressions and the lighter shaded portions, air rarefactions. Hence, all of the surrounding air is agitated or set in motion, and we speak of this particular type of air motion or vibration as SOUND WAVES.

GRAPHIC REPRESENTATION OF SOUND WAVES

Our representations of waves have thus far been confined solely to water waves and "rope waves," but each of the points discussed concerning them applies as well to sound waves. Your first example of a sound wave appears in Fig. 12, where you will immediately observe that the wave-form looks the same as that of the other waves that you studied

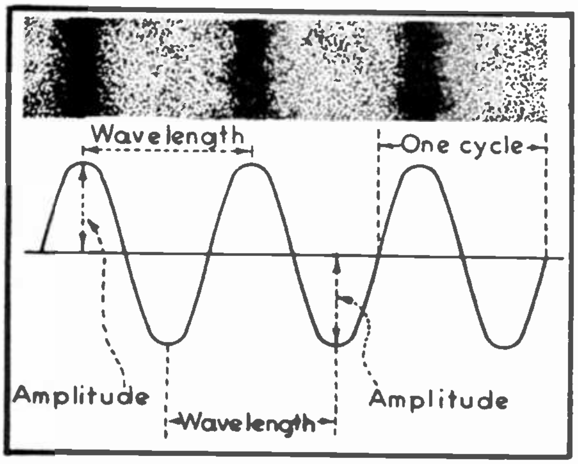

FIG. 12
SOUND WAVES GRAPHICALLY ILLUSTRATED

about earlier in this lesson.

For your convenience, we are showing you in the upper portion of Fig. 12 a representation of how the air compressions and rarefactions would actually appear, if they could be seen, as the wave-motion spreads outward through the air. Directly below it is shown the "curve" which represents this same wave-motion.

The horizontal line drawn through the central portion of this curve represents the condition of the atmosphere or air when at rest or in its natural state--that is, at the time when no sound waves exist. That part of the curve which extends above the horizontal line represents the compressed portion of the air, while that part of the curve below the horizontal line represents the rarefied portion of the air.

Notice in Fig. 12 that the wave length of the sound wave is indicated as being equal to the distance between two adjacent compressed sections, or the distance between two crests of the wave-form. The wave length of that particular sound wave can, of course, also be considered as being equal to the distance between two adjacent troughs or rarefied regions of the air. So, you can see that sound waves and the other types of waves can be compared quite closely.

In Fig. 12, also observe that the amplitude of this particular sound wave is indicated as being the distance of the crest above the horizontal line, or the distance of the trough below the horizontal line. As in water waves, the amplitude of the sound waves constitutes the violence of the wave, and the greater the amplitude of the sound waves--or the more violent the wave-motion--the louder will be the sound.

In the case of sound waves, we must also deal with the expression "frequency". That is, each sound wave is considered as setting up a certain number of vibrations per second--or better still--a certain number of CYCLES PER SECOND.

To illustrate this point even more clearly, let us look at Figs. 13 and 14. In Fig. 13 we have a sound wave consisting of 4 complete vibrations, or 4 cycles per second; while in Fig. 14 the sound wave consists of 8 complete vibrations, or 8 cycles per second.

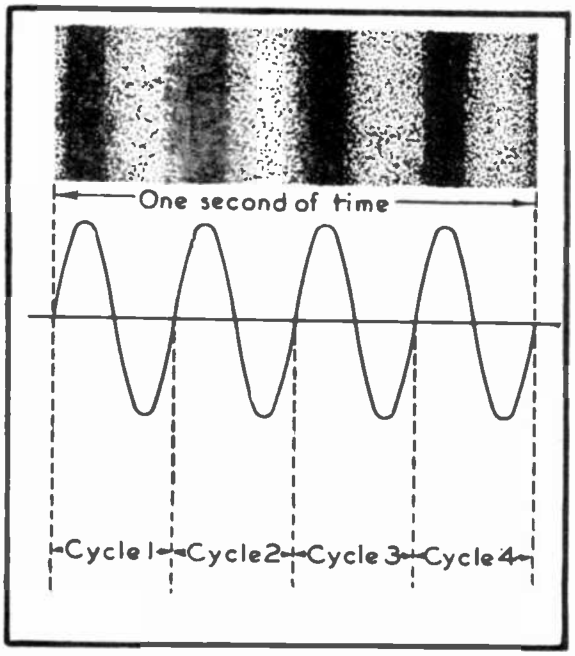

FIG. 13
SOUND WAVE OF 4 CYCLES PER SECOND

HOW AMPLITUDE AND FREQUENCY AFFECT SOUND WAVES

If we assume that the amplitude of the wave forms illustrated

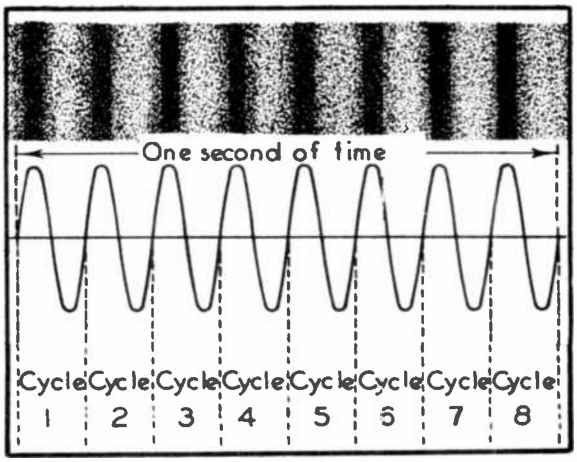

FIG. 14
SOUND WAVE OF 8 CYCLES PER SECOND

in Figs. 13 and 14 are the same, it is apparent that these waves will differ only as to frequency. That is, they will be of like amplitude, but the frequency of the latter will be greater.

Since the amplitude of the wave-forms in Figs. 13 and 14 is alike, the intensity or loudness of the sounds produced by both will be the same. However, the FREQUENCY OF SOUND WAVES DETERMINES THE PITCH OF THE SOUND PRODUCED; and for this reason, the sound produced by the wave-form of Fig. 13 will not be the same as that produced by the wave-form of Fig. 14. The latter will be higher in pitch; that is, a higher tone will be produced than that produced by the wave of Fig. 13.

In other words, sound waves of high frequency produce sounds that are high in pitch. Another way of saying the same thing is that THE GREATER THE FREQUENCY OF THE SOUND WAVE, THE HIGHER WILL BE THE PITCH OF THE TONE. Conversely, sound waves of low frequency produce sounds of low pitch; and the lower the frequency, the lower will be the pitch of the sound.

This serves to explain why a conventional violin produces high tones; whereas, a bass violin produces low tones. For example, the strings on the bass violin are comparatively long, and their tension is so adjusted that they will vibrate naturally at a correspondingly low frequency, when plucked. This vibration sets the surrounding air into motion at the same frequency; and upon striking the ear drum, this wave-motion of low frequency produces a sensation recognized by the brain as a tone that is low in pitch.

The violin, on the other hand, employs shorter strings whose tension is rather great. Therefore, their natural tendency is to vibrate more rapidly so as to produce a sound wave of high frequency, which upon reception by the ear causes the sensation of a high-pitched sound.

The VIOLENCE with which the string is plucked has nothing to do with the pitch. It simply causes sound waves of greater amplitude to be generated, which affects only the intensity or loudness of the sound.

AUDIBLE FREQUENCY RANGE

There is a limit to the number of vibrations or cycles per second that the human ear can detect as sound; in fact, this limit differs between individuals. In general, the human ear will recognize as sound only those waves corresponding to frequencies ranging from 20 cycles per second to about 15,000 cycles per second. Persons with impaired hearing, however, are limited to a still smaller frequency range and may, therefore, lack the ability to recognize very high or very low tones.

In the present state of radio broadcasting, sound waves of frequencies over 7500 cycles per second are seldom transmitted, yet the sound reproduction is pleasing to the ear. In fact, most radio stations transmit only those sounds whose frequencies range from 50 to 5000 cycles per second.

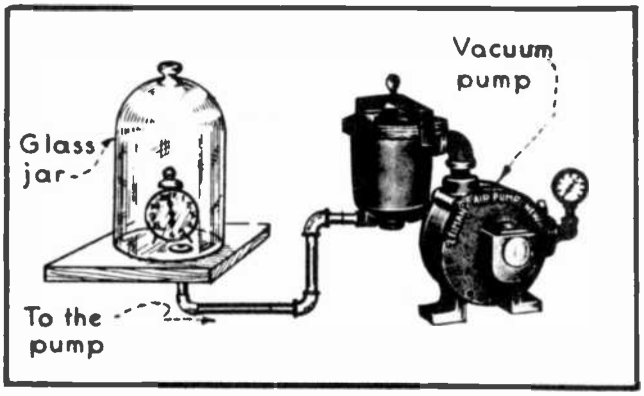

FIG. 15
THE VACUUM EXPERIMENT

CONDUCTING MEDIUMS OF SOUND

Another interesting and important fact to remember is that sound waves also require a conducting medium through which to travel, the same as in our example of water waves. As a general rule, the conducting medium for sound waves may be in the form of a solid, liquid, or gas (including air). Sound waves will not travel through a vacuum--in this respect they differ radically from the radio waves, which, as has been previously stated, are ether waves.

The fact that sound will travel through air and glass, but not through a vacuum, can best be demonstrated by the set-up illustrated in Fig. 15, where is shown an alarm clock enclosed in a glass jar. We will be able to hear the alarm under these conditions--in fact, the intensity of its sound will be practically undiminished because air serves as a good conductor of sound waves. Should we, however, draw all air from this jar by means of a vacuum pump so that the clock will be surrounded by a vacuum, no sound waves will reach our ears even though the alarm be in operation. In other words, no sound-conducting medium now exists between the clock, the glass jar, and the surrounding atmosphere.

VELOCITY OF SOUND

We will next consider the SPEED OF SOUND. No doubt, you have at times seen a steam whistle blowing at a considerable distance and noticed that you could see the steam being emitted from the whistle before hearing the sound. Several seconds may have elapsed before the sound reached your ears. This everyday experience is a fine example for demonstrating the fact that the transmission of sound is not instantaneous, but that sound waves extend outward from their origin in a gradual manner. In fact, sound waves travel through various substances at different speeds as is shown in Table I for some of the more common substances.

It is to be noted that the velocity of sound through various substances has been measured by numerous scientists, and their results differ somewhat. However, the values here given can be accepted as an approximate average that is sufficiently accurate for all practical purposes.

There are also many other factors that affect the speed of sound through solids and liquids, such as temperature, impurities in the substance, etc. In the case of gases, the temperature, pressure and moisture-content affect the speed of sound transmission quite noticeably. Although these variable factors are of importance to physicists, they need not be considered in our particular type of work. This lesson provides you with everything concerning sound to meet your present needs.

TABLE I

APPROXIMATE VELOCITY OF SOUND THROUGH COMMON SUBSTANCES

SUBSTANCE	VELOCITY IN FEET PER SECOND
Copper	10,800
Iron	17,390
Brick	11,980
Glass	16,410
Oak	12,620
Pine	10,900
Water	4,794
Air	1,129

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LESSON NO. 7

PRINCIPLES OF RADIO COMMUNICATION

In this lesson you will become acquainted with the most simple ways of producing radio waves, and learn how these waves are used for communication purposes. At the same time, you will have an opportunity to study the early history of radio and thus become acquainted with some of the more important developments that were made by pioneers in this field, and which were in a large measure responsible for making possible radio as we know it today. This approach to the subject of radio equipment, will make it easy for you to learn the basic principles as applied to such apparatus and will simplify your study of the modern receiver circuits presented in following lessons.

DISCOVERY OF RADIO WAVES

In beginning our study of radio waves, let us start with their discovery by the German scientist, Heinrich Rudolph Hertz, in 1887 and 1888. The experiments of Hertz paved the way for the work of Marconi and DeForest in this field many years later.

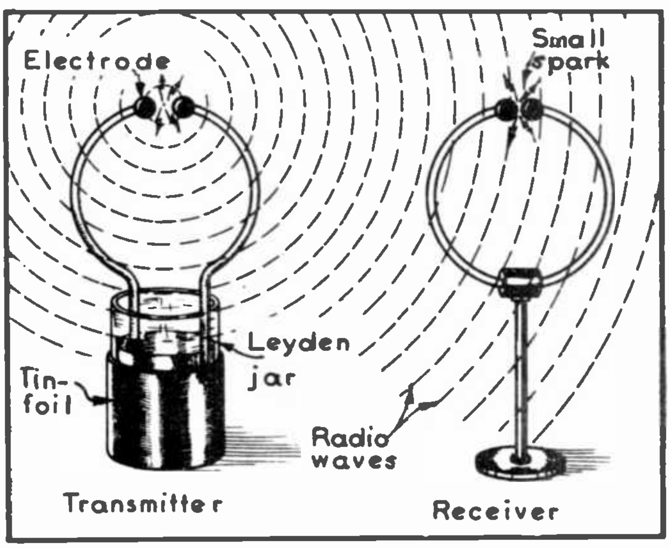


FIG. 1
APPARATUS USED BY HERTZ IN HIS EARLY EXPERIMENTS WITH RADIO WAVES

In Fig. 1, is shown the apparatus used by Hertz when he set up in his laboratory the most elementary transmitter and receiver. From a close inspection of this simple arrangement, you will observe that the transmitter consists essentially of a glass jar, the inner and outer surfaces of which are coated with a layer of tin foil. This device, which is still used for experimental purposes in physics laboratories, is commonly referred to as a Leyden jar. In reality, it is a form of condenser.

Notice in Fig. 1, that two copper balls, called electrodes, are connected to the Leyden jar by means of copper rods. One of the electrodes is thus connected to the inner foil-surface and the other to the outer foil-surface. The two copper balls are separated by a small air space.

For the receiver, Hertz employed a similar electrode arrangement in the form of a metal ring, with an air gap between the metal balls. He placed the "transmitter" at one end of the room and the "receiver" at the other end of the room.

When the Leyden jar (condenser) was charged sufficiently with electricity applied by an external source of voltage, a spark jumped the gap at the ends of the electrodes of the "transmitter"; and, at the same time that the spark appeared at the electrodes of the "transmitter", a spark appeared also at the electrodes of the "receiver", even though there was no wired connection between these two devices. Let us now see why this happened.

TRANSFER OF ENERGY BY MEANS OF THE SPARK-GAP OSCILLATOR

It should be noted that this device of Hertz' is really a fundamental spark-gap oscillator that is capable of transferring energy through space in the form of radio waves. This is accomplished in the following manner:

Electrical energy is applied to the Leyden jar (condenser) by an external source, such as a static machine, for example. Then, when the charge in this condenser attains a sufficiently high voltage, current will jump across the spark-gap in the form of an intense, blue spark; thus discharging the condenser.

Now, whenever a condenser discharges across a spark-gap, the current resulting from this discharge action flows back and forth through the conductors leading to the gap, in the form of extremely high-frequency (r-f) alternating current. We usually call this an "oscillating current". Thus, the purpose of the spark-gap and condenser combination is to utilize an applied voltage in such a way as to generate high-frequency (r-f), or oscillating current.

Whenever an alternating or oscillating current flows in a conductor, the magnetic field produced thereby around the conductor will alternately build up and collapse ("oscillate") at the same frequency as does the current in the conductor. If this magnetic field oscillates at a sufficiently high frequency (r-f), part of the energy which it represents will "break away" from the conductor and be ejected into space in the form of electromagnetic waves, which we call radio waves.

If these radio waves, in their movement through space, encounter any conducting material, they will induce alternating (oscillating) electromotive forces of corresponding frequency therein. This is what occurs when the waves encounter the loop of the Hertz receiving device.

The oscillating current which is induced into the receiver circuit (loop) represents electrical energy sufficiently great to cause a spark to appear across the gap. Since the spark at the gap of the receiver is visible to the eye, and audible to the ear in the form of a crashing sound, it is apparent that portions of the electrical energy available at the receiver are being transformed into light waves, and into sound waves. Still other portions of the energy represented by the spark will be transformed into heat and magnetism, and as such, will temporarily surround the loop and spark-gap.

As a matter of fact, whenever an electric spark occurs, radio waves are generated and radiated outward into space, somewhat as illustrated in Fig. 2. All electric sparks produce radio waves to a certain extent. It is for this reason that the sparking at the trolley wire of a passing street car causes a snappy or crackling noise to be heard in a nearby radio receiver.

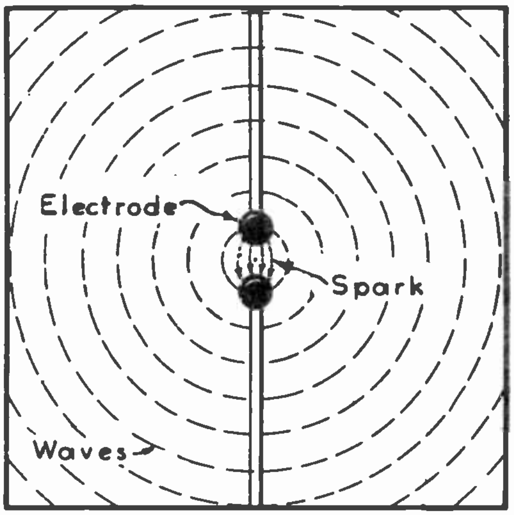


FIG. 2
WAVE RADIATION FROM A SPARK DISCHARGE

In one of his scientific papers, Hertz enumerated the following conditions that must be met in order to perform this experiment: First of all, the two loops must have approximately the same diameter so as to be in resonance or in tune with each other. Second, they must be placed with the plane of the loops parallel, one with the other. Third, the distance between them must not be too great--four to ten feet being considered an appropriate distance. Fourth, the Leyden jar must be charged to as high a voltage as possible. Fifth, the distance between the electrodes of the gap on the receiving loop must be much less than that of the transmitting loop.

Hertz also measured the velocity (speed) of radio waves, finding that they traveled at the same speed as light, or approximately 186,000 miles per second (300,000,000 meters per second).

HERTZIAN WAVES: Waves which were set in motion by the Hertz oscillator were called electromagnetic waves by their discoverer. Later, they were named Hertzian Waves in honor of Hertz. Present practice is to call them radio waves.

DEVELOPMENT OF WIRELESS AS A MEANS OF COMMUNICATION

While great importance was attached to the experiments and discoveries of Hertz, no immediate attempt was made to use Hertzian waves as a means of communication. However, by increasing the size of the receiver loop; increasing the voltage of the charge stored in the Leyden jar; and by connecting several of the jars in series so that the effect of their charges was additive; Hertz did find that it was possible to increase the distance over which the transfer of energy might take place. In his final efforts, he was rewarded by the coverage of several city blocks.

Hertz passed away in 1894, after a life rich in contributions to science and to the benefit of his fellow men. It remained for a young Irish-Italian, named Marconi, to adopt the device as a practical method of communication, and to make it a most necessary part of modern civilization.

MARCONI AND WIRELESS

Guglielmo Marconi, as a youth, became interested in the discoveries of the scientists of his day who were working, just as are our present-day scientists, to learn more about the behavior of things electrical. Intrigued with the discoveries of Hertz, as published in scientific papers, he began to construct similar devices. Having previously learned the telegraph code, he attempted to use these devices to send telegraph signals about his father's estate in Italy.

He soon eliminated many of the defects of the Hertz oscillator, when used as a means of communication. His improvements are listed in the following paragraphs.

CONSTANT SOURCE OF POWER: Marconi found that by connecting an induction coil to the Leyden jar, and operating the induction coil by means of a battery, a spark could be made to pass continually between the two electrodes of the transmitter's spark-gap instead of only at intervals as was the case in the Hertz system wherein a static machine was used to charge the condenser. Marconi's transmitter, at this stage of its development, is shown in Fig. 3.

AERIAL AND GROUND: Hertz had previously discovered that increasing the size of the resonating loops would increase the distance over which it was possible to transmit energy by means of electromagnetic waves. Marconi tried substituting two rather long wires, called "aerials", for each of the loops; and found that this worked much better than did even the largest loop that had been used previously. Later discoveries indicated that one of the aerial wires could be eliminated, and that a connection to a rod or pipe driven into moist ground could be used in its place with equal success. This aerial and ground connection is also shown in Fig. 3, for both the transmitter and receiver.

THE COMPLETE SYSTEM: Notice particularly, in Fig. 3, how one electrode of the transmitter's spark-gap is connected to the elevated aerial wire,

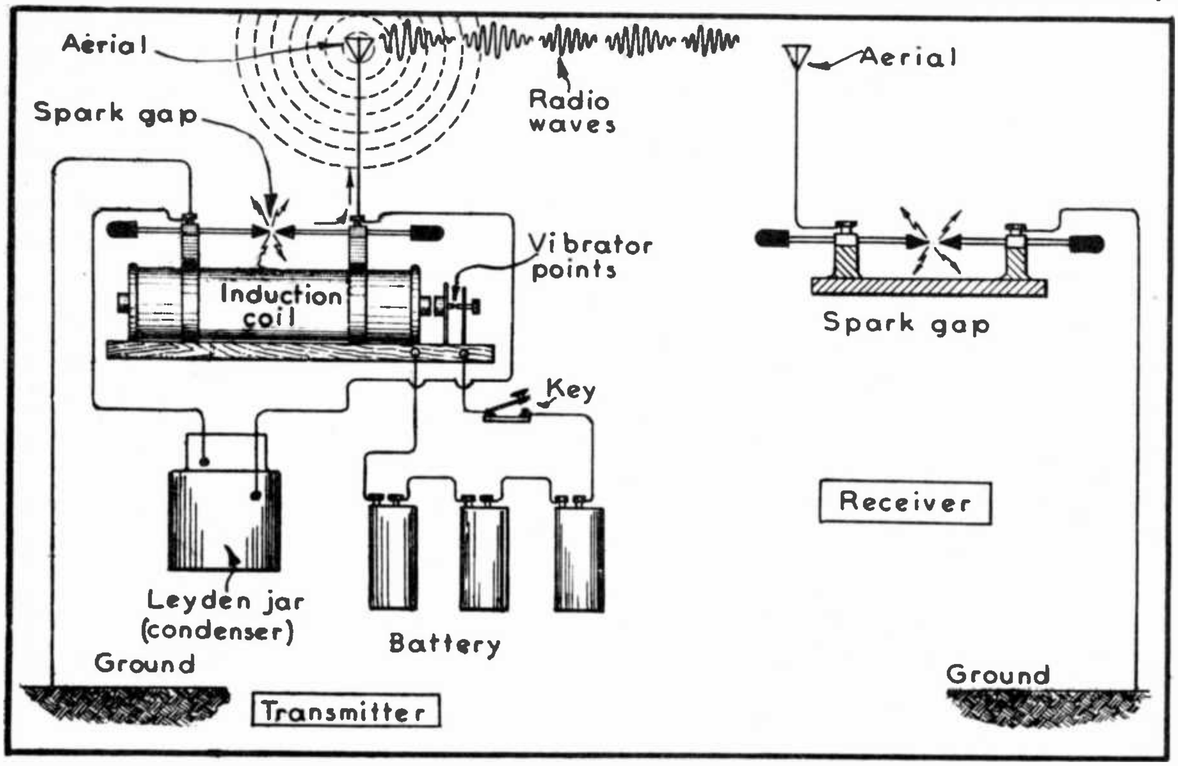


Fig. 3
Early Marconi Wireless System

and how the other electrode is connected to ground by means of another wire. The application of the Leyden jar, induction coil and battery is also shown.

The receiver which was used by Marconi at this time consisted of a spark-gap; a length of bare, elevated wire (the aerial); and a ground connection. This is also illustrated in Fig. 3. The length of bare wire which was connected to one side of each of the spark-gaps was named an "aerial" by Marconi; probably because he discovered that the distance spanned could be increased if the wire were elevated high in the air. Present practice is to call the elevated wire the "antenna".

Notice also in Fig. 3, how a telegraph key is connected in series with the battery and the vibrator circuit of the transmitter. Sparks will jump across the air-gap continuously as long as the key is kept closed; during which time a series of radio waves will be radiated by the aerial system, as shown in the illustration.

Also, by means of the key, the waves can be "broken-up" into predetermined code, as will be explained later in this lesson where the circuits of this Marconi system are discussed in greater detail.

At this point, Marconi, with the cooperation of his father--for he was still a very young man--was using his "wireless" apparatus, as he called it, for regular communication. Constant experimentation had enabled him to develop the sending part of the combination to the extent that he had a rather powerful and reliable method of producing Hertzian waves.

IMPROVED MARCONI RECEIVER

Turning his attention to a better method of receiving (detecting) the waves radiated by the transmitter, Marconi developed several devices which were great improvements over the spark-gap type of detector. In the most efficient type of detection which he developed, Marconi utilized the ordinary telephone receiver, such as is in use today. Extremely small currents flowing through the windings of a telephone receiver (headphone, or "phone") will make even a weak radio signal audible; and, when this means is employed for reproducing the signal, no spark-gap is necessary at the receiver. In other words, a stronger signal is required at the receiving station to produce a spark than a sound in a headphone.

CRYSTAL DETECTOR: In order to utilize the telephone receiver (headphone) for the reception of radio signals, it is first necessary that the high-frequency (r-f) signal currents, induced in the receiver circuit by the Hertzian waves, be converted into pulsating currents. That is, current which will flow through the headphone winding in one direction only.

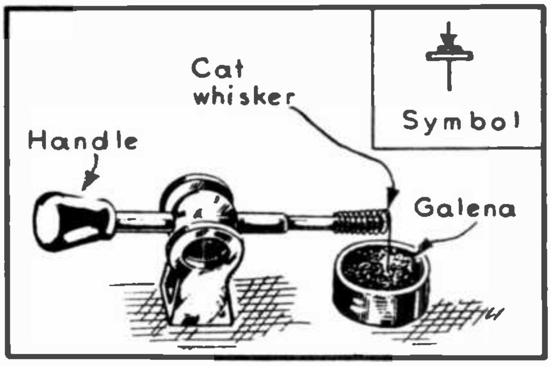


FIG. 4
CRYSTAL DETECTOR

If the high-frequency (r-f) signal currents were to be permitted to pass through the headphone winding, there would be no sound, as the diaphragm of the headphone would not respond to the rapid reversals of such current. Therefore, the r-f signal currents must be rectified (changed to pulsating d-c) before being permitted to flow through the headphone. Marconi was able to so rectify the incoming signal currents by means of a device called a crystal detector.

This crystal detector consisted of a small piece of some natural mineral--usually an ore containing lead-sulphur or copper-sulphur--such as galena, or pyrites. Such a crystal, and its mounting, is shown in Fig. 4, together with the symbol for this type of detector. Here, you will observe that the crystal is mounted in a small metal cup with which it makes electrical contact. The metal cup serves as one connection of this detector in the receiver circuit. An extremely fine wire, called a "cat-whisker", because of its size and shape, bears lightly against the crystal and serves as the other connection of the detector.

At (A) of Fig. 5, you are shown what would happen if the headphone were connected directly in the circuit between the antenna and ground connection, without using a detector. If this were done, the radio frequency (alternating)current that is induced in the antenna, would tend to flow through the headphone; but, since the headphone will not respond to current of such high frequency, no sound will be produced. At (B) of Fig. 5, on the other hand, we have the crystal detector connected in such a manner that it permits the high-frequency current that is induced in the antenna to flow through the circuit in one direction only. That is, the detector changes the high-frequency a-c to pulsating direct current; and the flow of this pulsating direct current through the headphone sets up sound waves and so makes the signal audible.

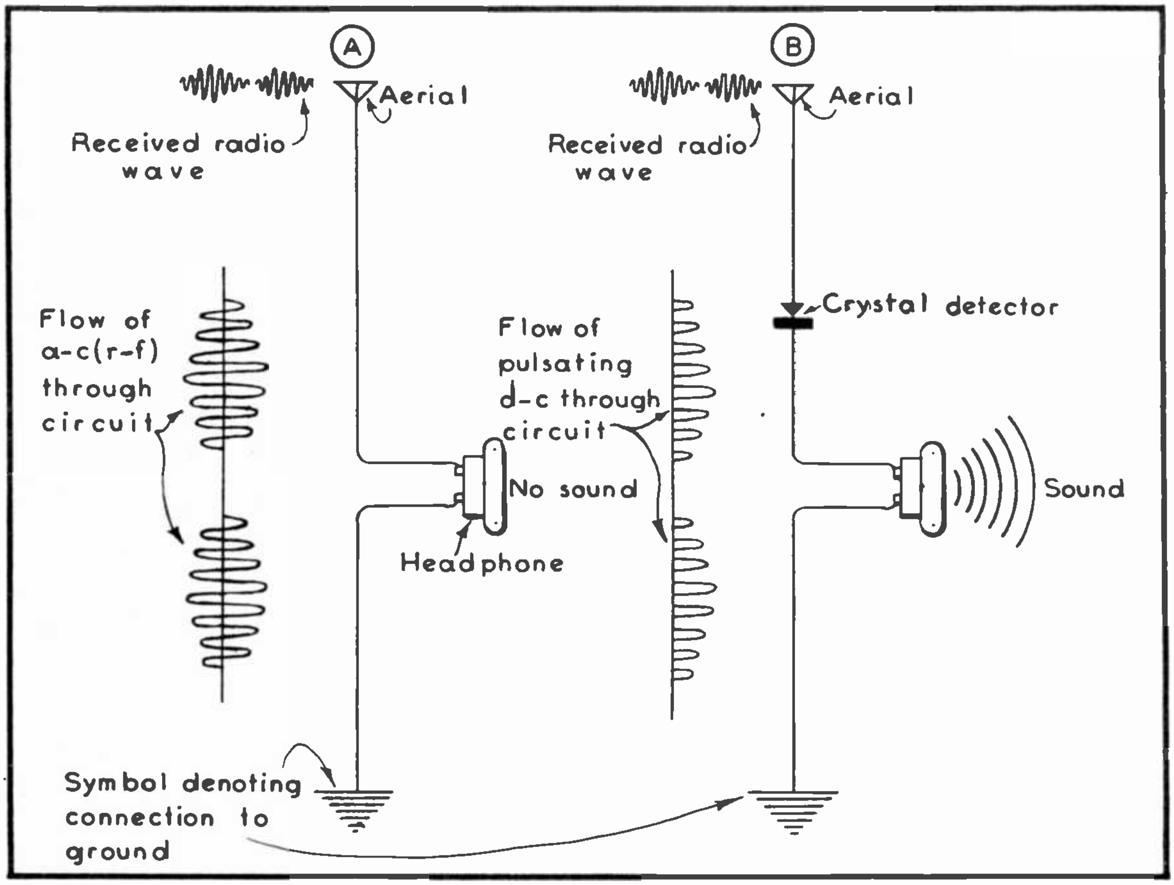


FIG. 5
ACTION OF CRYSTAL DETECTOR

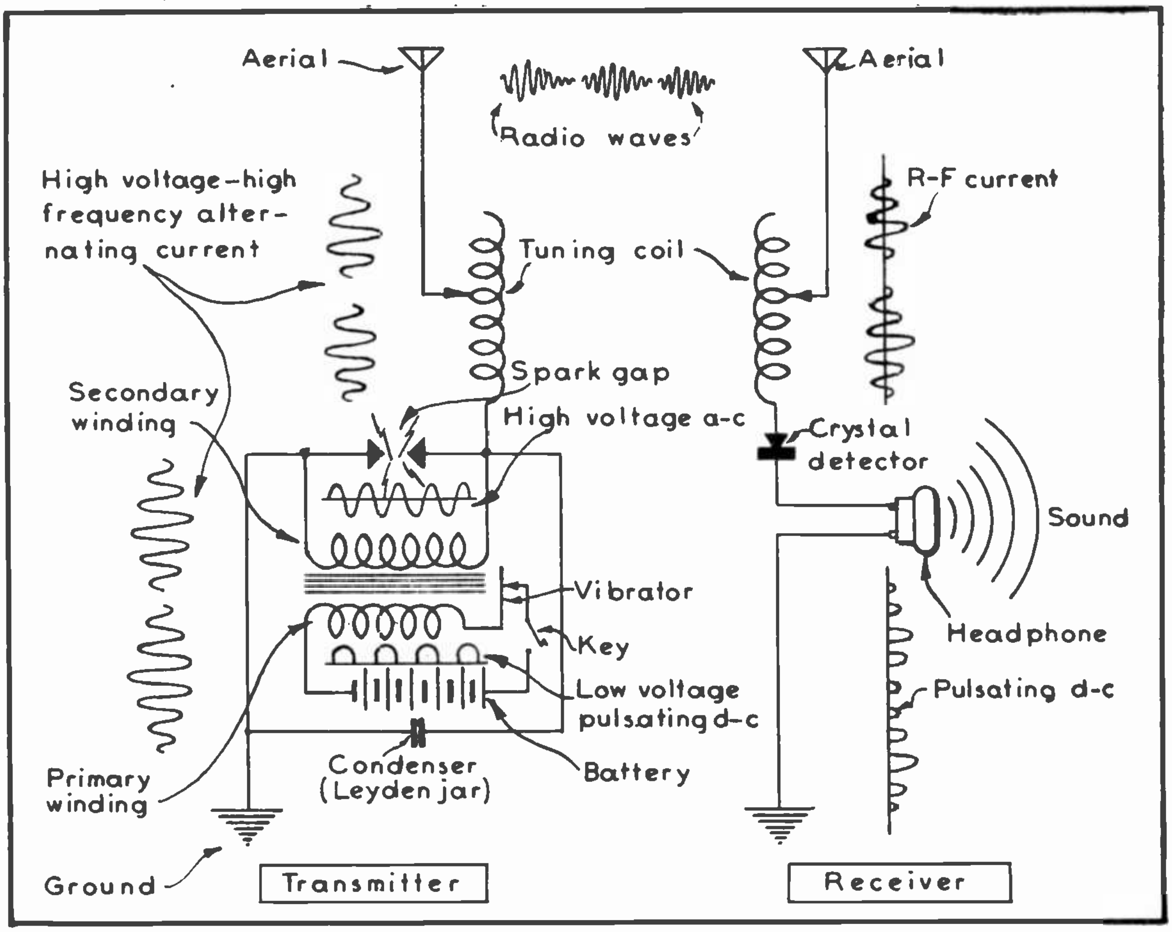


FIG. 6
COMPLETE MARCONI SYSTEM

The complete wireless equipment of that era (1905-1912) is illustrated diagrammatically in Fig. 6. Here, you will observe that the transmitter consists of an induction coil, condenser, spark-gap, battery, telegraph key, tuning coil, aerial, and ground connection. The receiver consists of a tuning coil, crystal detector, telephone receiver (headphone), aerial,and ground connection. This transmitter operates in the following manner:

When the operator depresses the key in the transmitter circuit with his fingers, a low-voltage emf (furnished by the battery) is applied to the primary winding of the induction coil. This low-voltage d-c emf is converted to a pulsating emf by the vibrator which is connected in the primary circuit of the coil. (Notice in Fig. 6 how the wave form of the current is indicated symbolically in each circuit of the transmitter and receiver to still further clarify this analysis.)

The low-voltage pulsating emf, applied to the primary, causes pulsating current to flow in the primary winding; and through mutual induction, a high-voltage a-c emf is developed across the secondary winding of the coil. This high-voltage emf charges the condenser that is connected across the secondary winding; and as soon as the condenser has been charged to a sufficiently high voltage, it discharges across the spark-gap. The surging of the spark between the electrodes of the spark-gap causes high-frequency a-c current (r-f) to flow between the antenna and ground circuits of the transmitter. These high-frequency (r-f) alternating currents, surging back and forth in the antenna circuit of the transmitter, set up an oscillating magnetic field around the antenna wire, so producing a disturbance of the ether and causing Hertzian waves (radio waves) to be radiated through space.

When these waves reach the antenna of the receiver, they induce high-frequency a-c voltages into it that tend to cause an r-f current of corresponding frequency to flow in the receiver circuit. However, the crystal detector in the receiver circuit permits the passage of current in one direction only; that is, it converts the a-c signal current into pulsating current. The pulsating current flowing through the headphone causes it to produce sound waves and thus make the radio signal audible to the listener in the form of a "buzz" or "whistle".

Therefore, every time the operator at the transmitter presses the key, the listener at the receiver hears a "buzz" in the headphone. This buzz is heard as long as the key of the transmitter is depressed. By pressing the key for greater and lesser durations of time, so that long or short buzzes are produced, it is possible to form the dot and dash characters of the International telegraph code, and thus send intelligible messages from the transmitter to the receiver.

There were at this time quite a number of wireless transmitting stations in operation, so it became necessary that some means be devised whereby a person operating a receiver could make an adjustment and select one particular station that he might wish to listen to from all the others. If this could not be done, it is quite obvious that all of the transmitters that happened to be in operation at the time would be received simultaneously by the receiving station. The person listening to them would then be unable to differentiate between the signals emitted by the various transmitters, and this would, naturally, lead to confusion.

TUNING FEATURES: To make possible the selection of one station signal from all others, Marconi placed a coil of wire in the antenna circuit of both the receiving and sending set. The number of turns of wire on the coil in the transmitter antenna circuit determined the frequency and wave length of the waves being radiated. By using a coil of approximately the same size and number of turns in the receiving circuit, it was possible to have the receiver respond only to waves of that same frequency and wave length for which the transmitter's antenna circuit was adjusted. This selection of the desired frequency is called tuning, and the coils are known as tuning coils.

In practice, the coils of both the receiver and transmitter were constructed so that the operator could make an adjustment and utilize any number of turns that might be desired. Thus, the transmitter and receiver could be adjusted by the operator for any frequency or wave length.

ADVANTAGES AND DISADVANTAGES OF SPARK TRANSMITTERS

Spark transmitters were used for many years as a means of communication. Even after they had been supplanted for general usage by more modern and efficient equipment, they were still retained in some maritime installations where they performed with a reasonable degree of satisfaction. In fact, spark transmitters are still found on some smaller vessels where they are used for emergency, or "stand-by" purposes--to be used for distress calls in case of failure of the regular transmitter.

The main advantage of a spark transmitter is its simplicity and ruggedness. Its chief disadvantages are that a tremendous amount of electric power is required to operate it, if reliable communication is

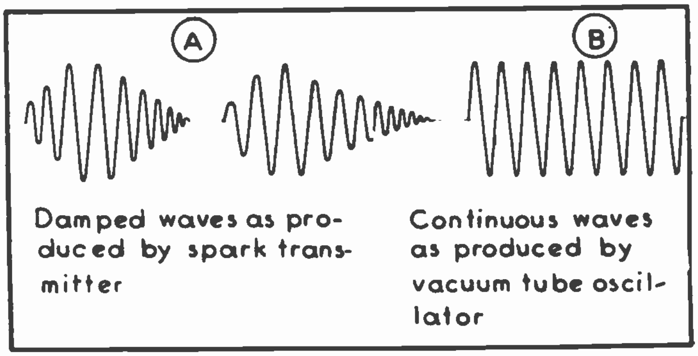


FIG. 7
DAMPED AND CONTINUOUS RADIO WAVES

to be expected over even moderate distances; and that it is of no value for the transmission of radio phone signals--that is, for the transmission of music, speech, or other intelligible sound.

WHY SPARK TRANSMITTERS ARE UNSUITED FOR RADIO TELEPHONY

In Fig. 7, you are shown the difference between radio waves of a continuous nature and those as radiated by a spark transmitter. Observe at (A), how the wave varies in amplitude and dies out periodically even when the key remains in the closed position. This is called a damped wave. The damping action is due to the periodic charge and discharge of the condenser.

At (B) of Fig. 7, we have a diagrammatic representation of a continuous type wave. You will observe that this wave is uninterrupted and of unvarying amplitude. Continuous waves are necessary to transmit voice and music, but they also provide a means for more efficient transmission and reception of code messages.

DE FOREST AND THE VACUUM TUBE

Dr. Lee De Forest developed the little glass bulb, called a vacuum tube or electronic tube, to the point where it was able to change or modify many of man's concepts of space and time. Born in 1873, at Council Bluffs, Iowa, and educated at Yale, Dr. De Forest is now known as one of the pioneers in the development and perfection of radio. By 1930, he had taken out over 300 patents of radio devices--the most important of these being the three-electrode vacuum tube.

To put it briefly--early in his career, De Forest applied his remarkable talents to the improvement of the vacuum tube, which was the original invention of Thomas Edison. He so improved it that it has made possible our present day radio, sound pictures, long distance telephones, public address systems, television, and practically all of the so-called electronic or radionic marvels. There is almost no industry of our modern civilization that does not use the vacuum tube in one form or another.

VACUUM TUBE APPLIED TO RADIO COMMUNICATION BY CODE: The three-element vacuum tube, as developed by De Forest, made possible the construction of an oscillator, which rapidly replaced the spark-gap type oscillator, for most purposes. The vacuum tube oscillator sets radio waves in motion in the ether just as does the spark-gap oscillator, only it does it much better. For the transmission of code, the vacuum tube oscillator will operate with but a fraction of the amount of power required by the spark-gap oscillator, and it will permit reliable transmission over much greater distances.

VACUUM TUBE USED IN RADIO TELEPHONY: It is in radio-phone transmission that the tube proved its real worth. By its use, it is possible to transmit speech, music, or other intelligible sound through space.

VACUUM-TUBE TRANSMITTERS

In our present study of vacuum-tube transmitters, we are not going to discuss the circuits of such equipment, as to do so requires con-

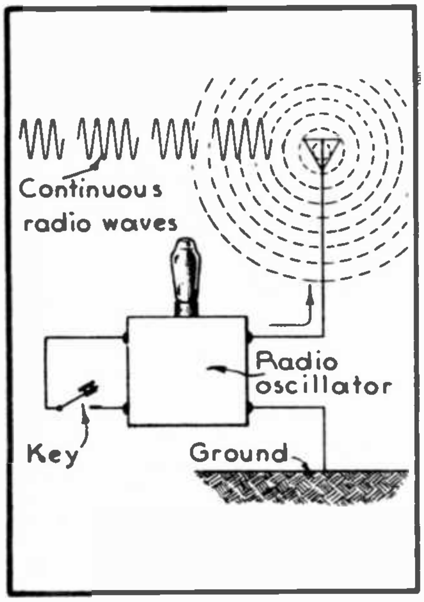


FIG. 8
SIMPLE VACUUM-TUBE TRANSMITTER

siderable knowledge on your part of vacuum tubes and other circuit components which have not yet been covered. We do, however, at this time want you to become acquainted with the basic principles concerning the units that produce radio waves by this means, and also the ways in which radio waves must be handled in order to make the transmission of speech and music possible. The various sections of vacuum-tube transmitters involved are, therefore, shown in the form of block diagrams only, but their proper names are employed so that you will know what each of them does to make the complete system operate. Later in the course, transmitters of all types will be covered in great detail.

The elementary knowledge which you will acquire concerning the production of radio waves by means of vacuum-tube transmitters, as obtained from the study of this lesson, will make our discussion of receivers in following lessons much more understandable than would be the case if you did not have this preliminary instruction.

An elementary representation of a vacuum-tube transmitter is shown in Fig. 8. Such a device will produce continuous radio waves, and is commonly referred to as a vacuum-tube oscillator.

When the key in Fig. 8, is closed, an uninterrupted flow of radio waves will be radiated from the antenna. By opening and closing the key at the proper intervals, the continuous wave can be broken up into groups to form the letters of the telegraphic code, as illustrated in Fig. 8. Notice, however, that each wave-group does not "dwindle" to a zero value in a gradual manner, as is the case of the wave generated by a spark transmitter, and as pictured at (A) of Fig. 7.

The waves which are set in motion by this continuous wave, key-operated transmitter, are called "interrupted continuous waves". The abbreviation "CW" is often used to denote continuous waves, and oscillators which produce this type of wave are called "CW oscillators".

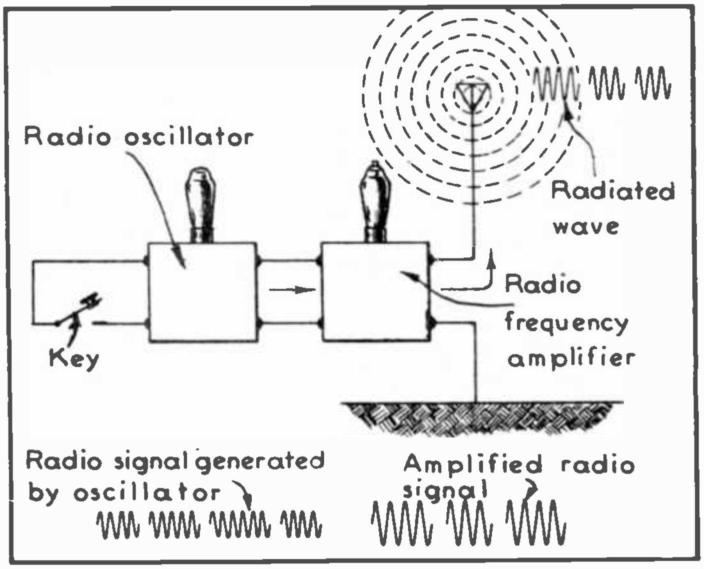


FIG. 9
VACUUM-TUBE OSCILLATOR
AND RADIO-FREQUENCY AMPLIFIER

THE VACUUM TUBE AS AN AMPLIFIER

Another important feature of the vacuum tube is its ability to amplify or to increase the intensity of signals being handled by it. Therefore, to increase the transmitting power of the oscillator shown in Fig. 8, we merely place a vacuum-tube amplifier (radio-frequency amplifier) between the oscillator and the antenna, as illustrated in Fig. 9. By this means, radio energy, as generated by the oscillator, will be intensified or amplified perhaps hundreds of times--depending upon the design of the amplifier. If still more amplification is desired, it is only necessary to add additional amplifying stages or tubes. Thus, as the original signal is passed through each successive amplifier stage, it will be increased by each stage until the desired point of intensification has been attained.

For simplicity, a one-tube amplifying stage is shown in Fig. 9. The key serves the same purpose in this system as in the other systems already described. In Fig. 10, you are shown a complete, modern vacuum-tube transmitter as used for the transmission of code signals.

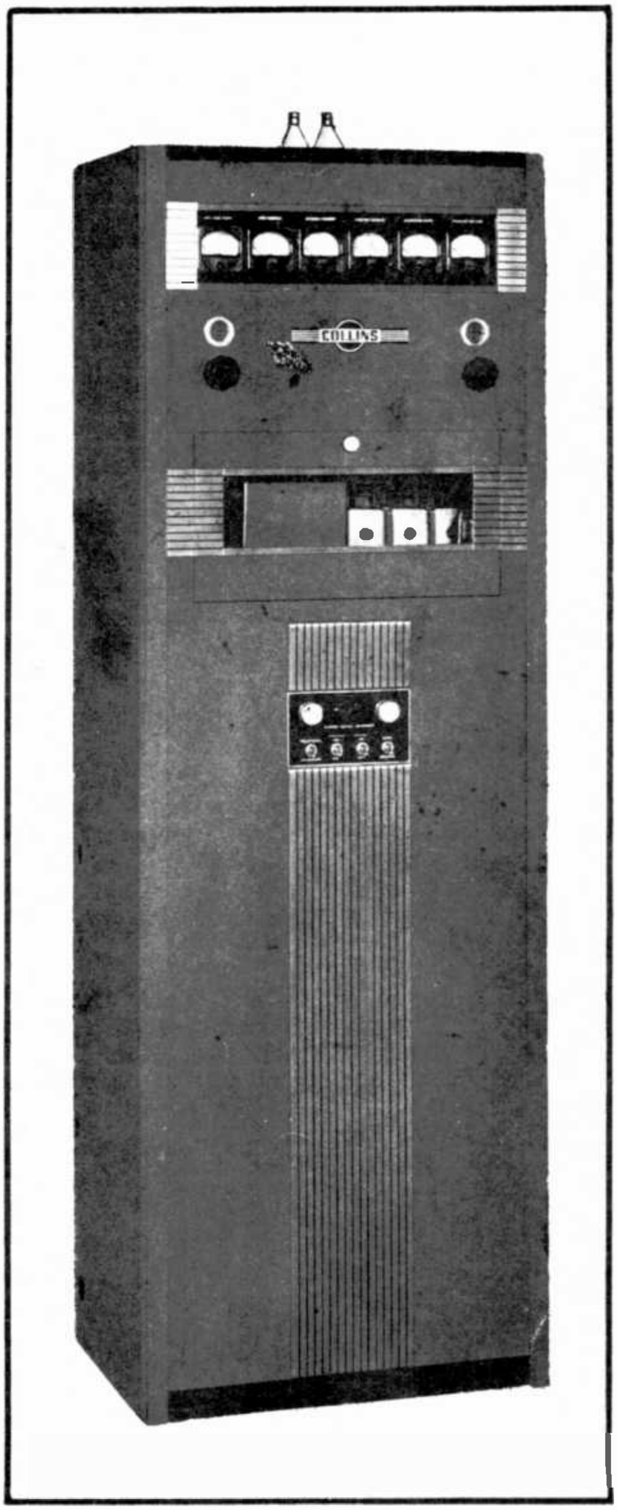


FIG. 10
MODERN VACUUM-TUBE TRANSMITTER

So much for "code transmitters". Now let us turn our attention to the equipment that is used for the transmission of voice and music by Radio.

A FEW WORDS CONCERNING SOUND

Whenever we speak, we subject the surrounding air to varying pressures, causing a series of "waves" to travel outward from the source of the sound, somewhat as pictured in Fig. 11. We call these sound waves.

As the sound waves spread outward through the air and act upon the ears of some nearby person, the latter hears the sound that was produced originally at its source. This is also pictured in Fig. 11.

Sound waves are quite unlike radio waves, as the latter are electrical in nature and cannot produce an audible (hearable) sound unless some form of electrical equipment is available for "extracting" the sound from the radio wave. Sound waves, on the other hand, are vibrations or motion of air, and can be transferred through the air directly from their source to the ears of the listener.

Let us now turn our attention to Fig. 12. Here, we have an arrangement consisting of a microphone, an amplifier, and a loudspeaker. The

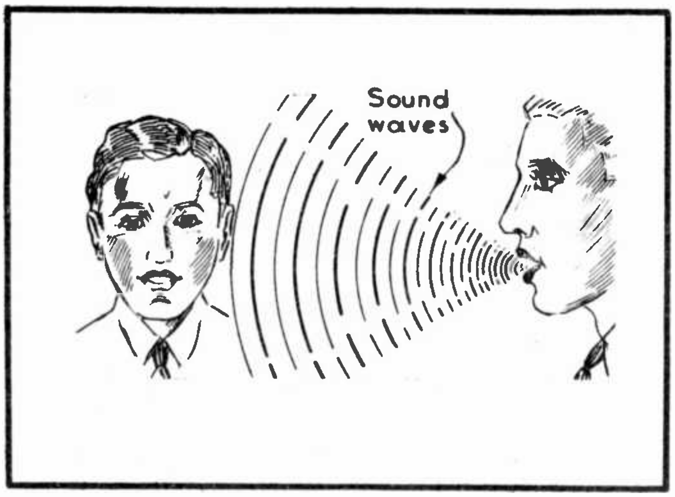


FIG. 11
SOUND WAVES

construction of the microphone is such that when speaking into it, sound waves will act upon it and produce electrical impulses. These electrical impulses are amplified or intensified by the audio amplifier (sometimes called an "audio-frequency amplifier"), as indicated by the wave-form above the amplifier in Fig. 12. The loudspeaker, in turn, converts the amplified electrical impulses back into sound; but, since amplification has occurred, the sounds produced by the loudspeaker will be much louder than those uttered by the person.

In Fig. 13, you are shown a commercial arrangement of the system just described. This equipment consists of a microphone, a vacuum-tube audio amplifier, and a loudspeaker. Such an arrangement is often referred to as a public address system.

ADDING SOUND TO RADIO

Even though sounds be amplified tremendously, sound waves will travel only a limited distance through space. Radio waves, on the other hand, have the ability to span oceans and continents. Fortunately, there is a means whereby we can combine radio waves and sound waves so that the effect of the sound waves can be transported as a radio wave, and thus be made to travel great distances. We do this by a process known as modulation.

MODULATION: The word "modulate" means to limit, or to modify. When we apply modulation to the radio wave output of a continuous-wave transmitter, we are limiting, or modifying, the radio wave by means of the audio waves which are impressed upon the microphone. This is illustrated in Fig. 14, where a modulator is shown as being connected between the oscillator of a continuous-wave transmitter and the antenna and ground.

It should be noted that the microphone is connected to the modulator through one stage of audio frequency amplification. Connected in this manner, the modulator will function as a valve, controlling the amplitude of the outgoing radio wave. This control is exercised while the output of the oscillator is still in the form of r-f current, and before it has left the antenna in the form of an r-f wave. Notice especially, in Fig. 14, that the amplitude of the

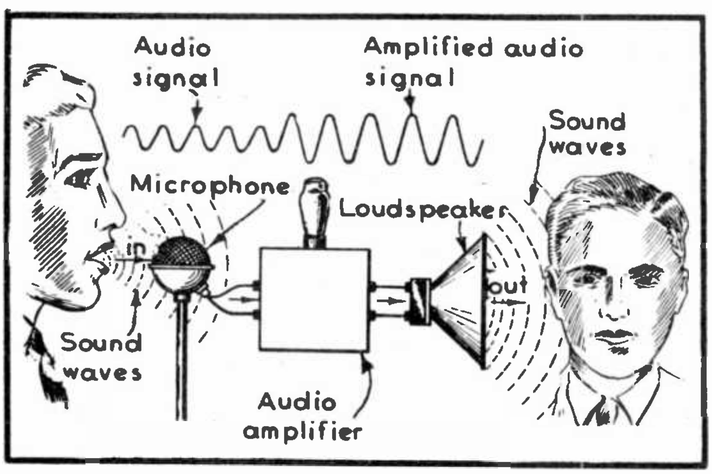


FIG. 12
SPEECH AMPLIFIER

CW wave at the output of the modulator varies in accordance with the audio-frequency (sound) wave form.

In Fig. 15, you are shown diagrammatically how the audio signal and the C-W (oscillator) radio signal are both fed intc the modulator, and how the C-W wave appears at the output of the modulator with its amplitude varied to conform with the shape of the audio or sound signal wave. We call the continuous wave, which has been so altered, a modulated wave.

It should be stressed here that the modulating audio-frequency never travels through space. Only the effect of the modulating audio frequency as impressed upon the modulated r-f is actually radiated into space.

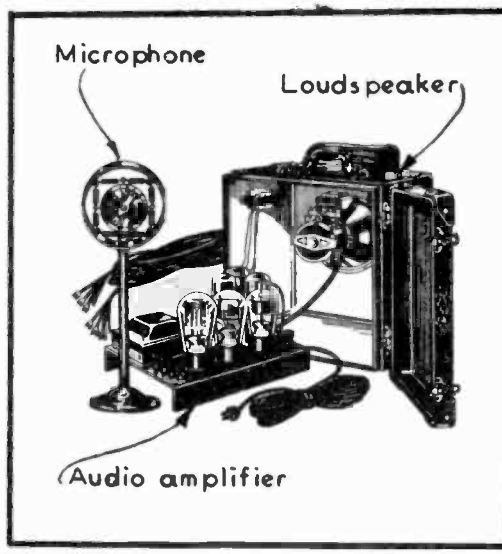


FIG. 13
PORTABLE PUBLIC ADDRESS SYSTEM

In Fig. 16, we show an unmodulated and a modulated wave in another graphic form, to aid still further in clarifying this point. Here, you will note that the amplitude which, it will be remembered, is the distance from zero (center line) to the positive or negative peak of the wave, is constant in the first section of the graph which represents that no sound is reaching the microphone at this time.

The latter portion of the curve shows the change in amplitude which takes place when sound is reaching the microphone. It should be noted

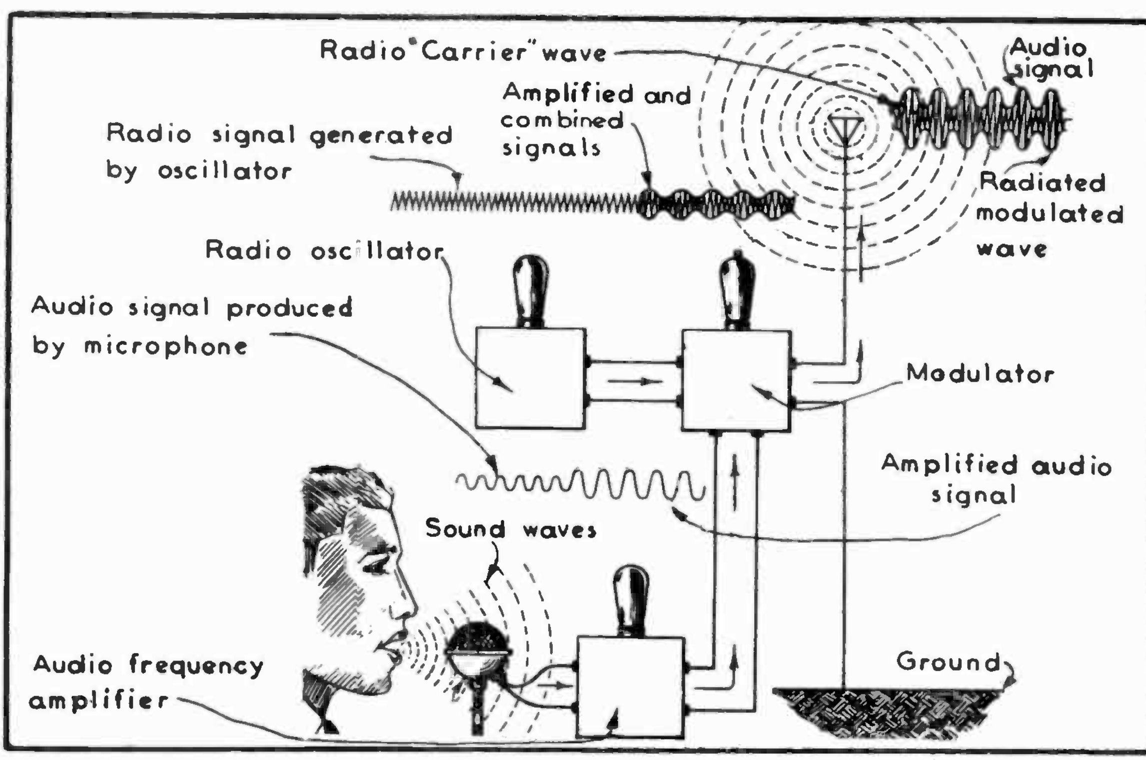


FIG. 14
BASIC PRINCIPLE OF A TYPICAL RADIO-TELEPHONE TRANSMITTER

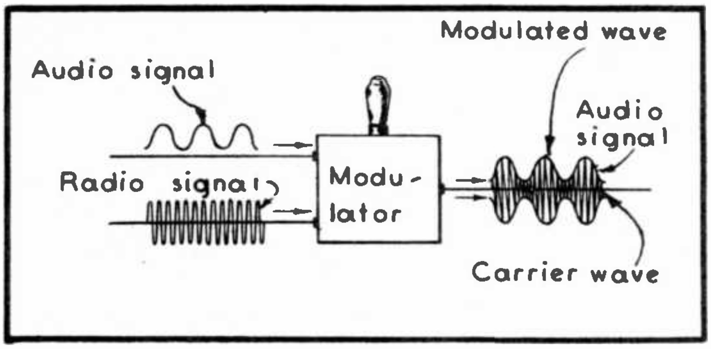


FIG. 15
PROCESS OF MODULATION

that with sound reaching the microphone, the amplitude of the r-f wave is constantly being changed, or controlled, by the frequency and amplitude of the a-f currents which are being fed from the microphone to the modulator. The peaks of some of the r-f waves in Fig. 16, are now higher than in the unmodulated section, while others are below the level of the unmodulated wave.

Thus, we can say that a MODULATED WAVE IS A WAVE, THE AMPLITUDE OF WHICH IS CONTROLLED BY THE AMPLITUDE AND FREQUENCY OF ANOTHER WAVE.

Notice that this form of modulation changes only the amplitude of our radiated wave ; and that it has no effect upon the frequency, wave length, or velocity of the r-f wave produced by the oscillator.

CARRIER WAVES: Because the sole purpose of the r-f wave of a modulated C-W transmitter is to carry the impression, or effect, of the audio frequency through space to the receiver, that section of the r-f wave which is present when no sound reaches the microphone is often called the carrier wave.

In this connection, it would be well to point out that the r-f waves or currents are of no value in themselves. They are for the sole purpose of transporting the a-f effect through space, and they are discarded soon after reaching the receiver.

R-F WAVES AND CURRENTS: The term r-f (radio frequency) is applied to any frequency of vibration which is greater than about 15,000 cycles

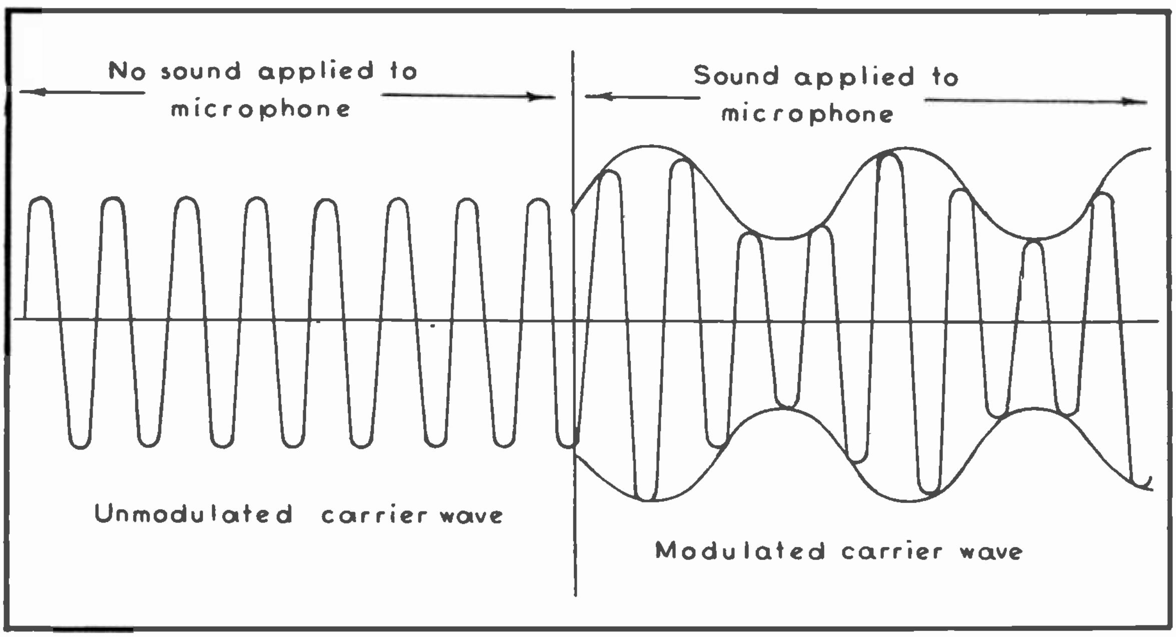


FIG. 16
UNMODULATED AND MODULATED CARRIER WAVE

per second, and less than 1,000,000,000,000 cycles per second. Another way of defining r-f is that it is a frequency too high for the average human ear to hear as sound; and, that if in the form of an r-f current, this current, flowing through the antenna circuit of a transmitter, is capable of setting r-f waves in motion. The r-f waves thus set in motion will travel through space as radio waves. Upon reaching the aerial of the receiver, these r-f waves will induce r-f current to flow in the aerial circuit of the receiver.

A-F WAVES AND CURRENTS: The term a-f (audio frequency) is applied to any frequency of vibration which is less than about 15,000 cycles per second. Or, it is a frequency which, if in the form of vibrations in air or some other physical substance, may be heard as sound by the average human ear. Audio-frequency waves must be conducted by air or some other physical substance, and cannot travel through space as waves in ether. Audio-frequency currents are formed in a circuit which contains a microphone with a-f waves being impressed thereon.

An a-f or r-f current may be in the form of either a pulsating current or an alternating current.

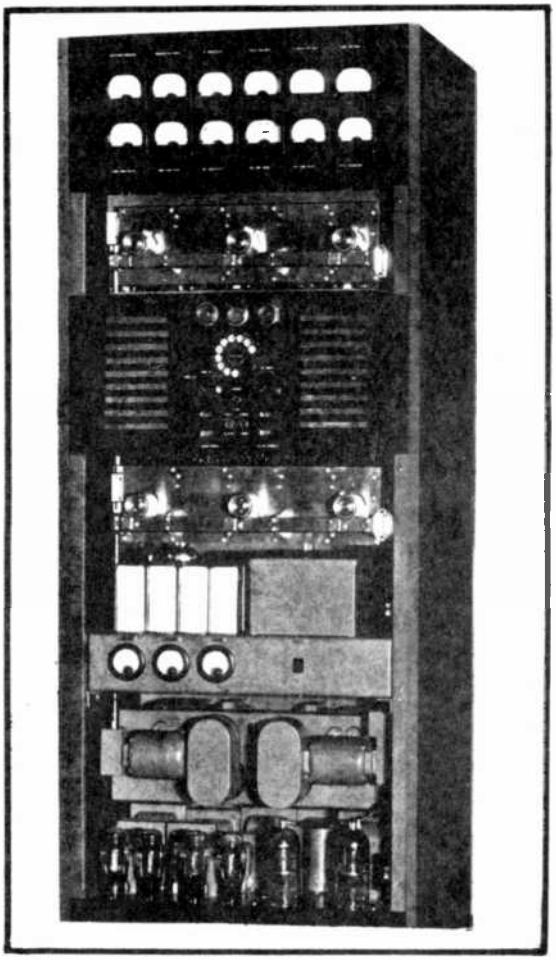


FIG. 17
MODERN RADIO BROADCAST TRANSMITTER

RADIO BROADCASTING

In 1907, Dr. De Forest constructed the first apparatus used for modulating continuous waves with speech--and the first "broadcast" of sound (speech) took place in New York City. So successful were the results, that Dr. De Forest equipped twenty-four warships of the United States Navy with radio-telephone installations during 1907. It is interesting to note that these units were sold with a positive guarantee of five miles, although in actual operation they consistently covered a distance of over 25 miles.

In 1908, Dr. De Forest went to France and installed his radio-telephone equipment on top of the Eiffel Tower, from where he broadcast phonograph music. Reports of this test showed that he was heard as far as 500 miles. In 1910, Dr. De Forest began a series of broadcasts, employing singers and grand-opera stars to provide the programs. However, in those days these efforts were wasted--it was too soon for broadcasting because only amateur radio operators had receiving sets, and there were very few amateurs at that time.

Because of the conditions just mentioned, broadcasting lay dormant until after World War I. However, radio-telephone conversations were broadcast across the Atlantic in the meantime. It remained for the Westinghouse Company to commercialize the experimental music broadcast by one of its engineers, Dr. Frank Conrad, who was broadcasting daily entertainment from his amateur station. This led to the construction of the first broadcasting station in the world (KDKA) which went "on the air" in 1920, and is still in daily operation.

Thus, you have the picture of radio broadcasting from its beginning to its present state of development. In Fig. 17 is shown an actual broadcasting transmitter that embodies the principles described relative to Fig. 14. This transmitter is so arranged that the audio-frequency amplifier is in the lower section of the cabinet; while the oscillator, modulator, and radio-frequency power amplifier are above. In some installations, the various units are separated and contained in individual cabinets. Nevertheless, in every radio-telephone or radio broadcasting transmitter, there must be an audio amplifier, an oscillator, and means for modulation. A radio-frequency amplifier is also generally used where a powerful signal is required. The latter is then placed between the modulator and the antenna so as to amplify the modulated signal before passing it on to the antenna.

RECEIVERS FOR C-W TRANSMISSION

Modulated continuous waves may be received quite satisfactorily on one of the simple crystal detection receivers described in our discussion of Marconi's wireless equipment. In fact, most people can remember the early days of radio broadcasting when crystal receivers were very popular.

However, just as it was possible to utilize the vacuum tube in constructing a more efficient transmitter, so also is it possible to use this little glass and metal wonder-worker in receivers which are much more satisfactory than are the best crystal receivers. A vacuum-tube receiver using but one tube, will be much more sensitive, will receive signals over a greater distance, and will produce a louder sound in the phones, than will the best crystal receiver.

VACUUM-TUBE RECEIVERS: It is for the reasons just mentioned that the vacuum tube has replaced the crystal as a detector in the majority of the receivers in use today. A simple vacuum tube receiver, consisting of a detector only, is shown in elementary block form in Fig. 18.

As in the case of vacuum-tube transmitters, we are showing vacuum-tube receivers in this lesson in block form only. Our sole purpose at this time is to bring to your attention how the radio waves are handled by this equipment during reception. In later lessons the circuits of such receivers will be described fully, as also will their operating principle.

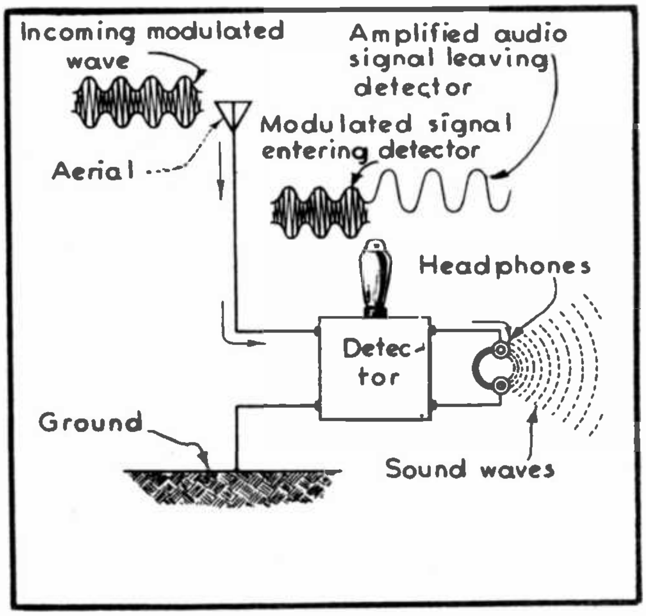


FIG. 18
RECEIVER EMPLOYING A VACUUM-TUBE DETECTOR

When the modulated r-f wave which is radiated by the transmitter strikes the aerial of the receiver, a corresponding r-f current is set in motion in the input circuit of the receiver. This is illustrated in Fig. 18. This r-f current possesses a modulated amplitude just as did the r-f wave, and therefore carries the effect of the original a-f as generated at the microphone of the transmitter. By means of appropriate circuits in the receiver, this

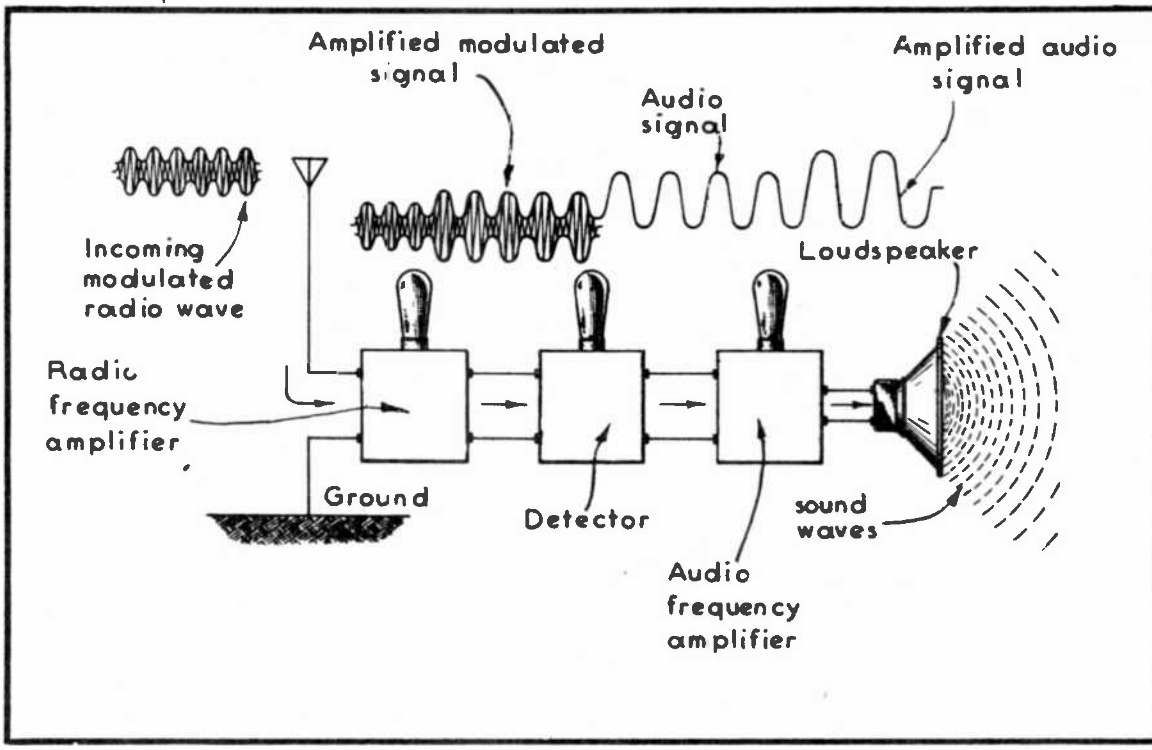


FIG. 19
RECEIVER CONSISTING OF A RADIO-FREQUENCY AMPLIFIER, DETECTOR, AUDIO-FREQUENCY AMPLIFIER, AND LOUDSPEAKER

a-f effect, which is superimposed on the r-f carrier is, through the action of detection, caused to pass electrical energy in the form of a-f (pulsating) current through the headphones. Thus, the latter reproduces the sounds that actuated the microphone at the transmitter and caused the carrier wave to be modulated.

We can therefore state that the detector in the receiver does just the reverse of the modulator in the transmitter. That is, it "extracts" the sound (a-f) wave from the carrier (r-f) wave, and with the aid of the headphones makes the variations in audio signal current audible.

In observing the action of this type of receiver in Fig. 18, notice that as the vacuum tube changes the incoming modulated signal to an audio signal, it also <u>amplifies</u> the audio signal considerably.

AMPLIFYING THE RECEIVED SIGNAL

We have mentioned previously in this lesson that vacuum tubes have the ability to amplify or intensify the signals handled by them. This is true whether the signal is of radio or audio frequency, and whether the amplification is being done in the transmitter or in the receiver.

<u>AMPLIFYING THE RADIO SIGNAL</u>: Every detector, whether it be of the crystal or tube type, has certain limitations as to its ability to handle weak signals satisfactorily. To increase the sensitivity of a receiver, an amplifier is placed ahead of the detector. The amplifier ahead of the detector is called a <u>radio frequency amplifier</u>, and is used to boost the strength of the extremely weak radio signals as they are intercepted by the aerial.

The usual practice is to include several stages of amplification in front of the detector. For the sake of simplicity, only one such

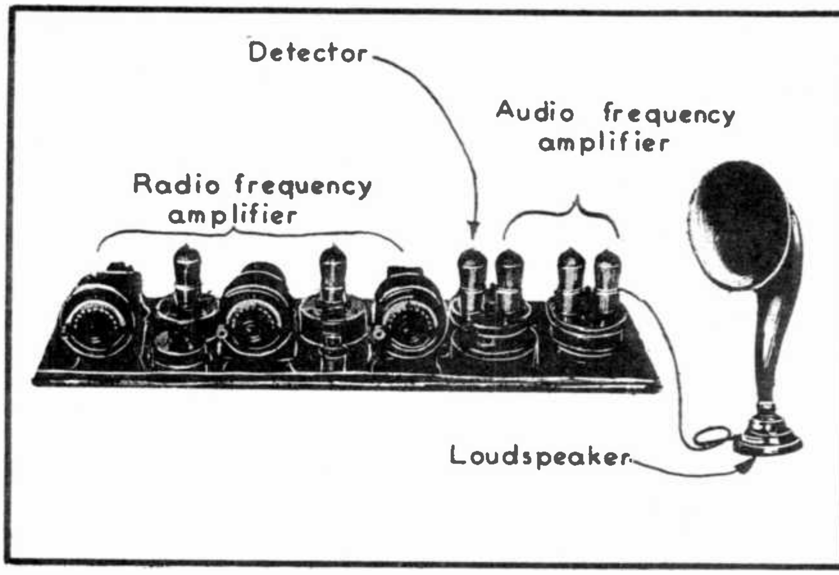


FIG. 20
TYPICAL VACUUM-TUBE HOME RADIO OF 1924

amplifying stage is shown in Fig. 19. In observing this arrangement, notice how the incoming radio signal is amplified as it passes through the radio-frequency amplifier, and before being applied to the detector.

AMPLIFYING THE AUDIO SIGNAL: Should we connect a loudspeaker in place of the headphones, shown in the receiver diagrammed in Fig. 18, it is very doubtful that we would hear any sounds. The reason for this is that the audio signals, as furnished by the detector, are not of sufficient intensity to actuate so large a unit as the loudspeaker, although they might be easily heard when the headphones are put over the ears. Therefore, an audio amplifying stage is included in all receivers that employ a loudspeaker.

The audio-frequency amplifier intensifies these weak audio signals sufficiently to properly operate the loudspeaker, so that the resulting sound waves will spread throughout the room and thereby make the sounds audible. Fig. 19 illustrates how the audio frequency amplifier is included in the complete receiver, and how it increases the amplitude of the a-f signal.

In Fig. 20, you are shown an early-model vacuum tube receiver designed for home use. It employs a radio-frequency amplifier, detector, audio-frequency amplifier, and loudspeaker--the same as illustrated in the diagram appearing in Fig. 19. Modern receivers still employ these fundamental principles, but they have been perfected most notably since the advent of radio broadcasting. By comparing the modern receiver shown in Fig. 21 with the older model appearing in Fig. 20, you will somewhat appreciate the remarkable progress which has been made in this field.

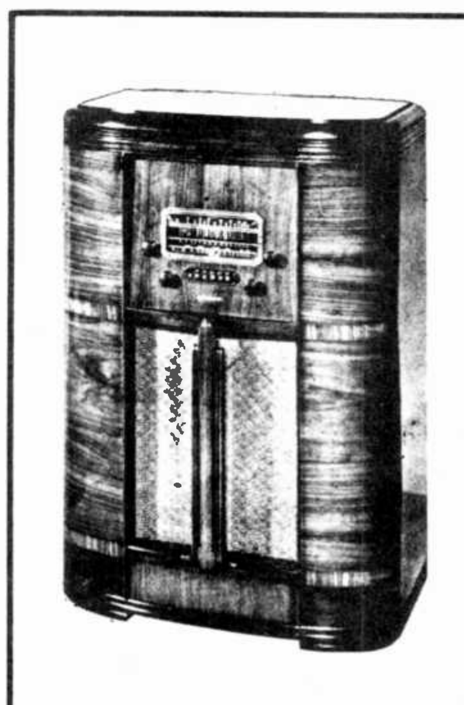


FIG. 21
MODERN HOME RADIO

FROM MICROPHONE TO LOUDSPEAKER

To still further assist you in acquiring a clear conception of radio transmission and reception, we have prepared the diagram appearing in Fig. 22. Here, you are shown the complete set up for both the transmitter and the receiver. Thus, you can follow the process from the

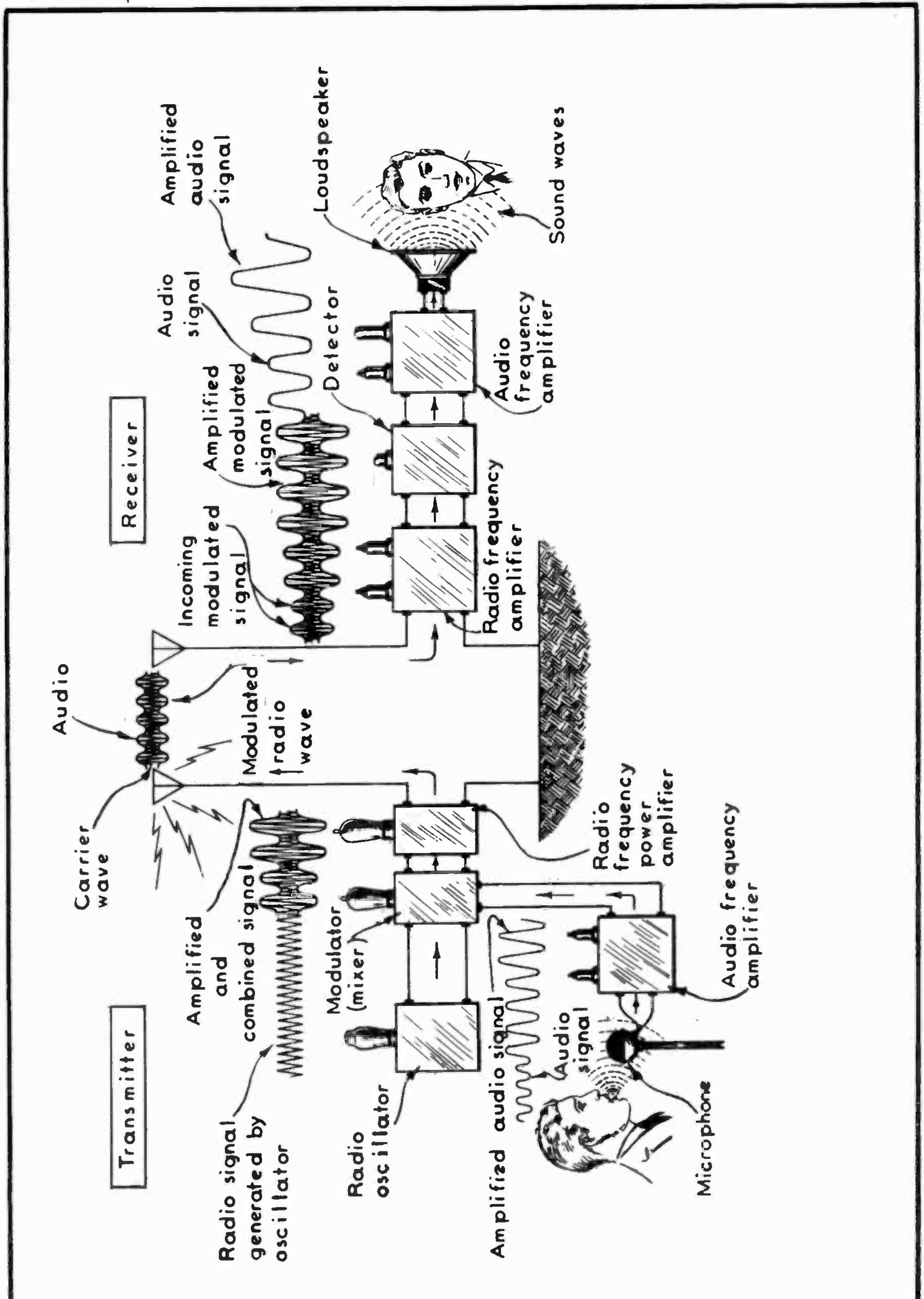


FIG. 22
TRANSMISSION AND RECEPTION OF RADIO PROGRAM

origin of the sound waves at the microphone of the transmitter, until they are finally reproduced by the loudspeaker of the receiver. This illustration also shows you how a radio-frequency power amplifier may be employed between the modulator and the aerial of the transmitter in order to intensify the modulated signal before radiation, so that greater distances can be covered.

From what has already been told you, the complete system illustrated in Fig. 22, should be self-explanatory. It is well that you note in Fig. 22, that several of the various amplifying units are shown as employing more than one tube. This is generally the case in actual practice where considerable amplification is required.

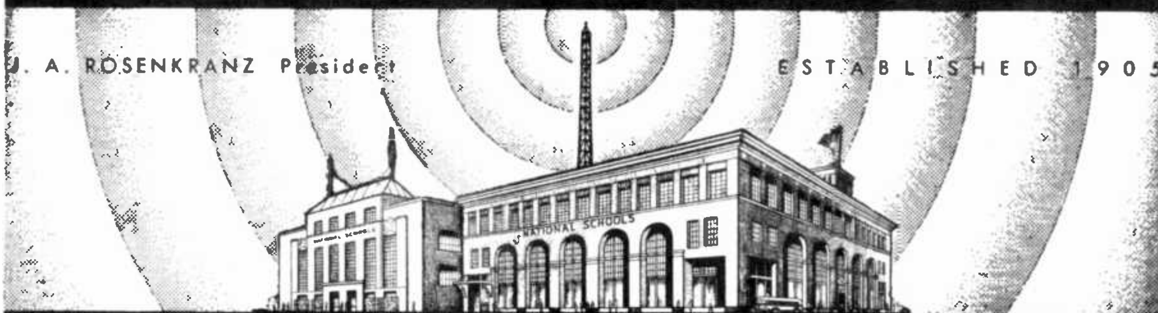
It is of special importance for you to observe in Fig. 22, how the wave forms of the audio, radio (carrier) and modulated r-f signals are affected by the various sections of the transmitter and receiver; and also how the modulated wave which is radiated by the transmitter's aerial acts as the "connecting link" between the transmitter and receiver.

You are now ready to apply this fundamental knowledge to a detailed study of receiver circuits, beginning with the next lesson. You have already learned several of the most basic and elementary principles which it required years of concentrated effort for early experimenters to discover. Yet, you learned them after only a few minutes of leisurely reading.

On first thought, this may hardly seem possible, but it is really quite logical when we consider that the pioneers in this industry had no concrete information on which to base their studies, while you, on the other hand, are provided through National Training with the unlimited wealth of information compiled from the data furnished by all these early scientists, experimenters, and engineers.

In preparing this course, National's chief aim has been to furnish you with complete instruction, presented in such manner that you begin with the most simple principle and gradually advance in logical steps through the most complex radio and electronic apparatus now being used. The following lessons are just as easy to understand as this one--in fact, quite often you will be absorbing so-called advanced technical information without actually being aware of it. All this is due to the systematic manner in which this entire course of training has been planned.

Practical Technical Training In
RADIO·TELEVISION
AND ALLIED ELECTRONICS



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LESSON NO. 8

HOW RADIO RECEIVERS OPERATE

Up to this point, we have concerned ourselves with the basic principles of electricity, magnetism, the electron theory, sound, light, heat, and radio waves. By combining the principles that you have learned from the study of these subjects, it is now possible for you to understand the construction and operation of one of the most common radionic devices in daily use -- namely, the radio receiver.

BASIC RECEIVER CIRCUITS

In Fig. 1, is shown the schematic diagram of a simple receiver employing a crystal detector. This receiver is capable of receiving radio signals from broadcasting stations over a distance of from 25 to 150 miles. Lest you think that the crystal receiver is an ancient device of little importance, we hasten to point out that while it is one of the oldest practical receivers, it does, nevertheless, have certain virtues which make it worthy of study in this day and age. Furthermore, a proper understanding of the theory of operation of this type of receiver will make it easier for

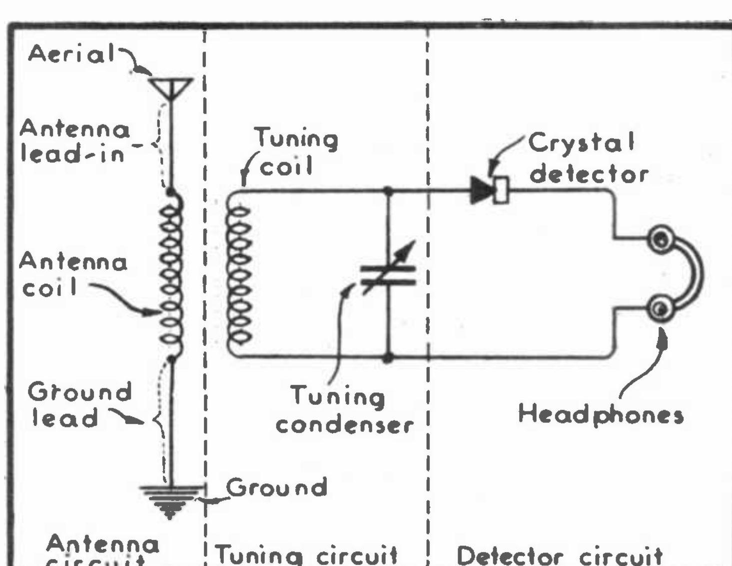


FIG. 1
CIRCUIT DIAGRAM OF CRYSTAL RECEIVER

you to understand the more complicated electron-tube circuits which are explained in the following lessons.

It should be noted that the crystal receiver, shown in Fig. 1, has been broken down into basic circuits, for the purpose of studying the system in detail. In fact, all electric, electronic, or radionic devices, however complex, can be broken down in this manner into individual circuits and studied as such. Then, by mastering each circuit individually, a thorough understanding of the operation of all the circuits combined in the apparatus will be arrived at.

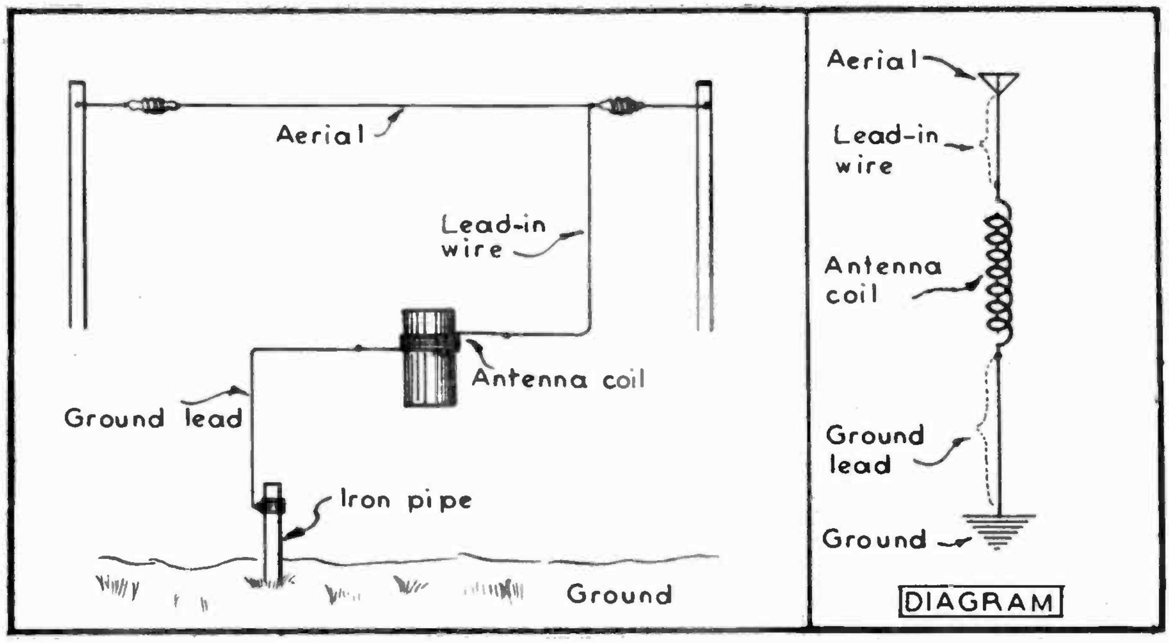


FIG. 2
ANTENNA CIRCUIT

It should be noted that this simple receiver consists of three distinct circuits. These are: the antenna circuit, the tuning circuit, and the detector circuit.

ANTENNA CIRCUIT: The antenna circuit is shown alone in Fig. 2, both pictorially and schematically. Here, you will observe that it consists of the aerial (often called the "antenna"), lead-in wire, antenna coil, and the ground connection -- all connected in series.

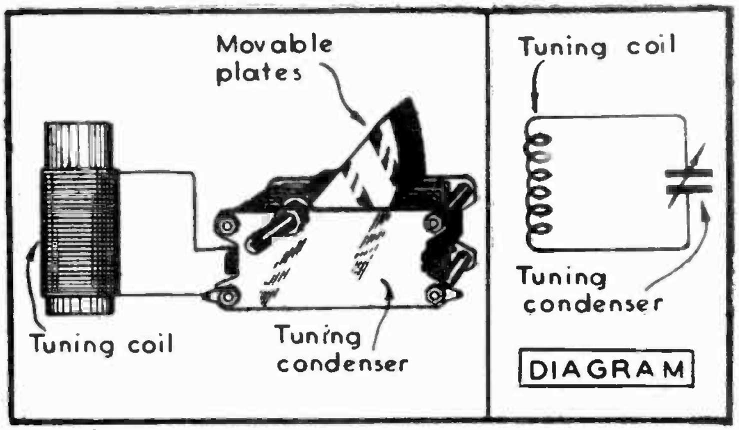


FIG. 3
TUNING CIRCUIT

TUNING CIRCUIT: The tuning circuit, shown in Fig. 3, consists of the tuning coil and the tuning condenser. These two parts are connected in series, one with the other.

DETECTOR CIRCUIT: The detector circuit, shown in Fig. 4, consists of the crystal detector and the headphones. The headphones and the crystal detector are also connected in series.

Observe particularly in Figs. 2, 3 and 4 how symbols are used to designate the various parts of these circuits.

WHAT YOU SHOULD KNOW ABOUT A CIRCUIT

In analyzing any circuit, it is necessary that you learn three fundamental things about it. These are:

(1) The purpose of the circuit, or what it is supposed to do.

(2) The name, purposes, structural features and operating principles of the individual parts employed in the circuit.

(3) The type of current, or currents, which flow in the circuit; including their origin and approximate intensity.

The paragraphs which follow will explain these things to you in an easily-understood manner.

CONSTRUCTION OF THE ANTENNA CIRCUIT

AERIAL AND LEAD-IN: The aerial usually comprises a piece of bare copper wire, 30 to 100 feet in length; and is connected to the antenna coil by means of another piece of wire known as the lead-in, (see Fig. 2). The aerial and the lead-in must be well insulated from the ground and from surrounding objects that may "absorb" radio energy -- such as, metal roofs, other nearby wires, etc.

The purpose of the aerial is to furnish the medium into which alternating currents can be induced by passing radio waves. The purpose of the lead-in is to conduct these signal currents to the antenna coil, which is located within the receiver.

ANTENNA COIL: The antenna coil is an air-core coil, consisting of several turns of copper wire wound on a supporting form made of in-

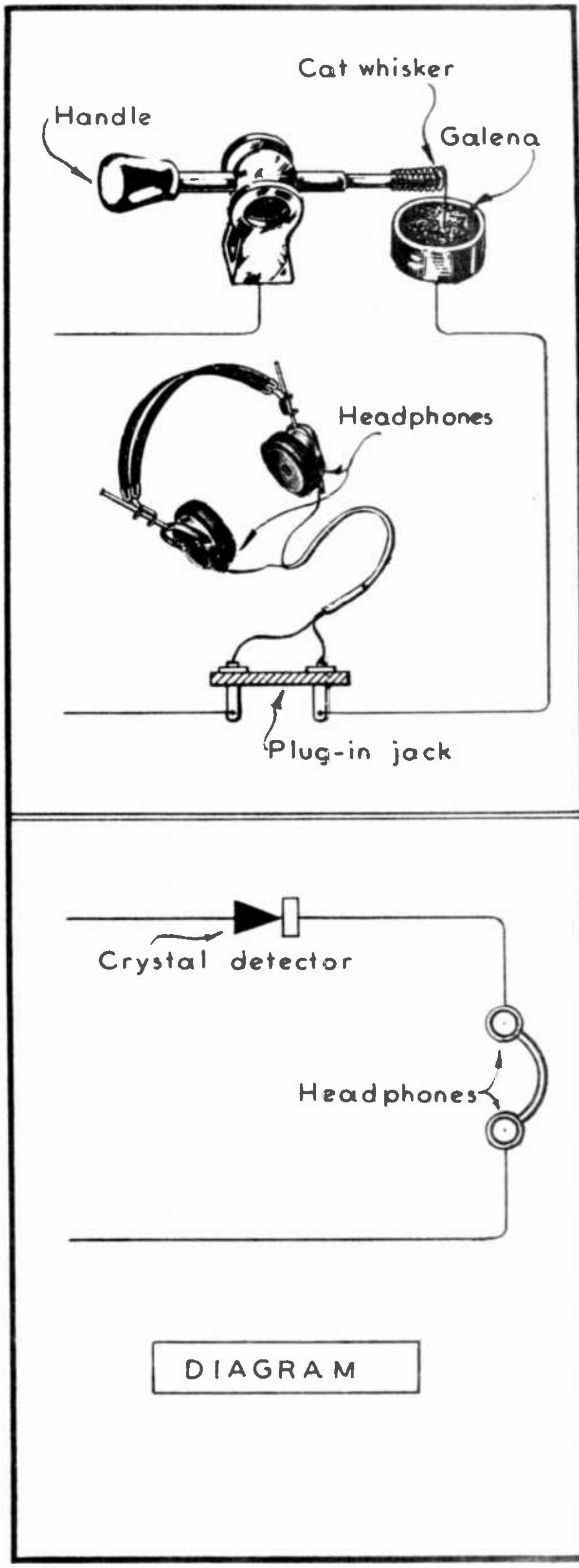


FIG. 4
DETECTOR CIRCUIT

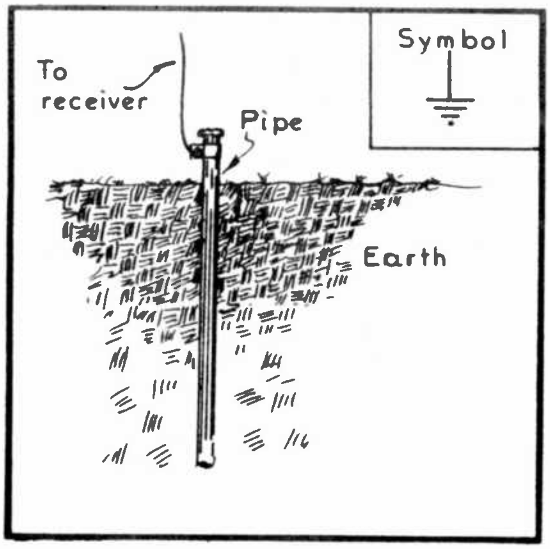


FIG. 5
GROUND CONNECTION

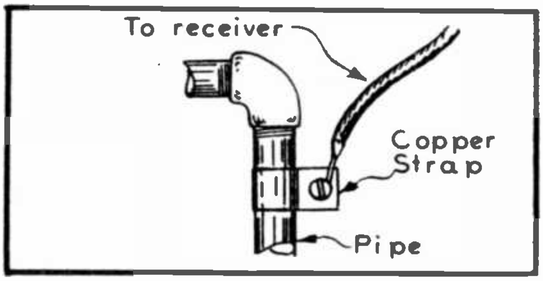


FIG. 6
WATER PIPE GROUND CONNECTION

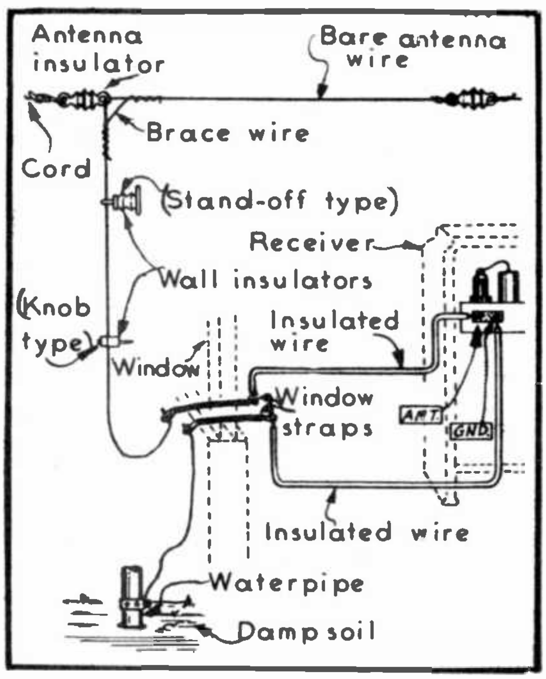


FIG. 7
DETAILS OF ANTENNA INSTALLATION

sulative material. This form is usually a fibre or cardboard tube, the diameter of which may be anywhere from 1/2-inch to about 3-inches. An insulated wire of small size is generally used for this coil; the adjacent turns being wound side by side as illustrated in Fig. 2.

The purpose of the antenna coil is to generate an alternating magnetic field by means of the signal currents flowing through its winding.

GROUND CONNECTION: The ground connection consists of a wire that connects one end of the antenna coil to the earth. Electrical contact with the earth can be established by driving an iron pipe or rod several feet into moist earth, and then fastening the ground lead to it by means of a copper strap, as shown in Fig. 5.

Often, a water pipe will serve as a satisfactroy grounding medium, because most water pipes are in contact with moist earth for a great part of their length.

The method of grounding the circuit to a water pipe is shown in Fig. 6.

A typical antenna installation is illustrated in Fig. 7, showing how the leads are connected to the antenna and ground terminals of the receiver. It is to be noted in Fig. 2 that the antenna coil is connected between the antenna and ground terminals within the receiver proper.

ENERGY PICKED UP BY THE AERIAL

Any radio wave which reaches the aerial will induce signal voltages in the antenna circuit, and thus cause signal currents of corresponding frequency to flow in this circuit. No matter how feeble the waves may be -- if they reach the aerial, current will be induced in the antenna circuit. This is always true -- though, often, the waves reaching the aerial are so weak that the signal currents induced therein are not strong enough to be detected by the most sensitive receiver.

In previous lessons you learned that a radio wave set in motion anywhere in the world will continue to

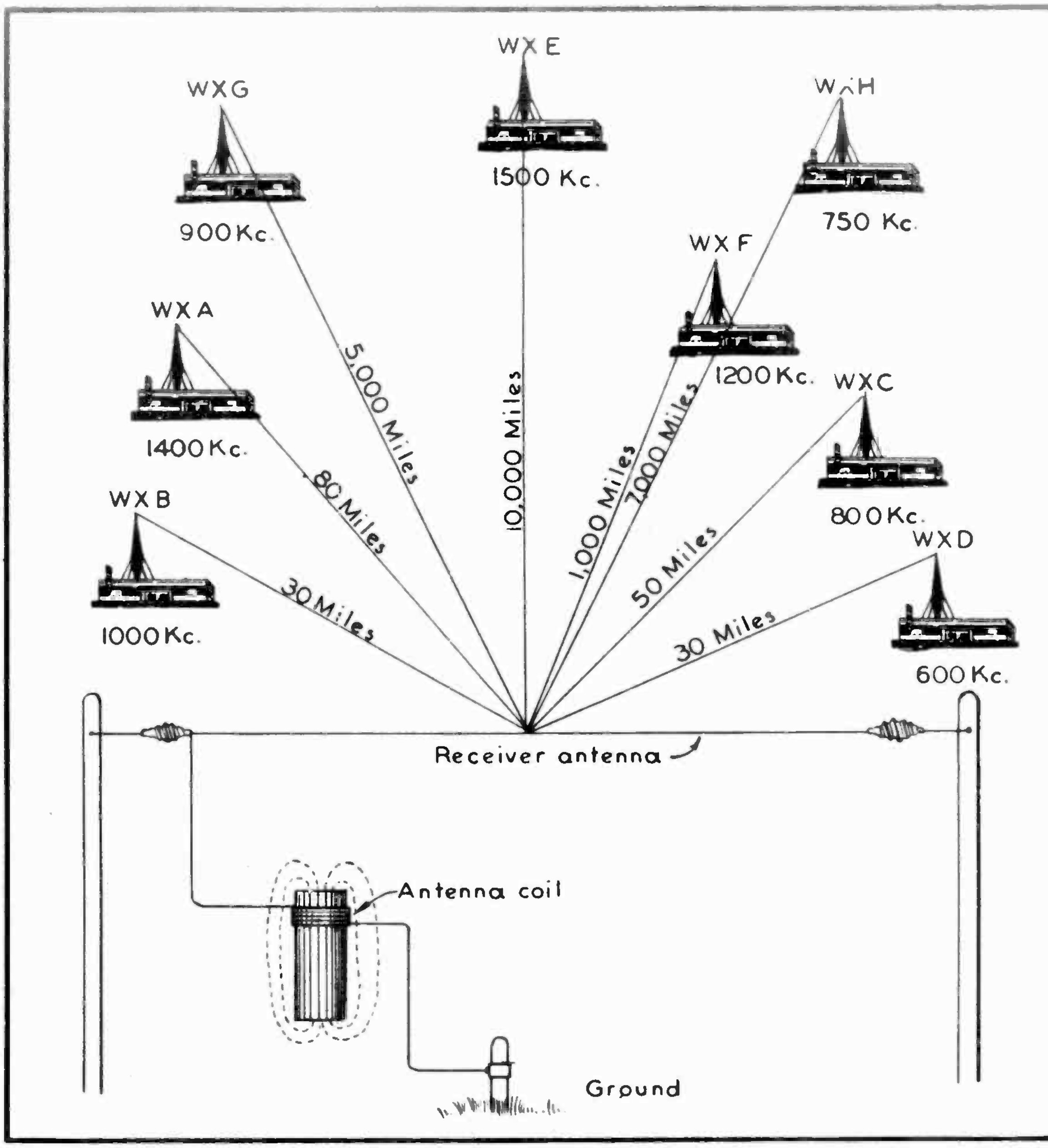


FIG. 8
WAVES OF VARIOUS TRANSMITTERS ACTING ON RECEIVER ANTENNA

travel away from the transmitter for an indefinite distance. All waves, of course, undergo a loss of strength, or a reduction in amplitude, as they travel farther from their point of origin.

In Fig. 8, we show the antenna circuit of our simple receiver, surrounded by transmitters located at various distances from the receiver. Two of the transmitters, WXB and WXD, are situated only 30 miles from the receiver, while the most distant one, WXE, is 10,000 miles away. It should be noted that waves from all these transmitters, no matter how distant, reach the aerial of the receiver. However, due to the distance spanned, the loss in amplitude will be so great that only the waves from the nearest stations -- WXB and WXD (30 miles), WXC (50 miles), and WXA (80 miles) -- will induce current of sufficient intensity in the antenna circuit to operate the detector of the simple receiver in which we are now particularly interested.

In Fig. 9, a very sensitive current-indicating instrument has been inserted in the antenna circuit. If this instrument is sufficiently sensitive, it will indicate the value of the induced currents. Each of the nearby stations would probably induce an alternating current of a few microamperes (millionths of an ampere) in this circuit, and the indicator would then indicate a total alternating current flow equal to the sum of these individual currents (all of them added together). We stress again the fact that practically all stations, no matter how distant, induce some a-c signal current in the antenna circuit, though it may be too weak to measure, or to do any useful work.

CONVERTING SIGNAL CURRENTS INTO SOUND

In Fig. 10, a crystal detector and a set of headphones have been connected in series with the antenna circuit. With the crystal detector rectifying the incoming signal currents, the headphones will now respond to the signal of several of the closer stations. Thus, we would hear the program from at least four of the broadcasting stations which are located within a radius of 100 miles from the receiving station.

Notice, especially, that with the arrangement of Fig. 10, the programs from all of the nearby stations will be heard in the headphones at the same time. This is because each of these stations is inducing sufficient current in the antenna circuit to operate the headphones. Obviously, the programs would be so mixed, or "hashed", that you could hardly distinguish one from the other.

TUNING

The purpose of the tuning circuit is to select any one of the signal currents induced in the antenna circuit from all others, and to permit only this desired signal current to operate the detector and headphones; excluding all others. Thus, the tuning circuit makes it possible

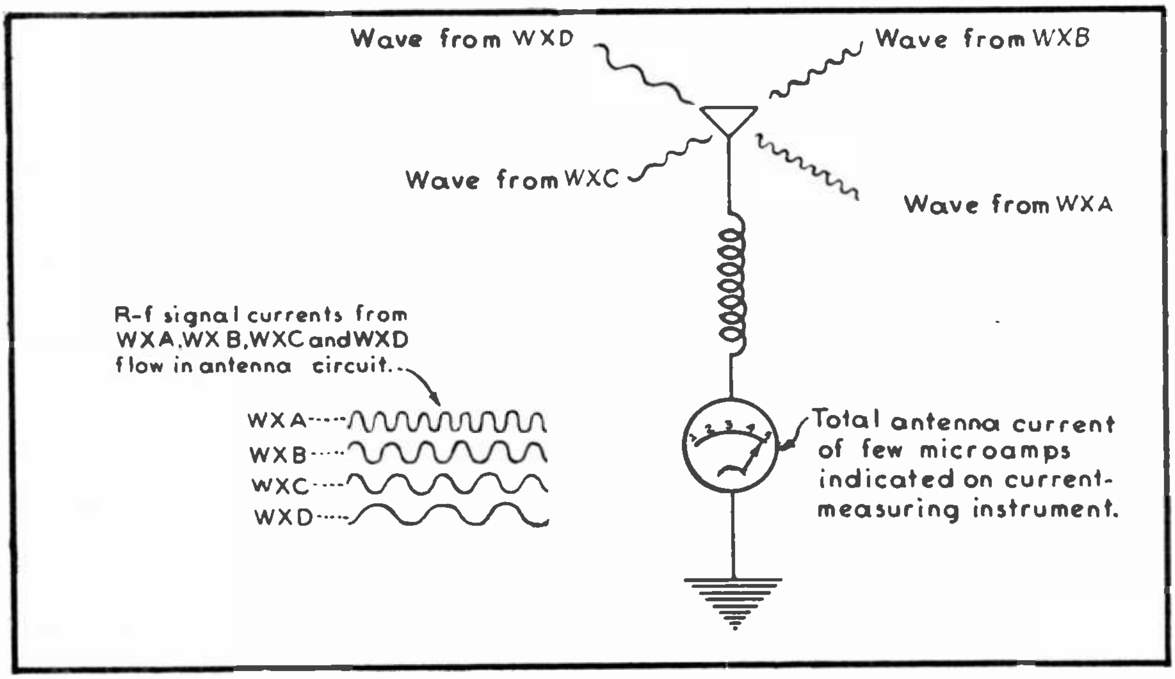


FIG. 9
R-F SIGNAL CURRENTS PRODUCED BY FOUR TRANSMITTERS

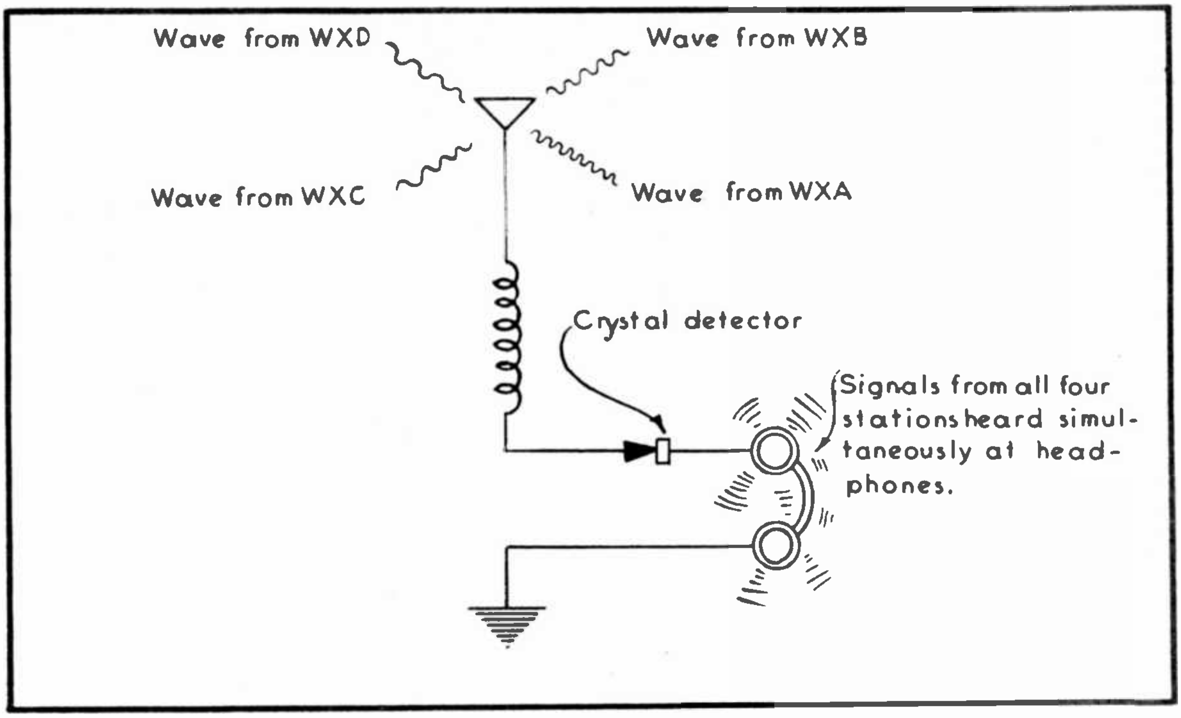


FIG. 10
MULTIPLE SIGNAL CURRENTS IN ANTENNA CIRCUIT CONVERTED INTO SOUND BY DETECTOR AND HEADPHONES

for the listener to select the signal current corresponding to any one desired broadcasting station, and to listen to that signal only. Now, let us see how this is done.

In Fig. 11-A, is shown the antenna circuit, together with the tuning coil. It should be noted that the tuning coil is so placed that it is in inductive relationship with the antenna coil. Or, to state it another way -- the antenna coil and the tuning coil are so placed that any magnetic field set up around the antenna coil will act inductively on

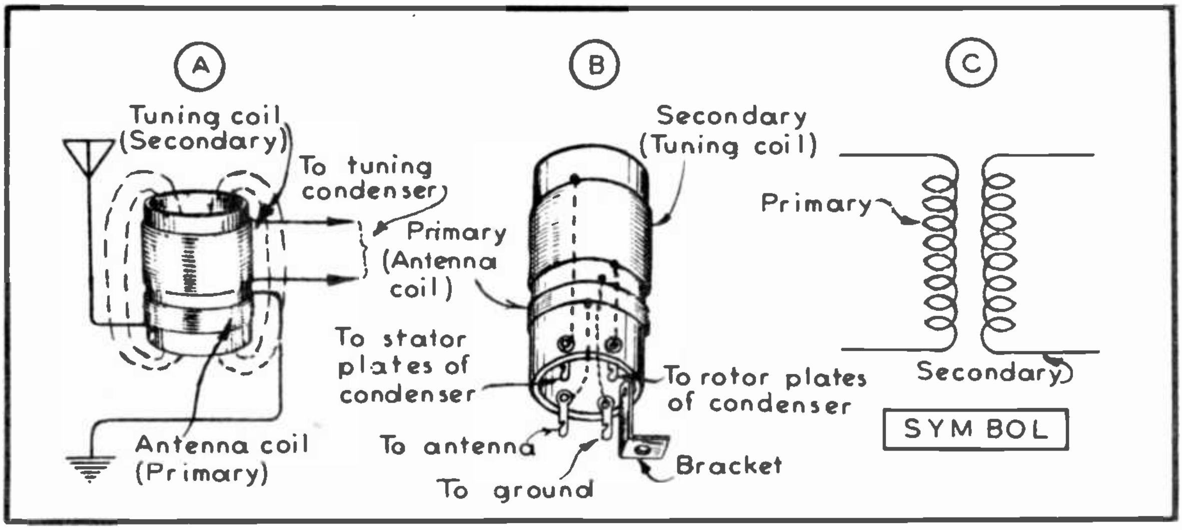


FIG. 11
DETAILS OF THE R-F TRANSFORMER

the tuning coil. In practice, these two coils are usually wound on the same tubular supporting form, alongside each other; and the ends of the windings are fastened to terminals so that the two coils can be connected to the receiver circuits conveniently (see "B" of Fig. 11). Regardless of the actual shape and placement of the windings on the form, the entire arrangement is always illustrated symbolically as at "C" of Fig. 11.

You will no doubt realize that the antenna coil and the tuning coil, together, constitute an air-core transformer -- the principle of which was described in an earlier lesson. The antenna coil functions as the primary winding, and the tuning coil as the secondary winding of this transformer. Radio men call this complete assembly or device an r-f transformer or an r-f coil.

The r-f transformer is mounted to the receiver base or frame by means of the bracket pointed out at "B" of Fig. 11.

HOW THE R-F TRANSFORMER HANDLES THE SIGNAL: By referring to Fig. 13, you will see the exact action which takes place in the antenna and tuning coils when a radio wave is reaching the aerial of the antenna circuit. Each section of this drawing (A-B-C-D-E-F-G-H-I) is designed to show you the conditions that exist in these coils at nine different instances of time corresponding to the lettered positions on the large sine wave at the top of the illustration. An analysis of this action follows in the next few paragraphs.

At "A" of Fig. 13, the radio wave reaching the aerial is not inducing any signal voltage in the antenna circuit, as the amplitude of the wave is at zero value at this time. When no signal voltage is being induced into the antenna circuit, no signal current will flow through the antenna coil; no lines of force will surround the antenna coil; and no induced emf will be present in the tuning coil. This is shown on the signal voltage graph to the left of the antenna coil, and on the induced emf graph to the right of the tuning coil.

At "B" of Fig. 13, the amplitude of the incoming radio wave is building up on the positive alternation. This increase in amplitude of the wave will cause a signal voltage to be developed across the antenna circuit. This signal voltage, in turn, will cause signal current to flow through the antenna coil, and a magnetic field to build up around the coil. The field, in building up, will cause an emf to be induced in the tuning coil by means of mutual induction. The curve of the antenna circuit signal voltage at this instant is shown on the graph at the left of the antenna coil. The induced emf which is developed across the tuning coil is shown on the graph at the right of the tuning coil. Notice that both coils now have polarity symbols. The "top" of the antenna coil, and the "bottom" of the tuning coil, are negative; the "bottom" of the antenna coil, and the "top" of the tuning coil, are positive.

At "C" of Fig. 13, the incoming wave is at peak value on the positive alternation. This causes a signal voltage of maximum intensity to be present in the antenna circuit. At the same time, induced emf of maximum value is being developed across the tuning coil, but of opposite polarity. In all transformers, it is true that the secondary emf will at all times have a polarity which is exactly opposite that of the primary emf. Thus, when a positive alternation of signal voltage is being formed in the primary circuit (antenna circuit), a negative alternation will be formed in the secondary circuit (tuning circuit).

At "D" of Fig. 13, the wave is decreasing in amplitude, at which time the voltage in both the antenna and tuning coils is also decreasing in value, as shown by the small graphs beside these coils.

At "E" of Fig. 13, the radio wave is at zero amplitude just before starting to build up on the negative alternation. The induced emf developed across the secondary coil has therefore dropped to zero. You will note that the positive alternation of the radio wave just completed has caused one alternation of signal voltage to be present in the antenna circuit; which, in turn, has caused one alternation of emf to be induced in the secondary, or tuning winding.

At "F" of Fig. 13, the wave is building up in amplitude on the negative alternation. The electrical action taking place will now be the same as in section B-C-D of the illustrations, except that all polarities will be reversed. Thus, you see that the signal voltage being induced in the antenna circuit is now such that the "top" of the antenna coil is positive, and the "bottom" end, negative. The polarity of the emf induced in the secondary coil is, of course, opposite to that of the antenna coil.

At "G" of Fig. 13, the wave is at peak amplitude on the negative alternation. Signal voltage in the antenna circuit is now at maximum value; and the induced emf is also at maximum value. You will observe that all conditions are the same as those shown at "C", except that the signal and induced emf polarities are reversed.

At "H" of Fig. 13, the wave is decreasing in amplitude on this alternation. Signal voltage in the antenna circuit is therefore again approaching zero; as also is the induced emf in the tuning coil.

At "I" of Fig. 13, the wave is again at zero amplitude, after having completed one cycle consisting of one positive and one negative alternation. This has produced one cycle of signal voltage in the antenna circuit, and -- by mutual induction -- one cycle of induced emf in the tuning coil.

If this were an actual working circuit, the next action to take place would be for the wave to again build up on the positive alternation. Another cycle of signal voltage in the antenna circuit, and induced emf in the tuning coil, would then begin to form; just as happened at "B" of this example. Cycles of signal voltage and induced emf would continue to be developed in this way as long as the wave was reaching the aerial.

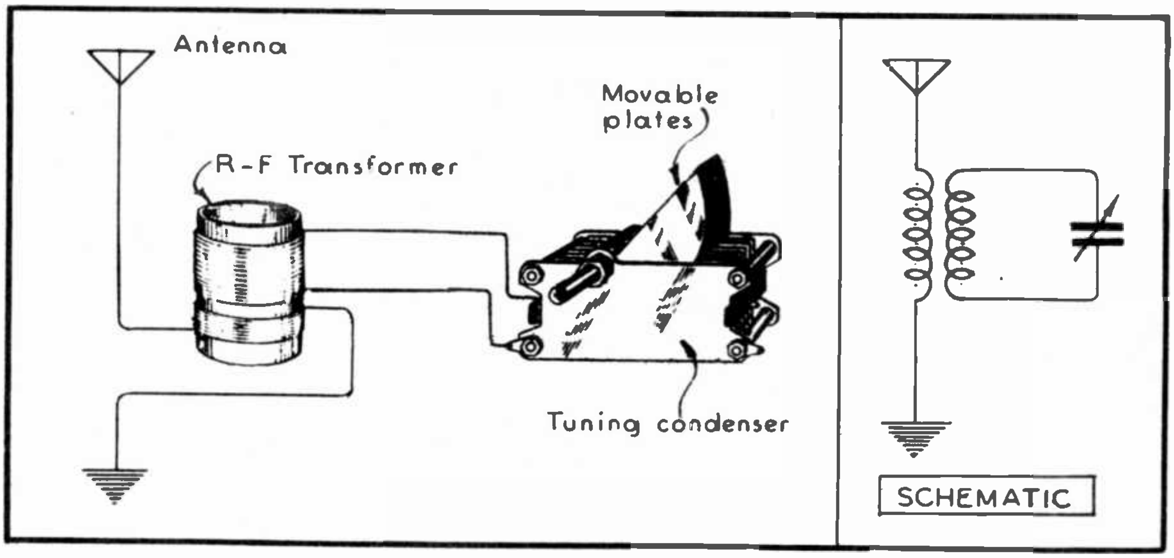


FIG. 12
ANTENNA CIRCUIT COUPLED TO TUNING CIRCUIT

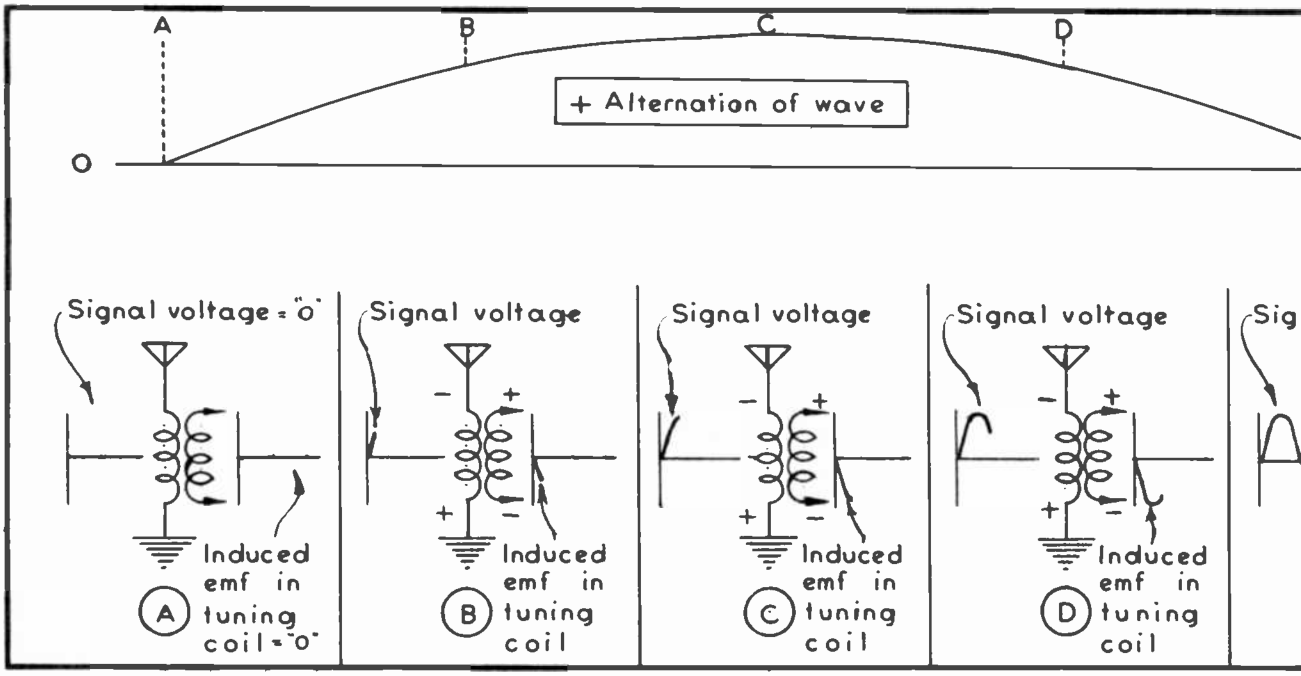
ADDING THE TUNING CONDENSER: Fig. 12, shows the addition of the tuning condenser to the secondary winding of the r-f transformer. This winding and tuning condenser, together with their connecting conductors, form a series circuit, as far as alternating current is concerned.

Earlier in this lesson, we established the fact that signal currents will, through mutual induction, induce an a-c emf in the secondary winding of the r-f transformer. If this winding were not connected to a circuit, no current would flow in it, regardless of the value of the induced emf. However, as soon as the condenser is placed in the circuit with the secondary winding, there is a path over which alternating current may move. Thus, the induced emf will cause current to flow through the secondary winding and charge the condenser.

This is shown at "A" in Fig. 14. At this instant, the top end of the secondary winding is "-" and the bottom is "+". Electrons are thus pulled away from the lower plate of the condenser, and forced toward the upper plate. The upper plate of the condenser will then contain an excess of electrons, and the lower plate will have a fewer than normal number of electrons. This is also shown in illustration "A" of Fig. 14, where the upper plate of the condenser is marked "-"; and the lower plate "+".

When the polarity of the induced emf in the secondary winding is reversed, as it will be when the polarity of the inducing current in the antenna coil reverses its direction of flow, current will surge back through the tuning circuit and charge the condenser in the reverse direction, or at reversed polarity. Thus, the upper plate will now be "+", and the lower plate will be "-", as illustrated at "B" of Fig. 14.

As long as an a-c emf is being induced in the secondary winding, these repeated surges of current (electron drift) will take place between the coil and condenser. Thus, an alternating current is always flowing in the tuning circuit whenever signal currents are flowing in the antenna circuit.



TUNING CONDENSER

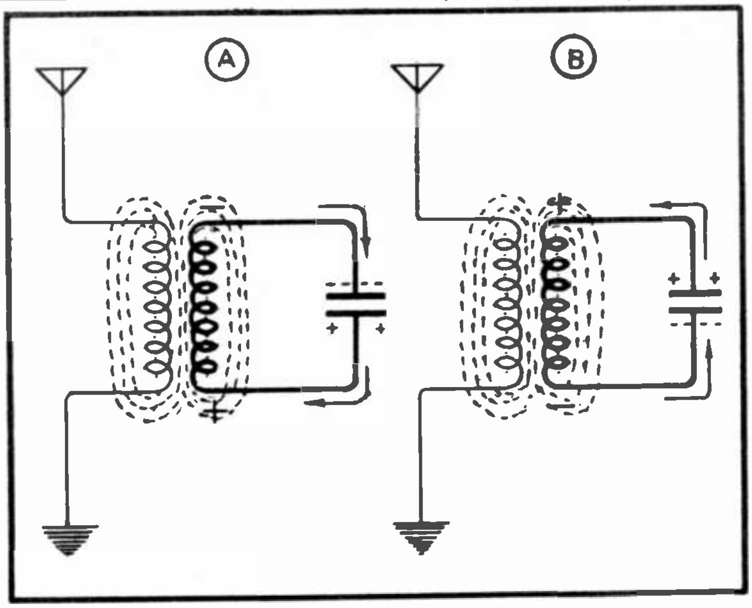
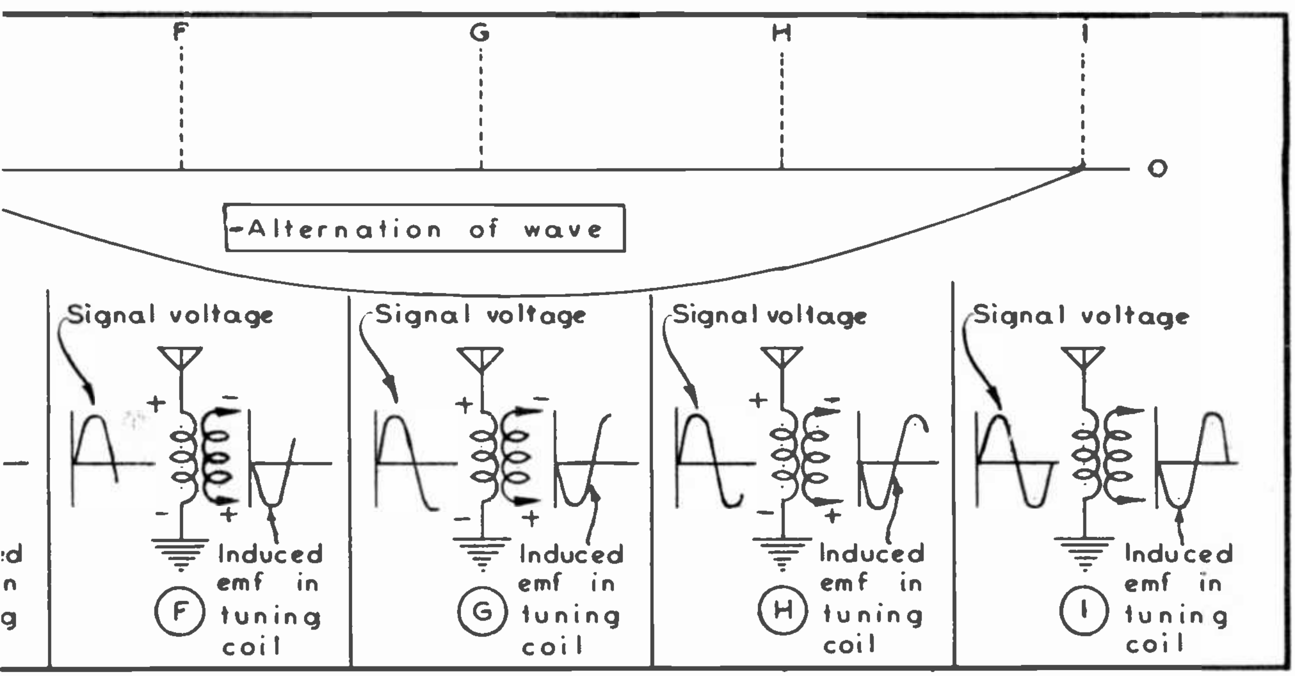


FIG. 14
FLOW OF ALTERNATING CURRENT
IN TUNING CIRCUIT

The tuning condenser, which is used in the tuning circuit, differs from condensers which have been described previously in this course. It is a variable condenser; that is, its capacity may be changed or varied, at the will of the operator. The picture of this condenser, together with its symbols, appears in Fig. 15. Notice how the symbol for the variable condenser at the left in Fig. 15 differs only from that of a fixed condenser in the fact that an arrow is drawn through the symbol to indicate that the capacity of this condenser can be varied.

Essentially, a variable condenser consists of two sets of metal plates -- usually made of aluminum. One set is mounted rigidly to the supporting frame of the condenser, but insulated from it. The other set of plates is mounted on a shaft which turns on ball bearings that are mounted in sockets set in the ends of the condenser frame. The plates which are rigidly secured to the condenser frame are called the stator plates, and are not movable. The plates which are mounted on the shaft are called movable or rotor plates. All plates are separated from each other by an air space; the air space between them serving as a dielectric.



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Quite often, a black dot is placed on one of the horizontal lines of the symbol to denote the rotor plate group. Or, the rotor plate group may be represented by a curved arrow as at the right of Fig. 15, and the diagonal arrow omitted.

All of the rotor plates are electrically connected together, and all of the stator plates are electrically connected together. There is no electrical connection between the rotor and stator plates. The rotor plates are all electrically connected to the frame of the condenser through the shaft, while the stator plates are insulated from the frame by some such material as bakelite or fiber. Terminals are provided on the condenser for connecting the rotor and stator plate-groups to the receiver circuits.

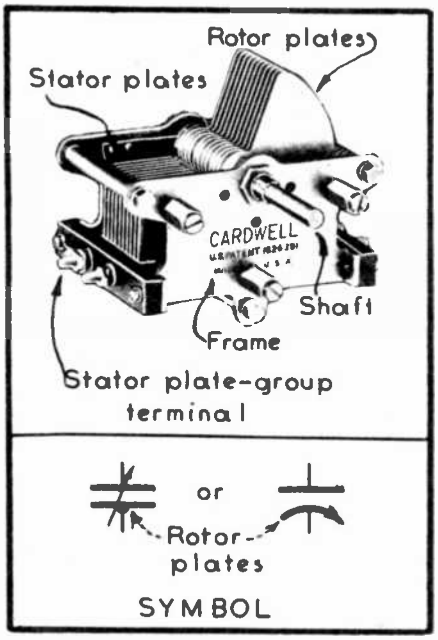

FIG. 15
TUNING CONDENSER

VARYING CAPACITY OF TUNING CONDENSER: When the shaft of the variable condenser in Fig. 15 is turning to the right, or in a clockwise direction, the rotor plates are so moved that they mesh, or interleave with the stator plates. Of course, the plates are so placed that none of the rotor plates ever touch any of the stator plates; otherwise, there would be a short circuit between the two sets of plates. In the case of the condenser appearing in Fig. 15, turning the shaft to the right increases the total meshed or effective area of the plates. Turning the shaft to the left, decreases the total meshed or effective area of the plates.

In an earlier lesson, you learned that the total effective area of the plates of a condenser is one of the factors which controls the capacity of the condenser. It should be obvious, therefore, that when the rotor plates are completely meshed with the stator plates, the total area of the plates will be in use, and the condenser will then have maximum capacity. Whereas, if the rotor plates are only partially meshed with the stator plates, the effective area of the plates is reduced and the capacity of the condenser will not be as great. When the rotor plates are completely out of mesh with the stator plates, the condenser is set for minimum capacity.

MAXIMUM AND MINIMUM CAPACITIES OF VARIABLE CONDENSER: Variable condensers are rated according to their maximum capacity, expressed in microfarads. Maximum capacities for typical commercially supplied variable condensers are .00004, .00014, .00025, .00035, .0005 and .001, microfarads. The .00035 mfd. condenser is most used for receivers designed to operate on the standard broadcast band (187.5 to 545 meters, or 1600 to 550 kc.). A condenser having a rated maximum capacity of .00035 mfd. (plates entirely meshed) will usually have a minimum capacity of not more than one-tenth the maximum value, or .000035 mfd (plates completely out of mesh).

When speaking of capacities which are less than one microfarad in value -- such as .00035 mfd, for example -- it is customary among technicians to verbally express these values so that they do not require too much tongue twisting. Thus, a condenser capacity of .00035 mfds is usually expressed as "point, triple '0', three five". A .001 mfd condenser would be spoken of as having a capacity of "point, double '0', one"; a .00015 mfd condenser, as "point, triple '0', one five", etc.

HOW THE TUNING CIRCUIT FUNCTIONS

In an earlier lesson, you were shown that the values of inductance and capacity in any circuit can be so adjusted that, together, they offer zero opposition to a flow of alternating current at any one particular frequency. Or, that the values of inductance and capacity may be selected so that they offer exactly the same value of inductive reactance (X_L), and capacitive reactance (Xc), so that there will then be a condition of resonance, or minimum opposition, to current flow of one specific frequency. This is exactly what is done in the tuning circuit of every radio receiver.

The complete tuning circuit, which consists of the coil and the variable condenser, is pictured in Fig. 12 -- inductively coupled to the antenna circuit. Here, the inductance of the coil has a fixed value of about 250 microhenries -- that being a typical value of inductance for coils which are to operate on the standard broadcast band. Now, with the coil and condenser connected in series as shown, any change in the setting of the condenser plates will cause a change in the capacity of the condenser. This, in turn, will alter the capacitive reactance of the condenser. When this change in Xc is made in the circuit, the X_L-Xc relationship will be changed; and the frequency at which the circuit will resonate (offer zero reactive opposition to alternating current) will also be changed.

<u>RULE</u>: Here is a simple rule, or principle, which governs the capacity-inductance frequency relationship of any tuned circuit:

1 - In any tuning circuit containing a fixed value of inductance, the <u>greater</u> the capacity of the tuning condenser, the <u>lower</u> will be the frequency to which the circuit will be in <u>tune.</u>

2 - In any tuning circuit containing a fixed value of inductance, the <u>lower</u> the capacity of the tuning condenser, the <u>higher</u> will be the frequency to which the circuit will be in tune.

ANALYSIS OF A TUNED CIRCUIT

You have been shown, in connection with Fig. 8 of this lesson, that the four nearby broadcasting stations -- WXA, WXB, WXC, WXD -- are each sending out waves which are acting on the antenna of our simple receiver; and that their amplitude is sufficient to cause usable signal currents to flow in the antenna circuit. You have also been shown that the electrical energy thus induced in the antenna circuit will be transferred to the tuning coil by means of mutual induction.

Now, here is where the tuning action of the tuning circuit is called into play. That is, this circuit separates the differing frequencies of these four station signals by accepting, with little or no opposition, the signal current from one of them and rejecting those of the other three. This is shown in Fig. 16.

In Fig. 16, you are shown the tuning circuit comprising the variable condenser and the tuning coil. The tuning coil, in this case, has a constant inductance value of 250 microhenries. The capacity of the tuning condenser can be varied between its maximum and minimum limits. The waves from the four nearby broadcasting stations -- WXA (1400 Kc), WXB (1000 Kc), WXC (800 Kc), and WXD (600 Kc) -- are all causing current to flow in the antenna circuit, and these four different currents are attempting to induce an emf in the tuning coil through induction.

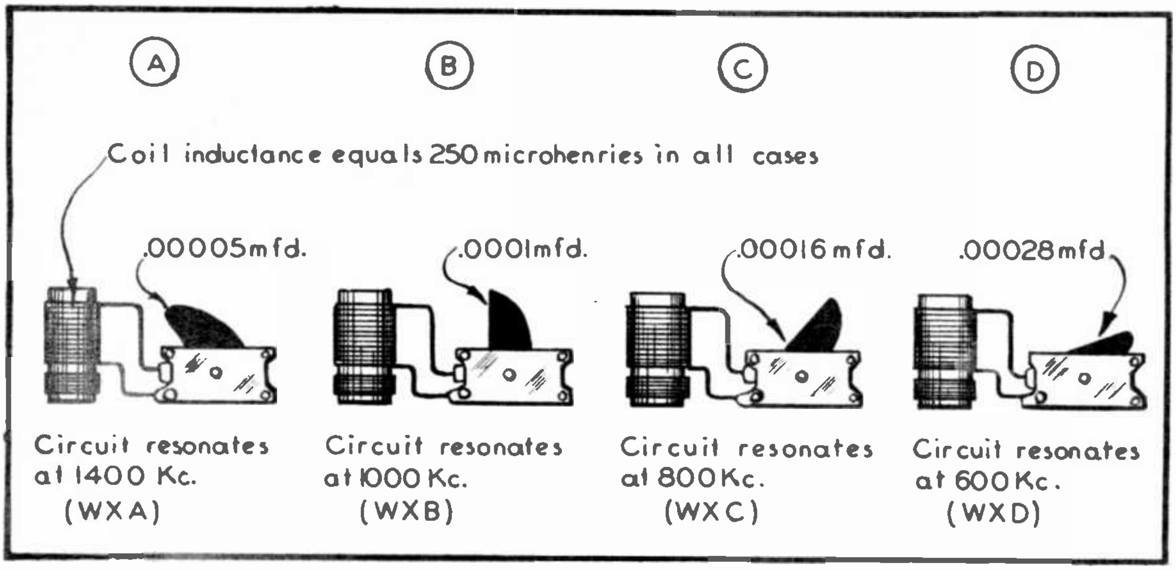

FIG. 16
TUNING-IN DIFFERENT STATION SIGNALS

At "A" of Fig. 16, the plates of the tuning condenser have been meshed until the condenser has a capacity of .00005 mfd. Now, a circuit which contains an inductance of 250 micrehenries and a capacity of .00005 microfarads will resonate to a frequency of 1400 kc. This means that circuit "A" of Fig. 16 will offer negligible opposition to an alternating current having a frequency of 1400 kilocycles, and will offer comparatively great opposition to alternating current of any other frequency. Thus, the frequency value has been adjusted so that this tuning circuit is in resonance with the 1400 kc signal of broadcasting station WXA. It is not in resonance with the 1000 kc signal from WXB, the 800 kc signal from WXC, nor the 600 kc signal from WXD. Therefore, we now say that the receiver is tuned to station WXA, as this is the only station signal which will be admitted by the tuning circuit with amplitude sufficient to operate the detector.

At Fig. 16-B, the plates of the variable condenser have been meshed further, until the condenser has a capacity of .0001 mfd. With this value of capacity, and an inductance of 250 microhenries, the tuning circuit will be in resonance with the 1000 kc signal from station WXB, and out of resonance with the signals from WXA, WXC, and WXD. Thus, the receiver will now be tuned only to WXB.

At Fig. 16-C, the plates will have been meshed still further, so that the capacity in the tuning circuit is .00016 mfd. This increase in capacity will cause the circuit to resonate at 800 kc, and permits only the signal currents produced by station WXC to flow through the tuning circuit with sufficient strength to operate the detector. At the same time, the tuning circuit will now oppose the signals of station WXA, WXB, and WXD.

SUMMATION OF TUNING: You have just been shown, in graphic form, the fundamental action of a tuning circuit. We can sum up everything that you have just learned in the following manner:

The signal currents from all of the four stations mentioned flow back and forth in the antenna circuit -- each setting up a concentrated, alternating magnetic field around the antenna coil; but due to the selective action of the tuning circuit, only one of the four fields present around the antenna coil is permitted to induce a signal current of any appreciable amplitude in the tuning coil. This selective action of the tuning circuit is controlled by using a coil of fixed inductance, and varying the capacity so as to cause this circuit to resonate at the frequency desired.

For convenience in operating the receiver, the position of the tuning condenser rotor plates is controlled by the listener through a dial mechanism. (See Fig. 17.). The scale of the dial on standard broadcast receivers is usually calibrated in kilocycles. Setting the dial needle at any one particular frequency mark will automatically turn the rotor plates of the variable condenser to the position required to resonate the tuning circuit to the frequency indicated on the dial. The receiver will then be tuned to a station-signal of that particular frequency.

TUNING AND WAVE LENGTH

As you have already been shown the relation between frequency and wave length, you should have no difficulty in understanding the effect that tuning has upon the wave length of the signal admitted into the tuning circuit. For instance, in the case of Station WXA, its frequency of 1400 kc corresponds to a wave length of 214.3 meters. The 1000 kc signal of station WXB corresponds to 300 meters; the 800 kc signal of station WXC corresponds to 375 meters; and the 600 kc signal of station WXD corresponds to 500 meters. As far as tuning is concerned, frequency and wave length are just two terms that express the same thing -- namely, the "identity" of a broadcasting station. Since present practice is to speak of stations in terms of frequency, we will do likewise throughout most of this course.

THE DETECTOR CIRCUIT

Now that there are signal currents flowing back and forth in the tuning circuit, we can easily "tap off" some of this current and utilize it to energize a pair of headphones.

However, from previous studies, you will recall that if alternating current of radio frequency is permitted to flow through the windings of a headphone, no sound will be produced because the diaphragm is physically unable to follow the rapid reversals of current. In order for the headphones to make the radio signal audible, it is necessary to insert a detector between the headphones and tuning circuit. This is shown in Fig. 18.

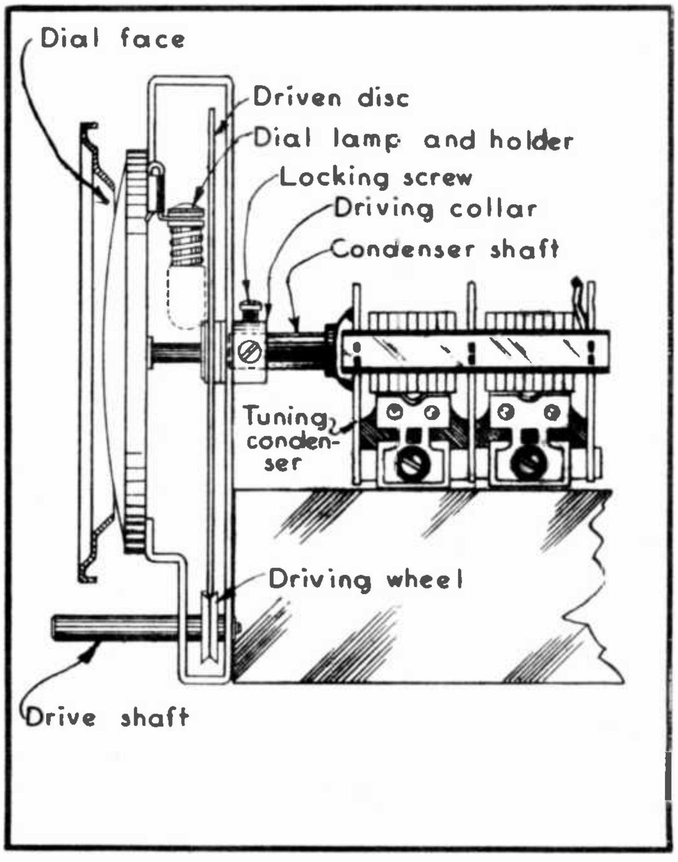

FIG. 17
DIAL AND CONDENSER DRIVE MECHANISM

ACTION OF THE CRYSTAL DETECTOR: The crystal detector acts as a rectifier, or a one-way valve, permitting current to flow through the

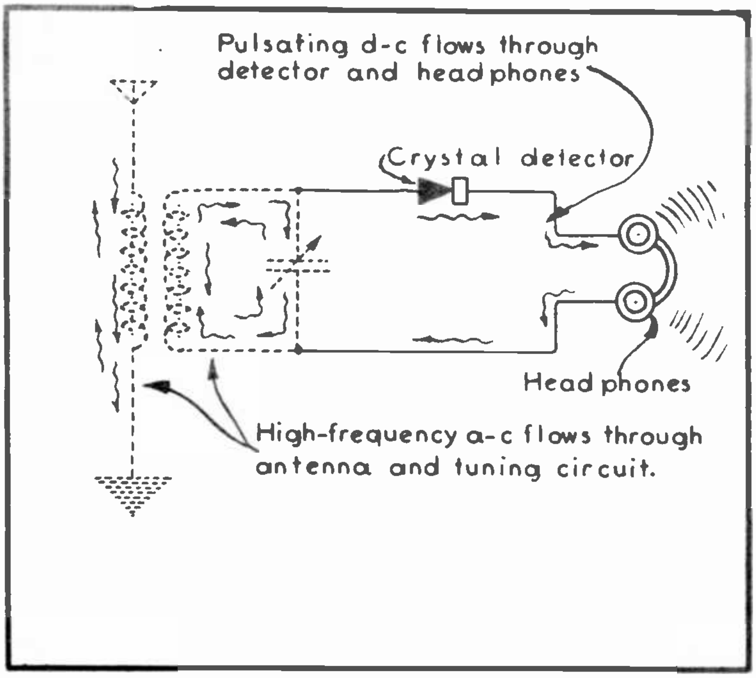

FIG. 18
ACTION OF CRYSTAL DETECTOR

detector circuit in one direction only. Thus, with radio-frequency alternating current of one particular frequency present in the tuning circuit, and being applied to the circuit comprising the detector and headphones, the detector will convert a portion of this a-c signal current into pulsating direct current, and permit the latter to flow through the winding of the headphones. This produces a magnetic reaction that will move the diaphragm of each headphone unit and so reproduce the audible component of the received radio signal.

This action is illustrated graphically in Fig. 19. At the left of this illustration, we have a curve that represents the modulated r-f signal which exists in the antenna and tuned circuit. This, of course, will be in the form of high-frequency alternations with respect to both voltage and current.

Since the crystal detector permits current to flow through it in one direction only, it will literally "cut off" one-half the wave form, as pictured at the center of Fig. 19. This current is then passed on to the headphone circuit.

To improve the performance of this type of receiver, we usually connect a fixed bypass condenser of approximately .001 mfd. capacity across the headphone terminals, in the manner illustrated in Fig. 20. This places the condenser in parallel with the headphone windings.

The condenser appearing in Fig. 21, is suitable for this purpose. This is a mica condenser, such as described in an earlier lesson.

A cartridge-type paper condenser of equal capacity can also be used for this purpose. Condensers of the latter class were also described in an earlier lesson.

By connecting this condenser across the headphones, the current that flows through the headphones is more uniform in nature, as pictured at

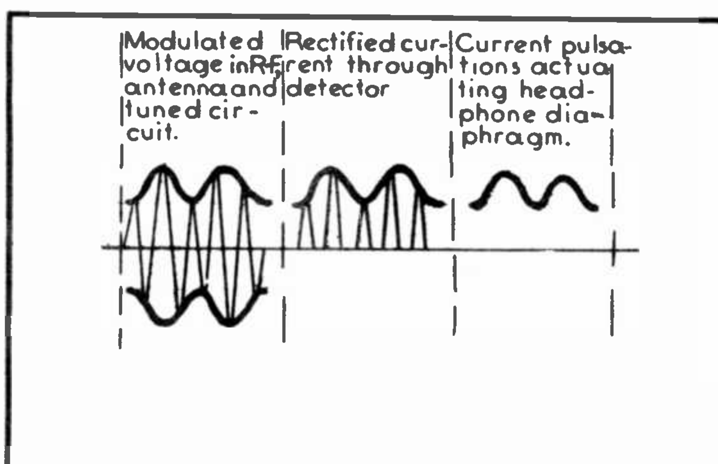

FIG. 19
HOW DETECTOR RECTIFIES SIGNAL

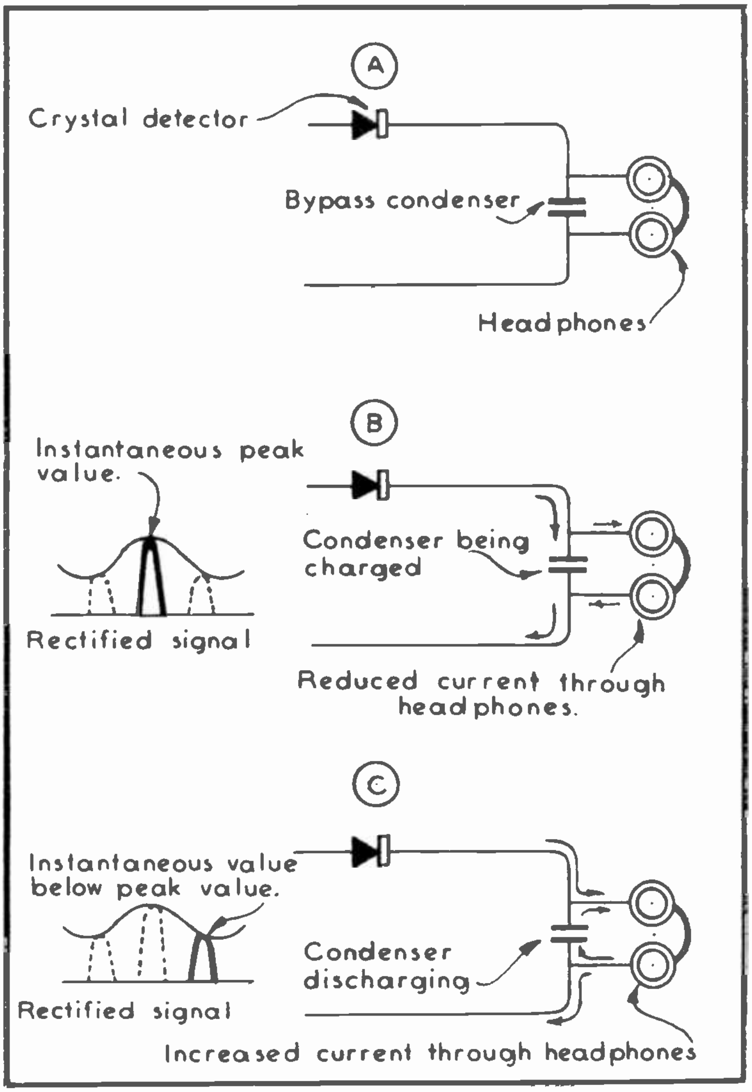

FIG. 20
APPLICATION AND ACTION OF "PHONE" CONDENSER

the right of Fig. 19. That is, the effects of the r-f ripple are eliminated from the rectified signal so that only the audio component of the original wave form operates the headphones.

This is made possible by the fact that instantaneous peak values of the rectified signal charge the condenser as at "B" of Fig. 20, because the inductance of the headphones opposes such sudden surges of current through it, whereas a condenser of suitable capacity readily accepts them as a charging impulse. Whenever the rectified signal voltage drops to a value below the voltage developed across the condenser by a preceding peak impulse, the condenser, in always attempting to maintain a voltage equal to that being applied to it at the time, discharges some of its excess energy through the headphone windings since they provide a "short circuiting" path between the plates. This is illustrated at "C" of Fig. 20.

In other words, the condenser serves somewhat as a voltage and current "equalizing device" -- accepting sudden peak voltage and current impulses, and returning this energy to the headphone circuit during such instants that the rectified signal is at low ebb. This charging and discharging action of the fixed condenser takes place at the approximate borderline between the audio and radio frequency bands; and the overall effect is to cause a more uniform pulsating direct current to flow through the headphone windings, due to the absence of high-frequency ripples. This serves to improve the tone quality; and often, the volume of sound obtained from the headphones.

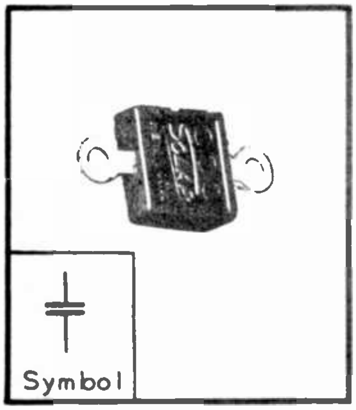

FIG. 21
FIXED CONDENSER

This current of varying intensity that flows through the headphone windings is called an audio frequency current, or simply an a-f current.

THE COMPLETE RECEIVER

The simple receiver just described will receive any station within its maximum range of 50 to 150 miles, and operating on a frequency covered by its tuning circuit (about 550 to 1600 kilocycles). It will select any desired station within these distance and frequency limits, and cause the energy supplied by that transmitting station to produce the desired sound at the headphones. The complete receiver circuit is shown in Fig. 22, with all currents graphically indicated. Fig. 23, shows you how the various parts and the circuit wiring would appear on the actual receiver.

The crystal detector is probably the most efficient form of detector ever devised, as no power in the form of batteries, or other local source of emf is required to operate it. It works entirely on the signal currents picked up by the aerial. It has no rivals from the standpoint of clarity and fidelity. But, it is physically delicate, and much time must be spent probing with the "catwhisker" to locate the most sensitive spot on the surface of the crystal so that the best possible performance can be experienced. Shocks or jars will disturb the setting of the "catwhisker", and will also produce objectionable noise. Working, as it does, on the minute power of signal currents, its sensitivity is very limited. This restricts the distance over which a crystal receiver is able to "pick up" station signals.

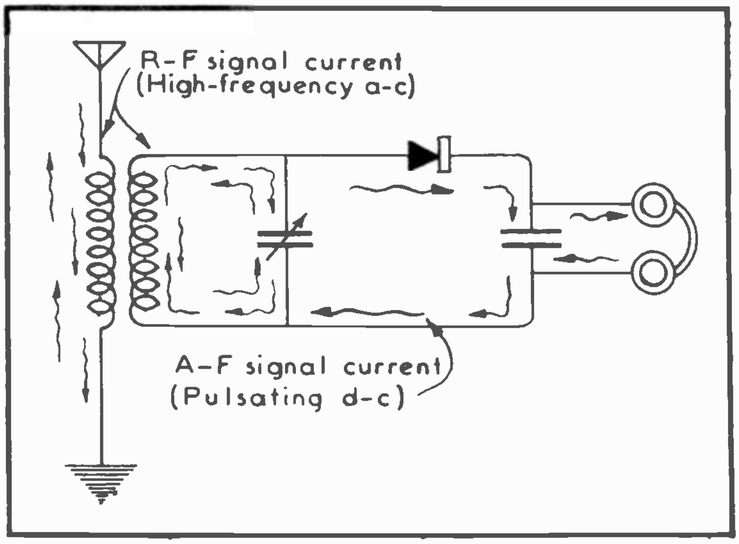

FIG. 22
CIRCUIT DIAGRAM OF COMPLETE RECEIVER

THE RADIO "BANDS"

STANDARD BROADCAST FREQUENCY BAND: Throughout this lesson, you have probably noticed continued reference to the "standard broadcast band", or "standard broadcast frequencies". Also, we have assumed that the simple receiver was designed to operate on frequencies that were within the standard broadcast band. Here are a few words of clarification on this subject:

By international agreement, radio waves of various frequencies, or wave lengths, have been allocated or earmarked for different uses. Thus we find that all stations which broadcast for entertainment or advertising purposes have been assigned to the standard broadcast band which includes all frequencies between 550 and 1600 kilocycles (187.5 to 545 meters). All receivers manufactured for home-use are designed to receive stations in this band.

LOW FREQUENCY OR LONG WAVE BAND: Many commercial radio-telephone and telegraph stations operate on the so-called, low frequency or long wave band. This band extends from 550 to approximately 10 kilocycles (545 meters to 30,000 meters), and is used when it is necessary to secure the maximum in reliability of transmission, regardless of the high power which is required at the transmitter. Very few home-radios will tune-in this band

HIGH-FREQUENCY, OR SHORT WAVE BAND: The high-frequency band -- often called the short wave band -- extends from 1600 to 60,000 kilocycles (5 to 187.5 meters). Many experimental, aircraft, amateur, and long distance broadcasting stations operate in this band. These frequencies are used whenever it is necessary to cover the maximum of distance with a minimum of power applied to the transmitter. Many home-radios are designed to operate on these frequencies, in addition to those of the standard broadcast band

ULTRA-HIGH FREQUENCIES: Those radio frequencies which are greater than 60,000 kilocycles (60 megacycles), and are below 5 meters, are called the ultra-high frequencies. They are used for many experimental purposes, television, as well as for small communication systems where portability and low power are the governing factors. The Army's famous "walkie-talkie" operates within this band, as do many of the wartime direction-finding devices. Practically no home-radios operate on this band, receivers of special design being required for this purpose.

The chart in Fig. 24 will help to make these designations of the different radio bands clear to you.

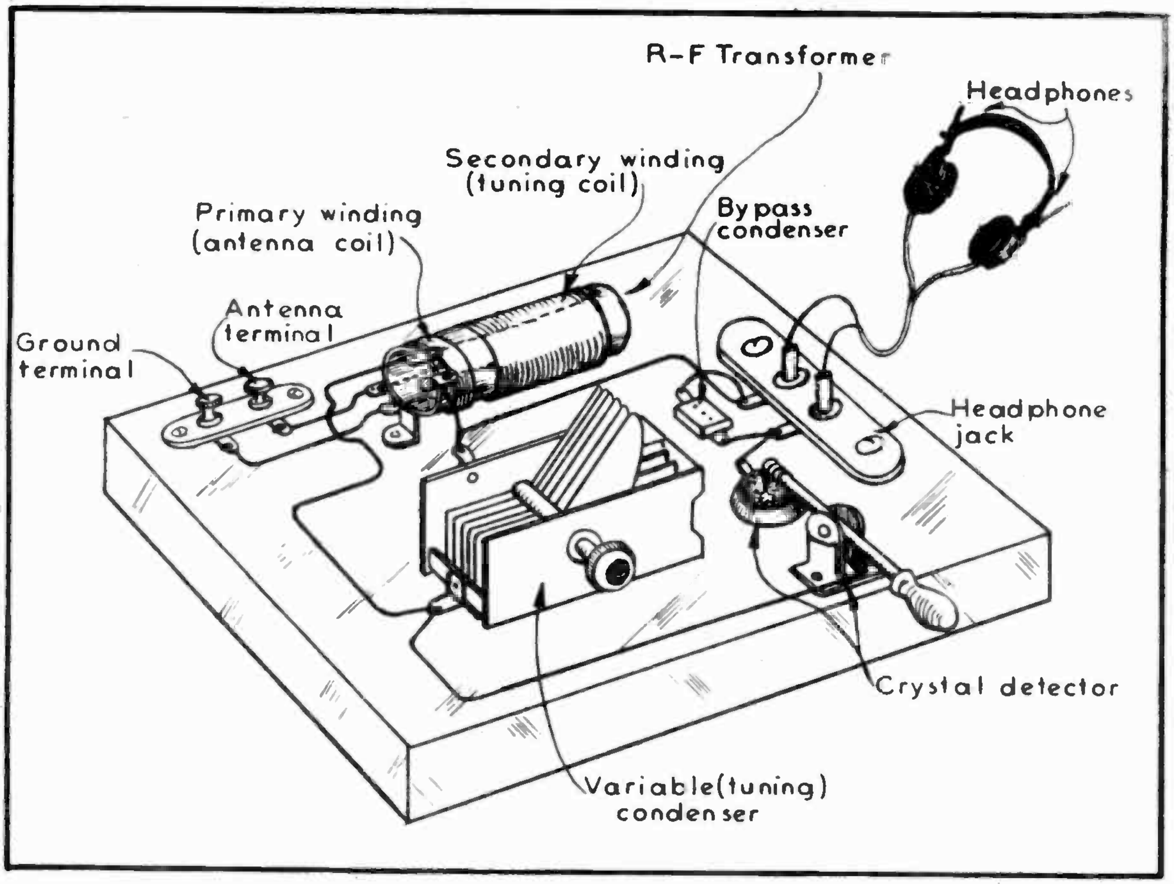

FIG. 23
SIMPLE CRYSTAL RECEIVER

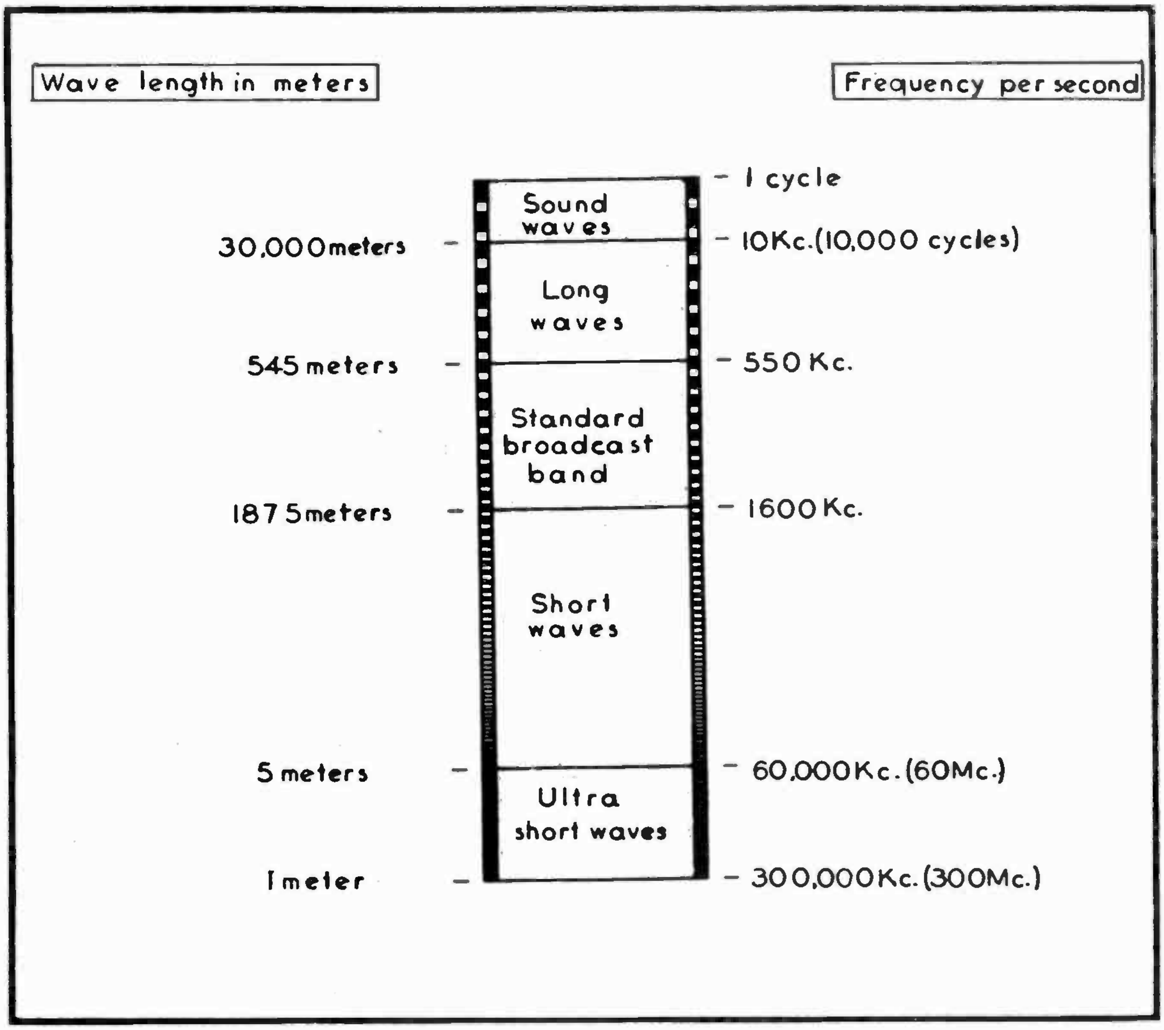

FIG. 24
FREQUENCY SCALE FOR VARIOUS RADIO BANDS

HOW THE SIMPLE RECEIVER COULD BE MADE TO OPERATE ON OTHER BANDS

By a few simple changes in the antenna and tuning circuits, the simple receiver described in this lesson could be operated on either the low-frequency band, or the high-frequency band. It would not be practical, however, to try to make it work on the ultra-high frequency band.

To operate the receiver on the low-frequency band, it would be necessary to replace the present antenna and tuning coils with coils having more inductance -- more turns of wire; and to replace the tuning condenser with one having a greater maximum cacacity.

To operate the receiver on the high-frequency band, the same coils would have to be replaced with coils having less inductance -- fewer turns of wire; and a tuning condenser of lower maximum capacity rating would be required.

Basically, this is what would have to be done to operate the receiver on a different band of frequencies. Later in the course, you will be furnished with the exact details regarding such changes.

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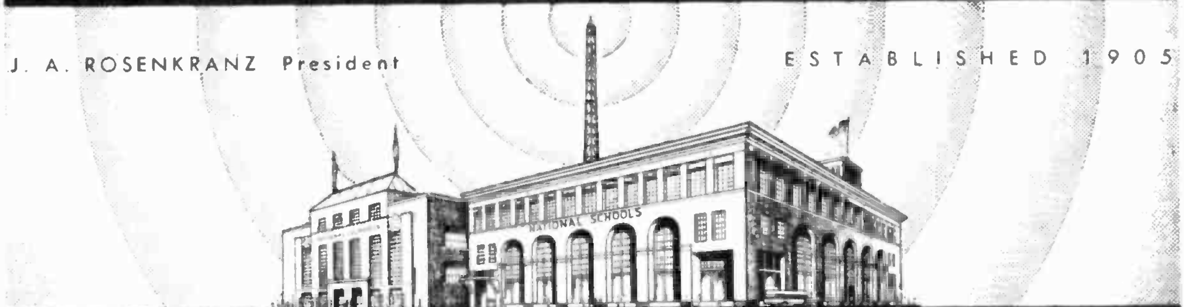

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LESSON NO. 9

ELECTRONIC TUBES

The electronic tube is the "heart" of every radio receiver and transmitter. It has made possible the long-distance telephone; sound pictures; modern phonograph; public address systems; television; and a tremendous number of electronic devices used in industry, the field of medicine, etc. There are already, today, a seemingly countless number of uses for this

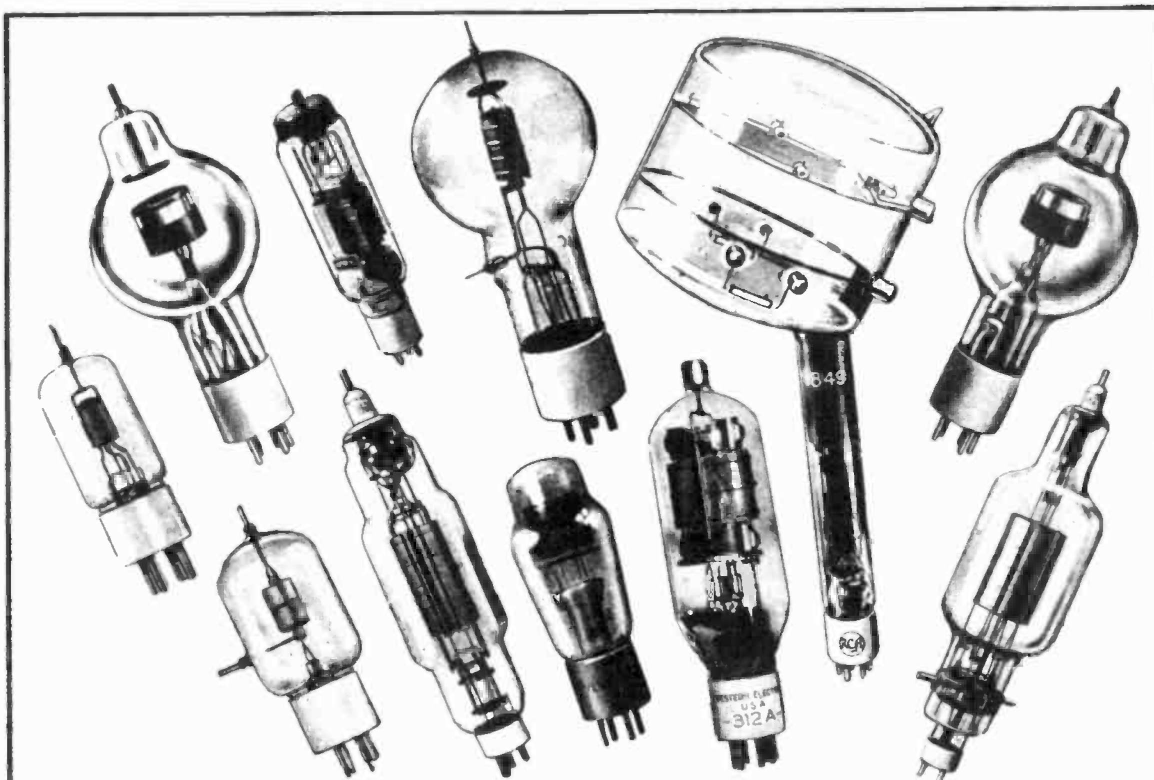

FIG. 1
ELECTRONIC TUBES ARE MANUFACTURED IN MANY SIZES AND SHAPES
TO MEET ALL NEEDS OF THE INDUSTRY

marvel of modern science -- and, yet, new applications are being developed constantly. It is self-evident, therefore, that the student who expects to associate himself with any one of the many branches of radionics must have a thorough knowledge of tubes.

This lesson will serve as your introduction to this highly important and interesting subject by teaching you basic tube principles. Following lessons will familiarize you with the structural features of some of the more complex types of tubes, and with their application in present-day commercial electronic equipment.

EARLY EXPERIMENTS WITH THE ELECTRONIC TUBE

Many of the principles employed in modern electronic tubes were discovered as long ago as 1883, while Thomas A. Edison was experimenting with his electric lamp. Edison found that it was possible to pass an electric current through a resistance wire (filament), and so heat the filament to a temperature high enough to radiate light; and that it was necessary to place this filament in an evacuated bulb (vacuum) in order to prolong its life.

In his efforts to improve the incandescent electric lamp, Edison set up an experimental circuit similar to that illustrated in Fig. 2. Here, you will observe that he placed a small metal plate inside of the lamp bulb, at a slight distance from the filament. A battery was connected to the ends of the filament, as shown; and the positive terminal of this same battery was also connected to the plate through a galvanometer (a sensitive current indicating instrument).

The battery furnished the emf necessary to force sufficient current through the lamp filament to produce light. The galvanometer showed that a very small current flowed in the circuit to which the plate was connected. It was further discovered that the galvanometer indicated zero when the plate was connected to the negative battery terminal, as illustrated by the dotted line; thus demonstrating that no current flowed through this circuit under such conditions.

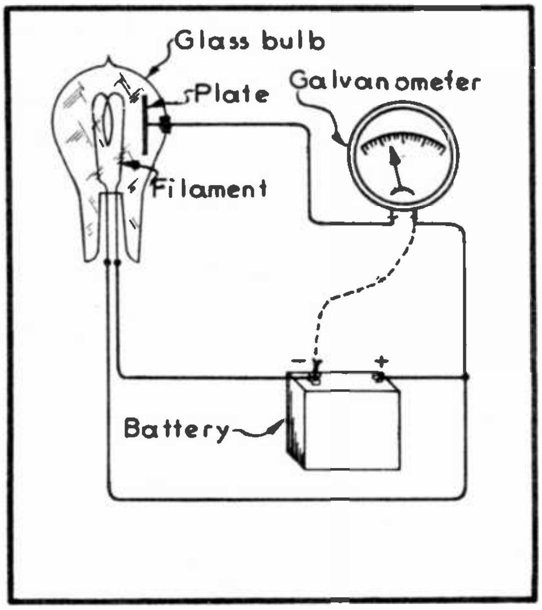

FIG. 2
APPARATUS USED TO DEMONSTRATE
THE "EDISON EFFECT"

These findings, logically, brought up the following questions: 1.- "How is it possible for current to flow in the circuit between the plate and the positive battery terminal, when the plate is actually insulated from the filament inside of the tube, and the circuit apparently 'open' at this point?" 2.- "Why is it that current flows in this same circuit only when the positive battery terminal is connected to the plate; and not when the negative battery terminal is connected to the plate?" For a number of years, these questions remained unanswered, and the condition was simply referred to as the "Edison effect".

THE "EDISON EFFECT" EXPLAINED

The first satisfactory explanation of the "Edison effect" was given by Sir J. J. Thompson, in 1900, when he announced to the scientific world

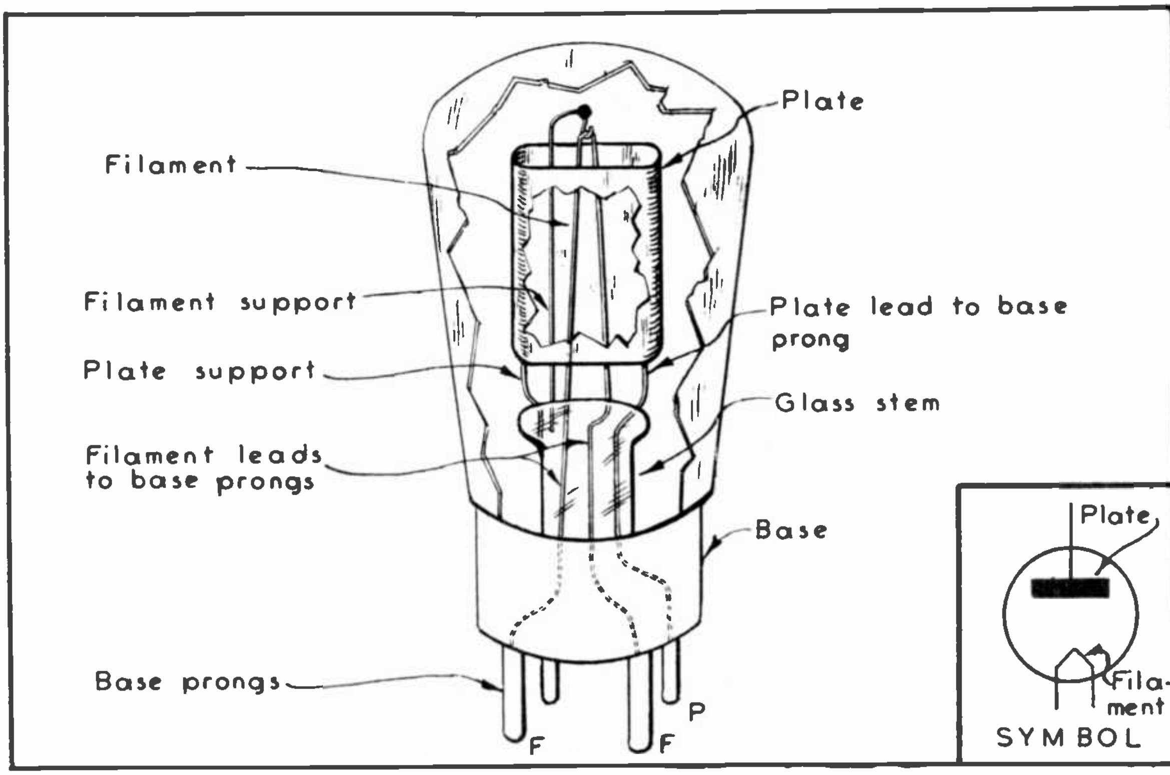

FIG. 3
STRUCTURAL FEATURES AND SYMBOL OF DIODE

his "Electron Theory of Matter". In terms of this theory, it was determined that the "Edison effect" is due to the ability of electrons to leave a heated filament, be projected through a vacuum to a positively-charged plate (Fig. 2), and thus cause a movement of electrons (current flow) in that part of the circuit in which the galvanometer is connected. As you will soon see, this is the basic principle of most modern electronic tubes -- the structural features and operation of which will now be described in detail.

You will find the descriptions in this lesson to be centered around glass tubes, as this form of construction was used exclusively in the early types of tubes and is still being employed extensively in tubes of modern design. Information on metal tubes will be offered in a later lesson.

While studying this lesson, bear in mind at all times that the information given herein relative to the elements or electrodes of electronic tubes applies to metal tubes as well as to glass tubes.

THE DIODE

The tube known as the "diode" will be discussed first because it is the most simple tube used in radio receivers and electronic apparatus in general; and also because it was the first tube developed expressly for radionic purposes.

CONSTRUCTION: In Fig. 3 is shown the construction of the diode, and the symbol for this type of tube. In Fig. 4, the physical structure of the elements and their relative position can be seen more clearly. You will observe in these illustrations that the diode contains two elements or electrodes -- namely, a filament and a plate.

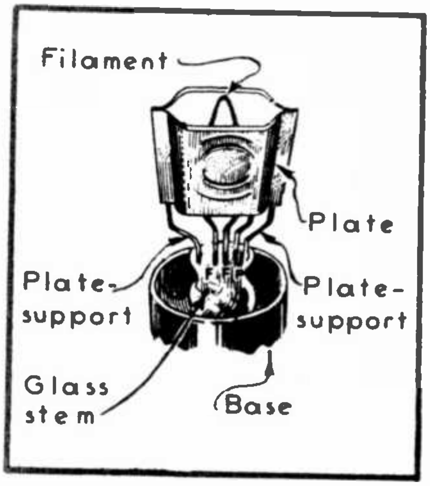

FIG. 4
DETAILS OF DIODE ELEMENTS

The filament is generally constructed of tungsten, carbon, or nickel wire; and is surrounded by the boxed-shaped plate which is made of a thin sheet of metal -- usually nickel. Notice, particularly, that there is no physical connection between the filament and the plate, but that these two parts are separated from each other by an appreciable distance.

The filament and plate are held in place by stiff wire supports, imbedded in a glass stem. The latter is fastened to a bakelite base which is equipped with four prongs, two of which are larger in diameter than the other pair. Each end of the filament is connected to a prong of large diameter, labeled "F" in Fig. 3; while the plate is connected to one of the small-diameter prongs, labeled "P" in the same illustration. These connections between the prongs and the elements, indicated by dotted lines in Fig. 3, are made within the tube structure at the time of manufacture. No connection is made to the remaining prong in Fig. 3 as the latter is provided on this particular base merely so that the tube can be inserted in a standard four-prong socket.

The filament and plate are enclosed in a glass bulb from which all air has been removed; thus, the expression "vacuum tube" has become associated with electronic tubes.

THE SOCKET: In Fig. 5, is shown the socket that is used to hold the diode in place in the radio receiver. It is mounted to the chassis (base) of the receiver by means of rivets or machine screws. The central portion or body of the socket is made of bakelite, fibre, isolantite of other material possessing good insulating properties. Four holes are provided in the socket to receive the four prongs of the tube base. Metal spring clips are anchored in these holes to hold the tube in place securely; and the spring clips are in turn connected to terminals at the bottom of the socket, to which the proper receiver circuits are wired. Thus, the socket serves as the medium of connection between the receiver circuits and the tube elements.

To insert the tube in its socket, grasp the tube by its base, line up the two prongs of large diameter with the large holes of the socket; and line up the small-diameter prongs with the small holes of the socket. Then force the tube downward into the socket firmly, but gently. To remove the tube from the socket, grasp it by the base, and pull upward firmly, but gently. Never grasp the tube by the glass bulb either while installing it or when removing it, as the application of force to the glass bulb may loosen it from the base and thus damage the tube.

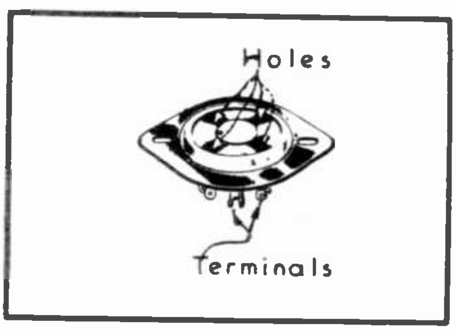

FIG. 5
TUBE SOCKET

So much for the structural features of the diode. Now, let us see how this tube works.

HOW THE DIODE OPERATES

In Fig. 6, you will observe that a low-voltage battery (6 volts in this particular case) is connected to the filament of the diode. This circuit, comprising the filament and battery, is called the filament circuit -- and, quite often -- the "A" circuit. When the latter expression is used, the source of the filament voltage is referred to as the "A" supply; and, if a battery is employed for this purpose, it is spoken of as the "A" battery.

The "A" battery forces an electric current through the filament and causes it to become white hot. Now, whenever a metal is heated, the velocity at which the electrons move through it increases. And, when a certain critical temperature is reached, their velocity becomes so great that many of them overcome the attraction tending to hold them within the atom and so fly out into the space adjacent to the metal. This phenomenon is not unlike the process of evaporation, and is spoken of as THERMIONIC EMISSION.

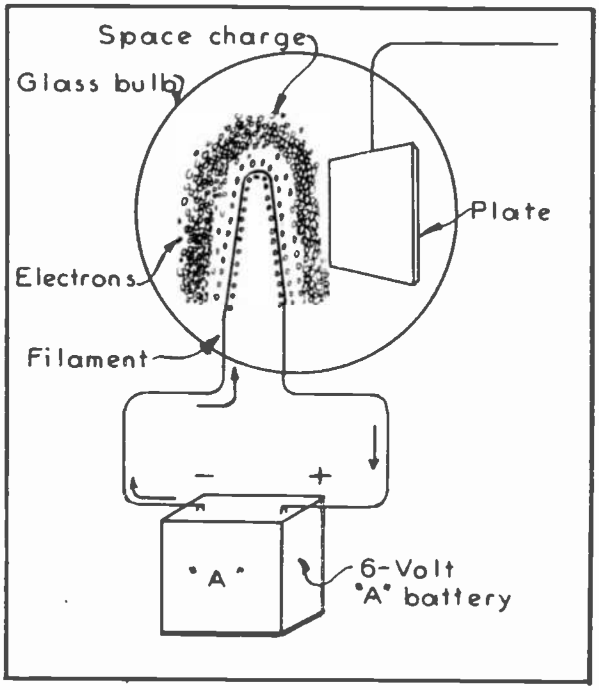

FIG. 6
ELECTRON EMISSION AND SPACE CHARGE

Tungsten and carbon filaments are usually impregnated with thorium, whereas filaments made of nickel are generally coated with oxides of barium, calcium, or other chemical elements to increase the emission of electrons from the hot filament. The electrons thus driven out of the filament, and into space, are often called "free electrons".

During thermionic emission, the force that drives the electrons out of the filament is only of such magnitude as to project the free electrons into space for a limited distance. This results in a rather dense "cloud" of free electrons surrounding the filament in a manner somewhat as illustrated in Fig. 6. This cloud of electrons is known as the space charge; and, since it is made up of a tremendous number of electrons that are actually negative charges of electricity, the space charge, as a whole, is negative in character.

After enough electrons have accumulated in the region near the filament to form the space charge, any additional electrons that attempt to enter this region are repelled and driven back toward the filament by the space charge, for the reason that like electrical charges repel each other. Thus, as long as the space charge and the flow of electrons from the filament are not subjected to any disturbing influence, the conditions just described will continue to exist as long as the emf is applied to the filament.

APPLYING A POSITIVE VOLTAGE TO THE PLATE: Now let us connect another battery(the "B" battery) between the plate and the filament of the diode, as illustrated in Fig. 7. Notice especially that the positive terminal of the "B" battery is connected to the plate of the tube through the milliammeter, and that the negative terminal of the "B" battery is connected to the filament. Thus, the plate is at a positive potential with respect to the filament, or the filament is at a negative potential with respect to the plate. To differentiate it from the filament

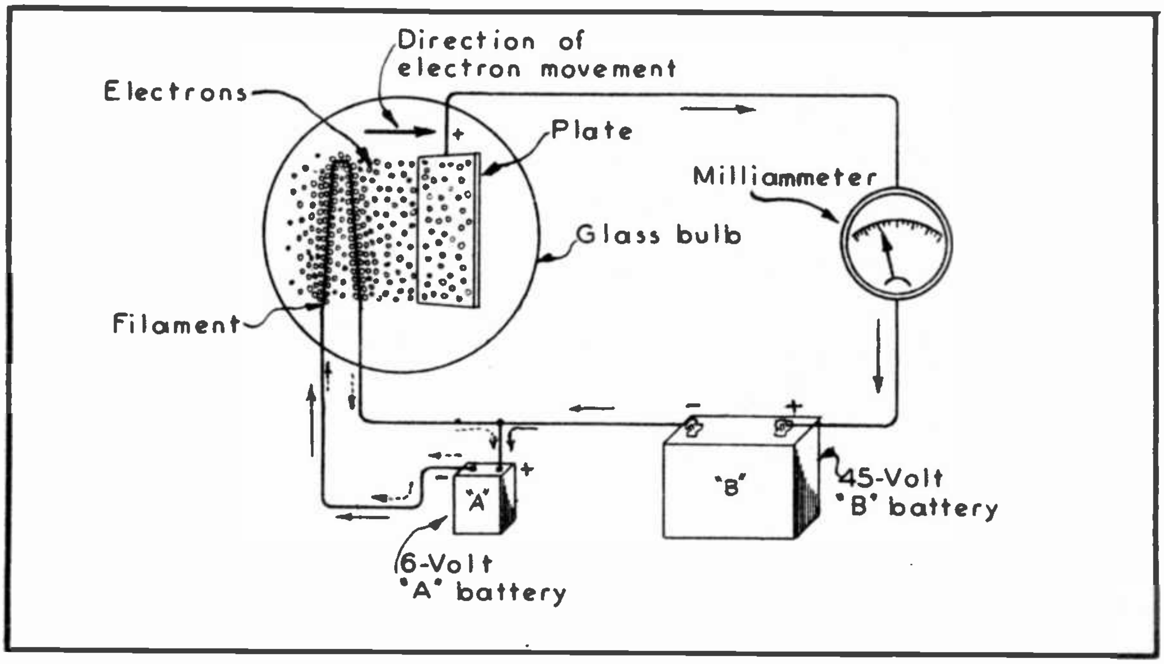

FIG. 7
APPLICATION OF POSITIVE VOLTAGE TO PLATE CAUSES PLATE CURRENT TO FLOW

circuit, we call the circuit comprising the plate, milliammeter and the "B" battery, the "plate current". Quite often, the plate circuit is spoken of as the "B" circuit; and its source of emf is then called the "B" supply. If the emf is furnished by a battery, the latter is known as the "B" battery.

With the circuit arranged as in Fig. 7, the "B" battery is applying a positive voltage to the plate of the diode; and, since unlike electrical charges attract, it follows, logically, that some of the electrons contained in the cloud forming the space charge will be drawn toward the plate. This movement of electrons constitutes a small electric current; and, simultaneously, current flows throughout the remainder of the plate circuit. This current flow will be indicated by the milliammeter, and is called the "plate current".

It is important to observe in Fig. 7, that the direction of the electron movement within the tube is from the filament toward the plate; and, that this direction of flow is maintained throughout the entire plate circuit outside of the tube, as indicated by the solid arrows. The dotted arrows in this illustration represent the filament current furnished by the "A" battery.

The surface from which the electrons are emitted within the tube (the filament, in this case) is called the cathode, whereas the positively-charged plate toward which they are attracted is called the anode. In some types of modern tubes, the cathode (electron-emitting surface) is not the filament itself, but rather a small metal cylinder that surrounds the filament and is heated by it. In either case, the electron-emitting surface is spoken of as the cathode. Within certain limits, increasing the temperature of the cathode increases the amount of emission, while decreasing the cathode temperature reduces the number of electrons emitted in a given length of time.

INCREASING THE POSITIVE PLATE VOLTAGE: In Fig. 8, we have the same fundamental circuit, with the exception that a "B" battery of higher voltage is being used so that the plate will now be more positive than formerly. By means of this experiment, we find that the higher positive

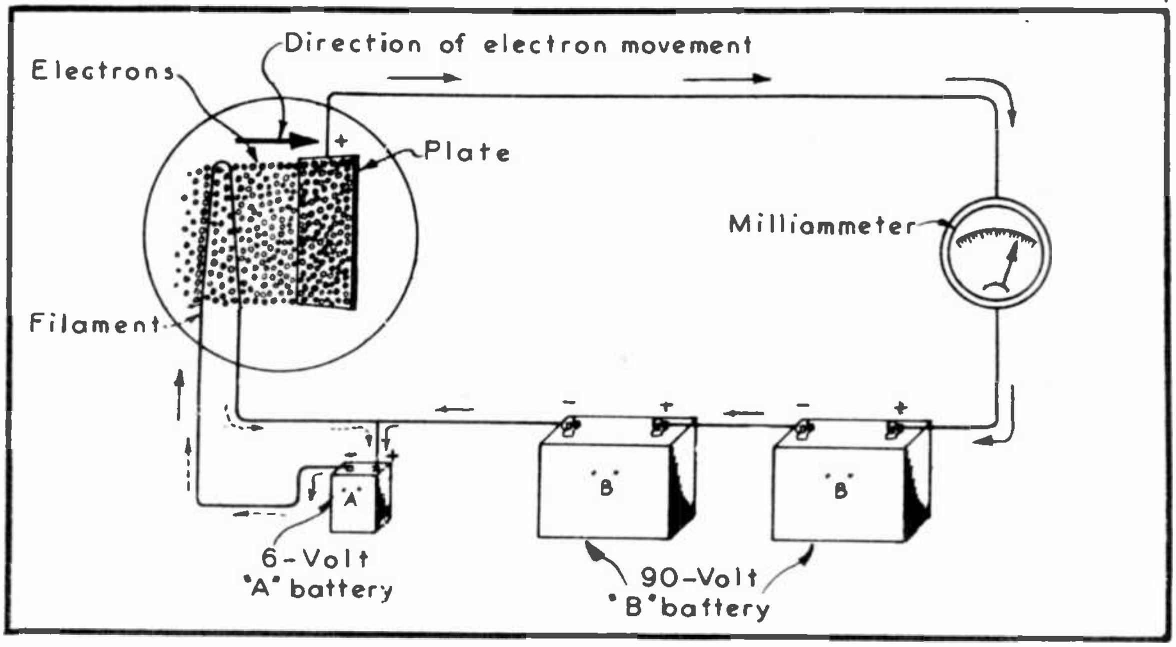

Fig. 8
INCREASING POSITIVE PLATE VOLTAGE INCREASES FLOW OF PLATE CURRENT

plate potential overcomes the repelling force of the negative space charge and attracts a larger number of the electrons to the plate. Now that the barrier of the space charge has been almost completely removed, a much greater flow of plate current is indicated by the milliammeter.

APPLYING A NEGATIVE VOLTAGE TO THE PLATE: As our next experiment, let us reverse the polarity of the "B" battery by connecting its negative terminal to the plate, and its positive terminal to the filament, as pictured in Fig. 9. We now note that because of the repelling effect of the

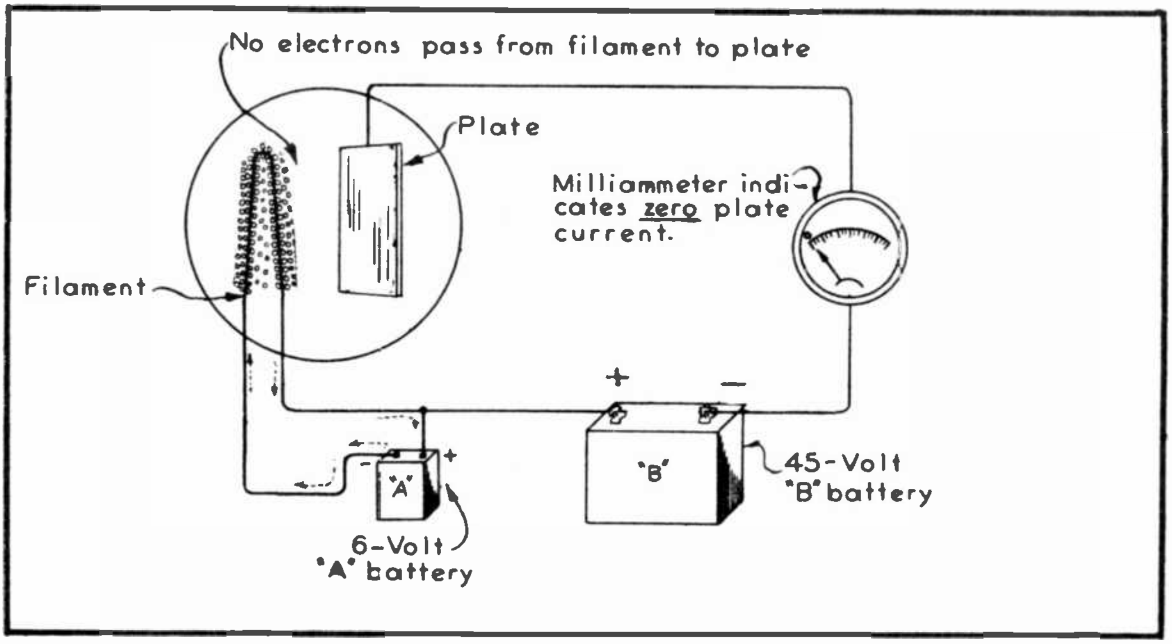

Fig. 9
APPLYING A NEGATIVE VOLTAGE TO PLATE PREVENTS FLOW OF PLATE CURRENT

negatively charged plate, and the attracting force of the now positive filament, the electrons liberated from the filament are being attracted back to it as fast as they are emitted. This prevents the space charge from forming. Also, since there is no passage of electrons from the filament to the plate, there is no flow of current in the plate circuit; as indicated by the fact that the milliammeter reading is "zero" at this time. This leads to the conclusion that the diode is definitely a one way device, allowing current to flow only when the plate is positive; but not when the plate is negative. This characteristic of the diode will be brought to your attention in connection with many useful applications, as they appear later on.

POINT OF CATHODE SATURATION

There is a limit to the amount of plate current that will flow through the diode. When the positive voltage as applied to the plate is increased to the point where all of the electrons being emitted by the cathode are attracted to the plate as fast as they are liberated, this results in plate current flow which cannot be increased. We then say that the tube is operating at the SATURATION POINT.

The temperature of the filament establishes the amount and rate of emission of electrons from the cathode. The plate voltage has no control over this action; as all it does is to govern the force of attraction that the plate has for the electrons emitted by the cathode. Thus, increasing the plate voltage after the saturation point of the vacuum tube has been reached, would be of no avail; for no matter how much the plate may attempt to attract more electrons, only a definite number are available within a given period of time. Therefore, the influence of the plate voltage is limited by the "saturation point" of the tube.

In normal applications, a vacuum tube is seldom, if ever, operated under such conditions that the plate current is allowed to reach the saturation point. The maximum plate current in a diode tube can be kept to a value below the saturation point by limiting the plate voltage.

APPLICATION OF THE DIODE

You have learned that the diode or two-element tube permits the passage of current through it in one direction only. This function enables it to be used as a rectifier; a device that converts alternating current to direct current. Such rectifying properties of the diode can be put to use as a detector of radio signals, replacing the crystal detector.

Diode rectifiers are also designed to handle larger amounts of current when employed in power supplies used to provide a source of direct current to replace "B" batteries. Radio receivers operating from the a-c line use a rectifier of this type as the source of "B" voltage.

All of these applications will be described in detail in later lessons. For the present, we will confine our discussions to the basic principles of tube operation

THE TRIODE

In 1907, Dr. Lee De Forest, by adding a third element (called the "control grid") to the diode,developed the triode (three-element tube); which greatly expanded the usefulness of the tube. The introduction of this third element gave to the field of Electronics a most valuable device, capable of seemingly unlimited applications.

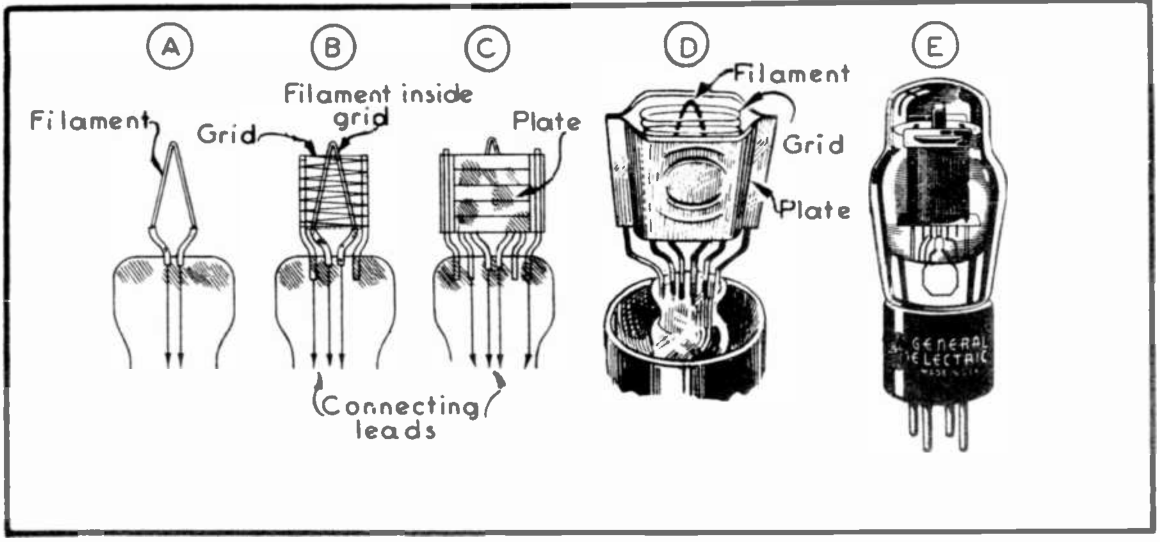

FIG. 10
STRUCTURAL FEATURES OF THE TRIODE

CONSTRUCTION OF THE TRIODE

In Fig. 10, you are shown the structural features and relative positions of the elements in the triode. The arrangement of the filament is illustrated in detail at (A), while the manner in which the filament is placed inside of the grid structure is shown at (B). The grid usually consists of a metallic mesh or coil of very fine molybdenum wire, the adjacent turns of which are rather widely spaced. The plate surrounds both the filament and grid, as shown at (C), and is constructed of a thin sheet or mesh of nickel or iron.

The construction of this tube is such that electrons emitted by all sides of the filament wire are attracted by the plate, but must first flow through the open spaces between the various turns of the grid. The illustration at (D) of Fig. 10 serves better to illustrate the position of the three elements; while (E) shows a widely used filament-type triode in its complete form. The symbol for a triode appears in Fig. 11.

HOW THE TRIODE OPERATES

APPLYING A NEGATIVE VOLTAGE TO THE GRID: In Fig. 12, is shown the triode, with an "A" battery furnishing the filament voltage; and a "B" battery providing the positive voltage for the plate. In addition, a third battery, which we call the "C" battery, is connected between the grid and the filament. It is important to note in this illustration that the (-) or negative terminal of the "C" battery is now connected to the grid of the tube, and therefore makes the grid negative with respect to the cathode or filament.

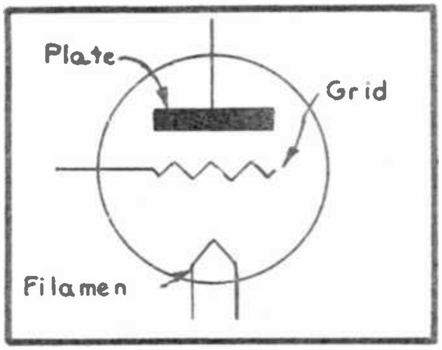

FIG. 11
SYMBOL OF TRIODE

This negatively-charged grid repels the electrons emitted by the filament because like electrical charges repel each other. Thus, it can be seen that many of these electrons will be driven back toward the filament. In fact, by making the grid voltage sufficiently negative,

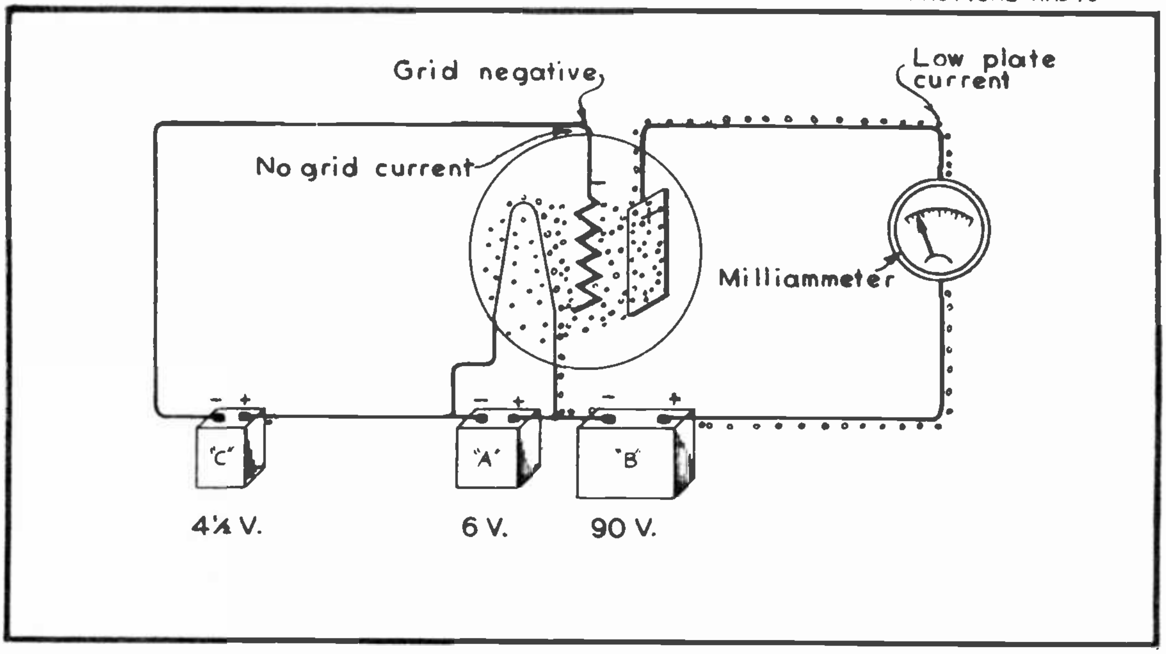

FIG. 12
NEGATIVE GRID VOLTAGE REDUCES PLATE CURRENT

it is possible to stop the flow of plate current entirely. However, in actual practice, the tube is usually operated so that some of the electrons will find their way through the open mesh of the grid and finally reach the plate. In Fig. 12, the negative voltage applied to the grid is of such value as to permit a sufficient number of electrons to reach the plate and thus produce a low plate current.

APPLYING A POSITIVE VOLTAGE TO THE GRID: Now let us reverse the "C" battery connections so that the (+) terminal of the "C" battery will be connected to the grid, as illustrated in Fig. 13. Under these conditions, we find that because unlike charges attract, the positively-charged grid will add its attraction to that of the positively-charged plate, and so greatly increase the number of emitted electrons that reach the plate.

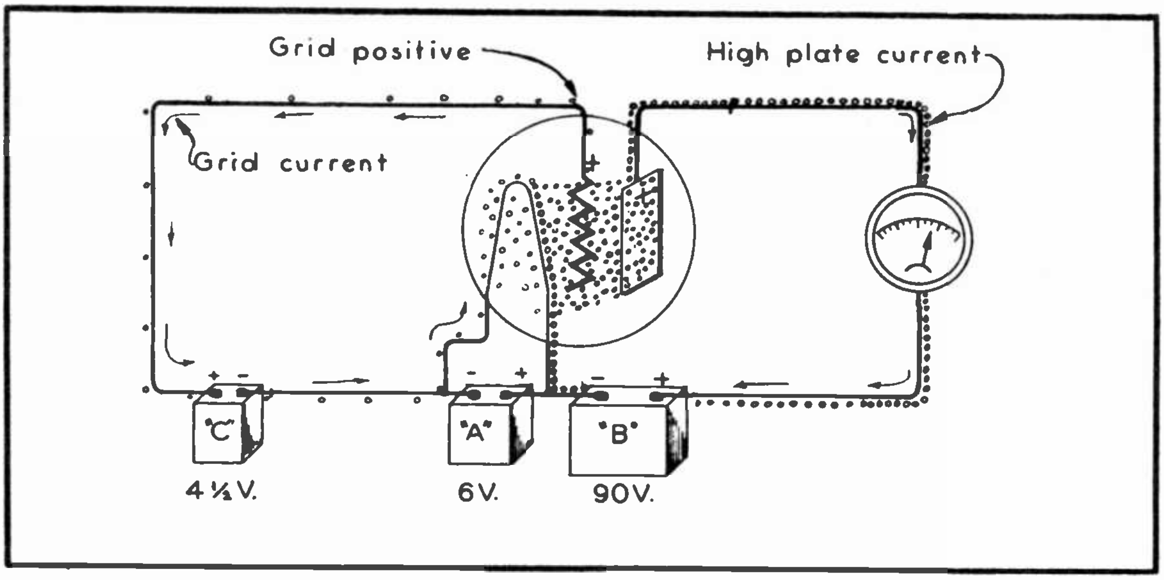

FIG. 13
POSITIVE GRID VOLTAGE INCREASES PLATE CURRENT

Of course, a small number of these electrons will strike the slender metal bars of the grid, and travel through the "C" battery circuit to the filament from whence they came. We call this drift of electrons through the grid circuit the "grid current". However, the important thing that the positively-charged grid accomplishes is to assist and accelerate the flow of electrons over to the plate and thereby produce an increase in the flow of plate current. So the more positive we make the grid, the greater will be the plate current.

Summing up this effect of grid voltage we see, then, that a negative grid voltage opposes the electron flow between the filament and plate, and thereby reduces the plate current; and that the more negative the grid voltage, the less will be the plate current. A positive grid voltage accelerates the flow of electrons from the filament to the plate, and in this way increases the plate current; and the more positive the grid voltage, the greater will be the plate current.

APPLYING AN ALTERNATING VOLTAGE TO THE GRID

An understanding of the effect of an ALTERNATING VOLTAGE on the grid of a triode becomes greatly simplified by keeping in mind what you have learned about such a tube when d-c voltages are applied to the grid. Namely, that any increase or decrease in grid voltage causes a corresponding, simultaneous, increase or decrease in the flow of the plate current.

In a previous lesson, we found that an alternating voltage differs from a d-c voltage in that the d-c emf is constant in value and polarity; whereas an alternating emf changes continuously in value as well as direction(polarity). Thus, by applying the vacuum tube theory that you have already learned, it becomes self-evident that with an alternating voltage impressed on the grid, the plate current will follow every change or variation of this alternating voltage.

To illustrate this point, let us turn our attention to Fig. 14. Here, we have the same fundamental tube circuit as previously used in

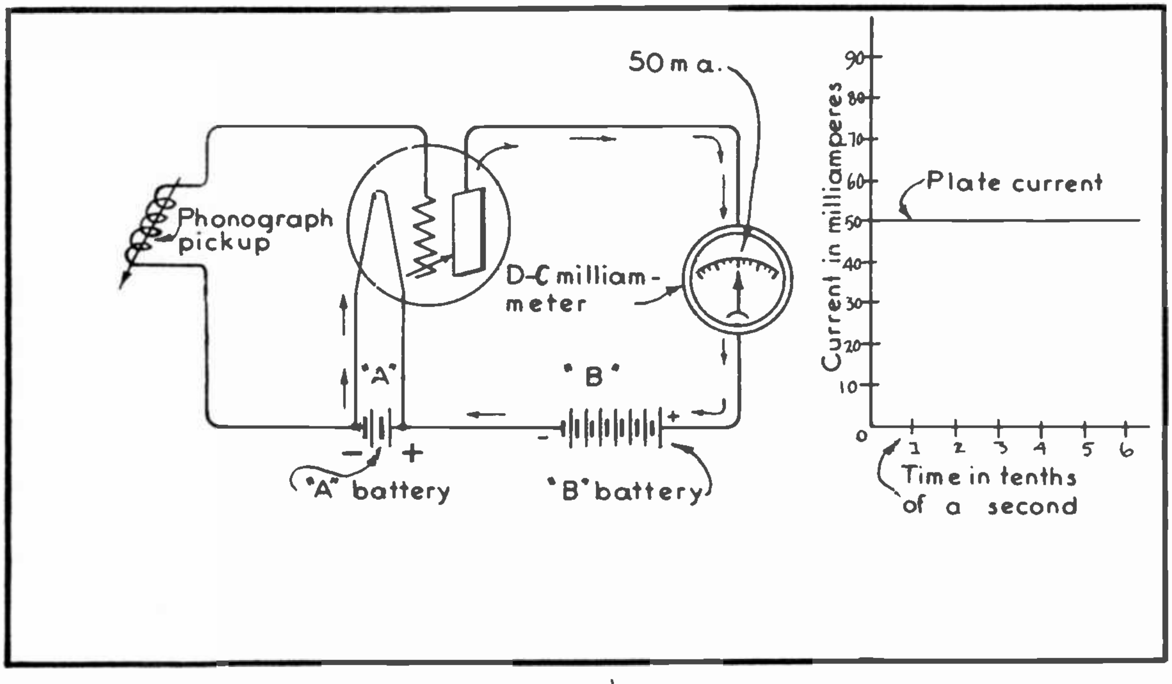

FIG. 14
TRIODE FUNCTIONS AS A DIODE WHEN NO VOLTAGE IS APPLIED TO GRID

our discussion, except that a phonograph pickup replaces the "C" battery formerly employed in the grid circuit. The "pickup" generates a small a-c signal voltage when the groove in the phonograph record vibrates the needle from side to side. However, for the present we will assume that the pickup is temporarily inoperative so that no signal voltage is being applied to the grid.

Under these conditions, the grid has no effect upon the passage of electrons from the filament to the plate; and the tube, therefore, functions as a diode. A steady current will now flow through the plate circuit as shown by the arrows; the value of this current being dependent upon the electrical characteristics of the particular tube in question. For the sake of illustration, we are assuming that this steady, no-signal plate current amounts to 50 ma., which value is indicated on the milliammeter that is connected in the plate circuit.

To the right of the circuit in Fig. 14, we have a small "plate-current graph" on which plate current values are scaled-off vertically; and time, in tenths of a second, horizontally. Since the plate current flow in this circuit now maintains a steady value of 50 ma. for an indefinite length of time, we indicate this fact by means of the straight, horizontal line which is drawn through the point on our graph that represents 50 ma. of plate current. This line, then, tells us that the no-signal or "normal" plate current in this particular case is 50 ma., of, that 50 ma. of plate current flows through this circuit when no signal is applied to the grid of the tube.

POSITIVE ALTERNATION OF SIGNAL VOLTAGE APPLIED TO THE GRID: In Fig. 15, the small "grid-voltage graph" shows us that a positive alternation of a-c signal voltage is now being generated by the phonograph pickup, and applied to the grid; and that 0.5 second is required to complete this alternation.

As the grid voltage gradually increases in value in a positive direction, the plate current increases at a corresponding time-rate; and the plate current is maximum at the instant that the signal-voltage charge on the grid attains its maximum or peak positive value. The plate-current graph in Fig. 15 shows how the plate current gradually increases

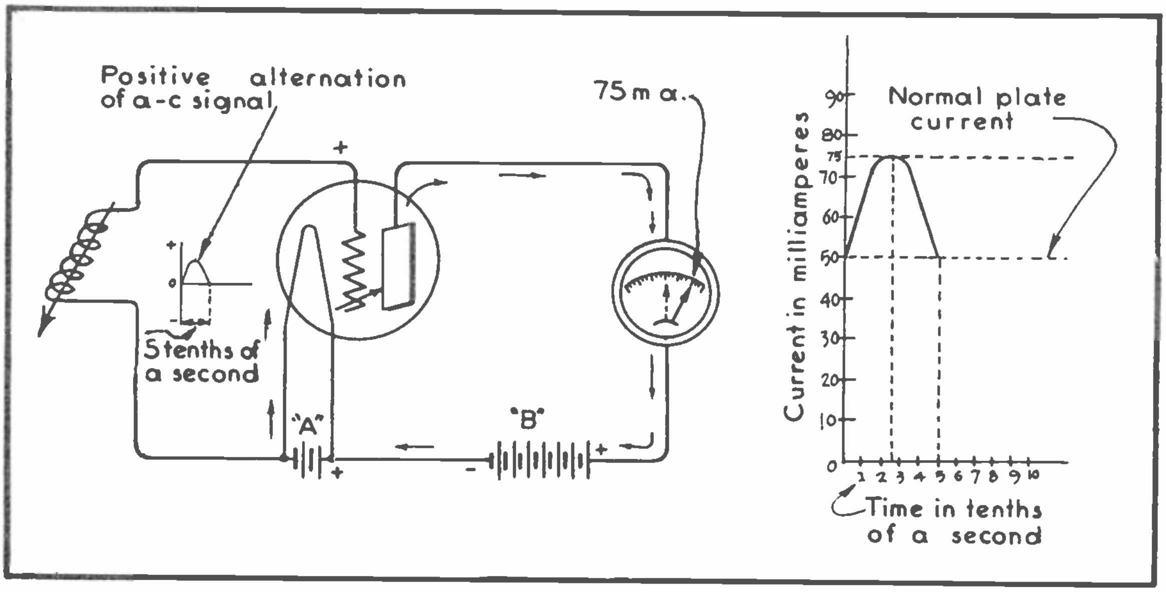

FIG. 15
POSITIVE ALTERNATION OF A-C SIGNAL VOLTAGE APPLIED TO GRID

and decreases, with respect to the normal or no-signal value, in exact step with the variation in grid voltage, during the time that this positive alternation of signal voltage is applied to the grid. Notice that 0.5 second is also required to complete this variation in plate current, corresponding to the positive alternation of signal voltage; and that the maximum plate current of 75 ma. occurs at the 0.25 second point, at which instant the signal has charged the grid to its positive peak value.

NEGATIVE ALTERNATION OF SIGNAL VOLTAGE APPLIED TO THE GRID: In Fig. 16, conditions are illustrated when the negative alternation of signal voltage is being generated by the phonograph pickup, and applied to the grid.

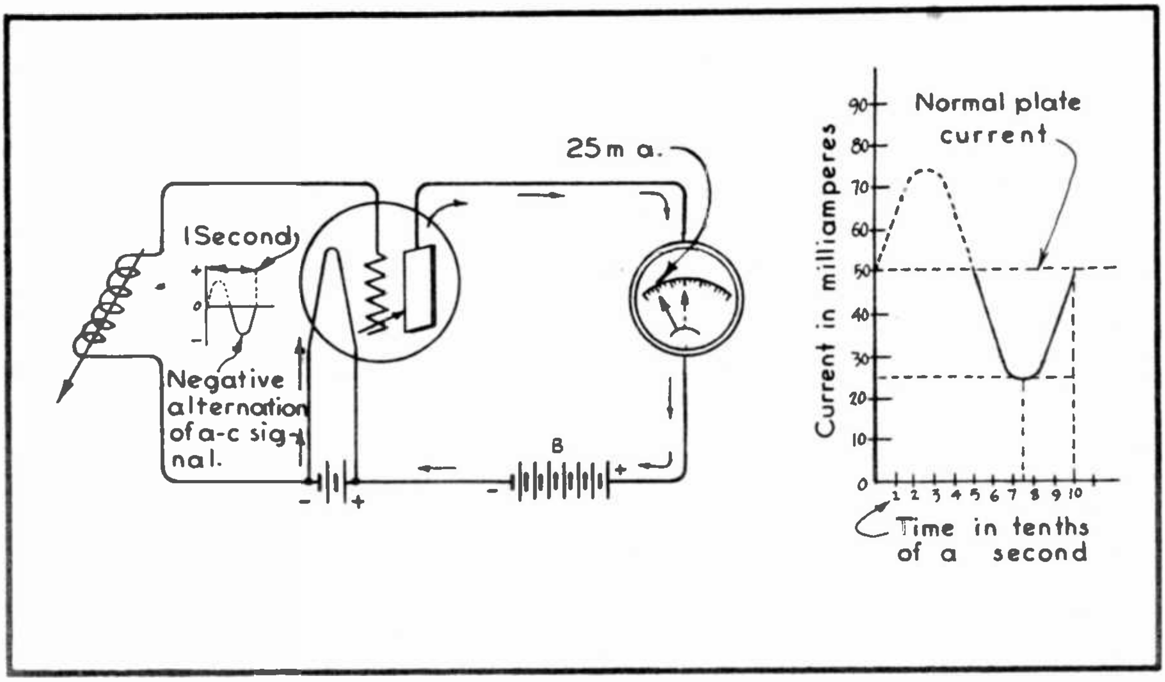

FIG. 16
NEGATIVE ALTERNATION OF A-C SIGNAL VOLTAGE APPLIED TO GRID

At this time, the signal causes the grid voltage to gradually increase from zero to maximum in a negative direction, and then back to zero, as indicated by the solid line in the wave form appearing on the grid-voltage graph. During this alternation of grid voltage, the plate current will decrease at a time-rate corresponding to the rate of change of grid voltage; plate current being minimum at the instant the grid is charged to the negative peak value of the signal. The plate current then increases as the grid voltage returns to zero; and at this latter instant, the plate current will again have been restored to its normal or no-signal value.

The variation in plate current corresponding to the negative alternation of signal voltage acting upon the grid is represented by the solid line in the wave form on the plate current graph in Fig. 16. Observe on this graph how the plate current attains its minimum value of 25 ma. at the same instant that the grid of the tube is subjected to its negative peak voltage by the signal.

Observe further in our graphs in Fig. 16 how we have actually applied one complete a-c cycle to the grid of the tube, and that the wave form representing the corresponding change in plate current also appears as one complete cycle of the same general shape as the grid-voltage wave form, but is somewhat larger in overall size. This latter fact is due to the amplifying ability of the tube which is explained fully later in this lesson. Notice, also, that the cycle representing the plate current variation is completed in exactly the same length of time as is the signal-voltage cycle at the grid, or one second.

Now, although the wave form representing the variation in plate current in Fig. 16 has the appearance of an a-c wave, it must be remembered that the plate current never reverses its direction of flow when the grid is subjected to an a-c signal voltage. The plate current merely rises above and drops below its normal no-signal value in step with the alternating grid voltage.

AMPLIFICATION FACTOR OF A TUBE

When dealing with the operating characteristics of tubes, you will frequently encounter the expression "AMPLIFICATION FACTOR" or "AMPLIFICATION CONSTANT" Therefore, it is well that you become familiar with this term before you are required to use it.

One of the most important features of radio tubes is the fact that a very small variation in voltage at the grid produces a large variation or change in the flow of plate current. This is made possible by the tube's ability to amplify

Besides a change in grid voltage producing a change in plate current, it is also possible to cause a change in plate current by altering the plate voltage. However, a much less change in voltage is required at the grid than at the plate to produce the same change in plate current.

For example, if the construction of a certain tube is such that its plate current increases by 5 milliamperes (.005 ampere) when the grid voltage is made more positive by 10 volts, whereas 30 volts more positive plate voltage is needed to produce this same 5 milliampere increase in plate current, it is apparent that <u>three times</u> as much change in voltage is required at the plate than at the grid to produce the same 5 milliampere change in plate current. We then say that this particular tube has an <u>amplification factor</u> or <u>amplification constant</u> of "3". It is common practice to speak of the amplification factor as the "MU" of the tube. MU is a Greek letter that is written μ.

Thus, you have seen that the amplification factor of any tube is the <u>ratio</u> between the change in plate voltage to the change in grid voltage required to produce the same change in plate current. This can be expressed as a simple and convenient formula in the following manner:

$$\text{"MU"} = \frac{\text{Change in plate voltage causing a certain change in plate current}}{\text{Change in grid voltage causing the same change in plate current}}$$

So as to be absolutely sure that you understand this perfectly, let us consider another example. This time, we will determine the amplification factor of a tube which requires an increase in plate voltage of 100 volts to bring about an increase of 10 milliamperes in plate current, and an increase in grid voltage of only 4 volts to produce an increase of 10 milliamperes in plate current. Substituting these voltage values in the formula just given, we have:

$$\text{Mu} = \frac{100}{4} = 25$$

Thus, the amplification factor of this tube is 25.

THE GRID VOLTAGE-PLATE CURRENT CURVE

To determine the effect of changes in grid or plate voltage upon plate current, we can set up a simple circuit similar to that illustrated in Fig. 17. Here, you will notice that the interchangeable battery connections are so arranged as to permit us to conveniently vary the plate voltage by merely connecting the plate circuit to different terminals on the "B" battery. In a similar manner, the vareable connections at the "C" battery enable us to make the voltage on the grid either more or less negative, or positive.

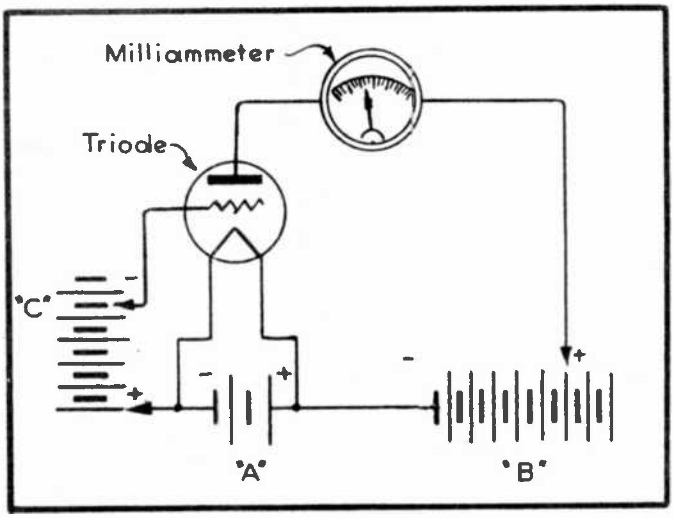

FIG. 17
SIMPLE CIRCUIT FOR CHECKING EFFECT OF GRID AND PLATE VOLTAGE CHANGES ON PLATE CURRENT

In illustration (A) of Fig. 18, for instance, the battery connections are such that -3 volts are applied to the grid, and +180 volts to the plate; and the milliammeter tells us that 25 milliamperes is flowing through the plate circuit. At (B) of Fig.18, we see that when -6 volts is applied to the grid and +180 volts to the plate, 15 milliamperes of plate current flows. Illustration (C) of Fig. 18 shows that with +3 volts on the grid, and +180 volts on the plate, 45 milliamperes of plate current flows.

By this means, we can change the grid voltage to practically any value we wish, negative or positive, within limits established by the design of the tube; and read corresponding values of plate current on the milliammeter. Or, we can leave the grid voltage set at one particular value, change the plate circuit connection at the "B" battery, and so observe how variations in plate voltage affect plate current. Or, we can determine what effect changes in grid voltage have upon plate current when different plate voltages are used.

The data acquired from the tests just described is often used by technicians and tube manufacturers in the preparation of graphs similar to that appearing in Fig. 19. This graph is known as a "grid voltage-plate current characteristic curve"(abbreviated as "Eg-Ip curve"), and its purpose is to tell us at a glance the relation between different grid voltages and corresponding values of plate current at a fixed plate voltage.

Upon examining the curve in Fig. 19 closely, you will note that if -3 volts is applied to the grid of the tube represented by this curve, 25 milliamperes of plate current will flow through it. An emf of -6 volts on the grid results in a plate current of 15 milliamperes; -9 volts on the grid reduces the plate current to 5 milliamperes; while -15 volts on the grid reduces the plate current to zero, which point we call "cut-off". This curve also shows that making the grid more negative reduces plate current, and that making the grid more positive increases plate current. We observe further that as the grid gradually becomes more positive, the resulting changes in plate current are not as great as for values located on the straight portion of the curve, for the reason that the operation of the tube is approaching its saturation point at higher positive grid voltages. Finally, if a sufficiently high positive vol-

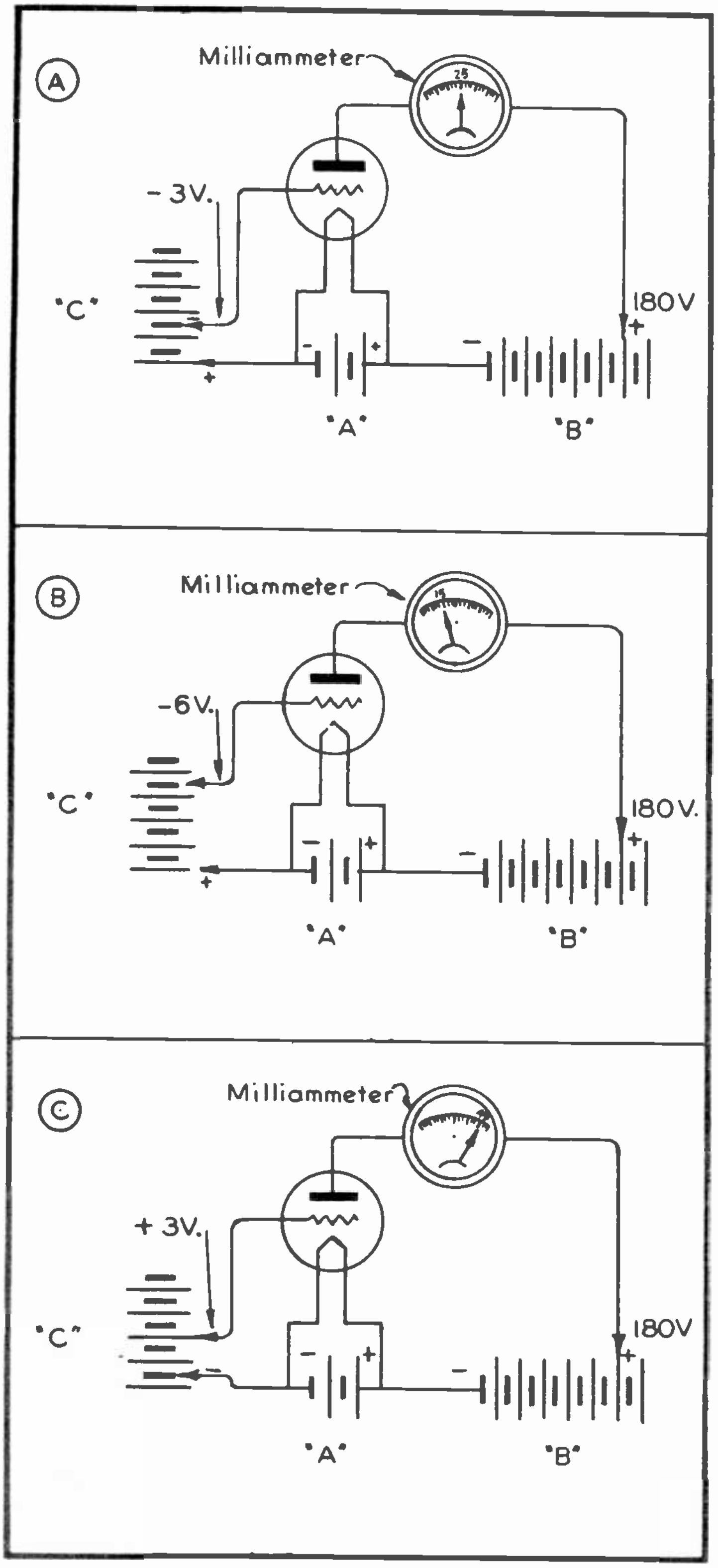

FIG. 18
CHANGING THE GRID VOLTAGE

tage were applied to the grid, so that a state of complete saturation would be attained, the curve would straighten out into a horizontal line, thus showing that no further increase in plate current is possible even though the grid be made more positive.

Notice, especially, that the characteristic curve in Fig. 19 acquires the specific slope here shown only when a certain positive voltage is maintained on the plate. If a different voltage were impressed on the plate of the tube, the slope of the curve would be altered, and the plate current values for given grid voltages would then be different from those appearing in Fig. 19. Broadly speaking, higher plate voltages result in steeper grid voltage-plate current characteristic curves, whereas lower plate voltages result in curves having a more gradual slope. Thus, we have a different grid voltage-plate current characteristic curve for a given tube whenever a different plate voltage is involved.

CHARACTERISTIC CURVE AND TUBE ACTION

Let us now make use of a grid voltage-plate current characteristic curve of a triode to illustrate graphically how a-c signal voltages at the grid of the tube can be converted to corresponding variations in plate current; and also how we obtain amplification of the signal by means of this tube.

In Fig. 20, is shown a grid voltage-plate current curve of a typical triode. Notice that for the sake of simplicity, the only lines appearing in the graph are those necessary to express the conditions in which we are now interested. The three vertical dotted lines indicate grid voltage values. The three horizontal dotted lines indicate plate current values. The center lines in each case, marked "Reference Line -No Signal", indicate the NORMAL grid voltage and plate current when no signal voltage is applied to the grid of the tube. This will be more easily understood from the following explanation.

In practice, the plate current flow with no signal on the grid of the tube is limited to a prescribed normal level, according to specifications supplied by the tube manufacturer. Therefore, every electronic tube has its own individual, predetermined "operating characteristics". Hence, for a given plate voltage, a grid voltage is specified that will "set" the NORMAL plate current within limits determined by the tube manufacturer as the best "operating point" for the particular tube. Of course, when an alternating voltage, such as an r-f or a-f signal, acts upon the grid of the tube, the plate current will vary above and below the normal plate current value.

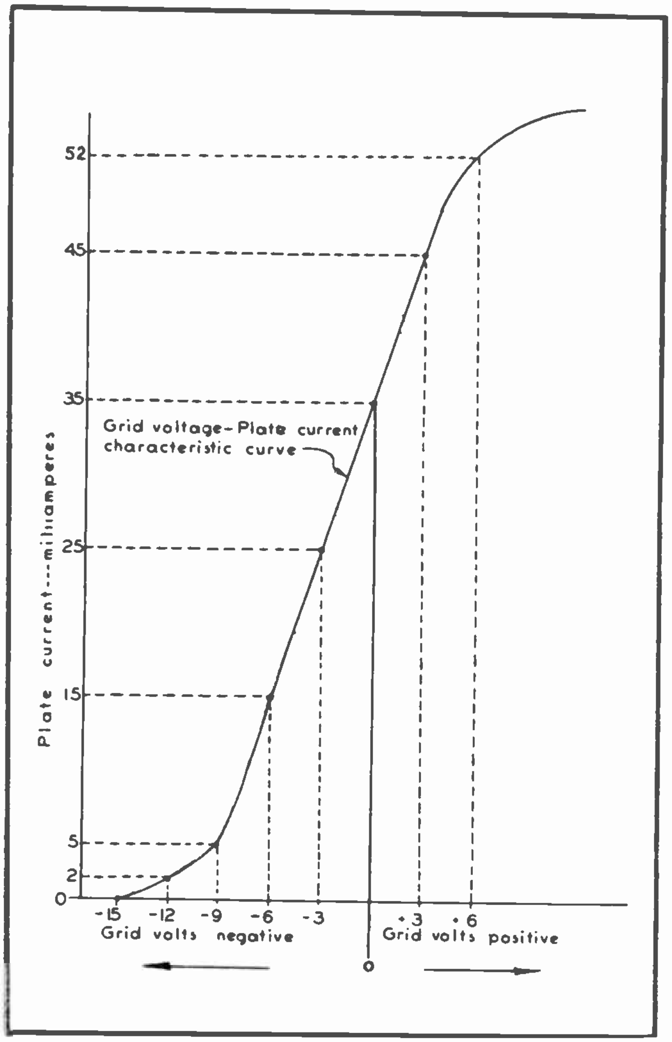

FIG. 19
GRID VOLTAGE-PLATE CURRENT
CHARACTERISTIC CURVE

Returning to the graph in Fig. 20, let us assume that an alternating voltage in the form of an a-f signal is acting on the grid of the tube. The small sine wave drawn at the bottom of the graph represents <u>one cycle</u> of this signal, and it is centered on the vertical "No-Signal Reference Line" that indicates normal grid voltage. Thus, we can follow the "movement" of this sine wave and compare its rise and fall with respect to this Reference Line. In the same manner, we can study the larger sine wave; centered on the horizontal "No-Signal Reference Line", which represents the amplified signal appearing in the plate circuit.

Now, if we think of the vertical lines as being reflected or projected in a horizontal direction to the right, upon "striking" the characteristic curve, we may then visualize the complete sine wave of the signal at the grid as likewise being projected or reflected in exact form and shape to produce the sine wave representing the AMPLIFIED SIGNAL in the plate circuit.

For instance, notice in Fig. 20, the start of the sine wave of the signal at "a" on the Reference Line, and follow it up to the characteristic

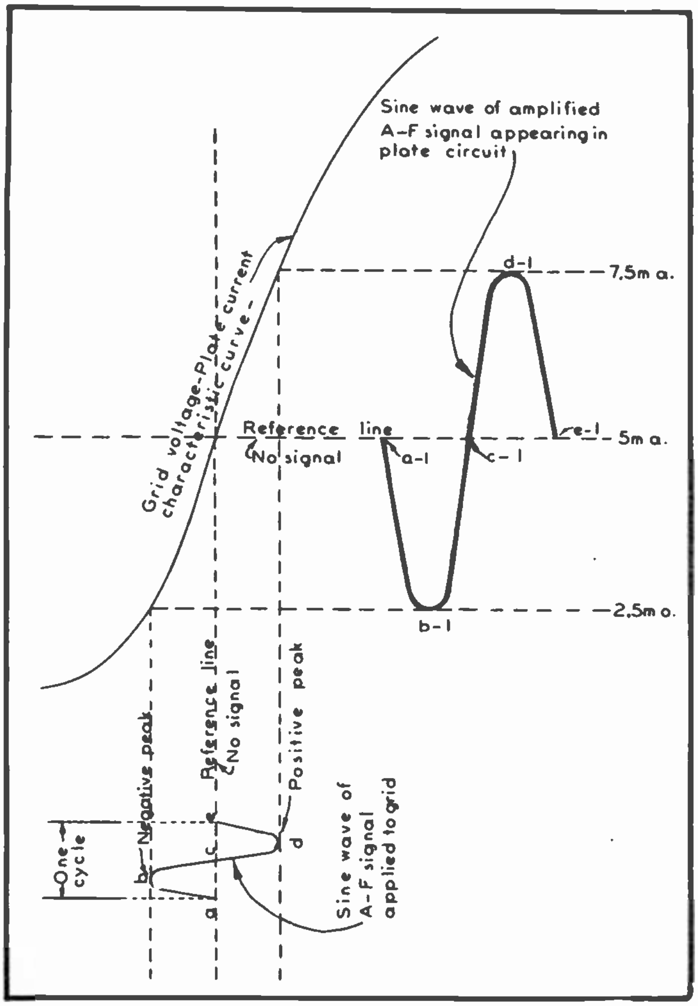

FIG. 20
GRAPHIC ILLUSTRATION SHOWING HOW
TUBE AMPLIFIES SIGNAL

curve where it is projected over to the point "a-1" on the sine wave of the AMPLIDIED signal. Point "b" shows the first rise in signal voltage at the grid as a negative peak, and which is reproduced at "b-1" of the amplified sine wave. At "c" the grid signal voltage drops back to zero (the Reference Line); correspondingly, the amplified signal also returns to zero at "c-1". At "d" is shown the positive peak of the grid-voltage signal, which by the same process is projected over to the amplified sine wave and reproduced at "d-1". The cycle is completed by the signal voltage at the grid returning once more to zero(from "d" to "e") at the Reference Line, which again is found duplicated from "d-1" to "e-1" on the sine wave representing the AMPLIFIED signal.

We now have justified our conclusion in assuming the AMPLIFIED signal to be a "reflection" of the original signal which we impressed on the grid of the tube; because a close comparison of the two sine waves in Fig. 20 will show them to be identical in pattern and form. However, we also observe in Fig. 20 that the wave representing the amplified signal in the plate circuit of the tube is a <u>magnified</u> or enlarged version of that acting on the grid.

We have learned, therefore, that the electronic tube is capable of reproducing and duplicating with exactness either an r-f or a-f signal, or any ALTERNATING VOLTAGE; at the same time magnifying or AMPLIFYING it.

As we advance, you will find this to be only one of the many startling accomplishments of this radionic device, credited with having literally revolutionized the scientific world with its practically unlimited applications.

FIG. 21
ELECTRONIC EQUIPMENT APPLIED IN THE FORESTRY SERVICE

YOUR education has been a failure, no matter how much it has done for your mind, if it has failed to open your heart.

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LESSON NO. 10

TYPES OF ELECTRONIC TUBES

In the previous lesson, we discussed the diode and triode, and their operating principles. This lesson will furnish you with a detailed explanation of the structural features and operation of electronic tubes of more complex design. The tubes covered in this lesson are used extensively in radio, sound amplifiers, and in many other types of electronic equipment.

HEATER-TYPE TUBES

In many tubes, the filament does not actually emit electrons. Instead, the electrons are emitted by a separate structure called the cathode, which is heated indirectly by the filament. The filament is, in this case, generally referred to as the heater.

At (A) of Fig. 2 is shown a typical heater-cathode assembly. The outer surface of the cathode-sleeve is coated with an electron-emitting material, usually barium or strontium oxides. The spiralled heater wire is wound on an insulating central support made of baked clay. The cathode is constructed in the form of a metal sleeve that surrounds the heater wire, but is separated from it. This

FIG. 1
SOUND AMPLIFIER AND POWER SUPPLY

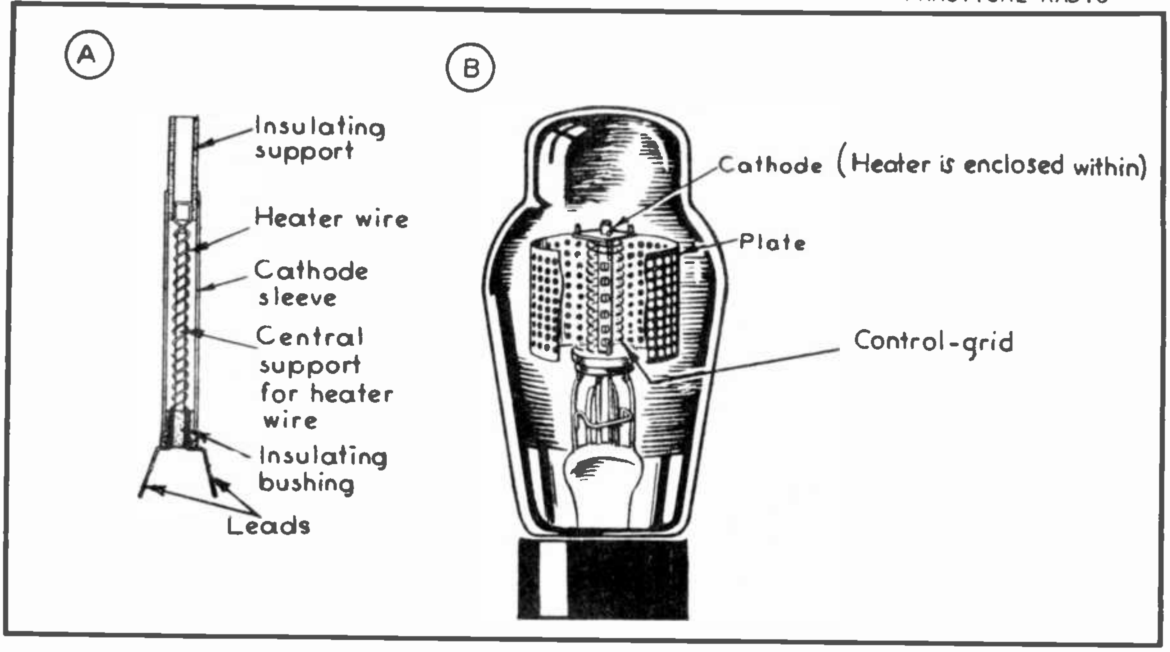

FIG. 2
CATHODE-TYPE TRIODE

type of construction electrically insulates the cathode from the heater.

Upon passing current through the heater wire, the latter will be heated to incandescence. This, in turn, will heat the clay support and cathode -- and the cathode, when heated sufficiently, will emit electrons the same as any other hot body. The cathode, being properly coated with the necessary oxides, permits electrons to be liberated from its surface. The installation of the heater-cathode assembly in a triode is shown at (B) of Fig. 2.

Indirectly heated cathodes require comparatively more heating-current than do the simple filament type electron-emitters previously described. Also, an appreciable length of time is required for the cathode to become heated sufficiently to emit electrons. For this reason, a lapse of 10 to 50 seconds, or even more, occurs from the time the line switch is closed until the signal is heard, in receivers using such tubes.

Heater-type tubes have one great advantage over the simple filament types, in that they possess the ability to reduce "hum" in a-c receivers. This is due to the greater mass of the cathode, and the characteristic of the central support to retain heat moreso than does the filament heating it. Thus, the minute variations in temperature caused by the alternations of the a-c voltage applied to the heater (filament) are not "followed" by the "slow-cooling" cathode. Also, the electrical separation between the heater and cathode provides complete isolation of the emitting medium (cathode) from the heater, through which alternating current is flowing.

It is well to remember that the filament is designated as one of the elements of the tube only when it acts as an electron emitter, such as in the filament type battery-operated tube described in the previous lesson. Where the filament is employed as a heater only, as in the heater-type tubes, its function is purely physical; and it plays no active part as an "element" in the tube. Hence, in a HEATER-TYPE TRIODE, we have a heater (filament) and three elements, comprising the cathode, grid and plate. In the FILAMENT-TYPE TRIODE we also have three elements --- the filament (functioning as the cathode); the grid; and the plate.

In the sectional view of the heater-type triode at (B) of Fig. 2, you will observe that the placement of the cathode (electron emitter), grid and plate is exactly the same as in the filament-type triode described in the previous lesson. The only difference is that the heater is surrounded by the cathode, and serves only to heat the cathode from which the electrons are emitted.

Another advantage of the cathode-type tube, from the standpoint of circuit design, is that the electrical separation between the heater and cathode provides greater simplicity and flexibility for connecting the tube to the required circuit.

Because of the electrical separation between the heater and cathode, heater-type tubes have an additional prong in their base for the circuit connection. Thus, while a filament-type triode has four prongs in its base --- one for the plate, one for the grid, and two for the filament --- as was shown in the previous lesson; the cathode-type tube has five prongs. The additional prong, or connection, is for the cathode. The socket arrangement as viewed from below, and also the symbol for such a tube, is shown in Fig. 3.

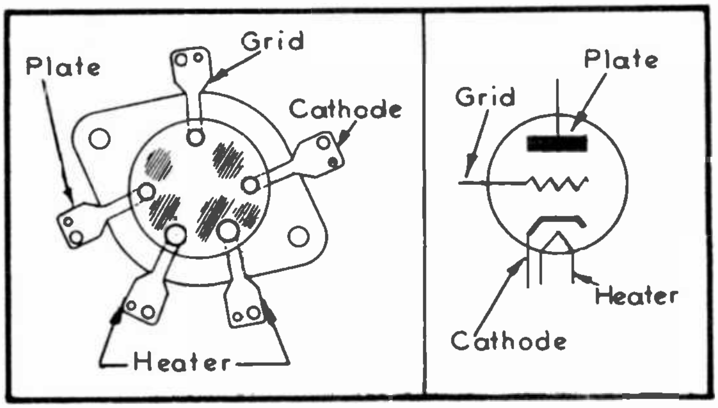

FIG. 3
SOCKET ARRANGEMENT AND SYMBOL FOR CATHODE-TYPE TRIODE

Because of the advantages mentioned relative to the heater-cathode construction, almost all tubes for modern a-c receivers have indirectly-heated cathodes; while tubes designed for dry cell operation nearly all employ the low-current consuming, filament-type of construction. Otherwise, the tubes are identical in operation and performance.

MULTI-ELECTRODE TUBES

Now you are going to learn about tubes that employ more than one grid, and which are broadly classed as the multi-electrode types. You will be able to understand the operating principles of such tubes very easily by bearing in mind that they are all based on the triode, and that the additional elements are included in the tube structure solely to increase the efficiency of the tube and to extend its range of usefulness. These additional elements will all be described, and their functions explained, as they are encountered in our discussion.

The first of the multi-electrode tubes to be discussed at this time is known as the tetrode.

TETRODES

The word "tetrode" is derived from the Greek word "tetrad", meaning four, combined with the word "electrode." Thus, all tubes that are classed as tetrodes have four elements.

The tetrode consists of the usual three elements of the triode, plus an additional grid that is called the screen grid. To avoid confusion, when speaking of the two grids in a tetrode, the one that serves the same purpose as does the grid in a triode is called the control grid.

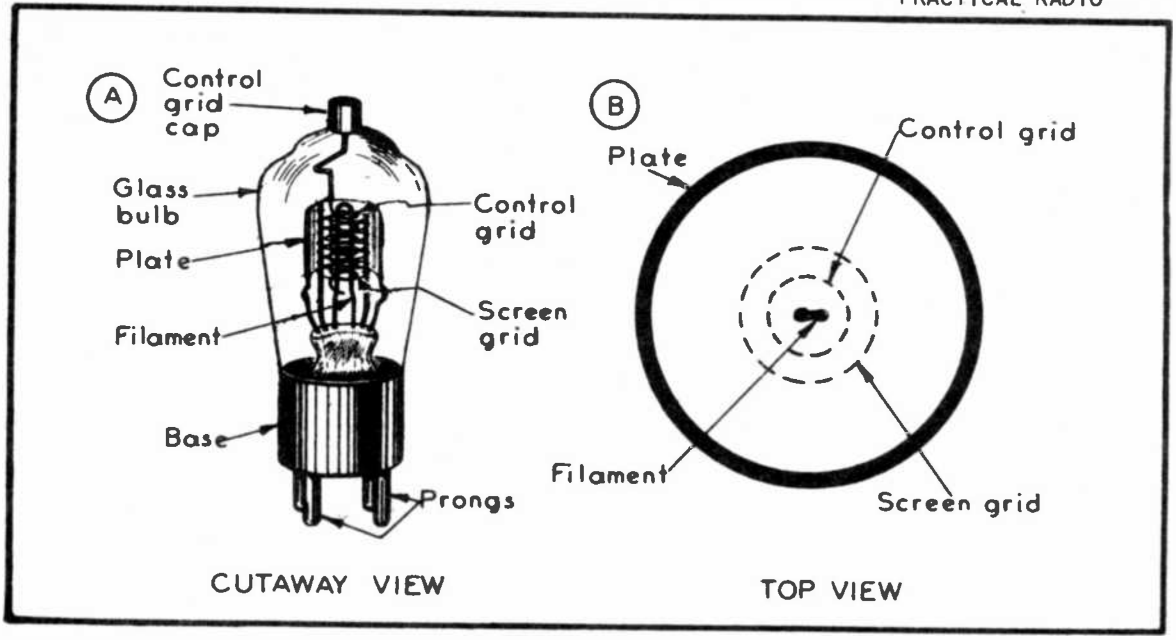

FIG. 4
FILAMENT-TYPE TETRODE

By referring to the cut-away view of the filament-type tetrode shown at (A) in Fig. 4, and also the diagrammatic top-view presented at (B) of Fig. 4, you will become familiar with the features of construction of this tube and the arrangement of the electrodes or elements therein. Quite often, tetrodes are spoken of as being "screen-grid tubes."

Upon studying both illustrations in Fig. 4, very carefully, you will observe that the filament is mounted in a vertical position at the center of the assembly, and is surrounded by a spirally-wound molybdenum wire which constitutes the control grid. This control grid serves the same purpose as does the grid within a triode.

The control grid is surrounded by another spirally-wound molybdenum wire grid; and since this second grid is inserted between the control grid and the plate, it acts as a shield between these two elements; and is therefore logically called a "shield grid" or screen grid. The term "screen grid" is more extensively used.

A conventional cylindrically-shaped plate surrounds the screen grid, but it is separated from the filament and control grid by a much greater space than is the case in triodes. Furthermore, the screen grid is located closer to the control grid than to the plate.

Observe at (A) of Fig. 4 that the outer appearance of the screen-grid tube resembles a triode, with the exception that a small metal cap is mounted on the top of the bulb for the control-grid connection; otherwise, the prong arrangement is similar to the filament type triode. Fig. 5 shows the symbol and socket connections of the filament-type tetrode. Note at (B) of Fig. 5, that the filament is connected to the prongs of large diameter, the same as in a filament-type triode; but that the screen grid is connected to that prong which is used for the control grid connection of a triode.

While the tetrode in Fig. 4 employs a filament-type electron emitter, this type of tube is made in two forms --- one with a directly heated filament for battery operation, and the other with a separately heated cathode for a-c operation. The construction of both is the same, with the exception of the electron emitter. A cut-away view of a typical heater-type tetrode is shown at (A) of Fig. 6, and a top view of the element arrangement at (B) of Fig. 6. The symbol for the heater-type tetrode also appears in Fig. 6. The operating principle of both types of such tubes is similar, the difference being merely in the method used to obtain electron emission.

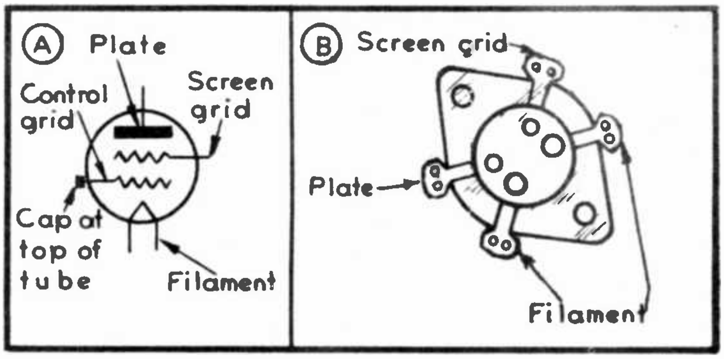

FIG. 5
SYMBOL AND SOCKET ARRANGEMENT OF FILAMENT-TYPE TETRODE

In tetrodes, where a separate cathode element is employed, an additional prong must be included in the base. Therefore, such tubes have a five-prong base --- two for the filament, and one each for the cathode, plate and screen grid. In this case, the socket arrangement is identical to the five-prong base shown in Fig. 3, with the exception that the former control-grid connection now becomes the screen-grid terminal, while the control grid connection is made at the metal cap on top of the tetrode's bulb.

HOW THE SCREEN GRID FUNCTIONS

A heated filament or cathode will emit millions of negatively-charged electrons. The ideal condition is for all of these electrons to reach the plate; however, as the cathode contunually emits more and more electrons, it has a tendency to gradually become more positive. Now, since LIKE electrical charges repel each other and UNLIKE charges

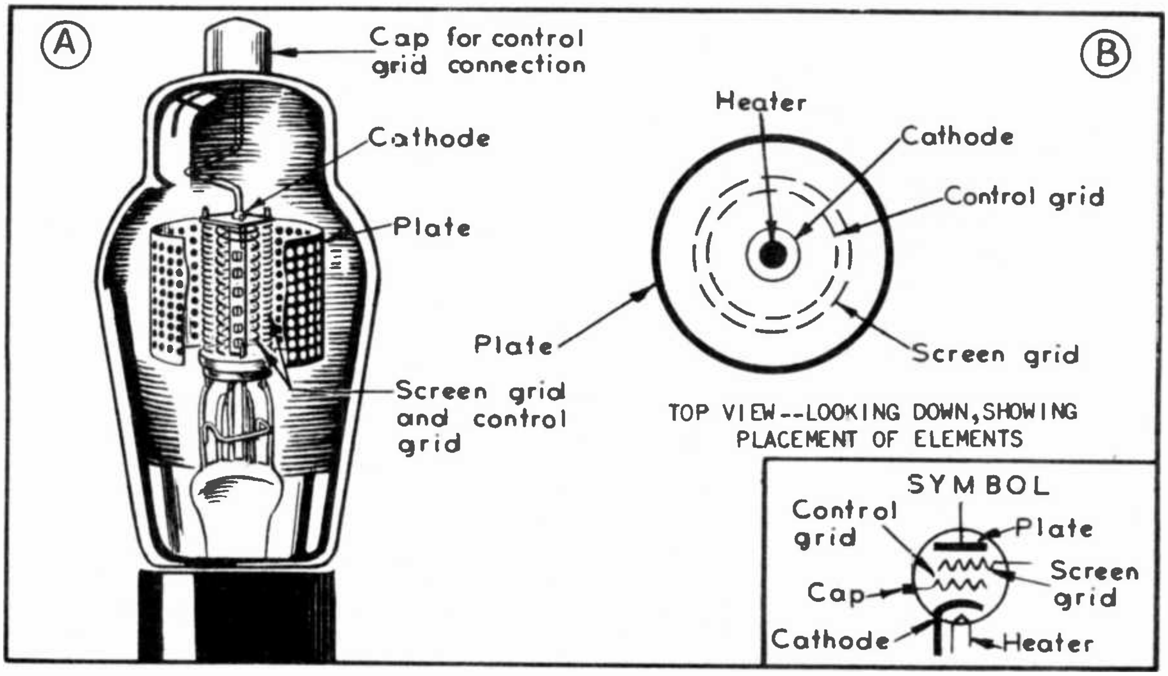

FIG. 6
HEATER-TYPE TETRODE

attract each other, many of the electrons (always negatively charged) which are at the time in the space between the cathode and the plate, have a tendency to repel any additional electrons which are on their way over to the plate. Thus, the electrons themselves are trying to force other electrons back toward the cathode.

This "fight" between the electrons takes place in the space between the cathode and plate, but closer to the cathode, and results in the formation of the dense cloud of electrons, which we call the "space charge." This is illustrated at (A) of Fig. 7. (Note: The control grid has been omitted from this drawing for the sake of simplicity.)

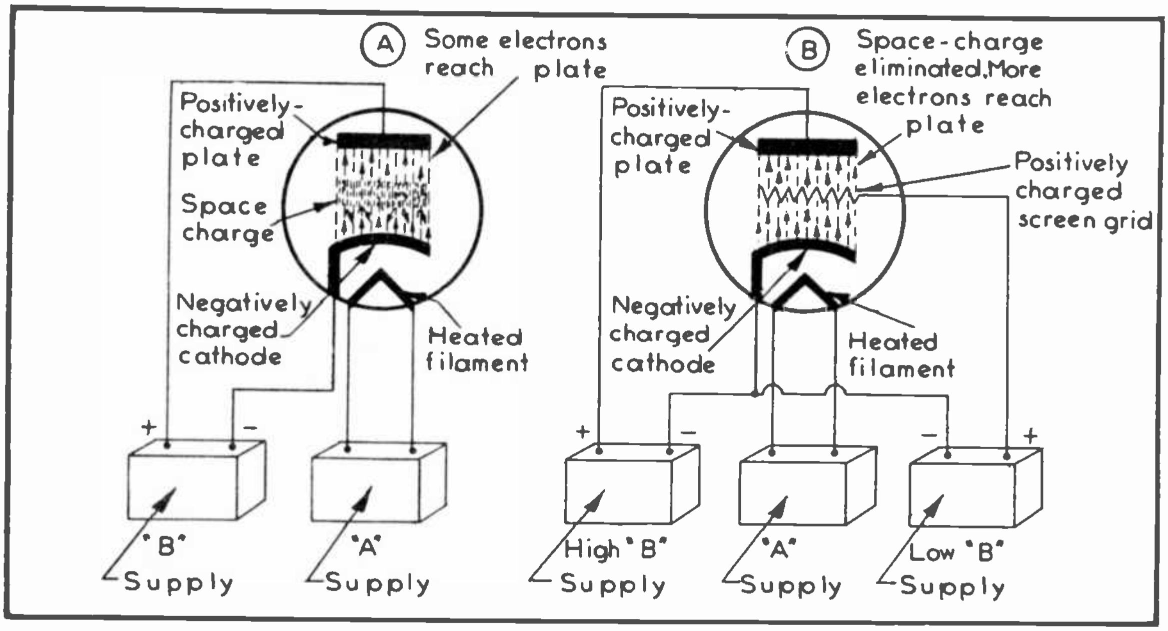

FIG. 7
HOW THE SCREEN-GRID ELIMINATES THE "SPACE CHARGE" IN A TUBE

This space charge has a tendency to retard the passage of electrons between the cathode and plate, and thereby limits the flow of plate current. However, by inserting an additional grid in the region where the electrons gather, and placing a positive charge on it, we have a means for speeding the electrons on their way over to the plate --- thereby breaking up the space-charge and increasing the flow of the plate current. The effect of this positively-charged grid is shown at (B) of Fig. 7.

Since the screen grid is in the form of a spiralled wire, it does not offer much of a mechanical obstruction between the cathode and the plate. Also, since the plate is operated at a much higher positive voltage than is the screen grid, the plate exerts a much greater attraction upon the electrons in the region of the screen grid than does the screen grid itself. Therefore,nearly all of the electrons reach the plate,and the screen grid acts only as a sort of an accelerating device that speeds them on their way over to the plate. Nevertheless,a relatively few electrons do attach themselves to the screen grid and flow through the circuit to which the screen grid is connected;and we logically call this the "screen current."You will hear more about screen current in a later lesson.

The chief advantages of tetrodes over triodes is that they provide greater amplification, and also permit the design of r-f circuits that are less likely to produce squealing and howling sounds than is the case of similar circuits employing triodes.

PENTODES

To increase the efficiency of the screen-grid tube still further, another grid was added --- thus giving us the five-element tube known as the pentode. This additional grid is placed between the screen grid and the plate, and is called a suppressor grid. The name "pentode" is derived from the Greek word "pentad", meaning five; thus, the name "pentode" tells us that this type of tube has five elements or electrodes.

Fig. 8 illustrates the placement of the suppressor grid (the fifth element) in the heater-type tube, and its relation to the other electrodes. Observe that the fundamental elements and structure of the tetrode have been retained, and that the use of the suppressor grid is the only point of difference. The symbol for the pentode also appears in Fig. 8.

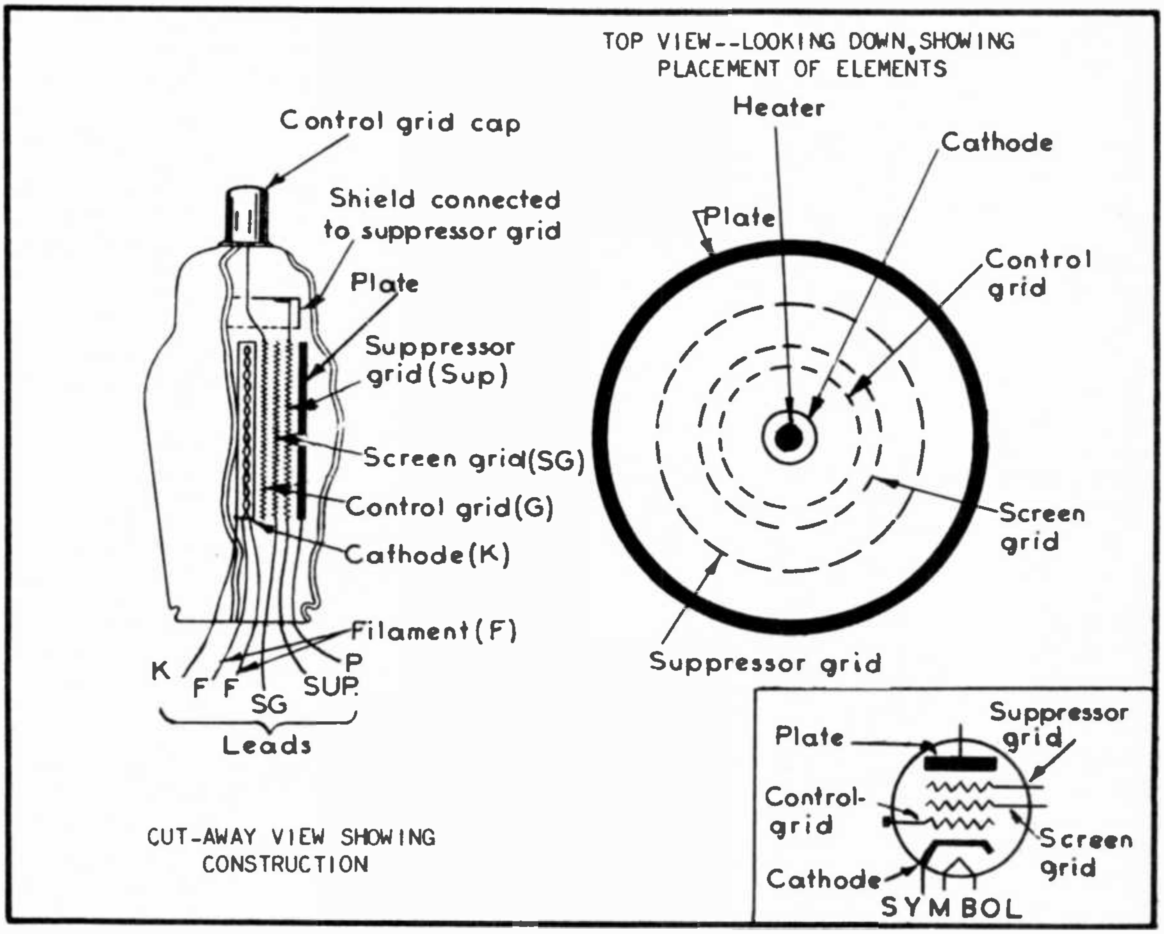

FIG. 8
DETAILS OF HEATER-TYPE PENTODE

The physical construction of the suppressor grid differs little from the screen grid used in screen-grid tubes. However, it does differ greatly as to the voltage applied to it. That is, where the screen grid usually has a positive potential of from 75 to 100 volts applied to it, the suppressor grid is subjected to zero potential, or else a negative potential of -1 to -3 volts. In many applications, the suppressor grid is connected to ground; in this way acting as an effective "shield" between the control grid, screen grid and plate. This practically "neutralizes" any feed-back energy that might exist between the electrodes in the tube.

In radio-frequency amplifiers, this shielding is extremely desirable; and, in order that it may be as nearly perfect as possible, pentodes for radio-frequency work have incorporated in them a small metallic shield, placed in the dome of the bulb, above the elements, as shown in Fig. 8. This saucer-shaped metal disc is connected electrically to the tube's suppressor grid --- the connection being made within the tube proper by the manufacturer. A hole is provided at the center of the dome shield, through which the control-grid lead may pass. This shield is not used in pentodes that are designed especially for audio-frequency work.

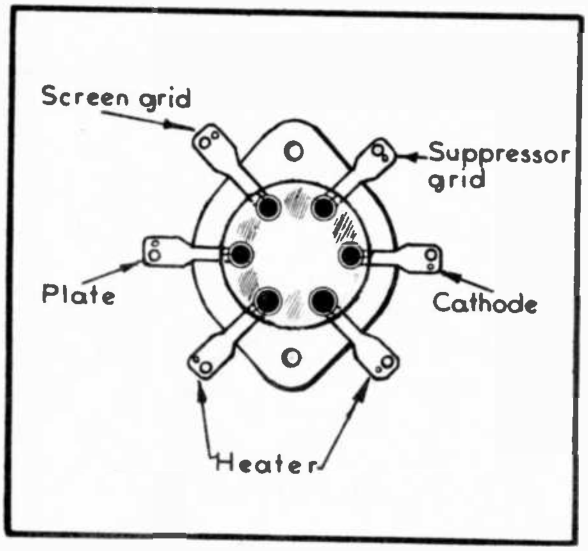

FIG. 9
SOCKET ARRANGEMENT OF CATHODE-TYPE PENTODE

The socket for this particular pentode, as viewed from below, is shown in Fig. 9. This terminal arrangement will vary in some instances, depending upon whether the pentode is of the filament or cathode-type. The base arrangement also depends upon whether the suppressor is connected to an independent external terminal; or connected internally directly to the filament or cathode, as shown at (F), (G), and (H) in Fig. 10.

It is to be noted also that certain pentodes are available where the control grid connection is made at a base prong.

With these structural details of the pentode well in mind, let us now investigate the purpose of the suppressor grid.

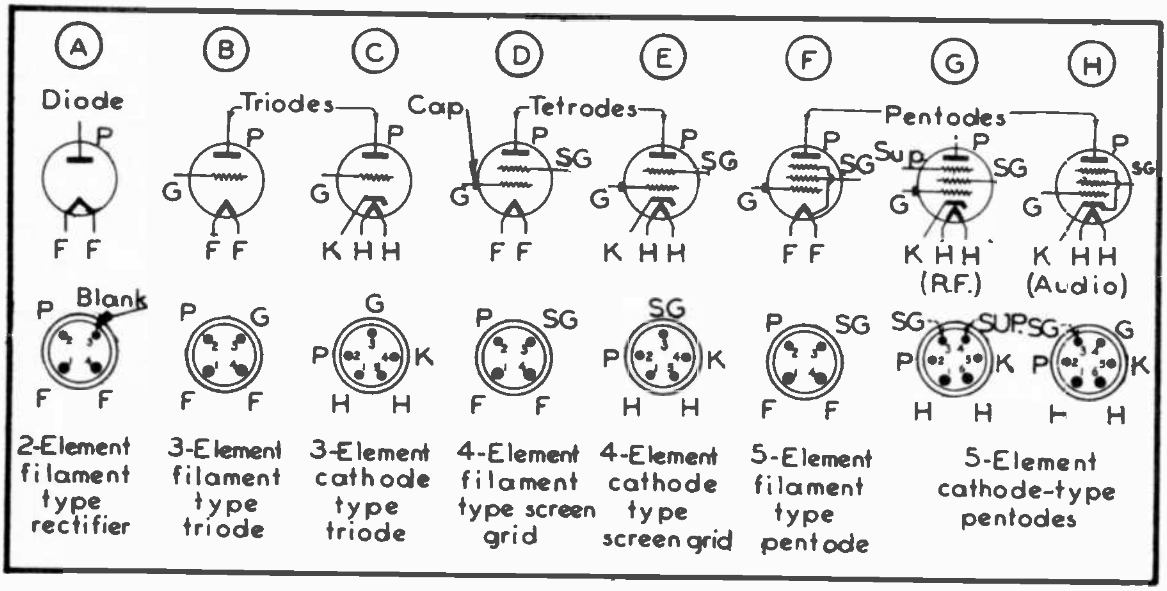

FIG. 10
TWO, THREE, FOUR AND FIVE-ELEMENT TUBE SYMBOLS
AND BOTTOM VIEW OF THEIR SOCKET ARRANGEMENTS

REDUCING SECONDARY EMISSION

When the space-charge between the plate and filament is reduced or eliminated by the presence of the screen grid, the flow of electrons toward the plate is speeded up so much by the accelerating force of the screen's positive charge, that they rush through it at speeds as high as 20,000 or more miles per second until they strike the even more highly charged plate behind it. See illustration (B) of Fig. 7.

However, as the electrons strike the plate at such high velocities, they not only give up their kinetic energy in the form of heat, but also tend to forcibly knock other electrons out of the plate as illustrated at (A) of Fig. 11. (Note: This is especially true in power

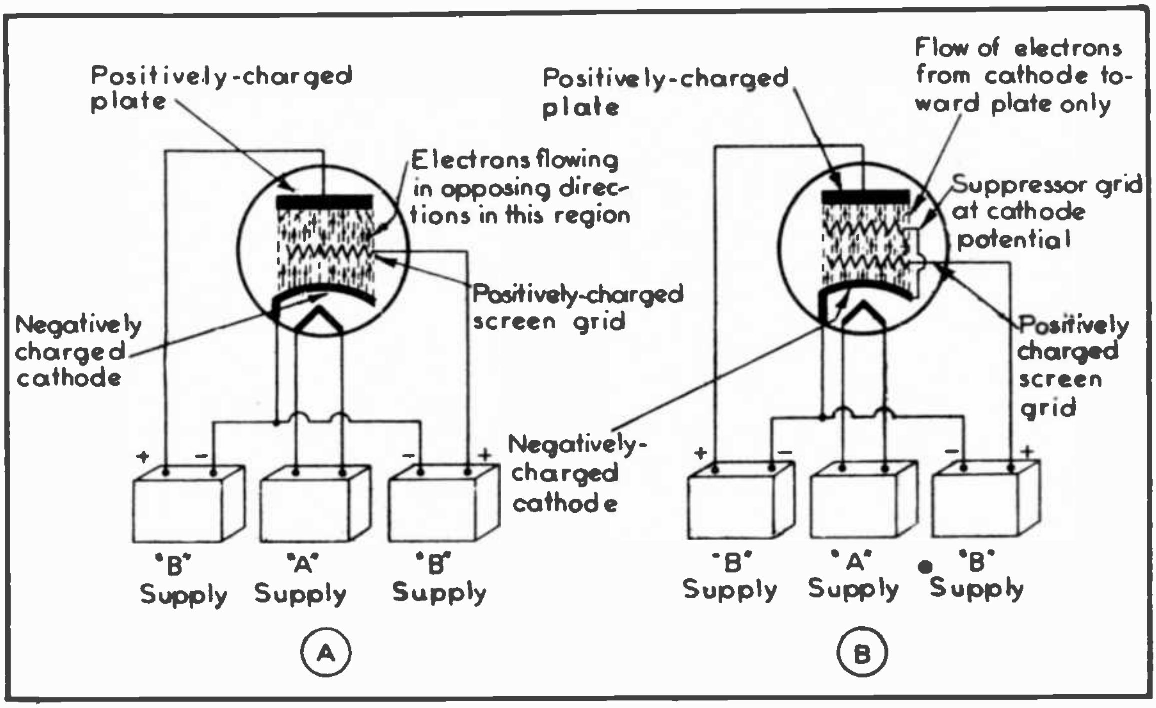

FIG. 11
HOW THE SUPPRESSOR GRID REDUCES SECONDARY EMISSION IN A PENTODE

tubes, the screen grid of which is often operated at a somewhat higher positive potential than the plate, due to the arrangement of the circuit.) The act of so driving electrons from the plate by force of collision is called SECONDARY EMISSION, because the effect is secondary to the primary or original emission offered by the cathode. In the ordinary screen-grid tube, these secondary electrons may float around for a fraction of a second and either return to the plate or to the screen grid.

Since one fast-moving electron may drive as many as 20 electrons from the plate, it is possible that so many secondary electrons may be liberated from the plate that the number leaving the plate may be even greater than the number arriving from the hot cathode or filament. In such a case, the main or effective electron - flow would be from the plate toward the cathode, or just reversed to its intended direction. Thus, we see that while we gain the advantage of reducing the space-charge by using the screen grid, we automatically create another serious problem in the form of secondary emission.

Now, let us see just how the fifth electrode in the pentode, the SUPPRESSOR GRID, reduces the secondary emission and thus makes it possible to take full advantage of the increased amplification offered by the use of the screen grid.

In the usual form of heater-type pentode, this third grid is connected to the cathode as shown at (B) of Fig. 11, and is commonly referred to as the suppressor grid, because it "suppresses" the secondary emission. In such a position, the suppressor grid forms a shield between the plate and the screen grid; and since it is at the same potential as the cathode, it has practically no effect on the electrons that have just left the cathode enroute to the plate. However, its negative potential, with reference to the plate, is such that the secondary electrons prefer to return to the positive plate rather than pass through the negative suppressor grid in order to reach the screen grid beyond. Thus, the suppressor grid tends to return to the plate those secondary-emission electrons that are dislodged from the plate by collision, and thereby maintains a more uniform electron flow toward the plate. In this way, the advantage gained by the use of the screen grid can be retained.

In filament-type tubes, the suppressor grid is connected to the filament as already mentioned, but its principle of operation remains the same as just described relative to the cathode-type pentode.

In lessons following, you will have an opportunity to study the various methods used for connecting pentodes in receiver circuits.

THE BEAM POWER TUBE

The beam power tube is constructed in the form of either a tetrode or pentode, designed specifically for audio frequency amplification; and derives its name from the fact that use is made of a directed electron beam which contributes substantially to its power-handling ability.

The internal structure of a beam power tube is shown at (A) and (B) of Fig. 12, and its symbol at (C). This tube contains a cathode, con-

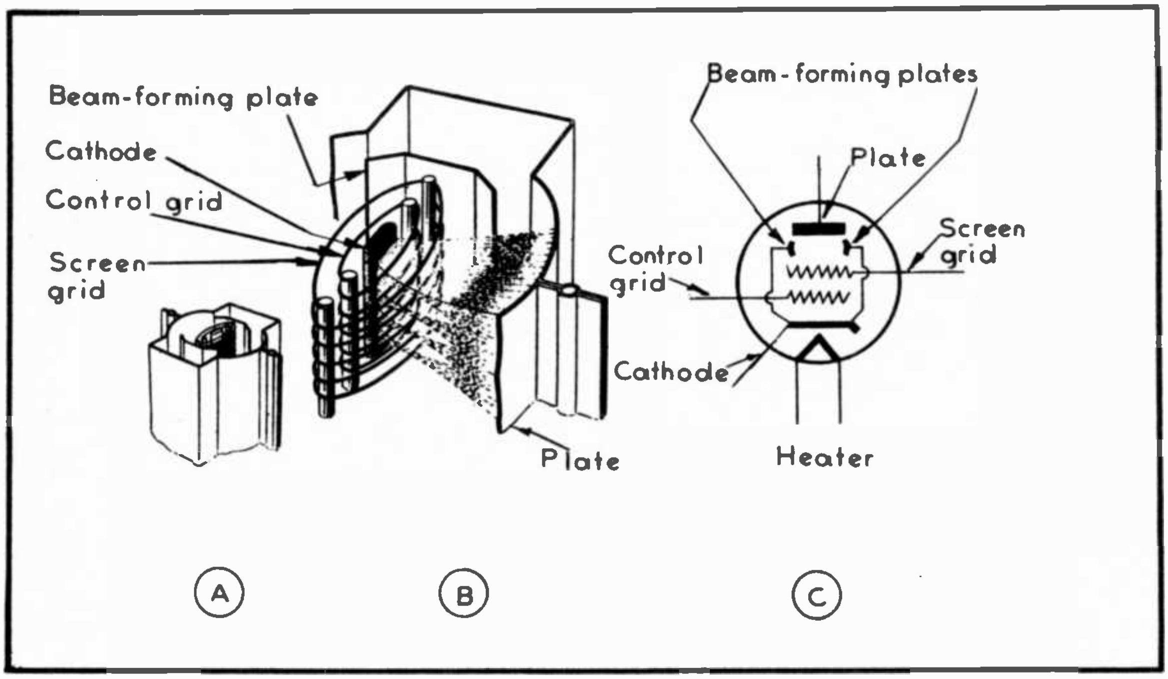

FIG. 12
INTERNAL STRUCTURE OF THE BEAM POWER TUBE AND ITS SYMBOL

trol grid, screen grid, plate, two-beam-forming plates, and in some cases, a suppressor grid. The particular beam power tube shown in Fig. 12 is not equipped with a suppressor grid, but the electrodes in this case are so spaced and oriented with respect to each other that secondary emission from the plate is suppressed by the space-charge between the screen grid and the plate. This is accomplished as follows:

The space charge is produced by the slowing-up effect of the electrons as they travel from the region of the screen, which is maintained at a high positive potential, to the plate which in this case is maintained at a slightly lower positive potential than the screen grid. In this low-velocity region, the resulting space-charge is sufficiently negative in characteristic to repel the secondary electrons which are emitted from the plate, and thus causes them to return to the plate.

Special beam-forming plates are incorporated in this power tube. The beam-forming plates are maintained at cathode potential and serve to assist in producing the desired beam effects so as to prevent any stray electrons, that may be dislodged from the plate, from returning to the screen outside of the beam. Notice at (B) of Fig. 12, how the electrons are confined to beams. The beam condition, as here illustrated, occurs when the plate potential is less positive than the screen potential. The high-density space-charge region is indicated in this same illustration by the darkened region in the beam. Observe also that the edges of the beam-forming plates coincide with the dashed portion of the beam, and thus extend the space-charge potential region beyond the beam boundaries to prevent stray electrons from returning to the screen outside of the beam.

In place of the space-charge effect just described, it is also feasible to use a suppressor grid to repel the secondary electrons. In fact, this method is employed in several types of beam power tubes, and the suppressor grid is then connected to the circuit in the same manner as already described for pentodes.

Also observe at (B) of Fig. 12 that the screen and control grid are made in the form of spiral wires, so wound that each turn of the screen is shaded from the cathode by a turn of the control-grid spiral. This alignment of the screen and control grid causes the electrons to travel in sheets between the turns of the screen and thus results in very few of them actually flowing into the screen.

Because of the effective suppressor action provided by the space-charge, and also because of the low current drawn by the screen and the focusing effect of the beam principle upon the electron flow, the beam power tube provides high power output, high power sensitivity, and good all-around efficiency.

TUBE SYMBOLS AND SOCKET ARRANGEMENTS

Now that you are acquainted with the more common or basic tubes, let us briefly review these different types as a whole, so that you may become acquainted with the standard practice of illustrating them in the form of symbols. These symbols are used extensively in circuit diagrams, and it is therefore important that you become well acquainted with them.

By referring to the tube symbols and their corresponding base (or socket) arrangements shown in Fig. 10, you will immediately recognize the essential difference between the various types. For instance, you will observe that the simple two-element tube shown at (A) is called a DIODE, while the three-element tubes shown at (B) and (C) are known as TRIODES of the filament and cathode or heater-type, respectively. The four element tubes, or TETRODES, are shown at (D) and (E). The five-element tubes, designated as PENTODES, are shown at (F), (G) and (H).

You will notice in studying the pentodes, that several different arrangements are used for effecting the control-grid and suppressor-grid connections at the base. In the filament or battery type pentodes, the practice is to connect the suppressor grid directly to the filament inside of the tube, as shown at (F); and in some of the cathode types, the suppressor grid is connected to the cathode within the tube, as shown at (H).

Some pentodes are so constructed that the control grid connection is made at the base of the tube, as illustrated at (H) of Fig. 10; while others employ a control-grid cap connection at the top of the bulb, as shown at (F) and (G).

All of the socket (base) connections are shown in Fig. 10 as viewed from the bottom. Also notice in Fig. 10 how a shaded area just outside of the tube enclosure at (D), (E), (F) and (G) indicates that the control-grid connection is made to the metal cap on the bulb.

The abbreviations given in Fig. 10 for the various elements have been adopted as standard by the industry, and have the following meanings:

F ---- filament
H ---- heater
K ---- cathode
G ---- control grid
SG ----- screen grid
SUP ---- suppressor grid
P ------ plate

On testing equipment, you will sometimes find the socket terminals to be numbered for reference purposes. When such is the case, the system of numbering corresponds to the various elements as shown in Fig. 10.

METAL TUBES

A great many refinements have been made from year to year in the design of vacuum tubes. One of these revolutionary changes was replacing the customary glass tube or enclosure with a metal envelope. Tubes of the latter design are known as METAL TUBES.

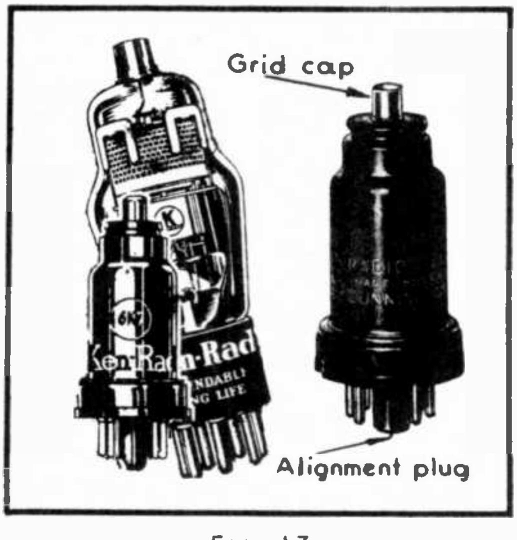

FIG. 13
TUBE COMPARISON

The chief reasons for the metal-tube structure are: It permits the construction of tubes that are smaller in over-all size than equivalent glass tubes; they require no additional external shielding; they are less susceptible to breakage; and they provide somewhat better heat dissipation. However, both types are practically identical insofar as electrical characteristics, performance, and efficiency are concerned. Glass and metal tubes are being used extensively; and, therefore, it is important that you be equally familar with both types.

The internal elements of the metal tubes are very similar to those used in standard glass tubes. This means that all of the technical knowledge which you are now acquiring relative to glass tubes can be applied directly to metal tubes as well.

At the left of Fig. 13, you are shown a comparison of size and appearance between a typical glass and metal tube; while at the right of Fig. 13, one type of metal tube is shown in detail.

Aside from the metal enclosure, the majority of metal tubes are smaller both in diameter and height than corresponding glass tubes.

Another great difference is that metal tubes are equipped with what are known as OCTAL BASES. An octal base is fitted with an aligning plug for inserting the tube in its socket in one position only.

You will acquire a more clear understanding of the internal construction of the all-metal tube by referring to the cut-away section which appears in Fig. 14. Study this illustration carefully and note that the index numbers appearing on this unit correspond with the particular names tabulated in the same illustration.

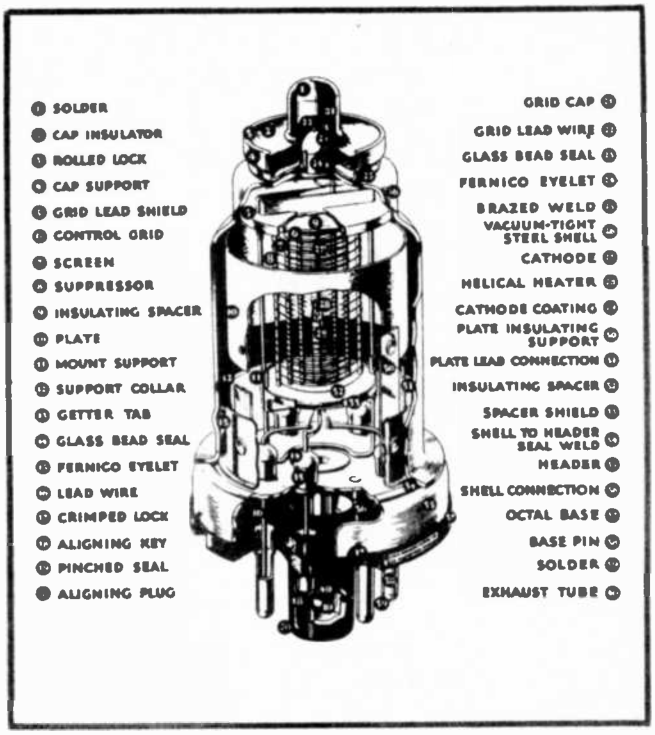

FIG. 14
INTERNAL STRUCTURE OF METAL TUBE

THE OCTAL BASE

The arrangement and connections of the small octal, 8-pin base, as used with metal tubes, conform with the socket illustrated in Fig. 15. When a total of eight prongs (pins) is mounted on the base, they are spaced equi-distant apart and numbered to correspond with the socket terminal numbers designated in Fig. 15. These prongs are all equal in diameter and length; and if the particular tube is of such type that all eight prongs are not required, the surplus prongs are simply omitted from the base by the manufacturer. However, regardless of the number of base prongs used, the spacing of those actually employed still remains the same as though all eight prongs were provided.

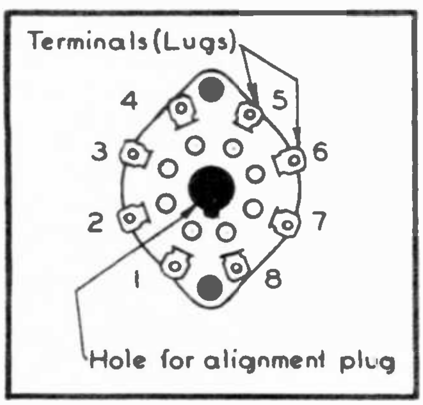

FIG. 15
OCTAL SOCKET

Since the base arrangement is standard for all metal tubes, it is clear that the same size and type of socket can be used for any of these tubes, and circuit connections made only at those points where necessary.

You will note in Fig. 15 that eight

holes are placed in a circular manner around the socket to accommodate the prongs of the tube base. A round hole is provided at the center of the socket, through which the aligning plug of the tube base can be inserted. A slot in the aligning hole accepts the key projection on the aligning plug of the tube base, and thus permits the tube to be installed in the socket in one position only, even though all of the prong holes of the socket are of the same size and equally spaced.

When viewing the base from the bottom, and with the key toward the observer --- as in Fig. 15. --- the numbering of the base prongs always starts from the shell connection of the tube, which is the first pin to the left of the locating key on the aligning plug. From this first pin, the others are all numbered in a consecutive order and in a clockwise direction.

SOCKET CONNECTIONS

In Fig. 16, you are shown the base connections for four common types of metal tubes in which we are at the present time interested. In another part of the course, you will receive complete information concerning the application of these and many other types of tubes.

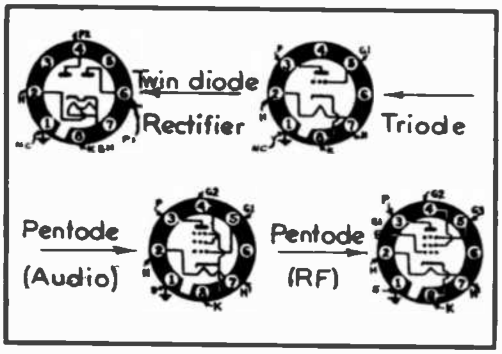

FIG. 16
OCTAL BASE CONNECTIONS

In each of the symbols appearing in Fig. 16, the following abbreviations are used: S means that the metal shell of the particular tube in question is connected to pin #1 of the base. (This pin connection is then grounded when wiring the circuits, and the metal shell thus serves as the shield for the tube --- thereby doing away with the need for the shield required by some glass tubes.) H is the heater connection; K is the cathode connection; P, P_1 and P_2 are plate connections; G_1, G_2 and G_3 are grid connections. (G_1 refers to the control grid, G_2 to the screen grid, and G_3 to the suppressor grid.) The abbreviation "NC" is used to designate that no connection is made to the terminal or pin so marked.

GLASS TUBES WITH OCTAL BASES

These tubes are equipped with a glass bulb enclosure, thus being similar in appearance to many common glass tubes. However, they differ from the conventional glass tubes in that they are supplied with an octal base of the same type as used on metal tubes. The control grid connection on top of the tube is also somewhat smaller than that used on conventional glass tubes;being of the "miniature type", the same as on metal tubes. Glass tubes with octal bases are frequently called "G"-type tubes.

The characteristics, operating conditions, and circuit applications for most "G" tubes are identical to equivalent or similar metal types. For this reason, many of the G-type tubes bear the same code number as the equivalent metal tube; the letter "G" is annexed to the code number to indicate the glass structure. For example, the type 6C5 is a popular metal tube, whereas, the 6C5G is an equivalent tube of the G-type.

The shell of the metal tube serves as an effective shield; therefore, no additional shielding is required for it. However, a metal shield is often placed over the conventional glass tubes, and tubes of the G-type --- particularly, when they are used in the r-f and detector stages. The problems of shielding are covered in detail in a later lesson.

CLASSIFICATION OF RADIO TUBES AS TO USE

In the early days of radio, only two types of tubes existed, namely, the diode and the triode. For many years, the triode was employed either as a radio-frequency amplifier, detector, or audio-frequency amplifier; while the diode was employed chiefly as a rectifier. However, the triode had several limitations, as mentioned earlier in this lesson --- hence, with continuous progress being made in radio, it soon became apparent that a tube should have specific characteristics for certain types of work. As a result, the tetrode was developed, and has for many years been used successfully as a radio-frequency amplifier, as well as a detector. Nevertheless, as we have already mentioned, the tetrode also had certain limitations which resulted in the development of the pentode --- the latter being designed specifically for radio or audio-frequency use. Other tubes were developed especially for use as detectors, while still others were designed specifically for use as rectifiers in power units, etc.

As a result of the progress made in the design of radio tubes, we have today a large variety of tubes, each designed especially for the purpose for which it is to be used. Although a few of the tubes on the market will perform satisfactorily in either radio or audio-frequency amplifiers, as well as detectors, the practice among designers is to employ a tube that is designed for the particular type of work it is supposed to do. This is done in order to obtain maximum performance and efficiency from the circuit in which it is used, and also from the tube itself. For this reason, the majority of radio tubes are now classified as to their intended purpose.

CLASSIFICATIONS AS TO VOLTAGES

Tubes are also classified as to whether their filaments are to be operated on direct-current, on alternating-current, from dry cells, or from a 6-volt storage battery. To meet these varying demands, filaments are constructed for voltages of 1.4, 2.0, 2.5, 5, or 6.3 volts. Battery-operated receivers generally use tubes whose filaments are designed for 1.4 or 2.0 volts; while voltages of 2.5, 5, and 6.3 are used for a-c sets. The 6.3-volt tubes are also used in automobile receivers, combination ac-dc receivers, and in receivers operated directly from the 110 to 220-volt d-c line. For special purposes, as in combination ac-dc receivers, tubes requiring filament voltages ranging from 12 to 117 or more volts are available.

As an increasing number of tube types were developed, a method was devised for identifying them with respect to approximate filament voltage and element type by a number and letter system known as a "code designation". However, except for the prefix or first number, the code designation assigned to the various tubes is purely arbitrary.

A few examples of the code expressions are as follows:

1 H 5; 2 A 5; 5 Z 3; 6 K 7; 50 L 6; 117 L 6.

The prefix, or first number, indicates the approximate voltage required by the filament. We say "approximate voltage" because a tube in the "6" series, such as 6 K 7, for instance, actually has a filament rated for 6.3 volts; while the 2 A 5 actually requires a filament voltage of 2.5 volts. So, for the sake of simplification, the fractional amount of the actual required filament voltage is omitted from the voltage prefix. Thus, a "K 7" type tube with a 6.3 volt filament is designated as a "6 K 7". By the same token, a "K 7" type of tube designed for a filament voltage of 12.6 volts has a code designation of "12 K 7".

Additional code designations will be presented later as specific tubes are brought tc your attention during your progress through the course.

MISCELLANEOUS TUBE DESIGNS

Besides the various types shown you thus far in the course, there are still others which are being used extensively, and which you should know something about before we arrive at that part of our instruction which treats with their applications in circuits.

STANDARD TUBE FORMS

The several styles and types of radio tubes which we are now about to compare and discuss may be classified as to shape, size, and general construction as follows: glass, metal, "G" type, bantam, loktal, miniature and acorn.

Let us first turn our attention to Fig. 17, where you are shown

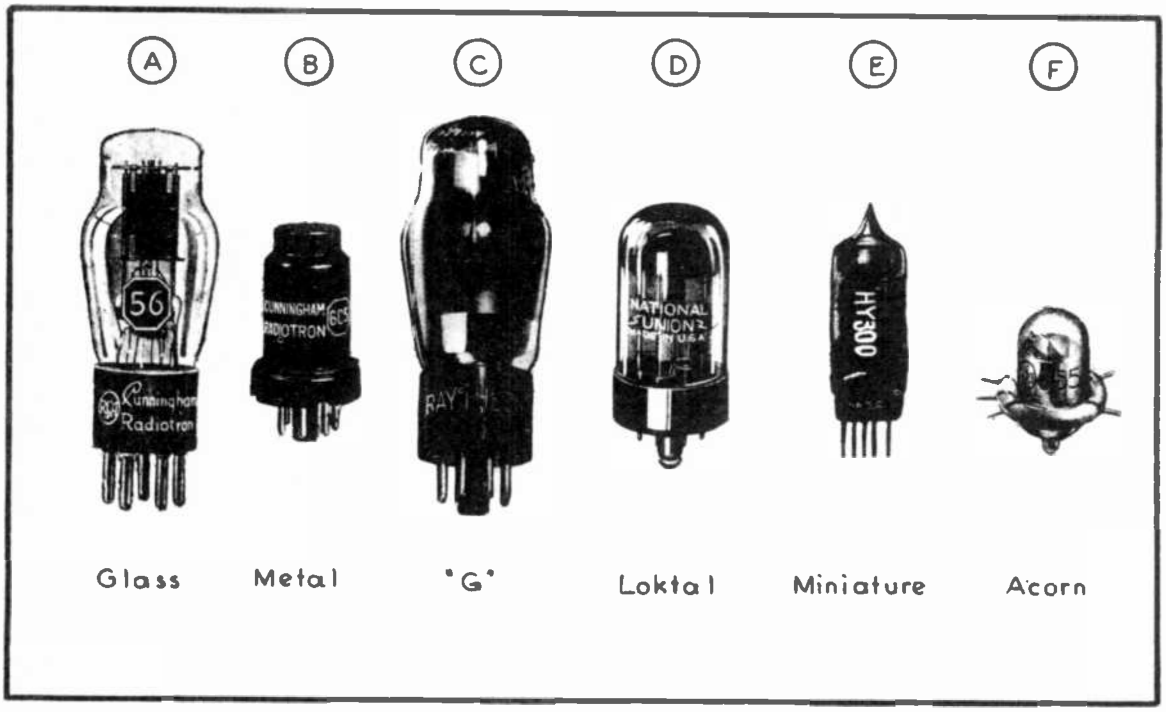

FIG. 17
STANDARD TUBE DESIGNS

illustrative views of a simple triode in these seven different standard forms. In actual size, these various tubes compare with each other approximately as here shown. Also bear in mind that it is possible to obtain tubes, other than triodes, in any one of these different forms --- and that a circuit employing pentodes, for instance, remains basically the same regardless of whether the pentode be of glass, metal, loktal type, etc. The same applies to tubes other than pentodes.

<u>GLASS, METAL AND G-TYPE TUBES</u>: You are already familiar with the tubes

shown at (A), (B), and (C) of Fig. 17, as they are representative of the so-called glass tube (A), which is equipped with from four to seven prongs, depending upon the type of tube; the metal tube (B), which is fitted with an octal base; and the "G" type tube (C) in which a standard glass bulb is mounted on an octal type base.

The characteristics, operating conditions, and circuit applications of these three tubes are practically identical for the same service. In fact, corresponding types of metal and "G" tubes are interchangeable with equal results, as they both employ the octal base in addition to an identical element arrangement. However, there might be a slight difference in operating characteristics due to a difference in their inter-electrode capacitance and shielding properties.

It is to be noted also that certain pentodes with octal bases are available in two forms of construction. In the one base, the control grid connection is made at the cap on top of the tube; while in the other, the control grid connection is made at one of the base prongs. Tubes of the latter design are called single-ended tubes, because of all connections being made at one end. Similar tubes that differ only in this one point of construction have identical electrical characteristics.

BANTAM TUBES: Some of the "G" type tubes have been made with a tubular shaped bulb, smaller in size than that used on the standard "G" types. These are commonly known as "Dwarf", "Bantam", or "Tom Thumb" tubes and are designated as such by the letter "T" placed after the "G", as "GT". The bantam is of the same size and shape as the loktal tube shown at (D) of Fig. 17, and differs from the latter only in the fact that the alignment plug and base prong arrangement is identical to that used on the metal and "G" type tubes.

LOKTAL TUBES: The LOKTAL type tube, shown at (D) of Fig. 17, is a somewhat radical departure from the conventional tube designs in that it does not have the familiar bakelite base. Instead, the contact pins are sealed directly into the glass bottom of the bulb, so as to eliminate soldered connections. The lower portion of the tube is fitted with a metal shell and locating pin, which assembly serves as a shield and also makes possible the lock-in feature. The latter is accomplished by a groove around the bottom of the locating pin which snaps into a ring in the special type socket provided for these tubes.

This locking arrangement holds the tube in the socket securely and assures good contact at all times. Removal of these tubes from the socket may be difficult when pulling them straight upward; however, applying a slight off-side pressure will release the socket lock and permit the tube to be removed readily.

In the case of screen-grid and pentode tubes of the loktal type, no grid cap connections are provided on top of the tube --- instead, all connections are brought out at the base. All connections thus being made at one end of the tube, such tubes are frequently spoken of as being single-ended tubes.

Loktal tubes are not directly interchangeable with tubes having octal bases because of the socket requirements. While they both employ an 8-prong base, the lock-in pin-hole of the loktal tube socket is of such construction that it will not accommodate the locating or alignment pin of the octal tube base. This difference is clearly shown in Fig. 18 where the arrangement for the octal base is shown at (A), and the base arrangement for loktal tubes shown at (B).

While both employ 8-pin bases of identical spacing, the locating

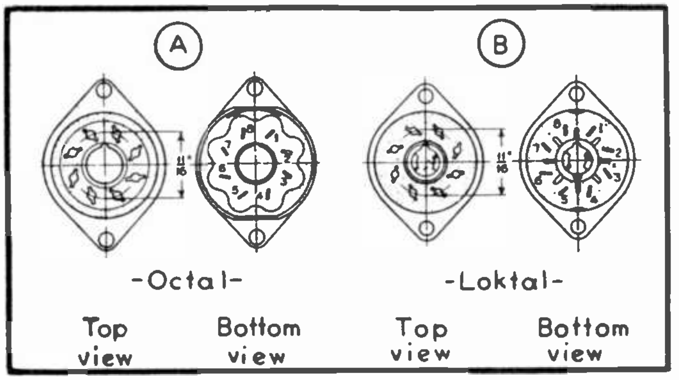

FIG. 18
OCTAL AND LOKTAL BASE ARRANGEMENTS

and lock-in pin-holes are of different dimensions. However, the electrical characteristics and circuit applications of the loktal tubes are similar to those of the glass, metal, "G", and "GT" tubes which are employed for use in the same type of circuit.

MINIATURE TUBES: The recent trend in receiver design has been toward constructing small, low-priced models. This, together with increasing popularity of portable battery-operated receivers, hearing aids, pocket receivers, and compact electronic apparatus in general, where size and weight are of primary consideration, has created a demand for even smaller tubes. The new miniature tubes, with their simplified construction and great reduction in size, have fulfilled this demand.

The reduction in dimensions accomplished by this new design will be better appreciated by comparing the size of this tube, shown at (E) of Fig. 17, with the more conventional tubes here shown. In Fig. 19 is shown a cut-away view of the miniature type as compared with a similar view of the "G" and "GT" types.

These miniature tubes are designed to operate efficiently with a 45 to 90-volt "B" supply, and with the filament operating directly from a single dry cell. As will be observed in Fig. 20, these tubes have a maximum overall length of about two inches and a diameter of three-quarters of an inch. This reduction in size has been made possible in a large measure by eliminating the conventional base and bringing the heavy wires from the seal directly through the bottom of a 7-pin base. These wires thus serve as the pin connections to the socket, which is a special miniature type.

THE ACORN TUBE: The ACORN tube, shown at (F) of Fig. 17, is one of the smaller miniature types. Is is used chiefly in ultra high-frequency transmitter and receiver circuits, and derives its name from the fact that it is similar in shape and size to an ordinary acorn.

These tubes are only about one-tenth as large as conventional receiver tubes --- nevertheless, they compare favorably with the larger tubes both as to characteristics and application. The inter-electrode capacities of the acorn tubes are only a fraction of those found in the larger tubes. It is for this reason that they are so well adapted to ultra-high-frequency circuits, operating at frequencies around 300,000,000 cycles per second.

At (A) of Fig. 21 are shown the dimensions and terminal arrangement of the acorn tube. You will observe that the terminals of this tube extend out

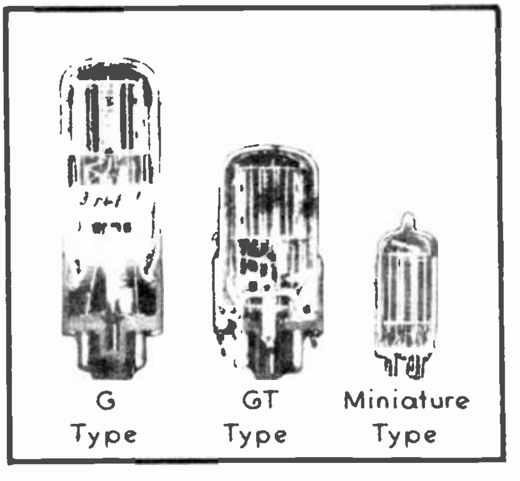

FIG. 19
COMPARISON OF MINIATURE, "G" AND "GT" TUBES

from the side of the glass envelope. At (B) of Fig. 21 is illustrated a typical mounting arrangement, showing how the tiny tube fits in its socket. While the tube is here shown mounted horizontally, it can, nevertheless, also be mounted in a vertical position.

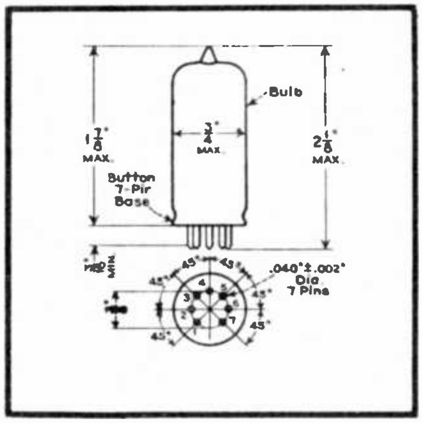

FIG. 20
DIMENSIONS AND BASE ARRANGEMENT OF THE MINIATURE TUBE

MULTI-PURPOSE TUBES

Multi-purpose tubes, also commonly called COMBINATION or DUPLEX tubes, are merely combinations of a diode and a triode, or a diode and a pentode, etc. --- the two sets of elements being placed with a single envelope purely for reasons of convenience and economy.

The names of these multi-purpose tubes are usually combinations of their component section-names. For example, the duo-diode-pentode contains two diodes and one pentode section, all operating with a common filament or cathode, but otherwise separate. The combination of tube functions within a single glass or metal envelope is dictated by the fact that the tube sections contained therein are always used in combination with each other; that is, with respect to their associated circuits.

Some of the more typical and commonly employed combinations are shown symbolically in Fig. 22. The first of these combinations, shown at (A), consists of two diode sections in a single envelope. So as to make each diode independent of the other, separate cathode elements are employed in this case.

The combination shown at (B) consists of two separate triodes in one envelope, and is therefore called a twin-triode or a duo-triode. In many tubes of this type, a common cathode is employed instead of individual cathodes as here shown.

At (C) of Fig. 22 is shown another "twin" or dual purpose tube. However, in this case, two pentode sections are housed in a single envelope. While the arrangement here shown does not provide for completely separate or individual control of the two tube sections, because of the two suppressor and screen grids being tied together internally, duo-pentode tubes are available which do have these elements separated for individual control. Tubes of this type are also available with a separate cathode and heater element.

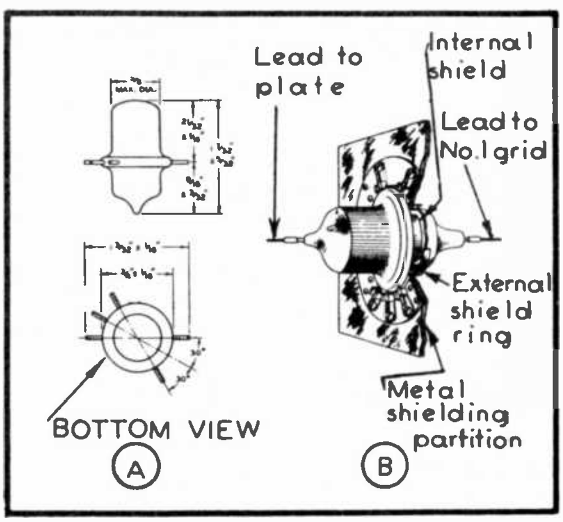

FIG. 21
DIMENSIONS AND MOUNTING OF ACORN TUBE

At (D) of Fig. 22, you are shown a diode and a triode section placed within the same envelope. As is usual in such combinations, a common filament and cathode is utilized for both sections. Also, two diodes are often employed instead of the single diode element here shown. The latter

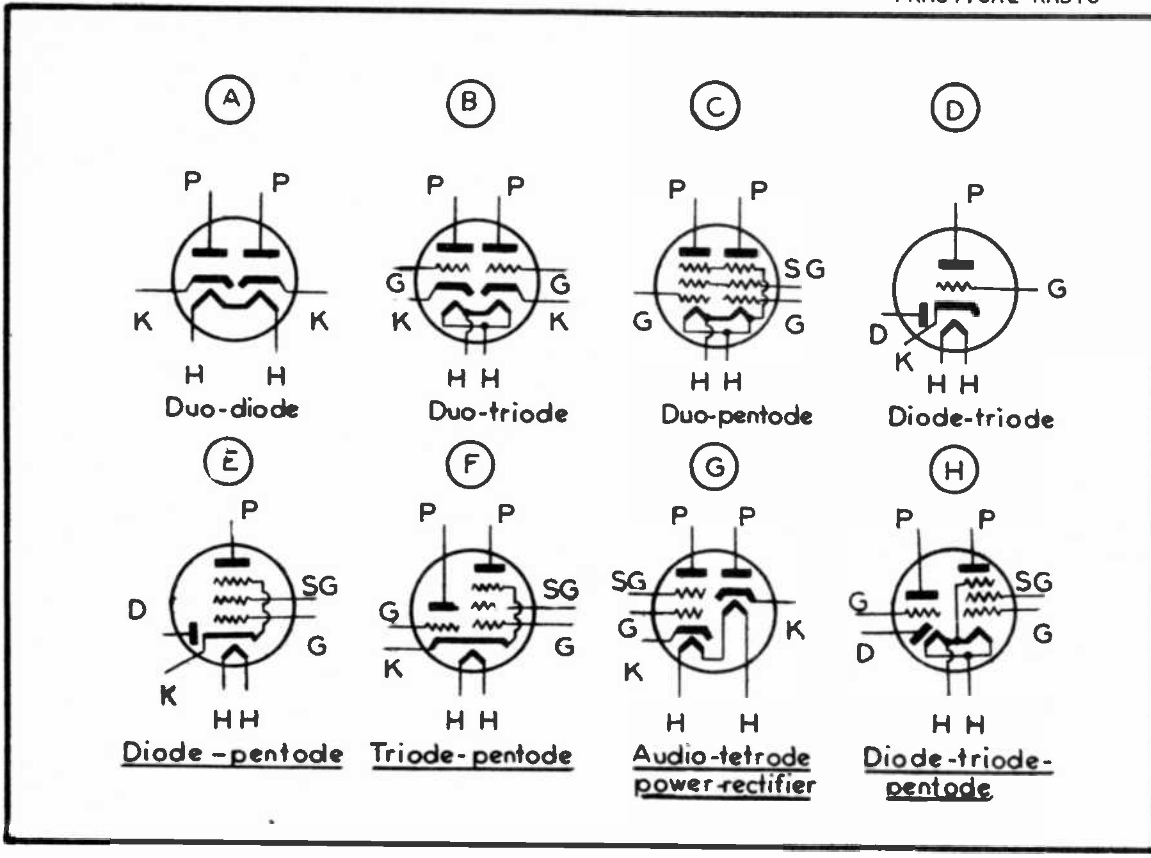

Fig. 22
Symbols of Popular Multi-Purpose Tubes

arrangement would be called a duo-diode-triode or duplex-diode-triode. A similar arrangement is shown at (E), where a diode section is used in combination with a pentode section.

At (F) of Fig. 22 is shown a combination triode-pentode. Here again, a common cathode is used for both sections.

The arrangement illustrated at (G) of Fig. 22 is a tetrode and cathode-type diode. Tubes of this design are commonly used in small, compact combination ac-dc receivers.

Some multi-purpose tube combinations have as many as three tube-sections within the same enclosure. An example of this is shown at (H), where we have a diode, triode, and pentode section all placed within the same envelope.

The applications of these multi-purpose tubes, and others, are illustrated and explained in later lessons.

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LESSON NO. 11

CIRCUIT ANALYSIS

In a previous lesson you had the opportunity to familiarize yourself in a general way with electromotive force, current flow and resistance. You are now going to investigate this subject further by learning more about the mathematical relations which exist between these three properties.

The ability to analyze electronic circuits from this stand point is going to be of great value to you throughout the study of this course, as well as in your work in the industry.

THE STANDARD CELL

The volt, as you already know, is the unit of electromotive force. Its value has been arbitrarily fixed in much the same manner as the "inch" has been chosen as the unit of linear measurement.

The U.S. Bureau of Standards and many laboratories and factories, where electrical instruments are manufactured, use a special chemical cell to provide an exact voltage of a value that has been approved throughout the world, to serve as a standard for comparison. These standard cells are kept in condition

FIG. 1
STUDENTS PERFORMING CIRCUIT ANALYSIS
EXPERIMENTS AT NATIONAL

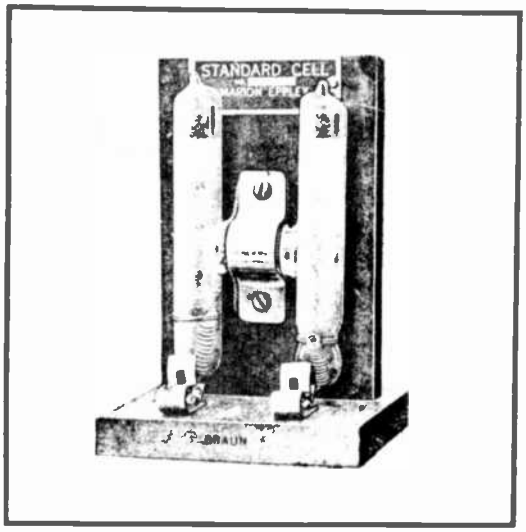

FIG. 2
STANDARD CELL

and handled with extraordinary precaution to prevent any variation in the voltage. Their use is confined to the calibration of the scales of precision type voltmeters, and other exacting work of this nature.

One of these standard cells is shown in Fig. 2. Its internal construction is illustrated in Fig. 3. Quite often, these cells are housed in a case to protect them against mechanical injury and severe temperature variations.

The "Weston" standard cell, which is being used extensively at the present time, maintains a constant voltage of 1.0183 volts at ordinary temperature; and does not vary after being in service for several years, provided it is not required to furnish a current exceeding .0001 ampere.

Besides the volt, we also employ the millivolt and the microvolt, as units for measuring very small voltages; and the kilovolt for measuring large voltages. The millivolt is equal to .001 volt (the one-thousandth part of a volt), while the microvolt is equal to .000001 volt (the one-millionth part of a volt). The kilovolt is equal to one thousand volts.

THE STANDARD OHM

We also have a standard unit, the ohm, for measuring electrical resistance. One ohm is the electrical resistance offered by a column of mercury 106.3 centimeters long, and having a cross-sectional area of 1 square millimeter. (Note: One centimeter is equal to approximately .4", and one millimeter is equal to .04".)

When referring to very small resistance values, we employ the micro-ohm as the unit of measurement. One micro-ohm is equal to the one-millionth part of an ohm. The megohm is used as the unit of measurement for very high resistance values, being equal to one million ohms.

OHM'S LAW

The ampere, which we use as the unit for current measurement, is the current which will flow under an applied electromotive force of one volt through a circuit having a resistance of one ohm. Thus, you see, that although the volt, ampere and ohm are all distinct units of electrical measure-

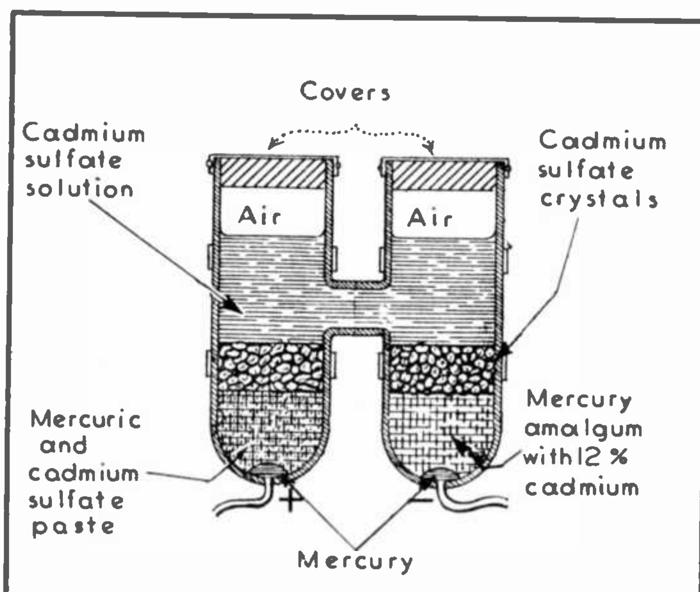

FIG. 3
CONSTRUCTION OF THE STANDARD CELL

ment, a definite mathematical relation exists between them, as was first discovered by the scientist, Dr. George Simon Ohm, after whom the unit of electrical resistance was named. This mathematical relation between the voltage, current and resistance is called OHM'S LAW. It is a very valuable tool for the industry because it enables one to calculate either the current, voltage or resistance of any circuit, if the values of the other two factors are known.

CALCULATING THE CURRENT

To calculate the current flow through any given circuit, we apply Ohm's Law in the following manner: "The current flow through the circuit is equal to the voltage divided by the resistance." Expressed as a formula, this would be:

Current = voltage ÷ resistance, which can also be written as, $\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$; or $I = \frac{E}{R}$, where "I" stands for current, "E" for electromotive force, and "R" for resistance.

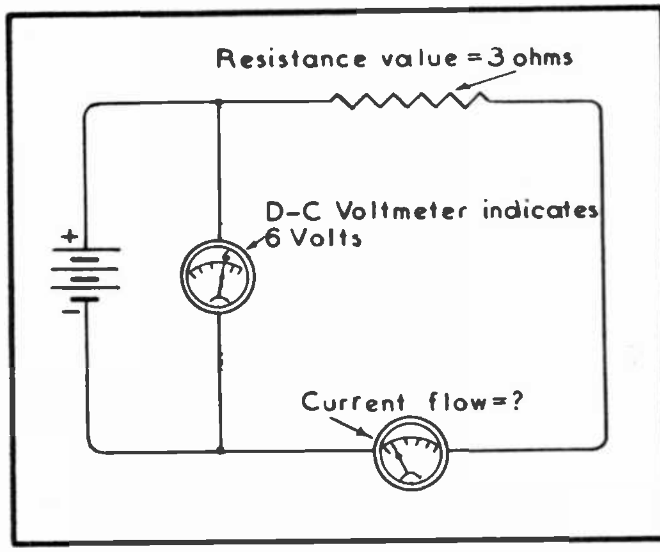

FIG. 4
PROBLEM: TO CALCULATE CURRENT

Let us apply this formula to the problem illustrated in Fig. 4. Here, we have a circuit, the resistance of which is known to be 3 ohms. A voltmeter shows that an E.M.F. of 6 volts is impressed across the circuit. The problem is to calculate how much current is flowing through the circuit. To do this, we use our formula, $I = \frac{E}{R}$. Substituting the value of 6 volts for "E" and 3 ohms for "R", we then have: $I = \frac{6}{3} =$ 2 amperes. In other words, a current of 2 amperes flows through this circuit.

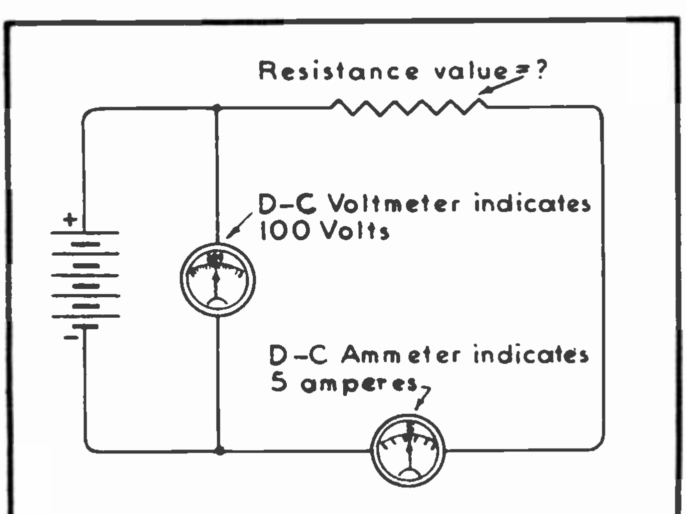

FIG. 5
PROBLEM: TO CALCULATE RESISTANCE

It is customary to abbreviate the term ampere as "amp." and amperes as "amps." The symbol (Ω) indicates ohms. Observe also in Fig. 4 how the presence of the resistor is indicated by means of a symbol.

CALCULATING THE RESISTANCE

To calculate the resistance of any part of a circuit, apply Ohm's Law in the form: "Resistance is equal to the voltage divided by the current". The formula for this is Resistance = voltage ÷ current, or $\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$, or $R = \frac{E}{I}$.

A problem of this type is illustrated in Fig. 5, where an E.M.F. of 100 volts is shown to be forcing a current of 5 amperes through the circuit. Then, since the voltage (E) is 100; and the current (I) is 5 amperes, we find the value of the resistor (R) by substituting the known values in the formula, $R = \frac{E}{I}$, thus: $R = \frac{100}{5} = 20$ ohms (answer).

CALCULATING THE VOLTAGE

To calculate the voltage which is applied across a given circuit, from the circuit's resistance and the current flowing through it, we use Ohm's Law in the form: "Voltage is equal to the resistance of the circuit multiplied by the current flowing through it". That is:

Voltage = Current x Resistance, or E = I x R.

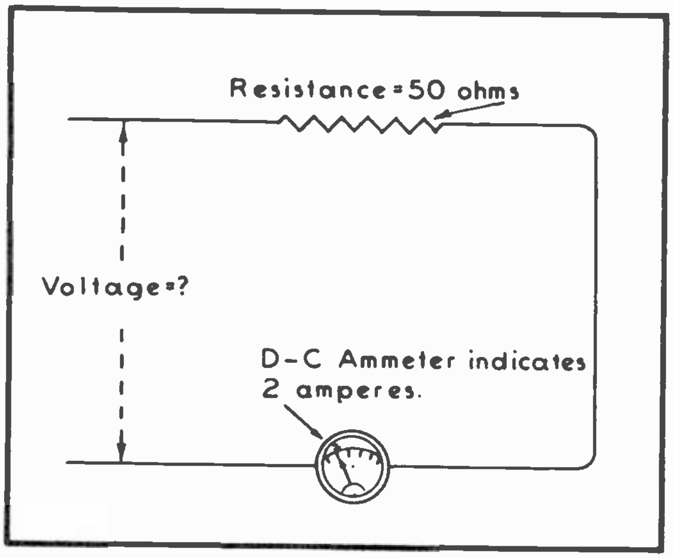

FIG. 6
PROBLEM: TO CALCULATE VOLTAGE

To illustrate the application of this formula, let us consider the circuit illustrated in Fig. 6. Here, we have a 50-ohm resistor connected in series with an ammeter and a voltage source of unknown value. The ammeter indicates a current flow of 2 amperes (answer).

To determine the voltage required to force this current through the resistor, we proceed as follows: E = I x R, in which case I = 2 amperes and R = 50 ohms. Hence, E = 2 x 50 = 100 volts. (ans.)

AN EASY WAY TO REMEMBER OHM'S LAW

Should you find it difficult to remember the different forms in which Ohm's Law may be applied, the suggestions offered in Figs. 7 and 8 may be helpful. In Fig. 7, the expression $\frac{E}{I \times R}$ is enclosed in a circle. If you wish to find "E", simply cover up the "E" as illustrated at the top of Fig. 8 and you have left the portion I x R, which means that E = I x R. Should you want to find "I", cover up the "I" as in the center of Fig. 8 and you see that $I = \frac{E}{R}$. Finally, if "R" is the value sought, cover it and you have $R = \frac{E}{I}$.

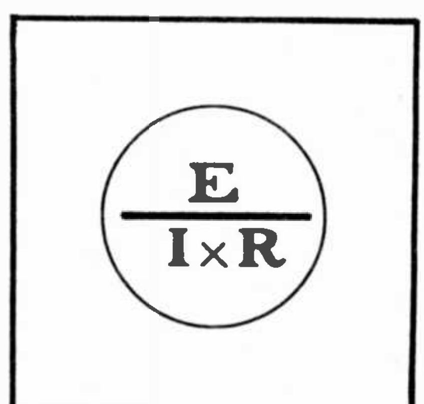

FIG. 7
"MEMORANDUM" FORMULA

SERIES CIRCUIT

Any circuit, in which all of its parts or sections are connected in series (one after the other) is classed as a <u>series circuit</u>. For instance, in Fig. 9, we have the filaments of two tubes connected in such manner that the <u>same current</u> must flow through <u>all parts</u> of this circuit. In other words, there is only one path for the current to follow through the wired circuit from the (-) battery terminal to the (+) battery terminal. The lamp filaments are therefore said to be connected in "series".

No matter at which point the circuit might be interrupted or opened, all current would immediately stop flowing; and all parts of the circuit would be "dead". That is, each part of the circuit is dependent upon the satisfactory operation of all other parts.

In series circuits, we must apply Ohm's Law in a manner slightly different from its use in our previous examples. To illustrate this, let us suppose that we wish to calculate the current flow through the circuit in Fig. 9. To do this, we must first determine the total resistance of the circuit.

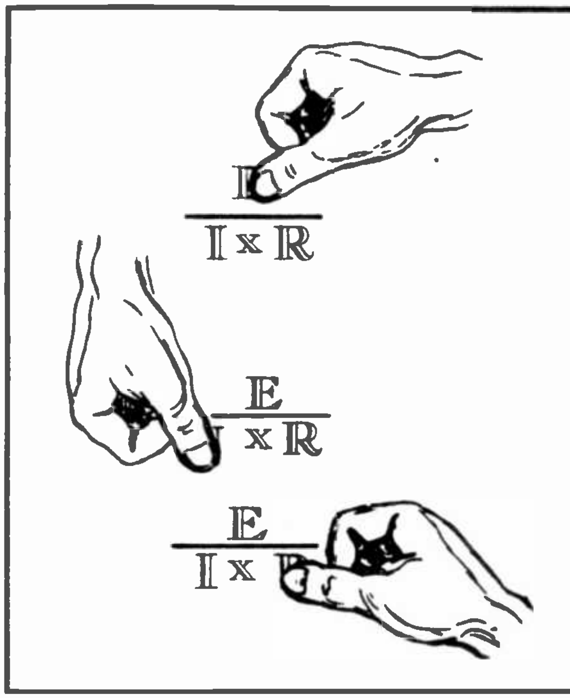

FIG. 8
USING THE MEMORANDUM FORMULA

In all series circuits, the total resistance is equal to the sum of the individual resistance values which are connected in series. That is, total resistance or $R = r_1 + r_2 + r_3$, etc., where r_1, r_2 and r_3 are the individual resistor values, and R is the total or combined value .

In Fig. 9, for example, the two filament resistances of 15 ohms are connected in series. Therefore, the total resistance of the circuit will be 15 ohms plus 15 ohms or 30 ohms.

The total resistance thus determined, we can calculate the current flowing through the circuit by using the formula $I = \frac{E}{R}$, where E = 120 volts and R = 30 ohms.

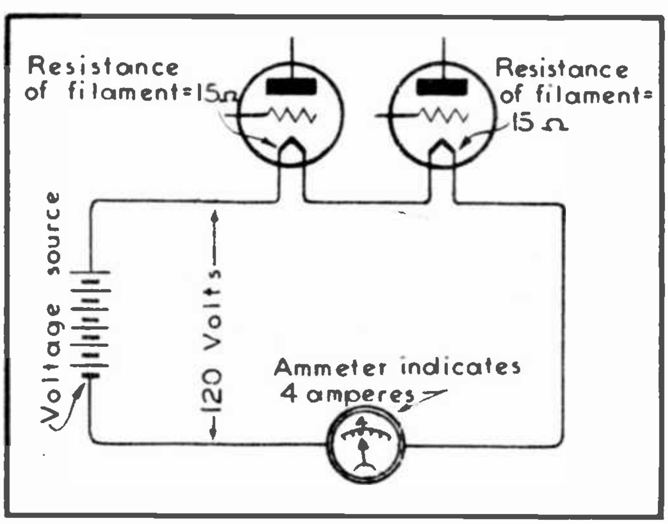

FIG. 9
SERIES CIRCUIT

Thus, $I = \frac{120}{30} = 4$ amperes. This same current of 4 amperes will flow through all parts of the circuit.

VOLTAGE DISTRIBUTION IN SERIES CIRCUIT

The next point to consider is the manner in which the voltage is distributed throughout a series circuit. In Fig. 10, we have two 2-ohm resistors connected in series with a 12-volt battery, and an ammeter. The ammeter indicates a current of 3 amperes.

Since 3 amperes flows through both of these 2-ohm

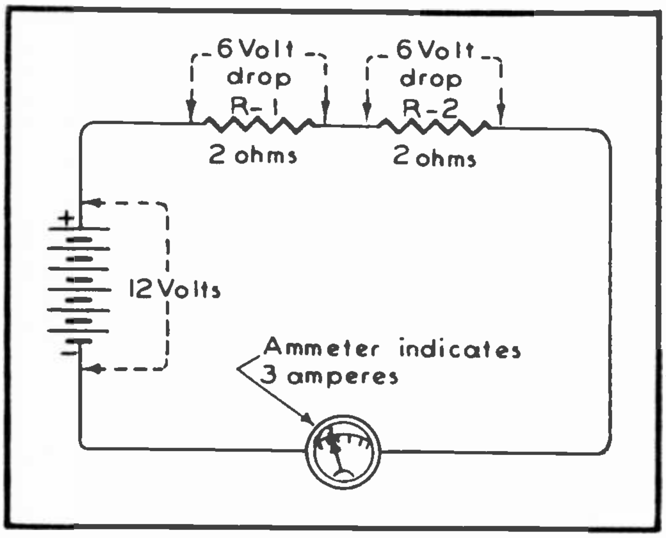

FIG. 10
PROBLEM: TO CALCULATE VOLTAGE-DROP IN SERIES CIRCUIT

resistors, the voltage effective across each of them can be found by using the formula E = I x R, where I is 3 amperes and R is 2 ohms. Hence, E = I x R = 3 x 2 = 6 volts. Thus, if we should measure the voltage across the ends of each 2-ohm resistor, the voltmeter would indicate 6 volts.

The voltage necessary to force the current through each of these resistors is called the voltage drop, because it will be subtracted from the total circuit voltage. Since we have a voltage drop of 6 volts across the resistor R-1 in Fig. 10, only 12 minus 6, or 6 volts, is available across resistor R-2.

It is also important to notice that the sum of the various voltage drops in a series circuit is equal to the total voltage impressed across the entire circuit by the source of E.M.F. That is to say, in the example illustrated in Fig. 10, the sum of the voltage drops is 6 plus 6, or 12 volts; which is equal to the voltage of the battery, or source of E.M.F. However, the current flow at each point in this series is the same, or 3 amperes.

CURRENT CALCULATION IN SERIES CIRCUITS

In Fig. 11, we have another circuit, consisting of four lamps connected in series; and the entire series combination is connected across the terminals of a generator. The lamp filaments have resistance values of 20-10-30 and 40 ohms, respectively, and the generator is supplying an E.M.F. of 200 volts.

To calculate the current through this circuit, first determine the total resistance of the circuit by adding together the various resistances included in it, which amounts to 20 + 10 + 30 + 40 = 100 ohms. This circuit is therefore equivalent to a 100-ohm resistor connected across the generator terminals.

Now, use Ohm's Law in the form $I = \frac{E}{R}$; and since E = 200 volts and R = 100 ohms, we have, $I = \frac{E}{R}$ or $\frac{200}{100} = 2$ amperes. This 2 amperes of current flows through every portion of the circuit.

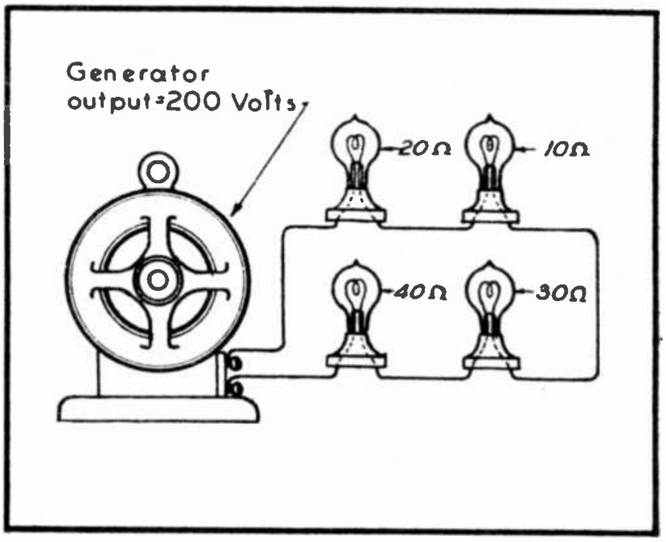

FIG. 11
PROBLEM: TO CALCULATE CURRENT IN SERIES CIRCUIT

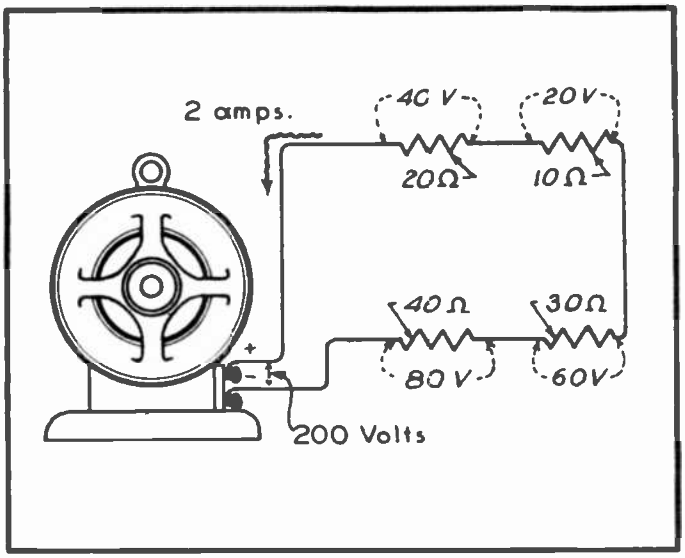

FIG. 12
DIAGRAM OF THE SERIES CIRCUIT

Having determined the current, the next step is to ascertain the voltage drop across the individual resistors. To simplify this, the same circuit is again shown in Fig. 12 in diagram form, each resistance being represented by a symbol.

Since the current through each of these resistances is 2 amperes, the volt drop across the 20-ohm resistor is: E = I x R, or 2 x 20 = 40 volts. The drop across the 10-ohm resistor is: E = I x R, or 2 x 10 = 20 volts. The drop across the 30-ohm resistor is: E = I x R, or 2 x 30 = 60 volts; and the drop across the 40-ohm resistor is: E = I x R, or 2 x 40 = 80 volts.

By adding together these individual voltage drops, we obtain 40 + 20 + 60 + 80, or 200 volts; which, you will note, is equal to the voltage produced by the generator.

PARALLEL CIRCUITS

In Fig. 13, we have a parallel electrical circuit. The three appliances comprising a bell, lamp and heater, are all connected separately across the two main circuit wires to which an E.M.F. of 30 volts is applied. We call the bell, lamp and heater circuits <u>branch circuits</u>. In a circuit such as this, each of the branch circuits is <u>independent</u> of all the others. The voltage impressed across each branch will be practically the same; that is, 30 volts.

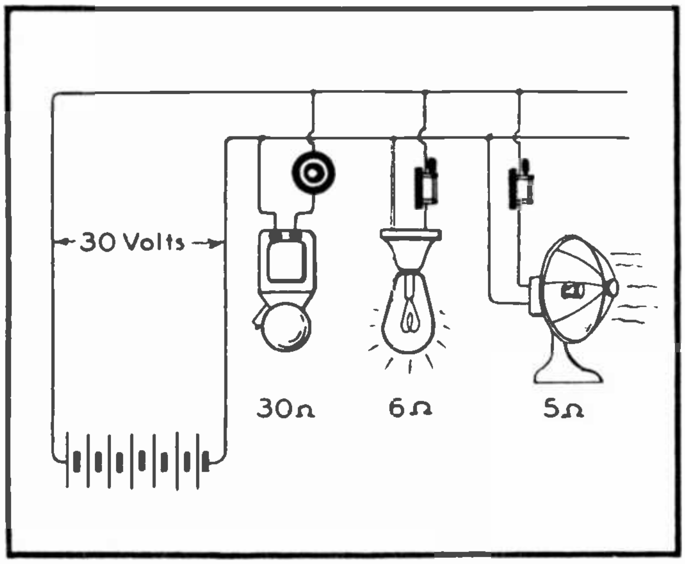

FIG. 13
PARALLEL ELECTRICAL CIRCUIT

A parallel electrical circuit can be compared to the parallel hydraulic system illustrated in Fig. 14, where three pipes with diameters of 1", 2" and 4", respectively, are all connected in parallel across the two main feeder pipes which serve to distribute the water through the system.

Each of these parallel-connected pipes has its individual valve, so that the flow of water through it can be controlled. Now, it is clear that practically the same pump pressure is exerted across each of the pipes; but if the valves are all opened, the current through the various pipes will be un-

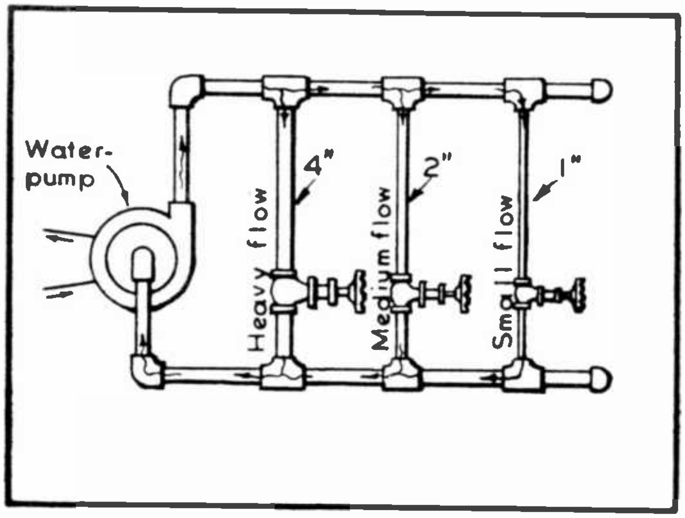

FIG. 14
PARALLEL WATER CIRCUIT

equal. That is, even though the pressure on the three pipes be the same, the resistance of each pipe will control the quantity of water flowing through it; and, since the diameters of the pipes in Fig. 14 differ, the pipe of largest diameter will have the least resistance --- and the pipe of smallest diameter, the greatest resistance. Therefore, the larger pipe will pass the most water; the medium-sized pipe will pass a little less water; and the smallest pipe will pass the least.

The same condition exists in parallel electrical circuits; for here, too, the voltage or electromotive force is practically the same across each of the parallel branches, and the current through any one of the branches is governed by the resistance of that particular branch. This is made a little clearer by considering the voltage and current distribution in the circuit of Fig. 13; which is again shown in Fig. 15, in diagram form.

Upon studying Fig. 15 very carefully, you will see that the same E.M.F. (30 volts) is impressed across each of the parallel branches or resistances. The current through each of these resistances can be calculated by using Ohm's Law in the form: $I = \frac{E}{R}$. To determine the current through the resistance of 30 ohms, substitute the value of 30 ohms for "R" and 30 volts for "E", thus: $I = \frac{30}{30} = 1$ ampere of current flowing through the 30-ohm resistance.

To determine the current through the 6-ohm resistor, use the same formula, but "R" will now be 6 ohms and "E" will be 30 volts. Hence, $I = \frac{30}{6} = 5$ amperes.

Finally, to calculate the current through the 5-ohm resistance, we substitute the value of 5 for "R" and 30 for "E", and thus obtain $I = \frac{30}{5} = 6$ amperes.

The total current, as supplied by the battery, will then be equal to the sum of the currents through each of the branch circuits. That is, the total current in the circuit of Figs. 13 and 15 will be 1 + 5 + 6, or 12 amperes, as indicated by the ammeter in Fig. 15 which is located at a point where all of the current supplied to the entire circuit must flow through it.

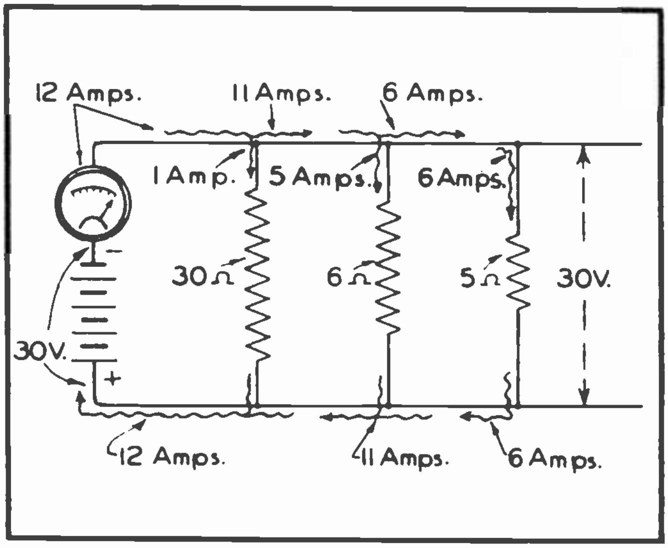

FIG. 15
DIAGRAM OF THE PARALLEL ELECTRICAL CIRCUIT

HOW MORE PARALLEL CIRCUITS AFFECT TOTAL RESISTANCE

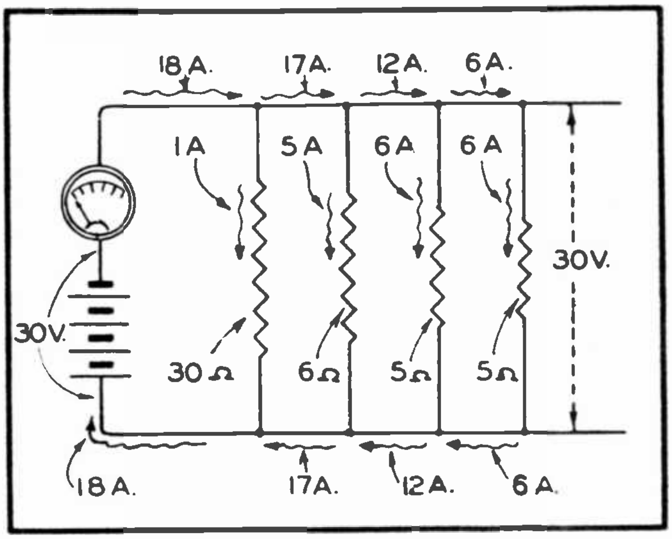

FIG. 16
ADDING ANOTHER PATH

In Fig. 16, we again have our circuit of Fig. 15; but, in addition, another 5-ohm resistor has been connected in parallel with the other three resistors. By applying Ohm's Law with this additional 5-ohm resistance in the circuit, we find that this resistor will permit another 6 amperes of current to flow through it ($I = \frac{E}{R}$ or $\frac{30}{5} = 6$ amperes).

Since you have already found that the other three resistors draw a total current of 12 amperes from the battery, the additional resistance in Fig. 16 will cause 6 amps to be added so that the total current becomes 12 plus 6, or 18 amps. This shows that the greater the number of resistors we connect in parallel, the less will be the total resistance of the circuit; and the total current flowing in the circuit will increase accordingly. The total resistance in this parallel circuit can also be calculated by applying Ohm's Law in the form $R = \frac{E}{I}$, where "E" is the applied voltage across the entire circuit, and "I" the total current. Hence, $R = \frac{30}{18} =$ 1.66 ohms.

Notice that the total resistance of a parallel circuit is even less than the smallest resistance value contained in any of the branches.

CALCULATING THE TOTAL RESISTANCE OF PARALLEL CIRCUITS

Your next step is to learn how to determine the total resistance of a parallel resistance combination when only the individual resistance values are known.

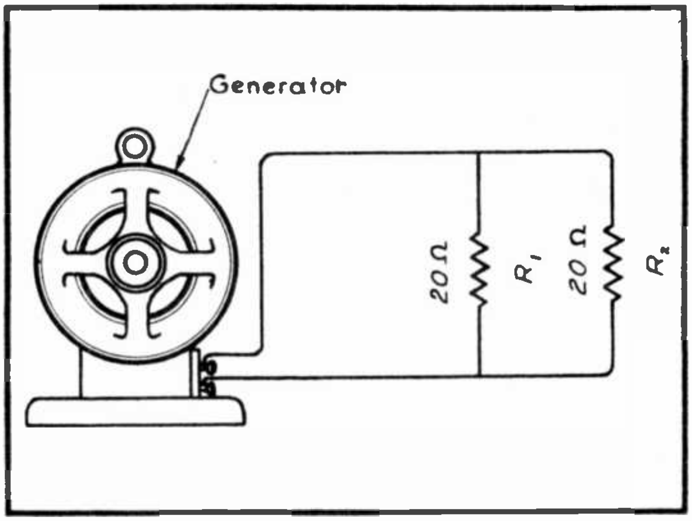

FIG. 17
PARALLEL RESISTANCE CALCULATION

The most simple parallel resistance combination is illustrated in Fig. 17, where the 20-ohm resistances, R_1 and R_2, are connected in parallel. The two resistance values here used are equal, in which case the total resistance of the parallel combination becomes one-half that of each individual resistance. That is to say, in Fig. 17, the total resistance of this circuit is 1/2 of 20 ohms, or 10 ohms.

Should the resistance combination comprise three resistances of equal value, connected in parallel, the total resistance of the circuit is reduced to 1/3 that of either resistance. In other words, if three 9-ohm resistances are connected in parallel, the total resistance of the combination will be 1/3 of 9, or 3 ohms, etc., for any number of paralleled resistors. It is to be remembered, however, that this relation applies only when the parallel resistances are all equal in value.

TWO PARALLEL RESISTANCES OF UNEQUAL VALUE

In Fig. 18, resistances of unequal value, R_1 and R_2, are connected in parallel. In such a combination, the total resistance of the circuit is equal to the product of the two resistances divided by their sum.

Expressed as a formula, this becomes:

$R = \frac{R_1 \times R_2}{R_1 + R_2}$, where R is the total resistance, and R_1 and R_2 are the individual resistance values.

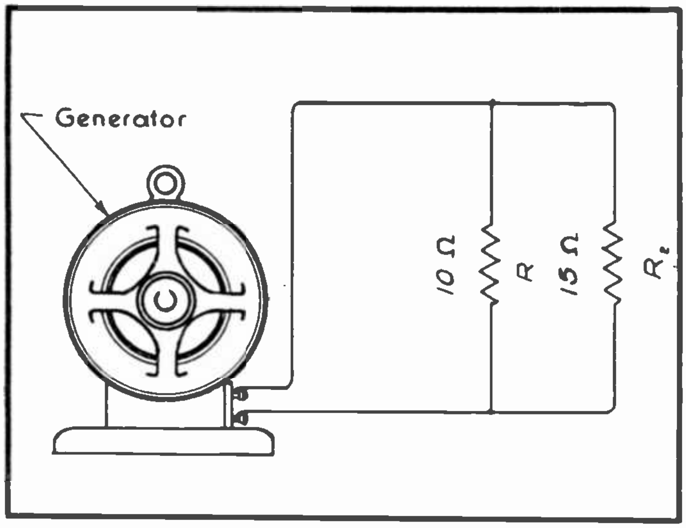

FIG. 18
UNEQUAL RESISTANCES CONNECTED IN PARALLEL

To illustrate the solution of a problem of this kind, let us consider the circuit illustrated in Fig. 18. Here, the individual resistance values are 10 and 15 ohms, respectively. To find the total resistance of this circuit, we proceed as follows:

$$R = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{10 \times 15}{10 + 15} = \frac{150}{25} =$$

6 ohms (the total circuit resistance).

CALCULATING TOTAL RESISTANCE OF PARALLEL CIRCUITS CONTAINING MORE THAN TWO UNLIKE RESISTANCES

When determining the total resistance of a parallel circuit containing more than two unlike resistances, separate the resistances into pairs and then solve for each pair individually, applying the laws pertaining to two unlike resistances in parallel. Although a circuit may appear to be complicated at first glance, a moment spent in careful thought will enable you to "break down" an apparently complex circuit into groups of simple individual problems that can be solved step by step with ease.

Let us proceed by applying these principles to the circuit illustrated at (A) of Fig. 19, where the three resistors R_1, R_2 and R_3 are connected in parallel.

To calculate the total or combined resistance of this circuit, first determine the resistance of R_1 and R_2, combined; temporarily disregarding the existence of R_3 --- as shown at (B) of Fig. 19.

Then, since $R = \frac{R_1 \times R_2}{R_1 + R_2}$, we have:

$$R = \frac{15 \times 10}{15 + 10} = \frac{150}{25} = 6 \text{ ohms.}$$

We can now replace resistors R_1 and R_2 of circuit (B) with a single resistor, having a value of 6 ohms; and which is connected in parallel with R_3. So as to be able to apply our formula for parallel-connected resistors of unequal value to the circuit of Fig. 19-C, we can consider the combination value of R_1 and R_2 as a new R_1 resistor, and R_3 as a new R_2 value --- as has also been done in Fig. 19-C.

Then, again applying the formula $R = \frac{R_1 \times R_2}{R_1 + R_2}$, where R_1 now has a value of 6 ohms, and R_2 12 ohms; the total resistance of the circuit becomes, $R = \frac{6 \times 12}{6 + 12} = \frac{72}{18} = 4$ ohms. (See "D" of Fig. 19.)

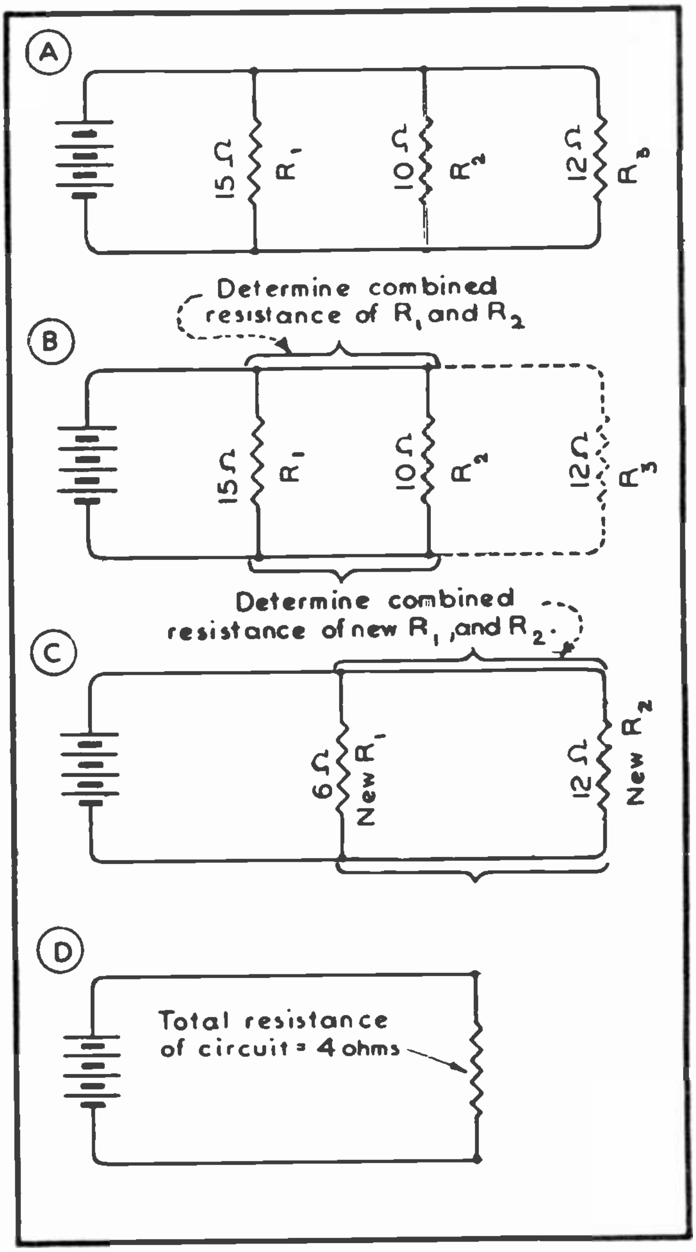

FIG. 19
"BREAKING DOWN" A PARALLEL RESISTANCE CIRCUIT

SERIES-PARALLEL RESISTANCE COMBINATIONS

In illustration (A) of Fig. 20, we have a circuit that is a combination of series and parallel-connected resistors. We can very easily determine the total resistance of this circuit in the following manner:

Step No. 1: Calculate the combined resistance of R_3 and R_4, thus:

$R = \frac{R_3 \times R_4}{R_3 + R_4}$; $R = \frac{10 \times 15}{10 + 15} = \frac{150}{25} = 6$ ohms. Eliminate resistors R_3 and R_4 from circuit Fig. 20-A and connect an equivalent 6-ohm resistance in their place as at (B) of Fig. 20. (Notice that we have labeled this 6-ohm resistance "R_a".)

Step No. 2: Calculate the combined resistance of R_2 and R_a, thus:

$R = \frac{6 \times 6}{6 + 6} = \frac{36}{12} = 3$ ohms. Now consider the 3-ohm resistance (R_b) to be equivalent to the parallel combination comprising R_2, R_3 and R_4 --- and that R_b is connected in series with the 2-ohm resistor R_1 as illustrated by Fig. 20-C.

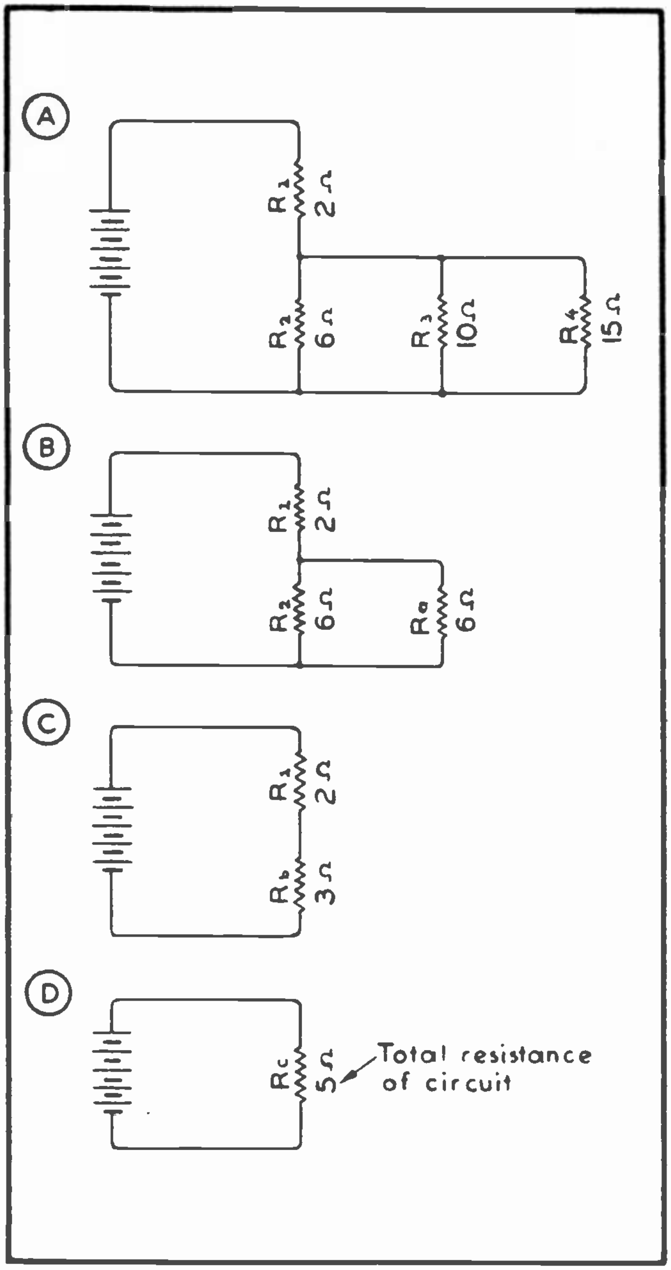

FIG. 20
RESISTANCE ANALYSIS OF SERIES-PARALLEL CIRCUIT

Step No. 3: Since the two resistors in Fig. 20-C are connected in series, their total resistance is 2 plus 3, or 5 ohms. Therefore, the total effective resistance of the circuit appearing at (A) of Fig. 20 has worked out to be 5 ohms (represented by R_c at "D" of Fig. 20).

Now, let us analyze this circuit further by determining the total current flow through it, and also the distribution of current throughout the various branches of the circuit.

Obviously, since we know the total resistance of the circuit to be 5 ohms and the applied E.M.F. as being 50 volts (see "A" of Fig. 21), the total current can be found by applying Ohm's Law in the form $I = \frac{E}{R}$. Substituting values in this formula, we have, $I = \frac{50}{5}$, or 10 amperes.

By inspection, it will be apparent that all of this current (10 amps) must flow through resistance R_1 in Fig. 20-A. Since the 5-ohm resistance in Fig. 21-A is composed of the 2-ohm resistance R_1 connected in series with the 3-ohm parallel combination comprising R_2, R_3 and R_4 (R_b in Fig. 21-B), we note that the voltage drop across R_1 is: $E = I \times R = 10 \times 2 = 20$ volts. Therefore, the voltage drop across R_b is 50 minus 20 or 30 volts, as also shown in Fig. 21-B. This means that 30 volts will be effective across R_2, R_3 and R_4 as shown at (C) of Fig. 21.

By knowing the values of the individual resistors R_2, R_3 and R_4, we can determine the current through each of these parallel branches, in the following manner:

1. Current through resistance R_2: $I = \frac{E}{R} = \frac{30}{6} = 5$ amperes.

2. Current through resistance R_3: $I = \frac{E}{R} = \frac{30}{10} = 3$ amperes.

3. Current through resistance R_4: $I = \frac{E}{R} = \frac{30}{15} = 2$ amperes.

This distribution of current through the various parallel branches is clearly illustrated in Fig. 21-D. Observe further how these individual currents add up to the total current through the circuit; which current all flows through the series resistor R_1. (Note: 5 amperes + 3 amperes + 2 amperes = 10 amperes.)

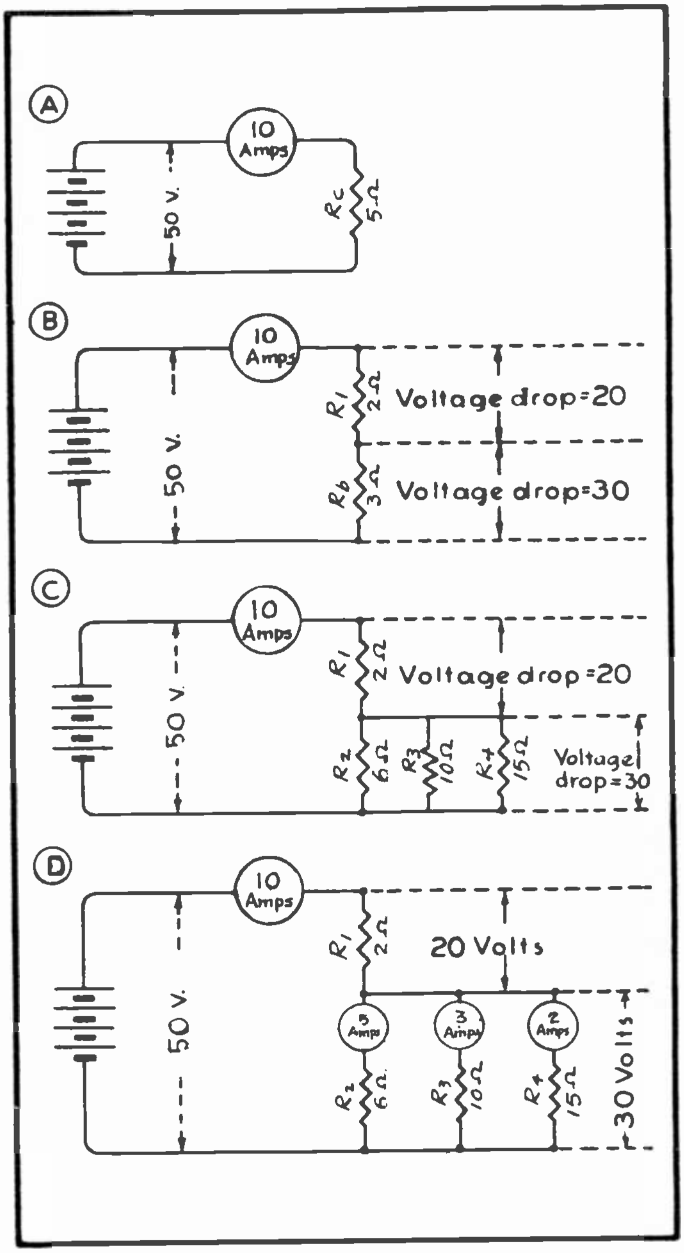

FIG. 21
VOLTAGE AND CURRENT ANALYSIS OF SERIES-PARALLEL CIRCUIT

APPLICATION OF OHM'S LAW WHEN CURRENT IS GIVEN IN MILLIAMPERES

Most problems encountered in radio and electronics involve current values that are expressed in units of milliamperes. In such cases, it is necessary to change the given milliampere value to the equivalent value expressed in amperes, before using it in the standard Ohm's Law formulas.

Since 1 milliampere is equal to the one-thousandth part of 1 ampere, we can express this relation mathematically, in the following way:

1 ma. = .001 ampere
or 1 ampere = 1000 milliamperes

Notice in the above examples that one-thousandth ampere can be written arithmetically as the fraction, $\frac{1}{1000}$ ampere; or in the form of the decimal number, .001 ampere. Also, observe that the term "ampere" is abbreviated to "amp."; and the term "milliampere", to "ma."

From the explanation just given, you will realize that in order to change any given value in amperes to its equivalent value in milliamperes, it is only necessary to move the decimal point (the period) three places towards the right. This is illustrated by the following examples:

.1 ampere = .100. or simply 100 ma.

.05 ampere = .050. or simply 50 ma.

.002 ampere = .002. or simply 2 ma.

.018 ampere = .018. or simply 18 ma.

.253 ampere = .253. or simply 253 ma.

By applying the same reasoning, we can change any given value of current expressed in milliamperes to its equivalent value in amperes by moving the decimal point three places toward the left. The following examples illustrate this:

150 ma. = .150. ampere, or .15 ampere.

25 ma. = .025. ampere, or .025 ampere.

2 ma. = .002. ampere, or .002 ampere.

100 ma. = .100. ampere, or .1 ampere.

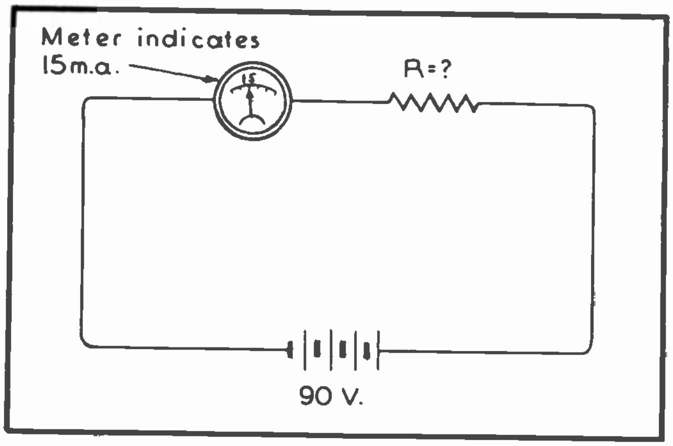

FIG. 22
PROBLEM: TO CALCULATE RESISTANCE

RESISTANCE PROBLEM

To illustrate the application of the information just given, let us consider the problem presented in Fig. 22. Here, an E.M.F. of 90 volts is causing a current of 15 ma. to flow through a resistance of unknown value. To calculate the value of this resistance, we use the same basic formula, $R = \frac{E}{I}$, but we must first change the current value of 15 ma to .015 ampere. We can then substitute values in the formula, thus:

$$R = \frac{90}{.015} = 6,000 \text{ ohms. (ans.)}$$

You can avoid working with decimal numbers in problems of this kind by using the formula:

$$\text{ohms} = \frac{\text{volts} \times 1,000}{\text{milliamperes}}.$$

The same problem can then be solved as follows:

$$\text{ohms} = \frac{90 \times 1,000}{15} = \frac{90,000}{15} =$$
6,000 ohms (answer).

Notice that the same answer is obtained by employing either method, but that it is not necessary to change milliamperes to amperes when using the latter formula.

VOLTAGE PROBLEM

To determine the voltage applied across the circuit illustrated in Fig. 23, we

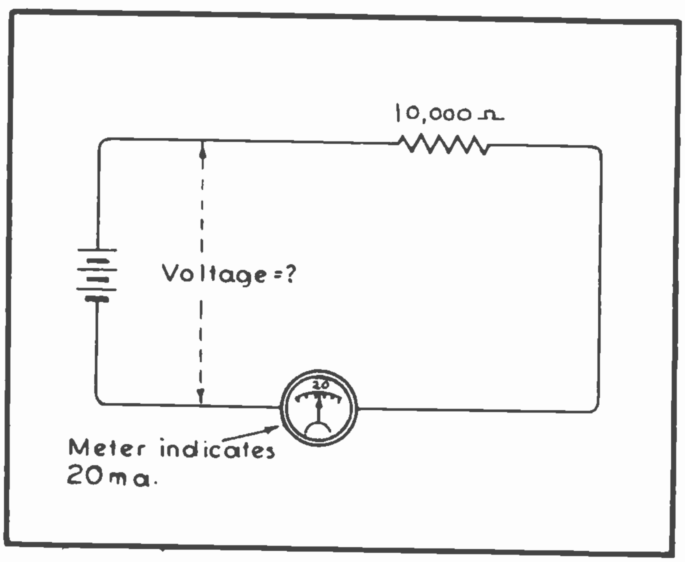

FIG. 23
PROBLEM: TO CALCULATE VOLTAGE

change the given current value of 20 ma. to its equivalent of .02 ampere and substitute values in our formula E = I x R, thus: E = .02 x 10,000 = 200 volts (answer).

To avoid the handling of decimal numbers in problems of this type, you can proceed as follows:

$$\text{volts} = \frac{\text{milliamperes x ohms}}{1,000}$$

$$= \frac{20 \times 10,000}{1,000}$$

$$= \frac{200,000}{1,000}$$

= 200 volts (answer).

CURRENT PROBLEM

To determine the current flow through the circuit in Fig. 24, substitute the given values in the formula $I = \frac{E}{R}$, thus:

$$I = \frac{100}{5,000}$$

= .02 ampere, or 20 milliamperes (ans.)

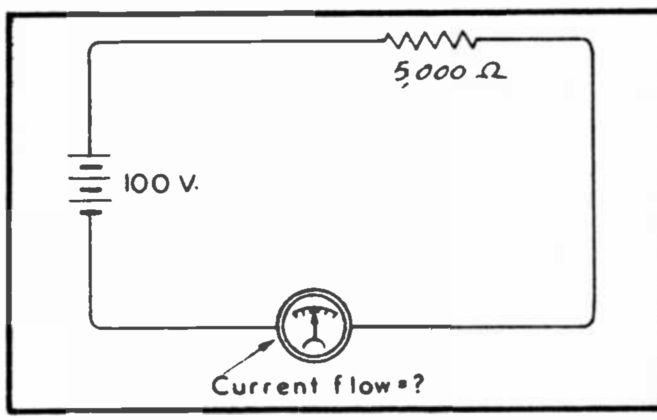

FIG. 24
PROBLEM: TO CALCULATE CURRENT

Here again, you have at your disposal a formula to avoid the use of decimals. The formula is:

$$\text{milliamperes} = \frac{\text{volts x 1,000}}{\text{ohms}}$$

$$= \frac{100 \times 1,000}{5,000}$$

$$= \frac{100,000}{5,000}$$

= 20 milliamperes (answer).

TYPICAL RADIO PROBLEMS INVOLVING OHM'S LAW

Having learned the basic Ohm's Law formulas, and the method of using them in connection with electrical circuits in general, let us now see how they apply to radio circuits in particular.

SERIES CIRCUIT PROBLEM

As our first example, let us consider the circuit shown in Fig. 25, where the filaments of five radio tubes are connected in series, and operated from a 110-volt lighting circuit. Conditions are such that a current of .3 ampere must flow through the filaments of all five of these tubes in order to heat them to the temperature required for pro-

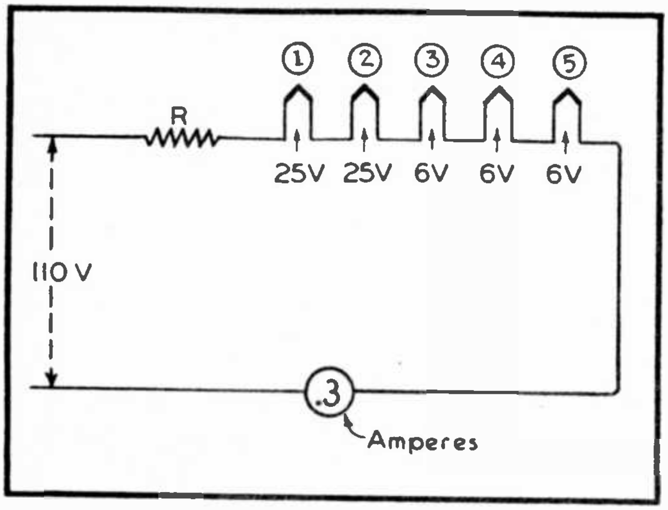

FIG. 25
PROBLEM: TO CALCULATE VALUE OF "R"

per operation. The tube manufacturer specifies that 25 volts be applied across the filaments of tubes No. 1 and 2, and 6 volts across the filaments of tubes No. 3, 4 and 5.

Each of these voltages may be considered as a voltage drop across the filament (resistance) of the tube in question. Therefore, the total voltage drop introduced in this series circuit by the five tube filaments is 25 + 25 + 6 + 6 + 6 or 68 volts.

Now, since only 68 volts is required across all five tube filaments, as shown in Fig. 26, it is logical that we cannot place this "string" of series-connected filaments directly across the 110 volt line. To do so, would result in nearly twice the required voltage being applied across the group --- which condition would burn them out.

To avoid such an occurrence, we connect an additional resistance (R) in the circuit to reduce the voltage from 110 to 68 volts. In other words, this series resistor must produce an additional voltage drop of 110 minus 68 or 42 volts, as indicated in Fig. 26. The question is, "What value of resistor should be used for this purpose?"

Since .3 ampere will flow through this resistor, and a drop of 42 volts is to be developed across it, we determine its value thus:
$R = \frac{E}{I} = \frac{42}{.3} = 140$ ohms.

Therefore, by placing a 140-ohm resistor in the circuit as indicated in Fig. 26, all required conditions will be fulfilled, and the various circuit values will be as presented in the diagram.

The different tube filaments can be considered as individual resistances, in which case those of tubes No. 1 and 2 would each have a value of 83.3 ohms. (Note: $R = \frac{E}{I} = \frac{25}{.3} = 83.3$ ohms.) The other tube filaments each have a resistance of 20 ohms. (Note: $R = \frac{E}{I} = \frac{6}{.3} = 20$ ohms.) The complete circuit can therefore also be illustrated as

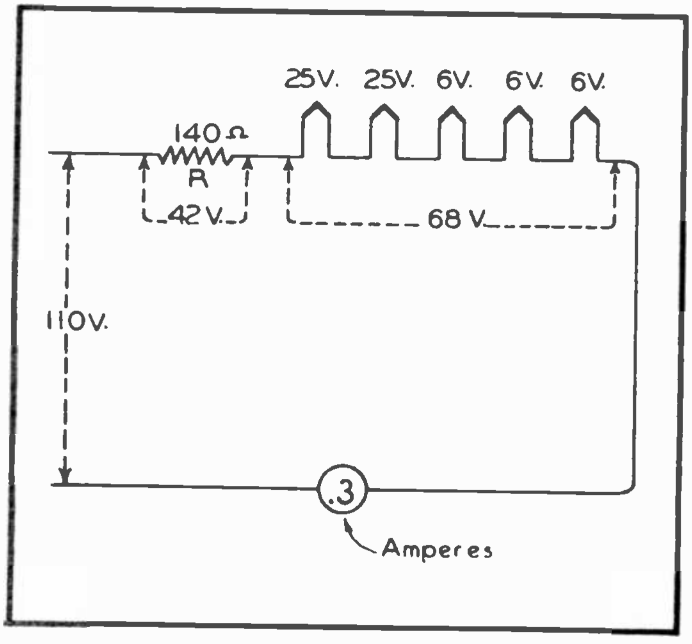

FIG. 26
VOLTAGE DISTRIBUTION IN SERIES FILAMENT CIRCUIT

in Fig. 27, where each of the tube filaments is represented by an equivalent resistance.

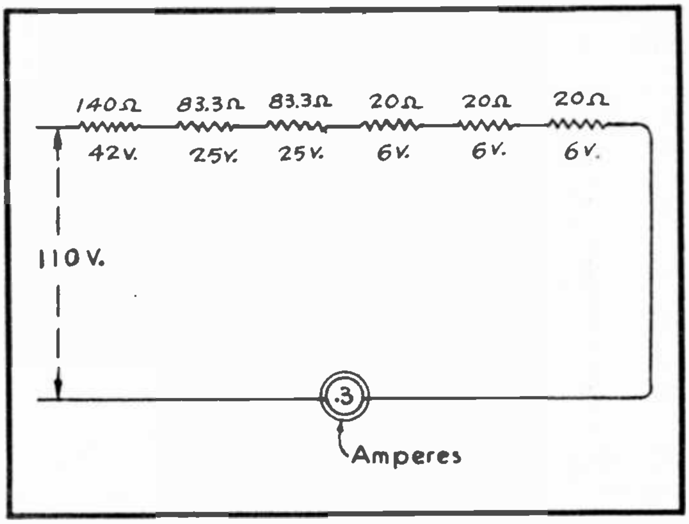

FIG. 27
THE EQUIVALENT CIRCUIT

PARALLEL CIRCUIT PROBLEM

In Fig. 28, three tubes, each requiring a filament supply of 2 volts, are connected in parallel. The filaments of tubes No. 1 and 2 are designed to pass .06 ampere; whereas that of tube No. 3 is designed to pass .12 ampere. The current distribution through this circuit will therefore be as diagrammed in Fig. 29. Notice in Fig. 29, how the total current through the circuit adds up to .06 + .06 + .12, or .24 ampere.

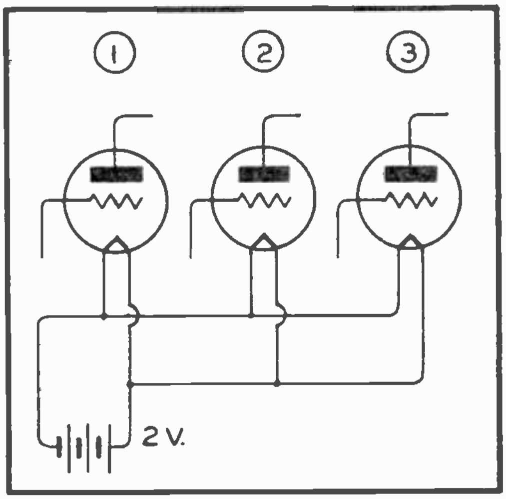

FIG. 28
PARALLEL FILAMENT CIRCUIT

Now, let us suppose that it becomes necessary to connect this group of tubes across a source of 4 volts. To avoid burning out the tubes, we connect an additional resistance in the circuit to bring about a voltage drop of 2 volts, so that only 2 of the original 4 volts will be available for the tubes. Fig. 30 shows how this is done.

Since the series resistor (R) is located in that part of the circuit through which the total current of .24 ampere flows, its value must be 8.33 ohms. (Note: $R = \frac{E}{I} = \frac{2}{.24} = 8.33$ ohms.)

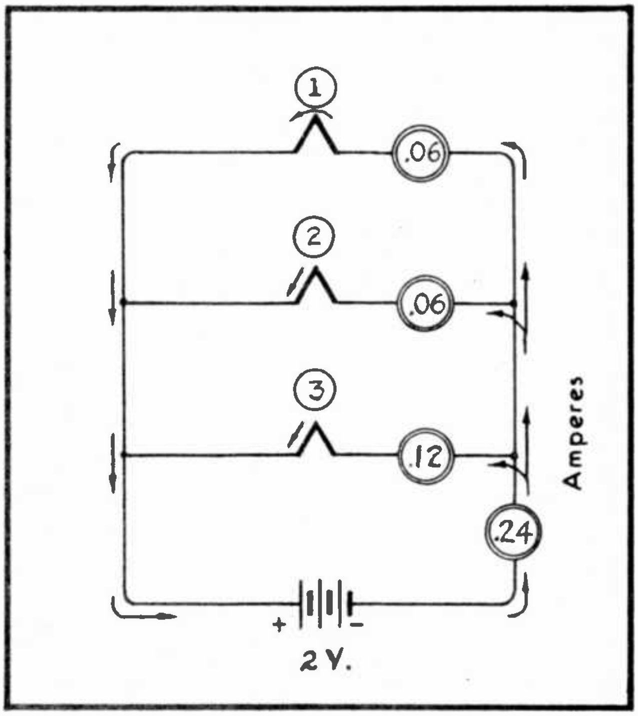

FIG. 29
CURRENT DISTRIBUTION

In Fig. 31, three resistors are connected in series across an E.M.F. of 250 volts; and terminals are supplied at points A, B and C. Such an arrangement constitutes what is known as a "Voltage Divider".

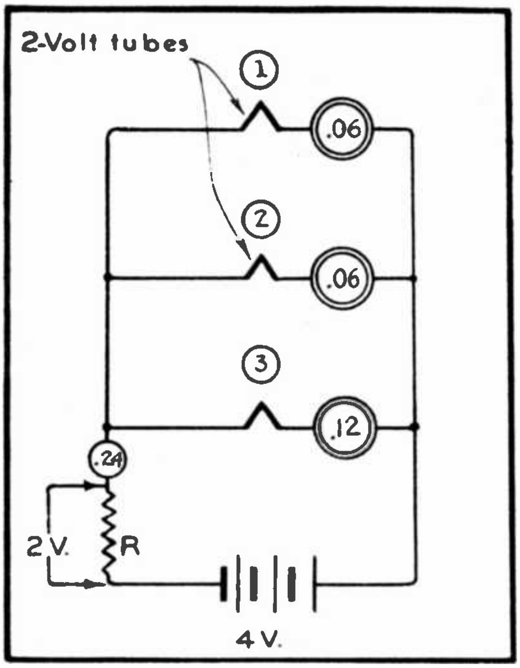

FIG. 30
APPLICATION OF VOLTAGE-DROPPING RESISTOR

Let us analyze this circuit and see what actually takes place. Our first step is to calculate the total resistance of the circuit, and the current flow through it. To do this, we proceed as follows:

Total resistance = 5,000 + 25,000 + 20,000

= 50,000 ohms.

The current flow can now be calculated by applying Ohm's Law, thus:

$I = \frac{E}{R} = \frac{250}{50,000} = .005$ ampere; or 5 ma;

or, $\text{milliamperes} = \frac{\text{volts} \times 1,000}{\text{ohms}} = \frac{250 \times 1,000}{50,000} = 5$ ma.

From what you have already learned, you will realize that a voltage drop appears across each of the resistors in this system. The presence of these voltage drops is clearly illustrated in Fig. 32 -- values of which are determined in the following manner:

1. Problem: Find the voltage drop across the 5,000 ohm resistor.

Procedure: $E = I \times R = .005 \times 5,000 = 25$ volts (Note that milliamperes must be changed to amperes before applying the formula.)

$$\text{Or, volts} = \frac{\text{milliamperes} \times \text{ohms}}{1,000} = \frac{5 \times 5,000}{1,000}$$

2. Problem: Find the voltage drop across the 25,000 ohm resistor.

Procedure: $E = I \times R = .005 \times 25,000 = 125$ volts

$$\text{Or, volts} = \frac{\text{milliamperes} \times \text{ohms}}{1,000} = \frac{5 \times 25,000}{1,000} = 125 \text{ volts}$$

3. Problem: Find the voltage drop across the 20,000 ohm resistor.

Procedure: $E = I \times R = .005 \times 20,000 = 100$ volts

$$= \frac{\text{milliamperes} \times \text{ohms}}{1,000} = \frac{5 \times 20,000}{1,000} = 100 \text{ volts}$$

Observe that the sum of these individual voltage drops is equal to the voltage supplied by the source of E.M.F. (25 + 125 + 100 = 250); and that this 250 volts is available between terminal A and ground, as indicated by the value +250 which is noted alongside of terminal A. Observe, also, that ground serves as the negative side of this circuit, and, that all points along the string of resistors are therefore at a positive potential with respect to ground (B-).

Now, since 25 volts is lost between terminals A and B because of the 5,000 ohm resistor, it stands to reason that only 250 minus 25, or 225 volts, will exist between terminal B and ground.

Similarly, the drop of 125 volts across the 25,000 ohm resistor will cause the voltage between terminal C and ground to be 125 volts less than that between terminal B and ground. Thus, the voltage between terminal C and ground is 225 minus 125 or 100 volts.

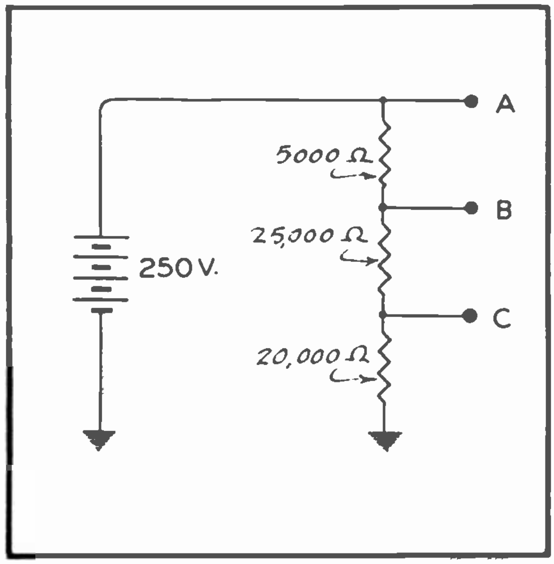

FIG. 31
VOLTAGE DIVIDER

Later in the course, you will learn how such voltage dividers are used extensively in radio receivers, amplifiers and other electronic equipment to provide different circuits thereof with various voltage values obtained from a given, centralized voltage source.

THE WATT --- UNIT OF ELECTRIC POWER

The "Watt" is the unit of electric power, and represents the work done by a current flow of one ampere being forced along by an electric pressure of one volt. To find the number of watts in a circuit, it is only necessary to multiply the number of amperes flowing through the circuit by the number of volts impressed across it. This relation between watts, amperes and volts is known as "Watt's Law"; usually written in the form W = E x I, where W stands for watts, E for volts and I for amperes.

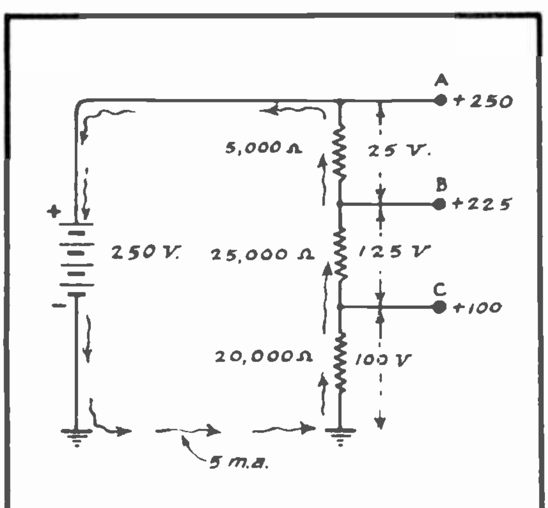

FIG. 32
ANALYSIS OF VOLTAGE DIVIDER

Thus, if a current of 3 amperes flows through a resistance across which 80 volts is impressed, the electric power required to accomplish this is determined in the following manner:

W = E x I = 80 x 3 = 240, or 240 watts.

It is this electric power (watts or wattage, as it is sometimes called) that produces the heating effect in a circuit. For this reason, radio resistors and other parts must be designed to handle the wattage normally encountered in operation, without attaining a temperature that will damage them.

For the present, this is all that you need to know about watts. Later in the course, you will receive more detailed and advanced instruction on this subject. We will also discuss Ohm's Law further, as the circuits encountered require this to be done.

Our chief aim at this time, is to teach you the very essentials of "breaking-down" and analyzing circuits from the standpoint of voltage and current distribution, on which to base your later studies.

A successful life must have Aim and Purpose. When we are without aim, we are without hope of accomplishing anything worthwhile. On the other hand, if we do have a set purpose and the courage and backbone to achieve it, we are bound to succeed.

On our pathway we meet discouragement, obstacles, even temporary failure, but we must not lose hope. We must have strength of character, and the determination to follow our aim consistently and courageously.

Let us remember that Aimlessness spells Hopelessness, and that Purpose spells Accomplishment.

J. A. ROSENKRANZ

Practical Technical Training In
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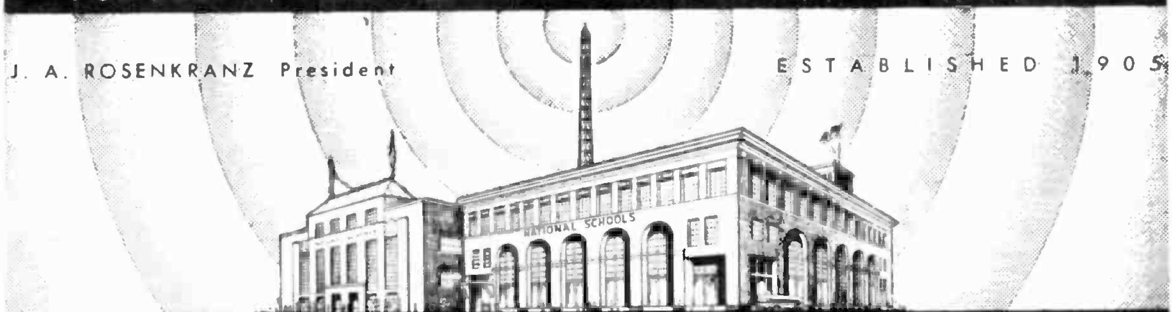

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LESSON NO. 12

POWER SUPPLIES FOR A-C RECEIVERS

In the various fundamental vacuum tube circuits which were brought to your attention thus far in the course, batteries were employed to furnish the necessary electrical power to operate them. However, the greater number of today's home-radios obtain their operating power from the 110 volt a-c lighting circuit. The electronic apparatus that makes this possible is called the power supply system, or power supply unit --- and more often, the "power supply".

The importance of the power supply system is illustrated in Fig. 1, where a block diagram of a complete a-c receiver is shown. You will note that the radio frequency amplifier, detector, audio frequency amplifier, and the loudspeaker are all dependent upon the power supply for their operation. If the power supply unit should become defective or inoperative, none of the other sections of the receiver can possibly function

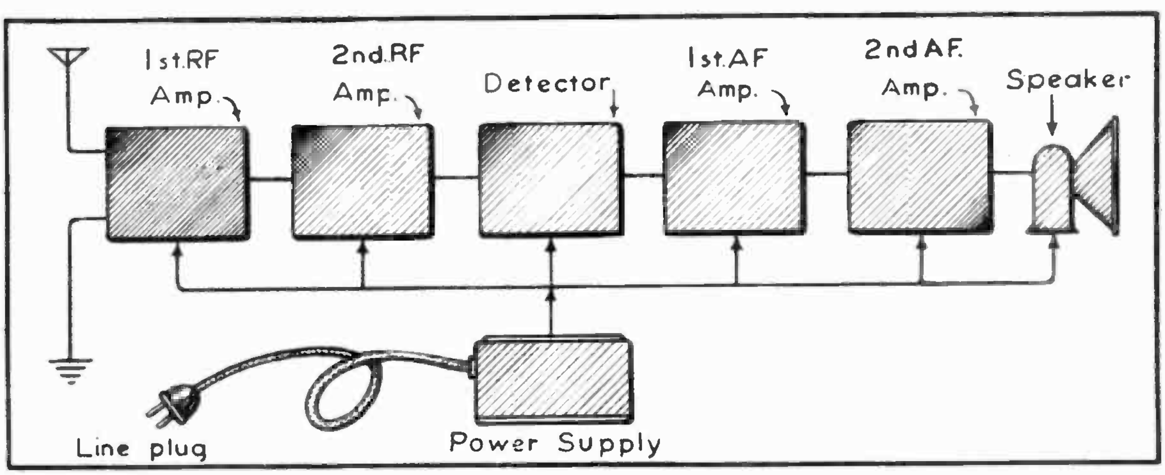


FIG. 1
ALL SECTIONS OF THE RECEIVER ARE DEPENDENT ON THE POWER SUPPLY

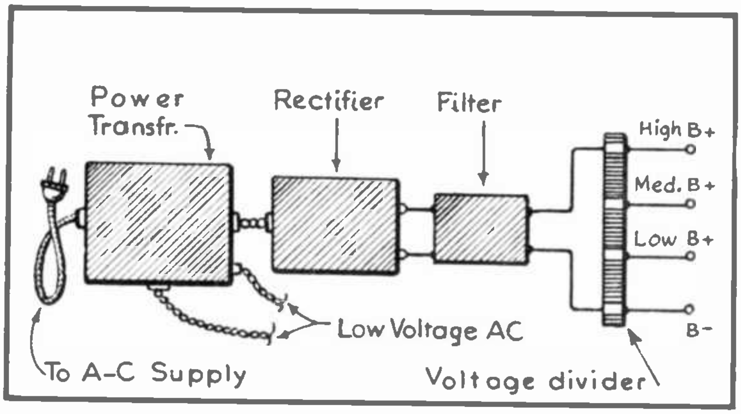


FIG. 2
SECTIONS OF THE POWER SUPPLY SYSTEM

in a normal manner --- any more than an automobile in good mechanical condition could run without gasoline reaching the carburetor. It is logical, therefore, that we discuss the power supply circuits before beginning our intensive study of the other receiver sections mentioned in Fig. 1.

SECTIONS OF THE POWER SUPPLY SYSTEM

Like other radionic or electronic equipment, the power supply system of an a-c receiver may be divided into basic sections, so that each section may be analyzed and explained separately. This has been done in Fig. 2, where the relation between the various sections is illustrated in block form. You will observe that they comprise:

1. The power transformer.
2. The rectifier.
3. The filter circuit.
4. The voltage divider.

These will now be described in the order named.

THE POWER TRANSFORMER

The power transformer is a conventional iron-core transformer, having a single primary and several secondary windings. Transformers of this type appear in Fig. 3, while the symbol for such a transformer is shown in Fig. 4.

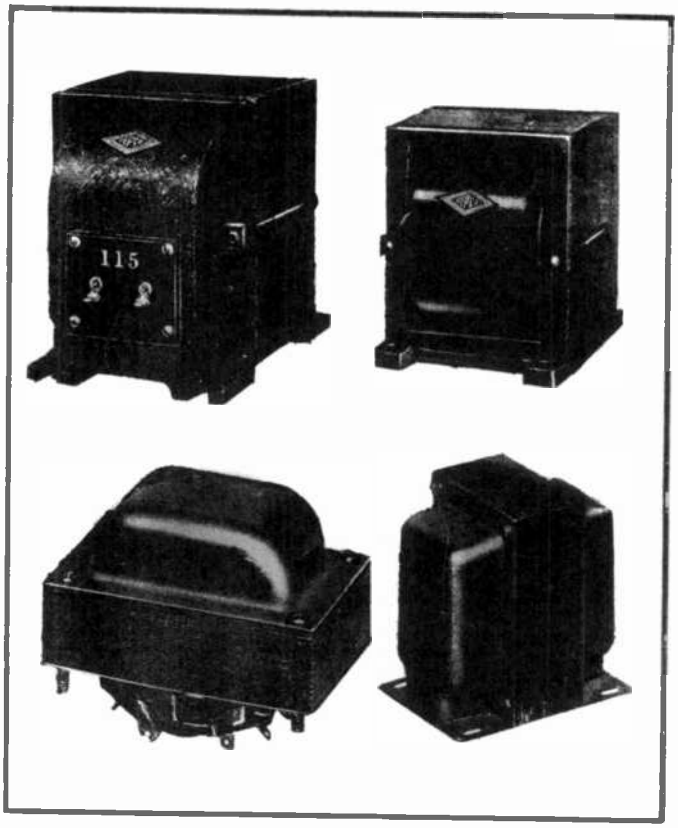


FIG. 3
POWER TRANSFORMERS OF VARIOUS DESIGNS

Two of the secondary windings on this transformer contain fewer turns of wire than are employed on the primary winding, and thus provide a step-down in voltage. These two secondaries are therefore logically called "low-voltage secondaries". They supply the low-voltage alternating current which is required by the heater circuits of the tubes, the dial lights, and other parts of the receiver which operate on low-voltage a-c.

One of the power transformer's secondary windings contains many more turns than does the primary, and therefore provides a step-up in voltage. We call this the "high-voltage secondary" to distinguish it from the other two secondaries. By means of this high-voltage secondary, the 110 volts delivered to the primary by the power line is stepped-up to several hundred volts, after which it is converted to direct current and applied to the plate, screen grid, and other high-voltage circuits of the receiver, as will be explained later.

Usually, one of the low-voltage windings supplies 5 volts, and the other 2.5 volts or 6.3 volts. The high-voltage winding generally supplies from 350 to 400 volts. However, the number of secondary windings used --- and their voltage rating --- varies on different transformers designed for specific applications.

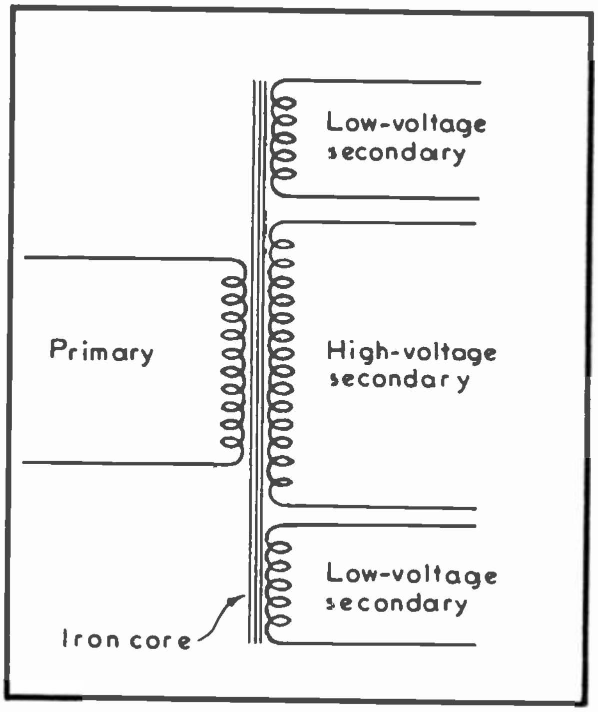


FIG. 4
POWER TRANSFORMER SYMBOL

THE RECTIFIER

The rectifier section of a power supply system converts the a-c output of the transformer's high-voltage secondary winding into pulsating direct current. As all power supply rectifiers used in present-day a-c radios are of the vacuum tube type, we will, at this time, confine our discussion to vacuum tube rectifiers.

Two distinct types of rectification are used in radio receiver power supply systems. One of these is known as half-wave rectification; the other, as full-wave rectification. As each of these types of rectification possesses certain characteristics that are different from those of the other, we will discuss them separately.

HALF-WAVE RECTIFICATION

Half-wave rectification is simpler, lower in cost, and requires a smaller power transformer than does full-wave rectification. Offsetting these virtues is the fact that the direct current delivered by a half-wave rectifier requires more filtering before being suitable for use in the receiver; and receivers using this form of rectification seldom provide the hum-free reception obtainable by the use of full-wave rectification. However, half-wave rectification is employed in many of the cheaper receivers.

APPLICATION OF HALF-WAVE RECTIFIER TUBE

In Fig. 5(A), you are shown a multi-secondary transformer, the high-voltage secondary winding of which is connected across a load resistor R. You will note that an a-c voltage is being applied to the primary winding. An alternating current of higher emf. is induced into the high-voltage secondary, and flows through the load resistor, as pictured by the curve appearing to the right of this resistor in Fig. 5(A).

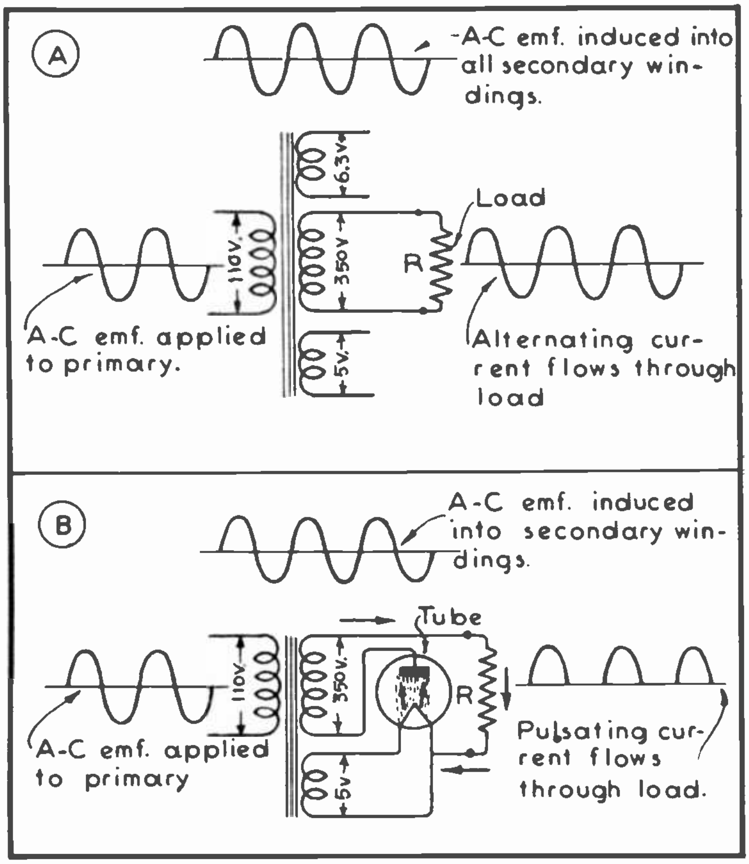


FIG. 5
HALF-WAVE RECTIFIER CIRCUIT

In Fig. 5(B), a diode (two-element tube) has been placed in series with the high-voltage secondary winding and the load. The 5-volt secondary is connected across the filament of the tube, thus heating it. The diode permits current to flow through it from the heated filament to the plate whenever a positive voltage is applied to the plate, but never when a negative potential is applied to the plate. Current can therefore only travel through the load resistor in one direction. This is illustrated in the graph at the right, which shows that a pulsating direct current now flows through the load circuit. Observe, also, that for each complete cycle (two alternations) of a-c emf. induced in the secondary winding, one pulsation of current flows through the load resistor.

OPERATION OF HALF-WAVE RECTIFIER

A step-by-step analysis of the operation of a half-wave rectifier is shown in Fig. 6.

An a-c emf. is being applied to the primary winding. At (A), the polarity of the emf. which is being induced into the high-voltage secondary is such that the plate of the rectifier is positive. As electrons will flow freely from the heated filament to the positively charged plate, a surge of current passes through the tube, high-voltage secondary winding, and the load resistor --- all of which are connected in series to complete the circuit. This current pulsation is shown on the graph of the output current at the extreme right.

At Fig. 6(B), the polarity of the line voltage and the emf. induced in the high-voltage winding has changed so that the plate of the rectifier is now negative. As no electrons will leave the cold plate to pass to the filament, no current flows through the rectifier's load circuit at this time.

In Fig. 6(C), the induced emf. has again undergone a reversal of polarity, the plate of the rectifier being positive once more. Therefore, another surge of current flows through the tube, as shown on the output graph.

Thus, you can see that whenever the induced emf. causes the plate of the rectifier tube to be positive, a surge of current flows through the circuit in which is incorporated the transformer's high-voltage secondary, rectifier and load. When the induced emf. makes the plate of the rectifier tube negative, the current flow through this circuit becomes zero.

A clear comparison between the sine wave of the induced high-voltage emf. and the rectified output current is shown in Fig. 7, where you will observe that one pulsation of direct current is produced for every two alternations of a-c emf. induced in the high-voltage winding. As most power transformers are operated on an a-c emf. of 60 cps, there will be 60 pulsations of direct current per second in the output circuit.

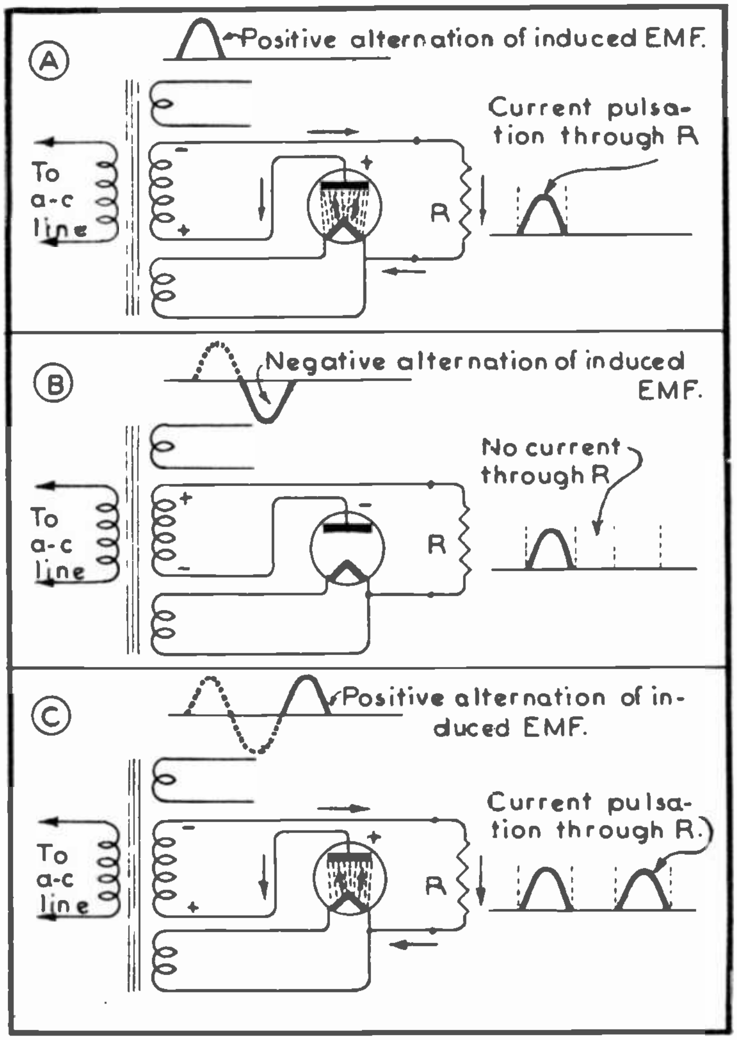


FIG. 6
ANALYSIS OF HALF-WAVE RECTIFICATION

FULL-WAVE RECTIFICATION

The full-wave rectifier differs from the half-wave rectifier in that for each complete cycle (two alternations) of a-c emf. induced in the high-voltage secondary, two complete pulsations of direct current appear in the output circuit. That is, instead of a 60 cps induced emf. providing 60 pulsations of direct current per second, 120 pulsations of direct current will appear in the output of the rectifier. This results in a much smoother rectified current which requires less filtering before it is fed to the vacuum tube circuits of the receiver.

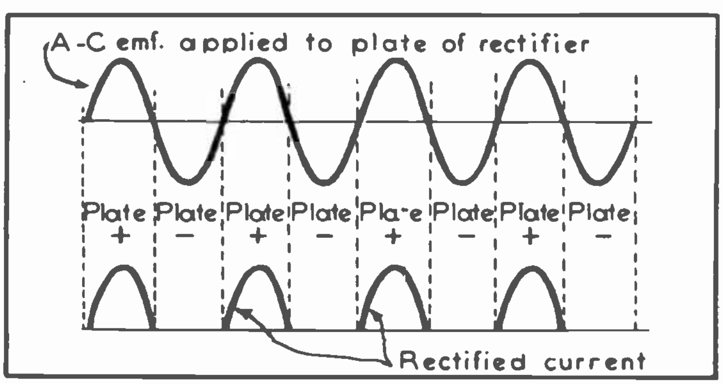


FIG. 7
COMPARISON BETWEEN A-C INPUT VOLTAGE AND RECTIFIED OUTPUT CURRENT

This characteristic is so important that the slight additional cost, and the increased size of the transformer necessary to secure this form of rectification, are more than offset by the improved performance and greater efficiency of the receiver.

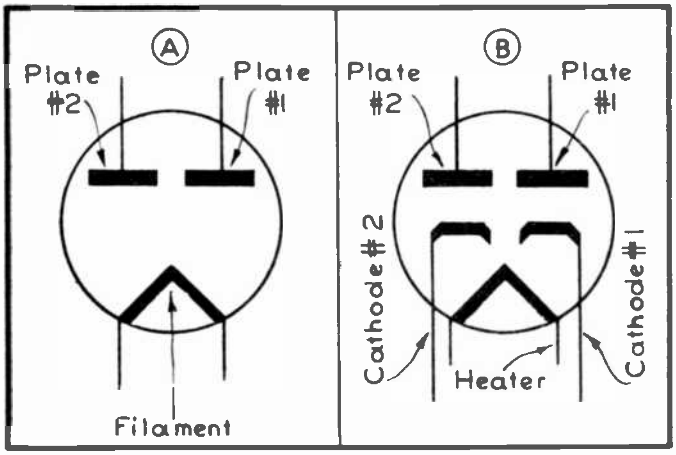


FIG. 8
SYMBOLS OF RECTIFIER TUBES

FULL-WAVE RECTIFIER TUBES

In modern radio receivers, full-wave rectification is secured by means of a duo-diode tube. The duo-diode tube consists of an evacuated envelope which contains two separate plates; and either a filament that serves as a cathode for both plates, --- or two separate, indirectly-heated cathodes (one for each plate).

In Fig. 8(A), you are shown the symbol of a filament type duo-diode. In this tube, the single filament supplies electrons for both plates; that is, electrons which are emitted from the filament will be attracted to whichever plate is positively charged at the time.

Fig. 8(B) shows the symbol of a duo-diode having two "separately-heated" cathodes; one for each plate. You will note that the two cathodes are indirectly heated by current flowing through the heater (filament) of the tube. Electron flow will then take place between that cathode which is at the time negative with respect to its corresponding positively-charged plate.

THE CENTER-TAPPED, HIGH-VOLTAGE WINDING

Power transformers designed for use in full-wave rectifier circuits are equipped with a center-tapped high-voltage secondary winding. "Center-tapped" secondaries are so named because a lead is brought out from their electrical and physical center at the time of manufacture. The turns-ratio is such that double the final desired a-c emf. will be developed across the extreme ends of the high-voltage winding. Measured from the center-tap (c.t.) to either end of this winding, the voltage will be equal to the desired emf. This is shown in Fig. 9, where it is desired that 350 volts be applied to each half of the full-wave rectifier tube with which this transformer is to be used. Therefore, a total of 700 volts must be developed across the entire high-voltage winding; or 350 volts on either side of the center tap.

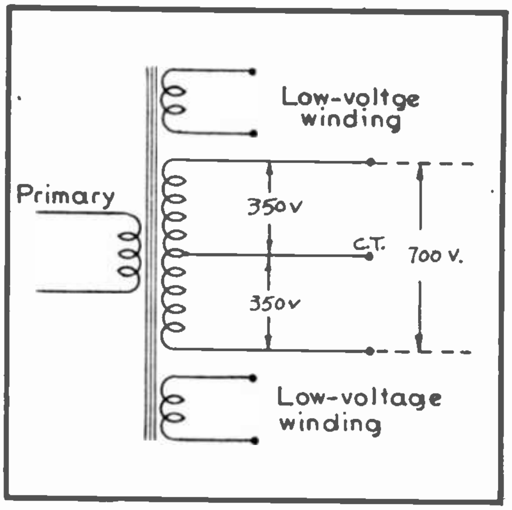


FIG. 9
POWER TRANSFORMER WITH CENTER-TAPPED HIGH-VOLTAGE WINDING

FULL-WAVE RECTIFICATION USING FILAMENT-TYPE DUO-DIODE

In Fig. 10, you are shown a full-wave rectifier circuit in which a duo-diode and center-tapped high-voltage secondary are employed. You will note that the tube being used here has a filament-type cathode, which is common to, or serves, both plates.

The two-section drawing in Fig. 11 shows the action of this circuit. When the a-c emf. induced in the high-voltage secondary is of such polarity that plate 1 of the tube is positive and plate 2, negative, current will move through the circuit from the center tap, through the load to the filament; and then in the form of a stream of electrons to plate 1, from whence it returns to the high-voltage secondary winding of the transformer. This current flow is indicated by arrows at (A) of Fig. 11.

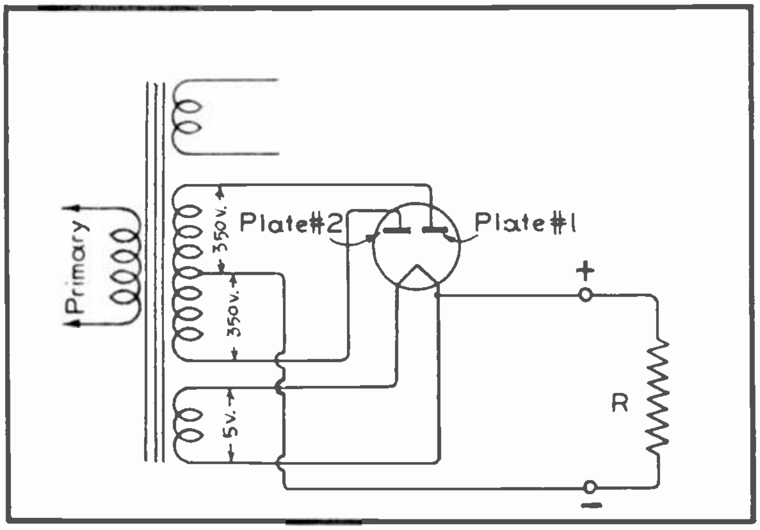


FIG. 10
FULL-WAVE RECTIFIER CIRCUIT

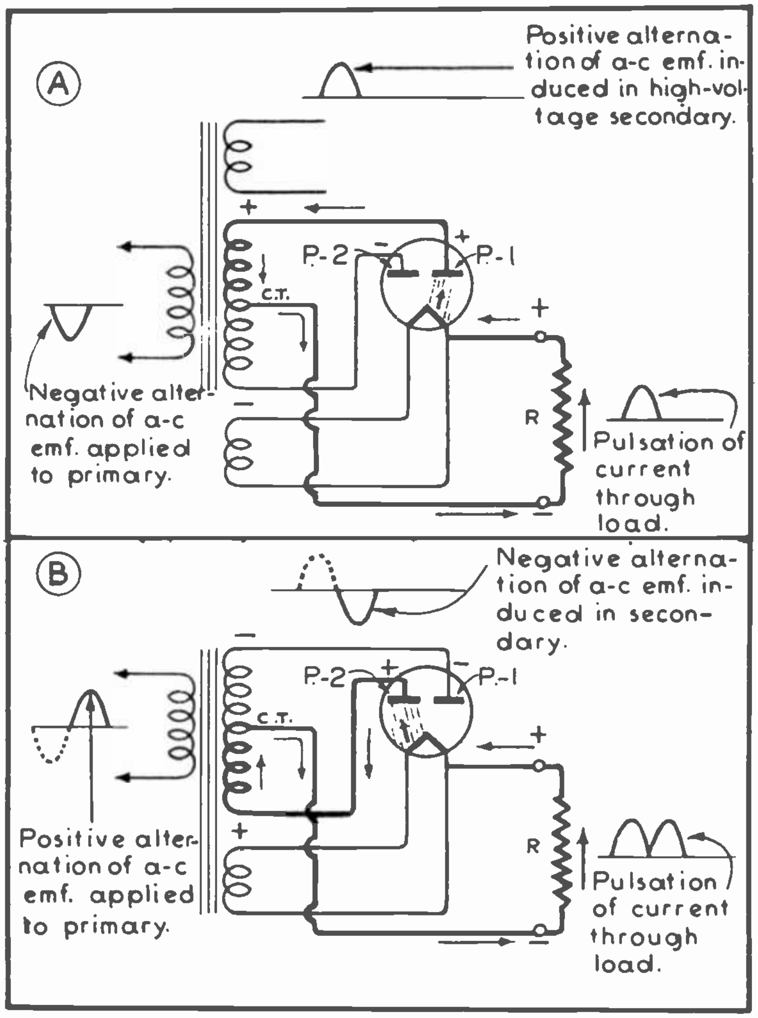


FIG. 11
ANALYSIS OF FULL-WAVE RECTIFICATION

When the polarity of the induced a-c emf. is such that plate 2 of the tube is positive and plate 1 negative (as at "B" of Fig. 11), current will move through the circuit from the center tap of the transformer's high-voltage secondary, through the load to the filament; and then in the form of a stream of electrons to plate 2. From plate 2, it returns to the high-voltage winding.

Thus, for each alternation of induced a-c emf. in the high-voltage secondary winding (regardless of its direction), there will be a surge of current in the output circuit of the rectifier. Or, each complete cycle of induced a-c emf. will produce two surges of direct current in the output circuit. Notice further that the center tap of the high-voltage transformer is always negative with respect to the load resistor R, while the filament or cathode is positive with respect to this resistor.

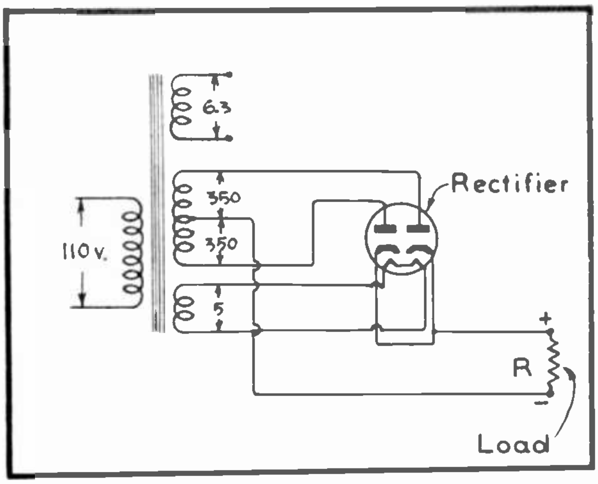


FIG. 12
APPLICATION OF TWIN-CATHODE RECTIFIER

FULL-WAVE RECTIFICATION USING SEPARATE CATHODE DUO-DIODE

In Fig. 12, you are shown the same fundamental full-wave rectifier circuit as appears in Fig. 10, with the exception that a duo-diode having two separate indirectly-heated cathodes is now being employed in place of the single, filament-type cathode. You will note that the two cathodes are connected together, and that the functioning of the tube in terms of electronic action is exactly the same as the one presented in Fig. 11. That is, both cathodes emit electrons simultaneously, which electrons are attracted to whichever of the two plates is positive at the time.

FULL-WAVE RECTIFICATION USING TWO DIODES: Having been shown how full-wave rectification is secured by the use of a duo-diode, you will readily realize that the same results can be obtained by using two separate diodes. A circuit which contains two diodes, connected to provide full-wave rectification, is shown in Fig. 13.

Here, the filaments of the two tubes are connected in parallel across the low-voltage secondary. The plate of tube No. 1 is connected to one end of the high-voltage secondary, and the plate of tube No. 2 to the other end. Then, when the plate of tube No. 2 is positive, current will flow through this tube and the load circuit in the direction of the arrows in illustration (A).

When plate No. 1 becomes positive during the following alternation of the line voltage's a-c cycle, current flows through it and the load circuit as indicated by the arrows in illustration (B) of Fig. 13.

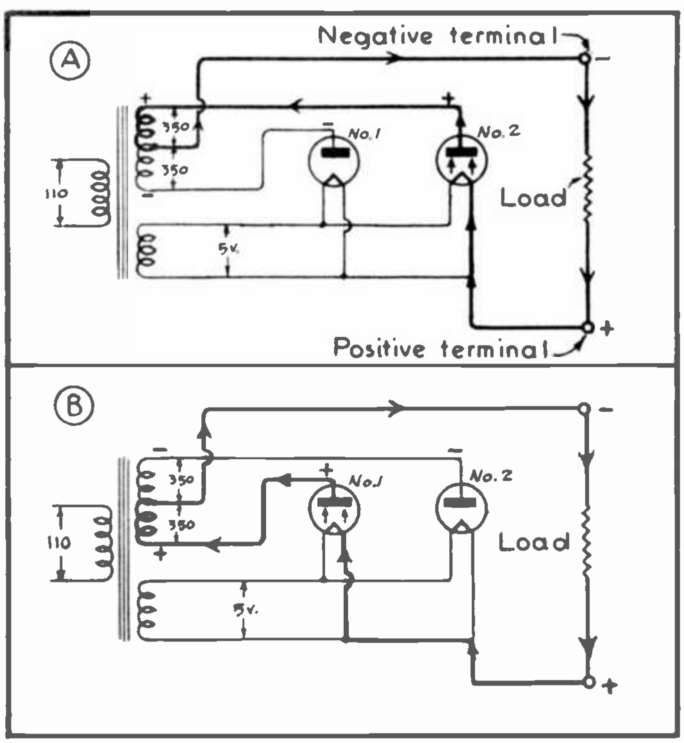


FIG. 13
FULL-WAVE RECTIFIER USING TWO DIODES

CENTER-TAPPED, LOW-VOLTAGE WINDINGS

The power supplies of many receivers contain transformers that have one or more center-tapped low voltage windings, in addition to the center-tapped high-voltage winding. The application of such a transformer is shown in Fig. 14. You will note that the center tap on the low-voltage winding which supplies filament current to the rectifier tube is being used as the positive side of the rectifier output; whereas the low-voltage secondary which supplies current for the heaters of the amplifier and detector tubes in the receiver has its center tap connected to ground, (the chassis). The purpose of a center tap on low-voltage windings is to reduce hum or other objectionable noises that might reach the signal circuits of the receiver by way of the power line.

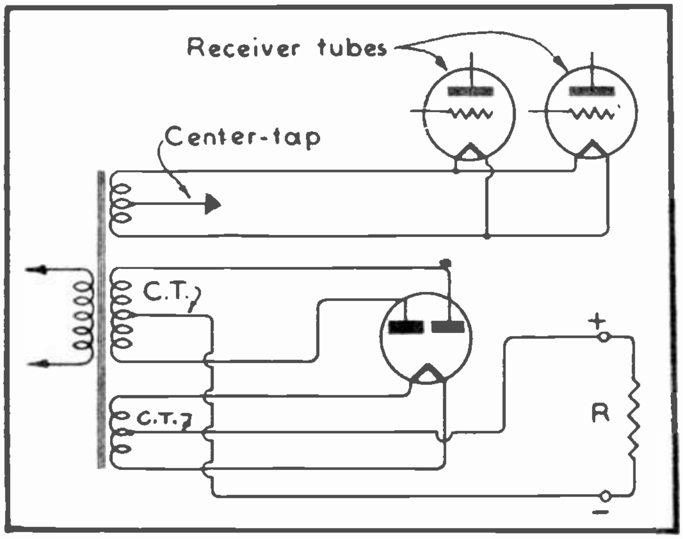


FIG. 14
CENTER-TAPPED LOW-VOLTAGE SECONDARIES

FILTER CIRCUITS

You have just been shown how alternating current from the power line is stepped up in voltage by the transformer, and then converted into pulsating direct current by the rectifier. As the plate and screen grid circuits of the receiver, as well as the electrodynamic speaker (if used), require a current which is very steady in value, or <u>pure d-c</u>, it is necessary to convert the pulsating current produced by the rectifier into <u>uniform</u> direct current. This is done by the <u>filter circuit</u>.

The filter circuit consists of a network of iron-core coils and condensers, so arranged that this changing of pulsating current into pure direct current is accomplished by the ability of the condensers to store a charge of electricity, and the opposition offered by iron-core coils to any change in the value of current (amperage) flowing through their windings.

In Fig. 15, you are shown a simple, though much used, filter circuit. You will note that it is composed of two filter condensers, C-1 and C-2; and the iron-core coil, L-1. The two terminals at the left of the diagram are known as <u>input</u> terminals; and those at the right as the <u>output</u> terminals. In the particular example shown, C-1 and C-2 each have values of 8 microfarads. L-1 has a value of 15 henries.

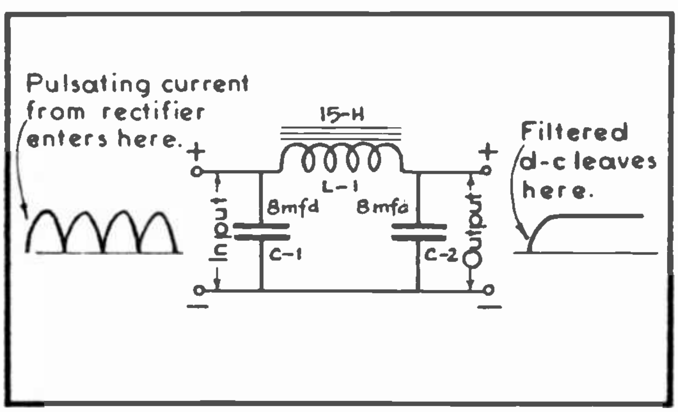


FIG. 15
FILTER CIRCUIT

Fig. 16 illustrates how this filter is connected to the rectifier.

ANALYSIS OF FILTER CIRCUIT OPERATION

The operation of this circuit can best be analyzed by describing how the various parts of the circuit (C-1, C-2, L-1) affect the output of the rectifier.

In Fig. 17(A), the circuit connections are such that the d-c current at the output

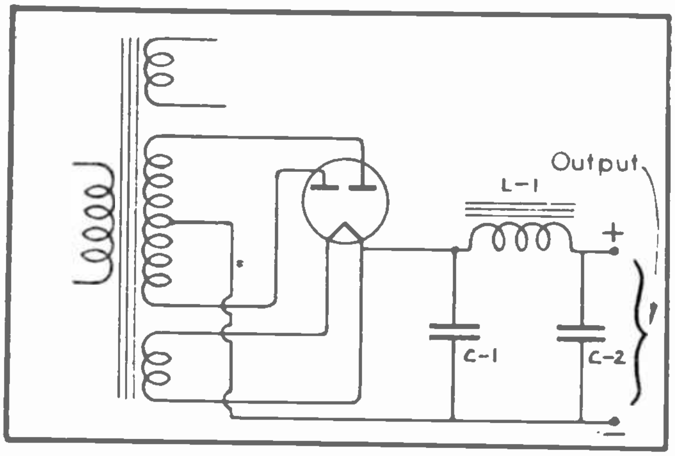


FIG. 16
FILTER CONNECTED TO RECTIFIER

of the filter must flow through resistor R. This resistor has been connected to our demonstration circuit for the purpose of providing a "load" or path of high resistance through which current may flow, and is equivalent to the actual load supplied by the plate and screen circuits of the various tubes which will eventually be connected to the power supply system. The current that flows through the load resistor is, of course, in the form of d-c surges --- following each other at the rate of 120 pulsations per second. Let us suppose that a d-c voltmeter, connected across the 50,000 ohm load resistor, indicates that 300 volts is being applied to the load by the power supply unit. With 300 volts available across 50,000 ohms of resistance, a current of 6 milliamperes will flow through this resistance.

EFFECT OF CONDENSER C-1: In Fig. 17(B), condenser C-1 has been connected to the output of the rectifier. No other changes have been made. The same d-c voltmeter, connected across the output, would now show us that the voltage across the load resistor has increased from 300 volts to 350 volts. Since the voltage applied to the load has been increased, the current through the load must also increase; so, instead of 6 milliamperes, 7 milliamperes will now pass through the load. Thus, the effect of condenser C-1 in the circuit is to increase the rectifier output voltage and current. The series of illustrations in Figs. 17 and 18 show how this raising of voltage and current is accomplished by the condenser.

When the current and voltage of any one pulsation in the rectifier output is building up from zero toward peak amplitude, the condenser is being charged as at (B) of Fig.17. Then, when the peak value of this current surge is reached, the condenser has accumulated a charge whose voltage is equal to the peak voltage of the rectifier output. This action is illustrated by the horizontal row of small graphs at (A) and (B) of Fig. 18.

At the extreme left in row (A) of Fig. 18, you are shown how the emf. induced in the high-voltage secondary winding gradually increases. The graph directly to the right of this one shows how such an increase in the rectifier tube's plate voltage brings about a corresponding increase in rec-

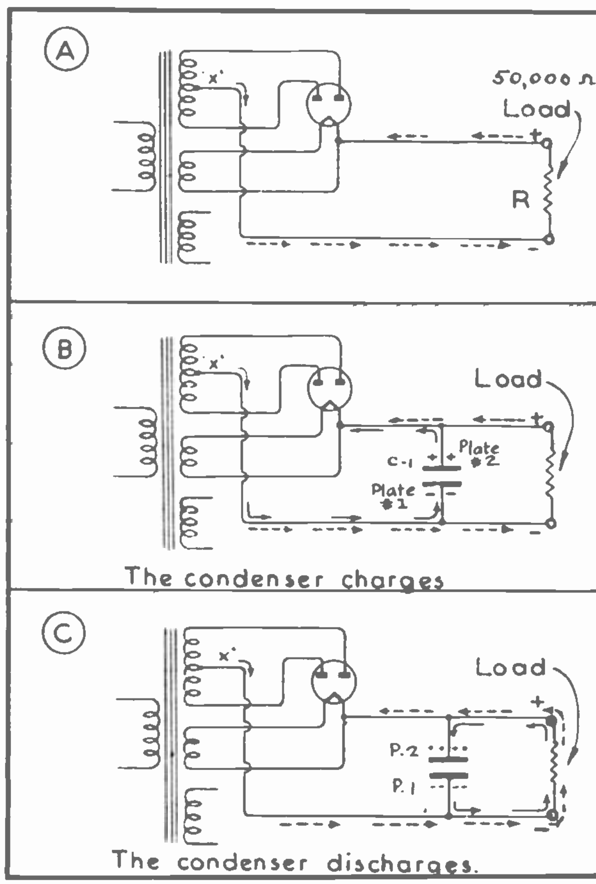


FIG. 17
HOW CONDENSER C-1 AFFECTS FILTER

tified current that starts to flow through the rectifier circuit from point "X". (Fig. 17.) The graph at the extreme right shows how the filter condenser accepts a charge during this time.

In a similar manner, the graphs in row (B) show plate voltage, rectified current and condenser charging conditions as they are when the plate voltage has attained its maximum value. It is to be noted that the voltage across the condenser and load resistor are both at their peak value.

Now, as the a-c voltage begins to decrease as shown at the left of row (C) in Fig. 18, the flow of rectified current also decreases; and the condenser begins to discharge through the load resistor as illustrated at (C) of Fig. 17, and also at the extreme right of row (C) in Fig. 18. This discharge of the energy stored by the condenser is then present in the circuit containing R, in addition to the declining current from the rectifier. The effect is to add to, or reinforce the output current. This brings about a considerable increase in the effective values of current and voltage, as the condenser discharge fills in the gaps between the pulsations of rectified current; and therefore the current and voltage at R never decline completely to zero, as they would if the condenser were not included in the circuit. All of this will become quite clear as you completely analyze Fig. 18, in alphabetical order.

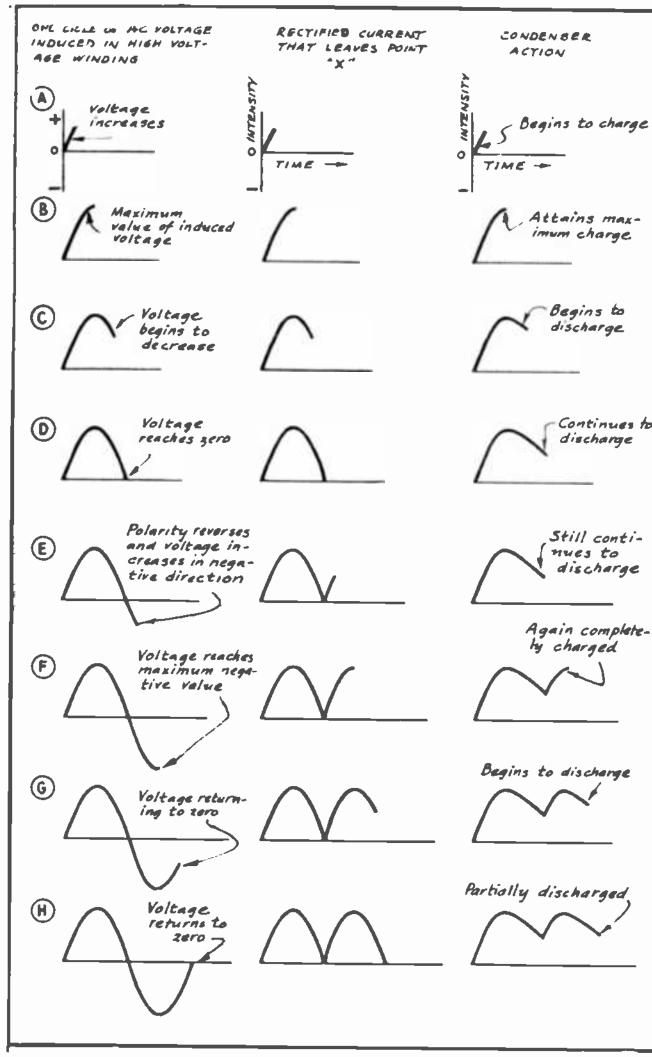


FIG. 18
EFFECT OF CONDENSER C-1 ON RECTIFIED OUTPUT

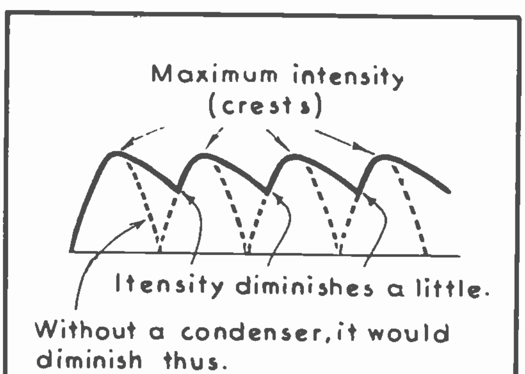


FIG. 19
CURRENT FLOW THRU LOAD

The output current is illustrated again, in greater detail, in Fig. 19. Here, the heavy line shows the reduced pulsation in the direct current flow through the load resistor because of the condenser's action, while the dotted lines show how the current in the load circuit would vary between maximum and zero if this condenser were omitted from the filter. Current of this type is often called "rippling current", and the alternate rise and fall of current above and below the average value, is sometimes called an "a-c ripple".

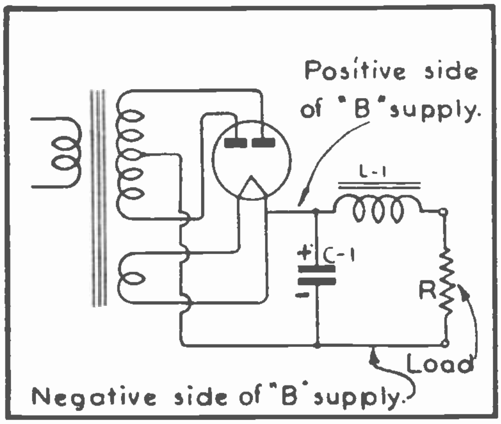


FIG. 20
CHOKE ADDED TO FILTER

ADDITION OF THE CHOKE TO THE FILTER

In Fig. 20, you are shown the same circuit as presented in Fig. 17, with the exception that a filter choke (L-1) of about 15 henries inductance has been added. You have previously learned that a choke coil (inductor) will offer great opposition to a varying current, and but slight opposition to a steady or non-varying current which is passing through its winding. Therefore, the choke will tend to prevent any change in the varying current which flows in the circuit shown in Fig. 20. This results in a more steady current at the output of the filter, with little or no variations or ripple in it. This is illustrated in Fig. 21.

The voltage across R has been reduced slightly by the addition of the choke, due to the voltage drop across it, and which must be subtracted from the total available voltage in order to get the voltage drop across R. As you have been told previously in this course, a voltage drop appears across any piece of electrical equipment through which current is passing, the amount of this drop being dependent upon the current flow through it and the resistance offered by it. This applies also to our filter choke.

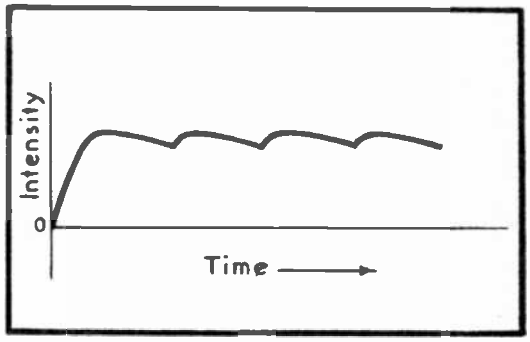


FIG. 21
EFFECT OF CHOKE ON FILTERED CURRENT

ADDITION OF THE SECOND FILTER CONDENSER

In Fig. 22, the second filter condenser, C-2, has been added to the circuit. This condenser has little or no filtering effect upon the output of the power supply, but it does serve an important purpose, which is to compensate for any sudden and momentary changes in the current requirements of the receiver that is being operated from this power supply. It does this by accepting a charge equal to the normal voltage of the power supply output. Then, if the current drawn by the receiver were to increase suddenly, C-2 would instantly discharge some of this stored charge through the load, thus compensating for the temporary increase in current drain. If the current drain of the receiver were to suddenly decrease, condenser C-2 would accept a greater charge and thus absorb some of the excess current momentarily present in the filter circuit.

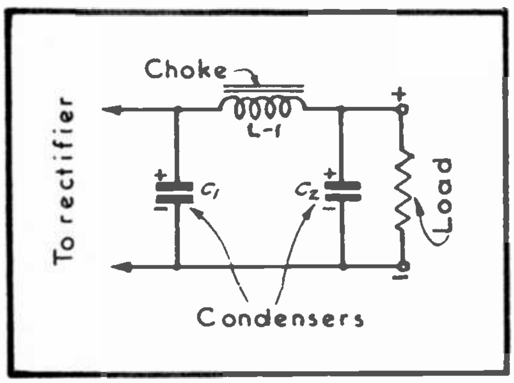


FIG. 22
CONDENSER C-2 ADDED TO FILTER

Thus, we can say that C-2 provides voltage and current regulation; or, it acts as an electrical "shock absorber". This more uniform flow of direct current which is now available at the output of the filter is illustrated graphically in Fig. 23.

VARIATIONS IN FILTER CIRCUIT DESIGN

The filter circuit just described is the most popular type now being used to operate receivers. A few variations of this design are shown in Fig. 24. You will note that these circuits differ only in the number of condensers and chokes they contain, and in the order in which they are connected. However, they all function according to the principles just explained.

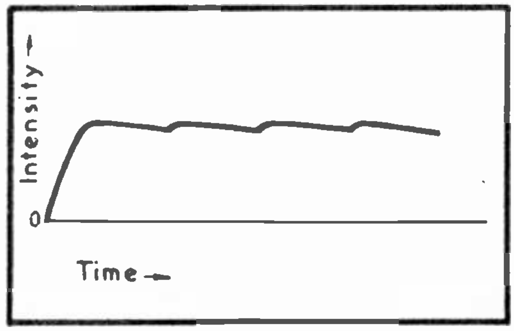


FIG. 23
EFFECT OF CONDENSER C-2 ON FILTERED CURRENT

The filter circuit at (A) of Fig. 24, for example, is identical to the one already described. Various names or terminologies have been applied to this particular circuit, including "brute force filter" and "condenser-input filter". It is best known by the latter name.

At (B), we have a filter which consists of two chokes and two condensers, and with a choke preceding a condenser at the input end. This is often called a "choke-input filter". The choke-input filter furnishes a more constant output voltage than does the condenser-input filter; however, for a given input voltage, the output voltage of a choke-input filter is not as high as that of a condenser-input system.

In circuit (C) of Fig. 24, three condensers and two chokes are included in the filter. This arrangement provides more filtering action than either circuit (A) or (B).

At (D) of Fig. 24, the choke is connected in the negative side of the filter circuit, rather than in the positive side. However, the same basic principles of filtering apply in either case, because the choke is connected in series with the output of the filter and load resistor in both systems.

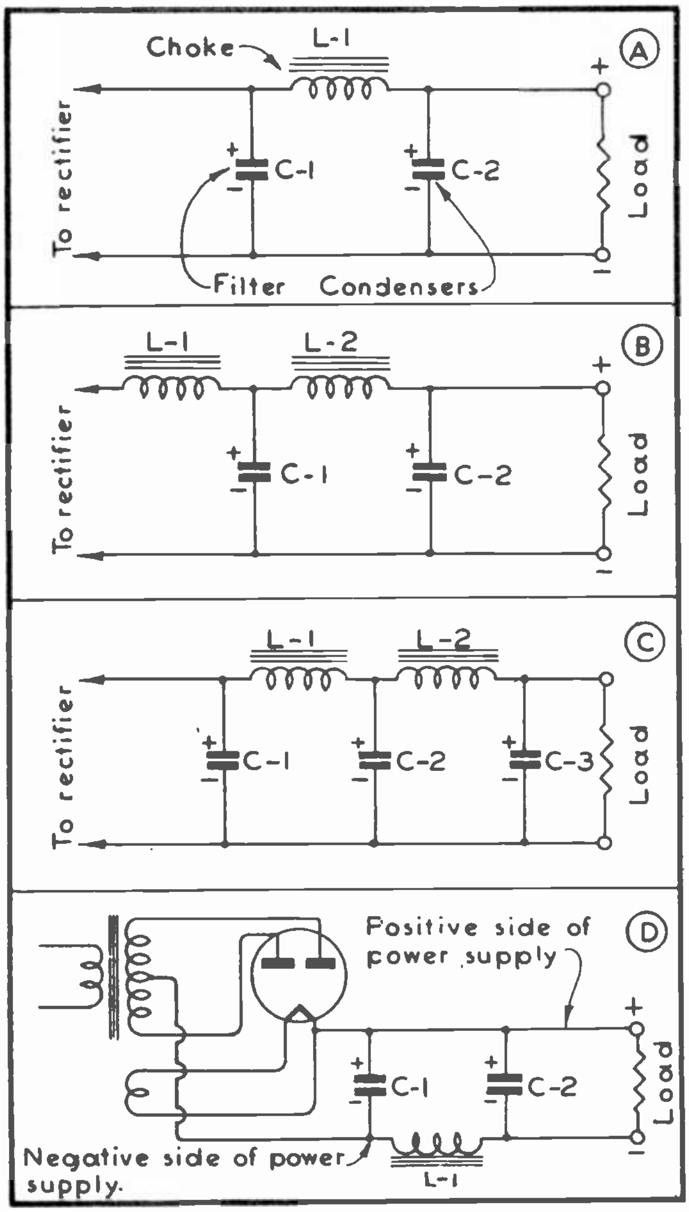


FIG. 24
VARIATIONS IN FILTER DESIGN

FILTER CONDENSERS

The condensers used in filter circuits are known as filter condensers. They are usually of the high-capacity type --- ranging all the way from about 4 to 60 microfarads. The dielectric of filter condensers must be able to stand the highest voltage which will ever be applied to them in service.

PEAK VOLTAGE RATINGS OF FILTER CONDENSERS

You have previously learned, that in dealing with alternating or pulsating currents, two values of voltage must be considered. They are the peak, or maximum voltage, which is reached for only a brief instant during each alternation or pulsation; and the RMS, or effective voltage.

The peak voltage is always greater than the RMS voltage, and may therefore cause the dielectric of a condenser to break down if it is not capable of withstanding voltages as high, or greater than, the peak value encountered. Therefore, all filter condensers must be designed so that they will safely withstand temporary applications of peak voltages as high as, or higher than, are likely to be encountered in the filter circuit.

WORKING VOLTAGE

The effective, or RMS voltage, is considered to be applied to a filter condenser constantly, as long as the filter circuit has current flowing through it. It is always lower than the peak voltage. Since filter condensers must be able to withstand continuous application of the effective voltage, they are rated for it. This is generally called the "working voltage" rating of the condenser. The majority of condensers supplied by radio parts manufacturers have their ratings as to capacity, peak voltage, and working voltage printed on the body of the condenser itself. The technician is guided by these ratings when replacing defective condensers, and thus makes certain that the replacement condenser is an exact electrical duplicate of the original. (It need not necessarily be an exact physical duplicate, as condensers vary in shapes and sizes.)

DIELECTRICS USED IN FILTER CONDENSERS

Several different insulating materials are used as dielectrics in filter condensers. Most common among these are oil, waxed paper, mica, cellophane, and certain non-conducting gases. As far as filter circuits in receivers are concerned, our discussion may be definitely confined to two types; the paper-dielectric condenser, and the gas-dielectric condenser. The former are commonly called paper condensers; and the latter, electrolytic condensers. The term "electrolytic" is applied to gas-dielectric condensers because the insulating gases are generated or formed by an electro-chemical action, called "electrolysis", that takes place in the condenser.

PAPER FILTER CONDENSERS

Paper condensers were already described in a previous lesson. And, as you will no doubt recall, they consist of two long strips of metal foil (tinfoil or aluminum foil), separated by a slightly longer and wider strip of waxed paper; the whole being rolled into a compact bundle.

The advantages of paper condensers are that they may be made to withstand higher peak and working voltages than can the electrolytic types; and they have a somewhat longer natural life. The disadvantages of paper condensers are that they are usually rather bulky and therefore require more mounting space than do electrolytic condensers of equivalent capacity; and that even a temporary surge of current through their dielectric will generally damage them permanently.

ELECTROLYTIC FILTER CONDENSERS

Basically, the electrolytic condenser consists of a water-tight container, such as a copper can, filled with an electrolyte. The electrolyte is a solution of distilled water, borax and boric acid, to which is sometimes added a small amount of glycerine. A rod or bar of pure aluminum, called an electrode, (or anode), is suspended in the electrolyte, and insulated from the copper can. This is shown in Fig. 25.

OPERATION OF THE ELECTROLYTIC CONDENSER

In Fig. 25, the positive terminal of the battery is connected to the aluminum electrode (anode) of a basic electrolytic condenser, and the negative terminal to the copper can. Since the electrolyte is in contact with both the copper can and the aluminum electrode, and since a borax solution is a rather good conductor of electricity, current will flow from the can, through the electrolyte, to the positively charged aluminum electrode, and back to the battery. But, due to the electro-chemical action which takes place in any chemical solution through which current is passing, a gas will be generated in the solution. This gas, the exact composition of which is not known, is a very good insulator. As this gas is generated, it immediately forms a coating on the aluminum electrode.

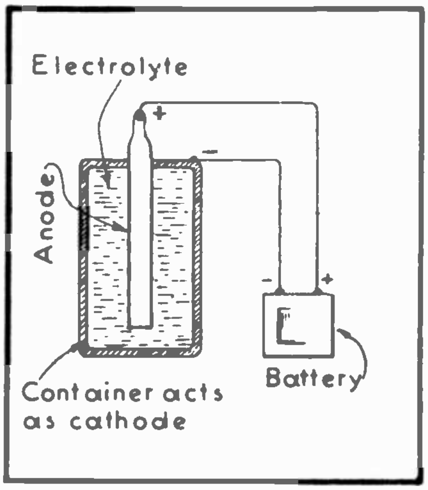


FIG. 25
SIMPLE ELECTROLYTIC CONDENSER

Thus, in a very few seconds, the aluminum electrode is completely covered with an exceedingly thin layer of non-conducting gas. This effectively insulates the electrolyte from this electrode, so that current can no longer pass from the electrolyte to the electrode. As we now have two conducting surfaces --- the electrolyte and the electrode --- separated by an insulator, you can see that all the essentials of a condenser are present.

The device will continue to function as a condenser as long as a d-c voltage is applied to its terminals. However, the aluminum electrode must always be connected to the positive terminal of the applied emf., in order to produce the electro-chemical action necessary to maintain the gaseous dielectric. All electrolytic condensers must undergo this forming process before being suitable for use.

If the negative terminal of the applied emf. were to be connected to the aluminum electrode, the gaseous dielectric would not be maintained. Therefore current would flow constantly through the device, preventing it from functioning as a condenser.

ADVANTAGES AND DISADVANTAGES OF ELECTROLYTIC CONDENSERS

The electrolytic condenser possesses several advantages over the paper condenser for some applications, particularly in power supply filters of radio receivers. As the layer of insulating gas which collects on the anode is exceedingly thin (from 1/1,000,000 to 1/100,000 inch thick), and as the capacity of the condenser is governed by its thickness, it may be readily understood that such a very thin dielectric makes it possible to have comparatively large values of capacity in a small space. Hence, it is possible to make an electrolytic condenser of a given capacity which is much smaller in physical size than would be a paper condenser of equal capacity. Another important advantage of electrolytic condensers is that in the larger capacities, they are much cheaper to manufacture than are paper condensers.

Also, to a certain extent, an electrolytic condenser is considered to be self-healing. By self-healing is meant that temporary surges of current through the dielectric, such as might be caused by a momentary application of too high a voltage, do not usually damage the condenser permanently. Of course, a prolonged voltage overload will destroy the condenser due to the internal heat generated by the passage of the heavy current resulting therefrom.

FIG. 26
ELECTROLYTIC CONDENSERS

The chief disadvantages of electrolytic condensers are that they can seldom be made to operate safely on voltages higher than about 450 volts, and the fact that no matter how well sealed the container may be, the electrolyte will eventually evaporate or dry-up so that the condenser must be replaced in time. Two typical electrolytic filter condensers are shown in Fig. 26. The one at the left is a single-anode type, while that at the right is a triple-anode type. The latter is actually the equivalent of three individual condensers, all housed in the same container that serves as the negative connection for all three units. This connection is made to the filter circuit by a metal strap, clamped firmly around the container. Connections to the positive side of the circuit are made by means of the terminals.

COMMERCIAL ELECTROLYTIC CONDENSERS

The inner construction of a commercial type single-anode electrolytic condenser is shown in Fig. 27. The anode, which consists of a corrugated tube of pure aluminum, is suspended in the center of the can so that it cannot make contact with the side-walls. A hard-rubber composition cover also prevents any possible electrical contact between the anode and the can. A check valve is installed in this cover to permit the gas formed within the container to escape before creating an excessive pressure. At the same time, this valve prevents dirt from finding its way into the condenser, and also prevents electrolyte from being sprayed out.

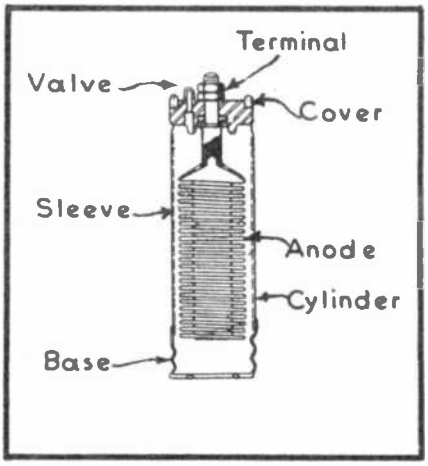


FIG. 27
CONSTRUCTION OF ELECTROLYTIC CONDENSER

A crimped gasket is installed between the cover and can to provide an air-tight joint at this point. The lower end of the can, here illustrated, is threaded to screw into a special socket and thereby provide a secure and conveniently made contact for the negative side of the circuit.

DRY ELECTROLYTIC CONDENSERS

The basic electrolytic condenser just described has been improved so that it is now available in a much smaller, "dry" form. The structural features of the so-called dry electrolytic condenser are shown in detail in Fig. 28.

The anode of this condenser is made of aluminum foil, which is subjected to a special electro-chemical forming process that completely covers one of its sides with a very thin film of oxide. This film acts as the dielectric of the condenser. (See "A" of Fig. 28.)

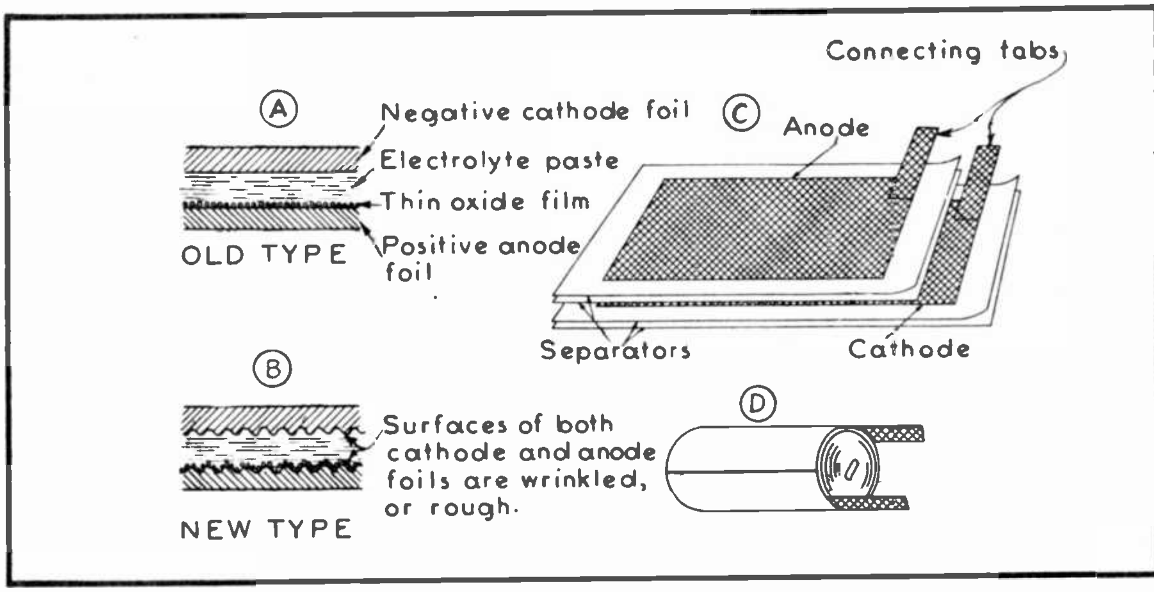


FIG. 28
CONSTRUCTION OF DRY ELECTROLYTIC CONDENSER

The oxide film on the surface of the anode serves as the dielectric by acting as a unidirectional conductor; that is, it conducts current in one direction only. In other words, when voltage is impressed between this film and aluminum foil in one direction, no current will flow, and we have a condenser effect; but, if the voltage be reversed, a fairly large current would flow --- and it will continue to increase if the voltage were applied for a longer time.

The electrolyte used in these condensers consists of a chemical mixture, in the form of a paste applied to an absorbent material such as gauze, paper or cellophane. This paste serves as the cathode; and at the same time, tends to maintain the film of the anode. The cathode plate or foil is also made of aluminum, but serves only as a connecting plate for the electrolyte, which is in reality, the cathode.

Illustration (C) of Fig. 28 shows the complete assembly, and how the electrolyte-bearing material is sandwiched between the anode and so-called cathode foil. This assembly, comprising the anode, electrolyte, and cathode is rolled into the form of a round cartridge from which two metal connecting tabs protrude. When this assembly is placed in the round metal housing, the tabs are connected to metal terminals imbedded in the insulating plug which fits in the end of the container, or, are connected to insulated wires.

In dry electrolytic condensers of more recent design, the electrolyte-contacting surfaces of the metal foil are etched or roughened.

This feature provides more effective plate area than was possible from the flat foil previously used, and thus results in a condenser of greater capacity without an increase in physical size. This form of construction is illustrated at (B) of Fig. 28.

While not dry in the absolute sense of the word, this type of condenser contains no spillable liquid, and may be made in an even more compact form than can the "wet" electrolytic condenser.

Dry electrolytic condensers are made in different capacities and with many different working ratings. When the condenser is to be used in a circuit operating at a low voltage, considerable capacity may be secured from a condenser of comparatively small size. The average dry electrolytic filter condenser, of say 8 microfarads capacity, will be in the form of a metal or paper cylinder about 1-3/8 inches in diameter and 6 inches long.

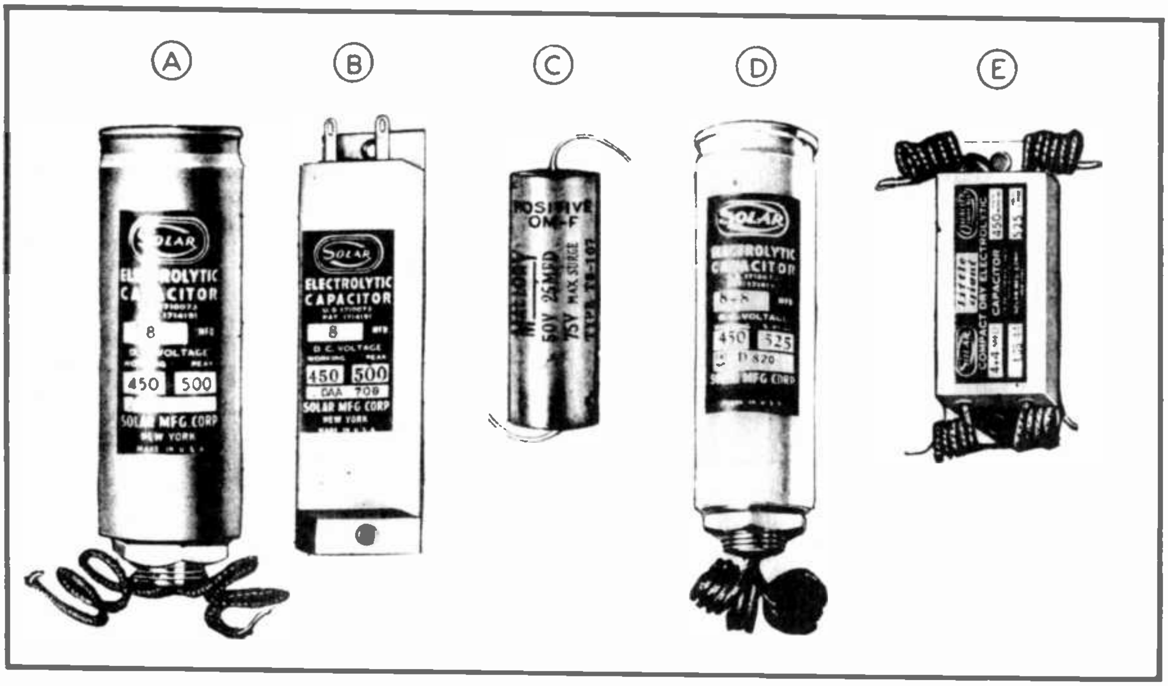


FIG. 29
DRY ELECTROLYTIC CONDENSERS

HOW ELECTROLYTIC CONDENSERS ARE CODED FOR POLARITY

The connecting leads or terminals of all electrolytic condensers (whether of the dry or wet type) are coded in some way to indicate their polarity; because the positive lead must always be connected to the positive terminal of the source of current being filtered.

Various methods of indicating polarity are used by different manufacturers of electrolytic condensers. Here are a few examples:

If terminals are supplied for connecting the condenser to the circuit, the positive terminal may be identified by means of a red plus (+) symbol stamped on the terminal, or near it. Sometimes, the positive terminal is colored red. Then again, the word "POSITIVE", or the abbreviation "POS" may be stamped near the terminal. Or, the terminals may be marked with little squares, triangles, or circles --- in which case, a code printed on the side of the condenser's container will tell you which of the terminals is positive.

If the leads are brought out in the form of insulated wires, the polarity will be indicated by the color of the leads. A red wire indicates positive; a black wire, negative. Where more than one condenser is assembled in the same container, and the connections brought out in the form of wires, you may find the positive leads to be red and blue, and the negative leads black and yellow, or black and brown; however, this is not a rigid rule.

Various designs of dry electrolytic condensers appear in Fig. 29. Although they may differ in size, shape and terminal arrangement, the basic principle of operation remains the same as already explained. Notice, particularly, at (D) and (E) of Fig. 29, how several condensers of this type may be grouped in a single container, the same as was previously described for wet electrolytics. The unit at (D) of Fig. 29, for instance, consists of two 8 mfd. condensers in a single metal container, equipped with three connector leads --- a common negative lead, and one positive lead for each 8 mfd. section. That at (E) of Fig. 29 consists of two 4 mfd. condensers in a paper case, and has two leads for each section.

FILTER CHOKES

The chokes which are used in filter systems are of the iron-core type. They are rated according to three important characteristics, namely: (1) Inductance; (2) Resistance; (3) Current-carrying ability.

The inductance values of chokes for this purpose vary from about 5 henries to as high as 60 henries.

The resistance rating of a choke is the pure ohmic resistance of its winding to a direct current. Resistances of filter chokes range from about 150 ohms to 800 ohms.

By the current-carrying ability of a choke is meant the maximum sustained current that can flow through its winding without causing it to overheat and burn out. These current ratings vary from about 10 milliamperes to as high as 500 milliamperes. Care should always be taken to be sure that the safe current-carrying capacity of a filter choke is not exceeded in service.

Two popular designs of filter chokes appear in Fig. 30. These are conventional single-winding iron core chokes of suitable inductance for the work they are to do, and are wound with wire of sufficiently large size to carry the required current.

It is common practice to provide an air-gap in the core of filter chokes, as shown in Fig. 31. The purpose of this air gap is to prevent magnetic saturation of the core, resulting from the flow of appreciable current through the choke's winding. Such saturation would reduce the choke's inductance appreciably and thereby impair its ability to function as a filtering device.

SPEAKER FIELD WINDINGS USED AS FILTER CHOKES

The field coil of an electrodynamic speaker requires direct current for its excitation. In many receivers, this requirement of the speaker field is utilized to advantage in the power supply system. Since the field

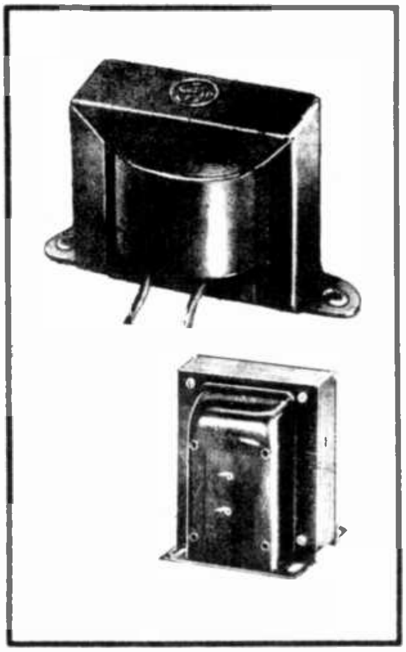


FIG. 30
FILTER CHOKES

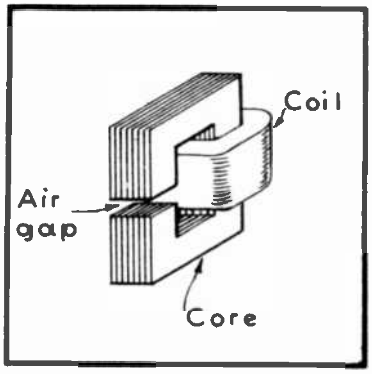


FIG. 31
CORE DESIGN OF
FILTER CHOKE

winding of such a speaker has electrical characteristics almost identical to those of a filter choke, the field winding can often be connected into the power supply circuit in place of the filter choke that would ordinarily be used at that point. Thus, the inductance of the field winding insures adequate filtering of the current flowing through it, and this same current simultaneously energizes the speaker field. This use of a speaker field coil in a filter circuit is illustrated in Fig. 32.

THE VOLTAGE DISTRIBUTION SYSTEM

A direct current of rather high potential (300 volts or more) is available at the output terminals of the filter just described. Now, if the d-c voltage requirements of the receiver to be operated therefrom were exactly 300 volts, we could simply connect the proper receiver circuits directly to the output of the power supply filter and thus secure the high-voltage direct current needed for proper operation. However, most receivers require plate and screen voltages of several different values. Therefore, it is necessary that some method be employed whereby it is possible to obtain these various voltages from the power supply system. This may be done in two ways. One is by the use of a voltage divider; the other is by means of individual load resistors.

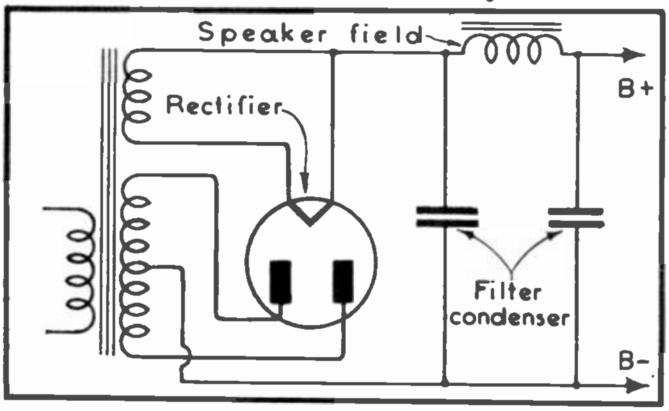


FIG. 32
SPEAKER USED AS FILTER CHOKE

VOLTAGE DISTRIBUTION, USING A VOLTAGE DIVIDER

You have already been shown how a voltage divider operates, and what it will accomplish. In Fig. 33, a voltage divider comprising three series-connected resistor sections is placed across the output of a filter. The top end of this voltage divider is positive (+); and the lower, or ground end, is negative (-).

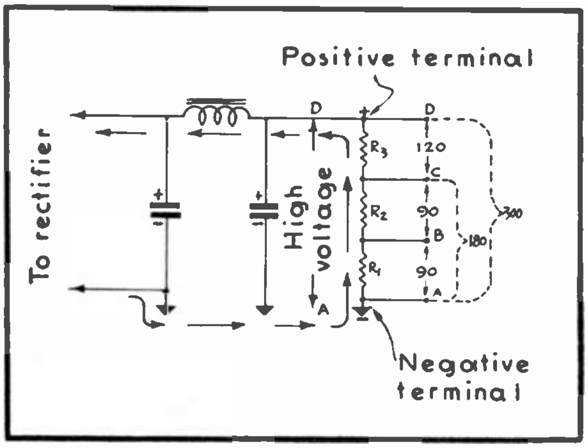


FIG. 33
VOLTAGE DIVIDER CONNECTED
TO OUTPUT OF FILTER

It is to be noted that the ground connection (denoted by the symbol ⏚) is made to the metal chassis or base on which the parts of this circuit are mounted --- the metal chassis structure thus serving to complete one side of the circuit just as though it were a copper wire. (This principle of grounding circuits was explained thoroughly in an early lesson of the course treating with Direct-Current Electricity.)

Now, the values of resistor sections R-1, R-2 and R-3 are such that the flow of rectified and filtered current through them will cause voltage-drops to appear across them, as indicated in Fig. 33. That is, 90 volts will exist between terminals A and B; 90 volts between terminals B and C; and 120 volts between terminals C and D. Therefore, 180 volts will be obtainable across terminals A and C, and 300 volts across terminals A and D. Observe that this latter value is equal to the total voltage output of the filter (90 + 90 + 120 = 300).

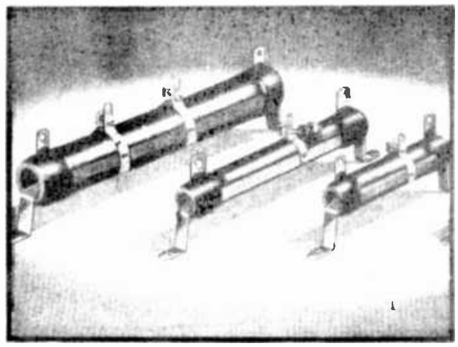


FIG. 34
VOLTAGE DIVIDER RESISTORS

Common forms of voltage divider designs suitable for this service appear in Fig. 34. In this particular case, the position of the two end terminals is fixed --- corresponding to terminals A and D in Fig. 33. The intermediate terminals are in the form of clips that contact bare portions of a continuous, coiled resistance wire that is partially exposed so that the clips can be moved along its length and clamped down on the resistor in the position necessary to furnish the voltage desired. The same effect may be obtained by connecting a group of individual resistors in series and making the various voltage connections to the different points at which they are united.

HOW TUBE CIRCUITS ARE CONNECTED TO A VOLTAGE DIVIDER

In Fig. 35, we have an example of how the voltage divider may be employed to apportion the different voltage values to various receiver circuits. In the particular case illustrated, 90 volts is being supplied to the plate of a detector tube, 180 volts to the plate of a 1st AF tube, and 300 volts to the plate of a power tube. The cathodes of the three tubes, and the negative end of the voltage divider, are grounded to the chassis (shown by the symbol ⏚), whence this common ground connection serves to complete the negative side of the entire circuit.

CURRENT DISTRIBUITION THROUGH VOLTAGE DIVIDER

Fig. 36 shows how the current supplied by the filter just discussed is distributed through the plate circuits of the three tubes, and also through the different resistor sections of the voltage divider.

Here, the solid, straight-line arrows (——►) represent a small current that flows through <u>each</u> resistor section without passing through any of the tube circuits. This is called the <u>bleeder</u> current, which may have a value of about 3 to 6 milliamperes. The bleeder current prevents the voltage across the filter condensers from reaching an excessively high value when the radio is first turned on, and until the tube filaments heat up sufficiently to pass plate current. As soon as all tubes pass their rated current, the total B current drawn by the receiver increases; and the voltage drops across the filter choke, rectifier tube, power transformer windings and other resistive loads

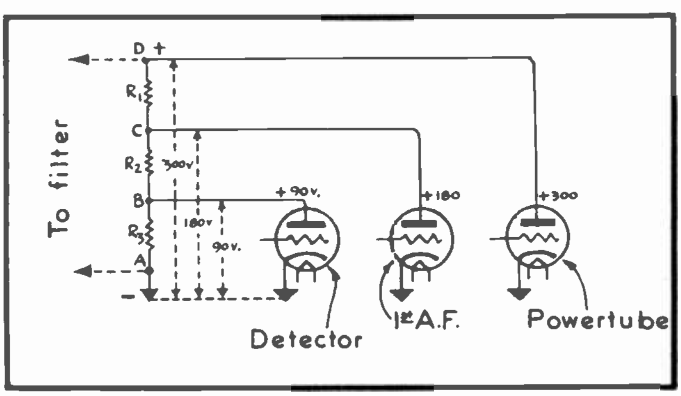


FIG. 35
HOW VOLTAGE DIVIDER IS APPLIED TO RECEIVER

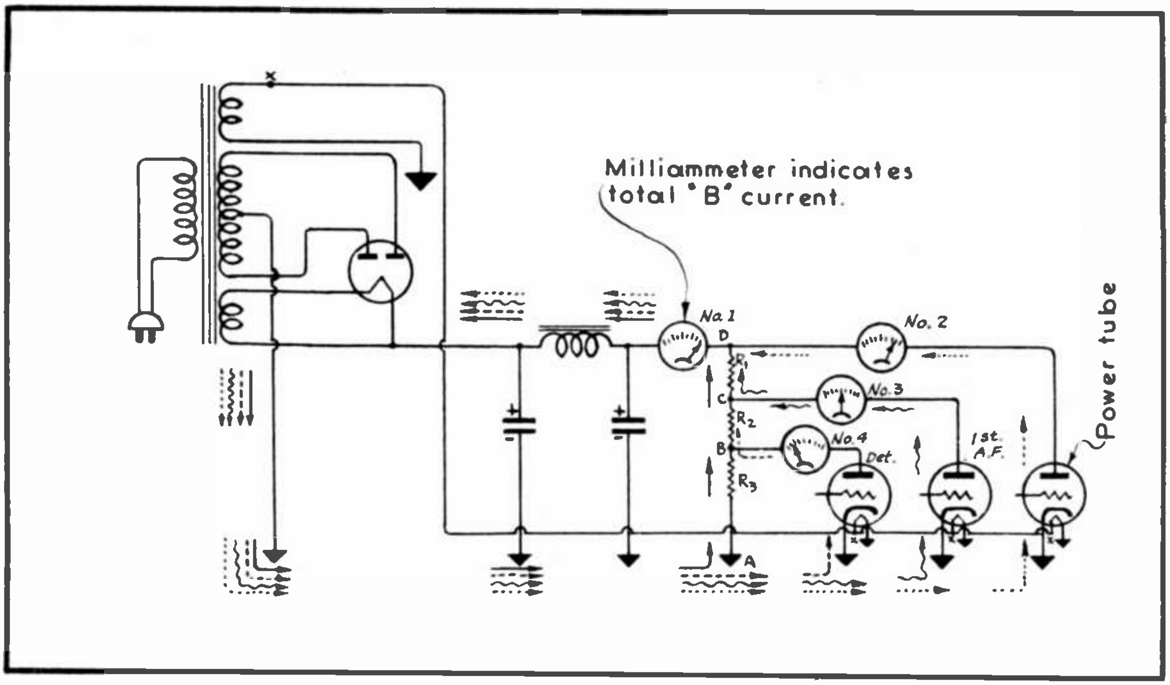


FIG. 36
CURRENT DISTRIBUTION THROUGH VOLTAGE DIVIDER AND RECEIVER

in the circuit then automatically decrease the voltages somewhat throughout all parts of the circuit.

The arrows drawn with dashes (---→) represent the plate current drawn by the detector tube; the wavy arrows (~~~→) represent the flow of plate current through the 1st AF tube; and the dotted arrows (·········→), that which flows through the power tube.

Notice, especially, how milliammeter No. 1 indicates the total current flow through the system. Milliammeter No. 2 indicates only the plate current of the power tube, none of which passes through the voltage divider. Milliammeter No. 3 indicates only the plate current of the 1st AF tube, which also flows through resistor section R-1 of the voltage divider. Milliammeter No. 4 indicates only the plate current of the detector tube, which current flows through resistor section R-1 and R-2.

An analysis of current distribution, as just given, is necessary when calculating resistor values for voltage dividers. Detailed instruction on this is given in a later lesson of the course. For the present, we are concerned only with this distribution of current as it affects the performance of the power supply and receiver, in general.

Fig. 36 shows also how the primary winding of the power transformer is connected to the lighting circuit, and how the heaters of the receiver tubes may be connected to their low-voltage secondary winding on the power transformer by using a common ground connection (the receiver chassis) to complete one side of this circuit; and a wired connection for the other. The wired connections for this circuit are made at the points marked "X" on the diagram, and the wiring arrangement is such that the heaters are connected in parallel. This is common practice in commercial receivers because it effects a saving in the amount of wire used, and enables the circuit connections to be made more easily.

APPLICATION OF INDIVIDUAL RESISTORS TO OBTAIN REQUIRED VOLTAGES

In Fig. 37, the circuit as a whole is similar to the one just described, but the voltage divider has been replaced by individual resistors.

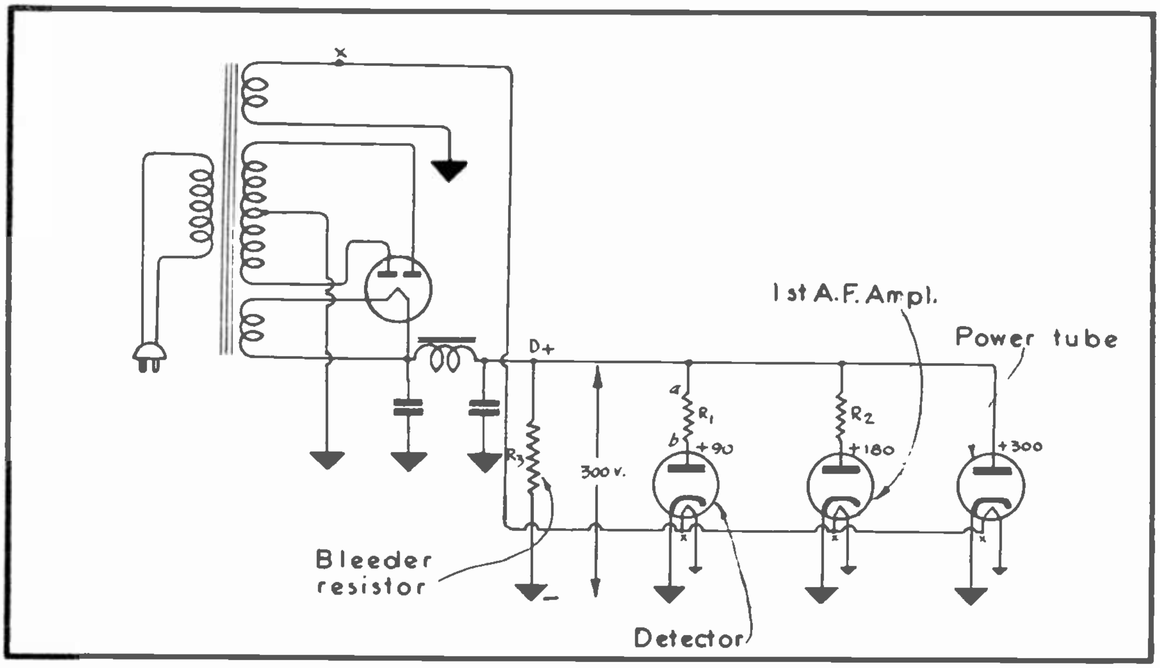


FIG. 37
INDIVIDUAL RESISTORS USED FOR VOLTAGE DISTRIBUTION

Here, the single resistor R-3 is connected directly across the output of the filter, thus serving to pass the bleeder current. It is therefore called a "bleeder resistor". Observe that 300 volts d-c is available across R-3, end D being positive with respect to the ground end. Since the cathodes of all the receiver tubes are at ground or B minus potential, and since 300 volts plate emf. is required by the power tube, we connect the plate of the latter direct to point D.

The 1st AF tube, on the other hand, needs a plate emf. of only 180 volts, so we place the resistor R-2 between it and the 300 volt line. The value of this resistor must be such that a drop of 300 minus 180, or 120 volts, will appear across it when conducting the plate current to this AF tube.

The detector tube requires only 90 volts on its plate, so we place resistor R-1 between it and the 300-volt line. Here, the flow of the detector tube's plate current through R-1 must produce a drop of 300 minus 90 or 210 volts between points "a" and "b".

BY-PASSING VOLTAGE DIVIDER RESISTORS

When using a voltage divider as a means of voltage and current distribution, it is customary to connect a condenser between each of the B+ terminals and the negative side of the rectifier circuit, as in Fig. 38.

Some of the receiver circuits which are connected to the voltage divider terminals carry a-f and r-f currents. If these currents were to reach the voltage divider and flow through its various resistor sections, a-c voltages of corresponding frequency would be developed across them. These voltages may find their way through the voltage divider into other circuits of the receiver where their presence can cause complications in the form of squealing or howling sounds being emitted by the loudspeaker, or otherwise prevent the receiver from operating properly.

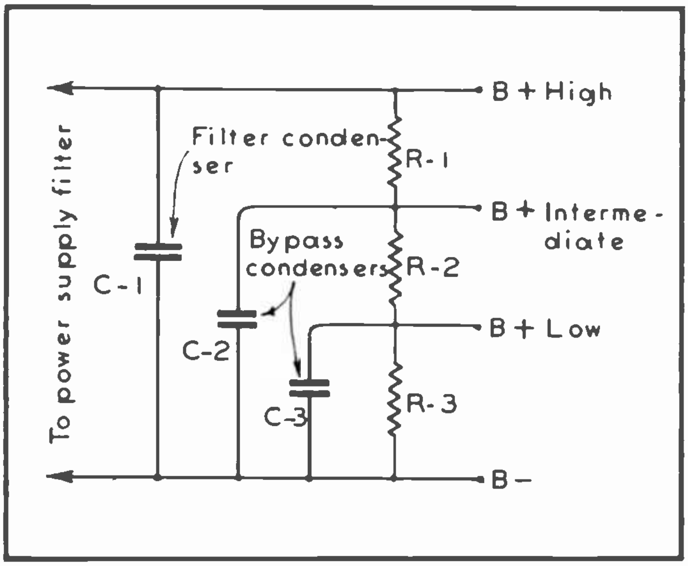


FIG. 38
BY-PASS CONDENSERS USED AT VOLTAGE DIVIDER

However, a condenser connected between each B plus terminal of the voltage divider and B minus, as in Fig. 38, presents a low reactance to these a-f and r-f voltages. These voltages therefore react through the condenser and are thus virtually "short circuited" around the resistor across which the condenser is connected. Consequently, only d-c voltages exist between the voltage divider terminals --- all a-f and r-f voltages being made ineffective by the condenser.

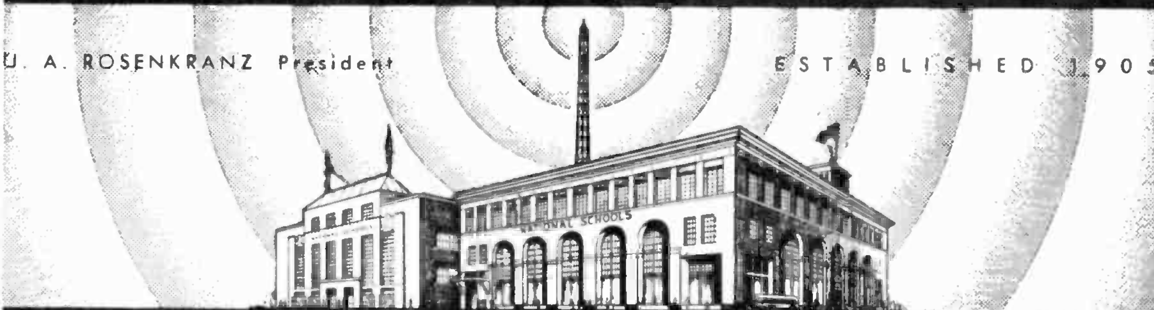
Because of the duty they perform, condensers used for this purpose are called by-pass condensers. Observe in Fig. 38 how condenser C-1 serves also as a by-pass condenser across the entire voltage divider.

In the lessons immediately following, you will learn about the r-f amplifier, a-f amplifier and the detector stage --- as used in radio receivers. You will then be shown exactly how the power supply is connected to each of the receiver sections so as to make their operation possible.

It is to be noted also that what you have learned in this lesson concerning power supplies is applicable as well to sound amplifiers, transmitters, television equipment, etc. In fact, to all kinds of electronic apparatus that derives high-voltage d-c and low-voltage a-c from an a-c lighting system.

Practical Technical Training In
RADIO·TELEVISION
AND ALLIED ELECTRONICS

J. A. ROSENKRANZ President ESTABLISHED 1905



NATIONAL SCHOOLS ★ LOS ANGELES 37, CALIF.

LESSON NO. 13

RADIO – FREQUENCY AMPLIFICATION

Before commencing the study of this lesson, it is advisable to first review thoroughly the lessons titled "Principles of Radio Communication" and "How Radio Receivers Operate", which you received earlier in the course. Give special attention to the way in which the modulated signal wave is picked up by the receiver's antenna, and how the handling of this signal by the detector enables the headphones or loudspeaker to convert it into sound. By refreshing your memory on these subjects, you will find this lesson on radio frequency amplification easy to master.

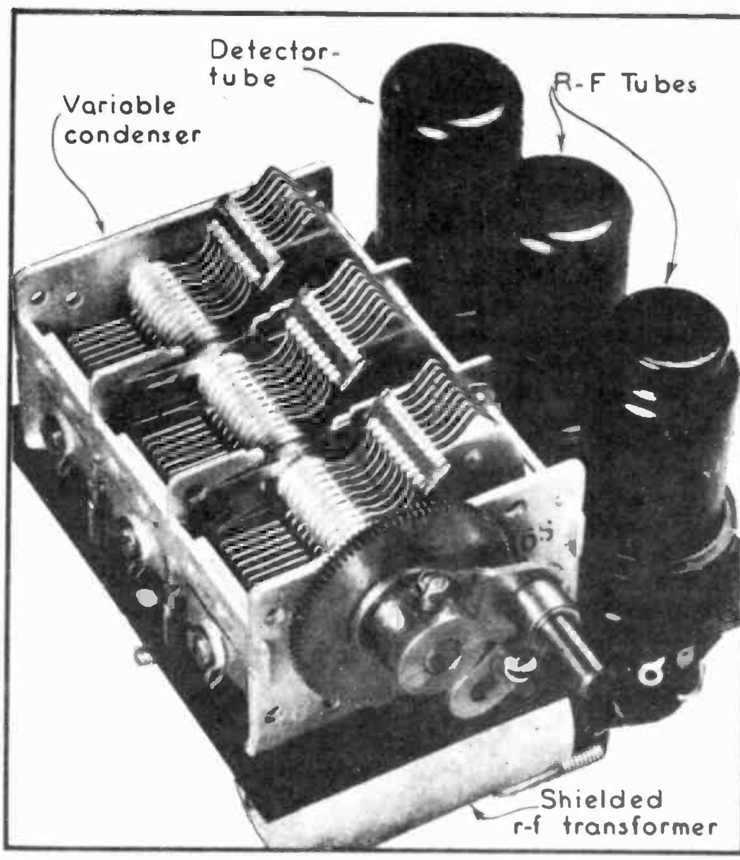


Fig. 1
Compact R-F Amplifier Assembly

WHY RADIO FREQUENCY AMPLIFICATION IS NEEDED

Theoretically, all radio waves cause an r-f current to flow in the receiver's antenna. Of course, the location and power of each individual transmitter has an influence upon the intensity of the r-f current

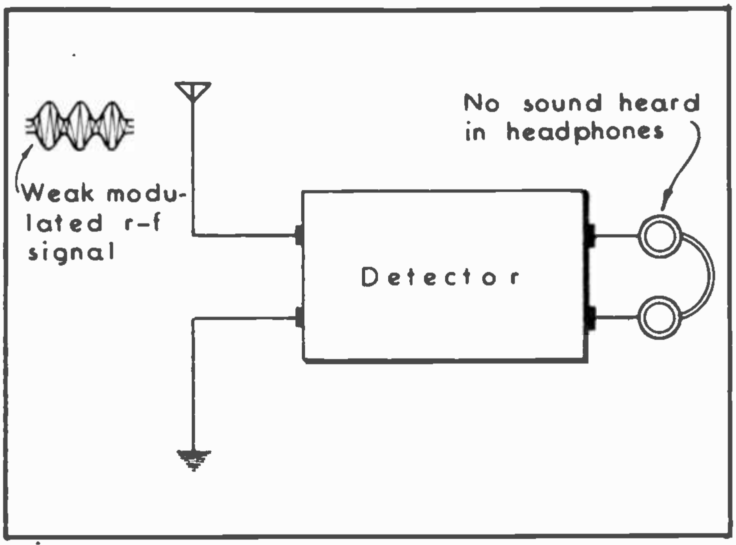


FIG. 2
SIGNAL TOO WEAK FOR DETECTION

which it is able to induce in the receiver's antenna circuit; but all of them transfer some energy to it, although it may be very feeble. These points have already been dwelled upon previously, and are recalled now to help give you a clear picture of why radio frequency amplification is necessary in a receiver.

In Fig. 2, we have a block diagram of a detector (or simple receiver). Let us assume that the signal of a powerful, nearby transmitter is being received satisfactorily; but that upon tuning our receiver to a frequency at which a very distant station is known to be transmitting, no signal is heard in the headphones. Now, we know, according to our previous theory, that the r-f signal from this distant station must be present in the antenna circuit. But, since we cannot hear it (assuming that the receiver is functioning perfectly), this signal must be of insufficient intensity to be detected and utilized to produce sound in the headphones.

This indicates the necessity for amplification of the feeble signal prior to detection, and this is where the RADIO FREQUENCY AMPLIFIER comes into the picture. It is to be noted, that since no audible signal is present in the headphones, there would be no point in attempting amplification after detection.

WHAT THE R-F AMPLIFIER DOES

Study the block diagram in Fig. 3 for a moment. Here, we have placed a RADIO FREQUENCY AMPLIFIER ahead of the detector.

The weak r-f signal that was inadequate to actuate the diaphragms of the headphones, must now first pass through the r-f amplifier before it reaches the detector and is finally reproduced as sound by the headphones. Since the r-f amplifier magnifies or makes stronger any r-f signal that passes through it, the weak signal appearing in the antenna circuit will now be intensified sufficiently to operate the detector satisfactorily and thus make an audible signal at the

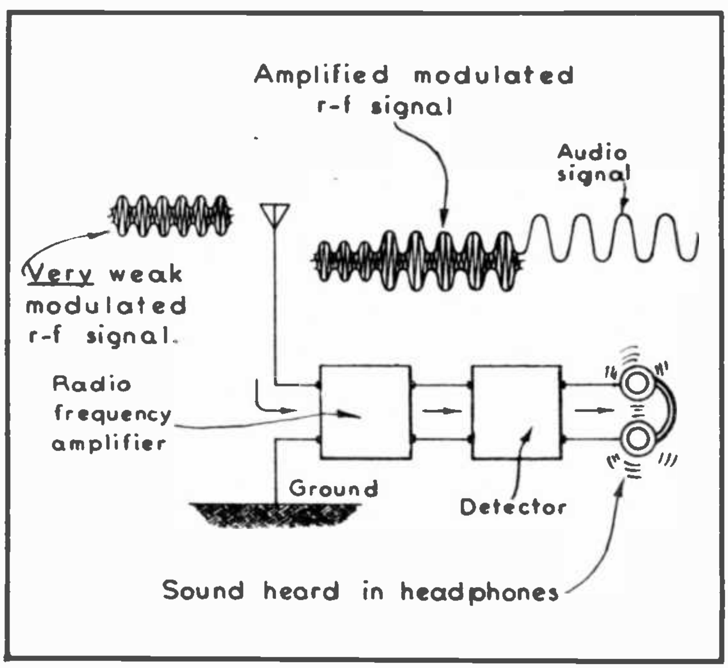


FIG. 3
ONE STAGE OF R-F AMPLIFICATION ADDED TO RECEIVER
MAKES WEAK SIGNAL AUDIBLE

headphones possible. Naturally, the greater the amplifying ability of the r-f amplifier, the better will be the reception of the weak signals.

Next, let us suppose that a still weaker r-f signal is impressed on the antenna of the receiver illustrated in Fig. 3. Although the amplifier, here used, was sufficient for the weak signal previously received, it is inadequate for the much weaker signal that now exists in the antenna circuit.

To solve this problem, we simply add another section of r-f amplification, as pictured in Fig. 4. We call each of these sections a "stage". The wave forms in Fig. 4 show clearly how the amplitude of the modulated signal is increased by each stage of r-f amplification, and also how the signal is de-modulated by the detector for use by the headphones.

Now that you are familiar with the basic principles of the r-f amplifier, and its application in the receiver, let us continue with a study of the circuits used therein.

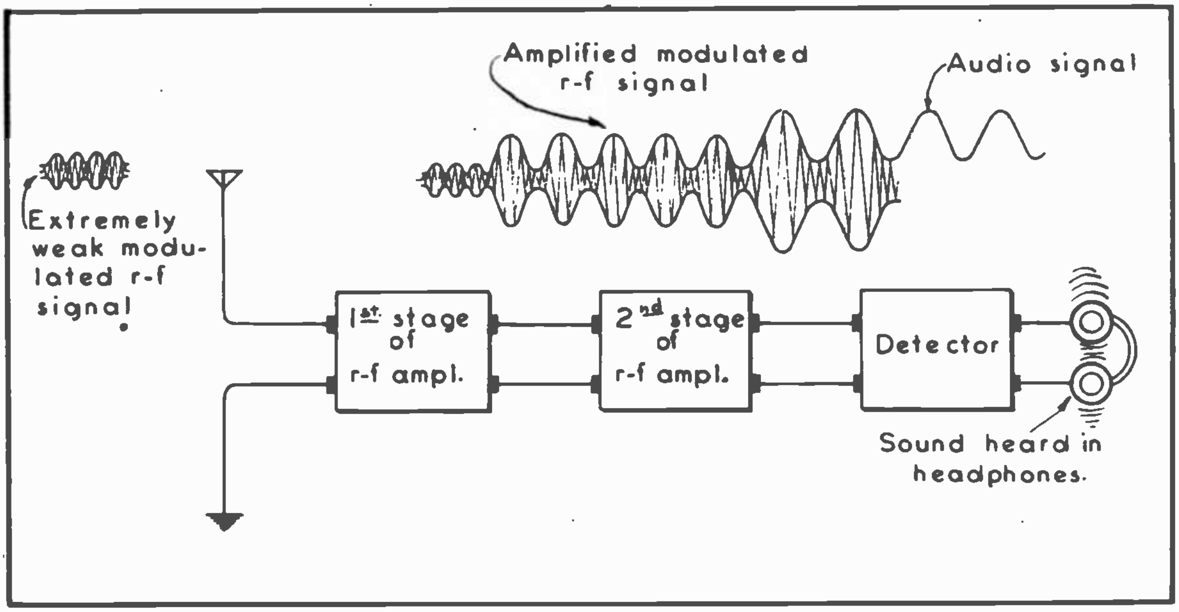


FIG. 4
TWO STAGES OF R-F AMPLIFICATION ADDED TO RECEIVER MAKES EXTREMELY WEAK SIGNAL AUDIBLE

A REVIEW OF THE DETECTOR CIRCUIT

In Fig. 5, we have a diagram of a simple crystal receiver (detector), the operation of which you studied quite thoroughly earlier in the course. At that time, you learned that a radio wave, upon striking the antenna, causes an r-f current to flow in the primary winding or "antenna coil" of the r-f transformer; and that since this current is of an oscillatory nature, it will induce a voltage of corresponding frequency in the receiver's tuning circuit. This voltage will appear across points "X" and "Y" in Fig. 5. Rectification of this signal by the detector then makes the signal audible in the headphones. This applies also to vacuum tube detector circuits about which you will learn in a later lesson.

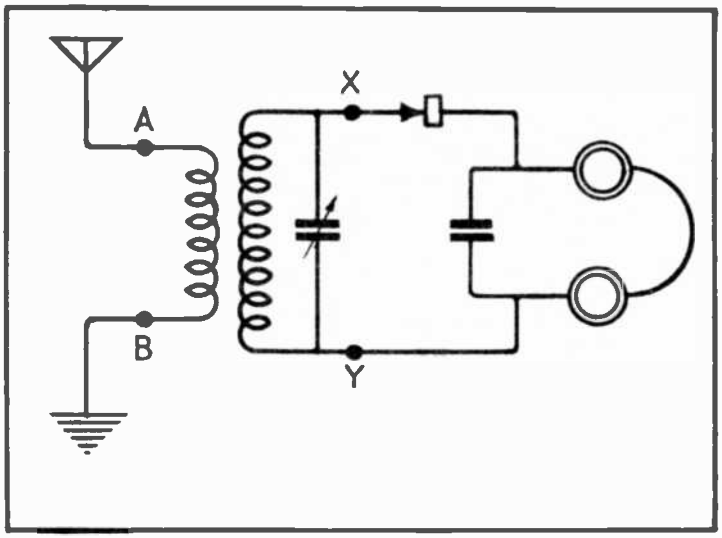


FIG. 5
SIMPLE RECEIVER (DETECTOR)

BASIC R-F AMPLIFIER CIRCUIT

The most essential parts of an r-f amplifier circuit are shown diagrammatically in Fig. 6. The tuning condenser, ordinarily used in this circuit, has been eliminated to simplify matters.

Notice that the antenna and ground leads have been disconnected from terminals "A" and "B" of the antenna coil primary, and that the latter has been connected in series with the plate circuit of the r-f amplifier tube (usually called the "r-f tube"). Another r-f transformer has been placed ahead of the r-f tube --- its primary winding being connected in series with the antenna circuit, and its secondary winding between the grid and cathode of the r-f tube.

When no signal voltages exist in the circuit, a plate current of definite value flows through the r-f tube. We call this the normal or no-signal plate current. The exact value of this no-signal plate current is dependent upon the electrical characteristics of the r-f tube, the voltage applied to its plate, etc. Now let us see what happens when a station signal is being handled by this circuit.

Signal currents flowing through the antenna circuit cause a-c voltages of corresponding frequency to appear across the ends of this transformer's secondary winding (points "C" and "D" in Fig. 6). In this way, the grid of the r-f tube is made to be alternately positive and negative with respect to the tube's cathode --- such cyclic changes taking place at a rate conforming to the signal frequency. The flow of plate current through the tube will therefore alternately rise above its normal value, and drop below its normal value, in step with the reversals of polarity in grid voltage as caused by the incoming signal.

Because of the r-f tube's ability to amplify (due to the amplification factor of the tube), the variations in plate current, as caused by the signal, will be considerably greater in magnitude than are the variations in the intensity of the signal current flowing in the antenna circuit. Then, since this plate current flows through the primary winding of the second r-f transformer, the

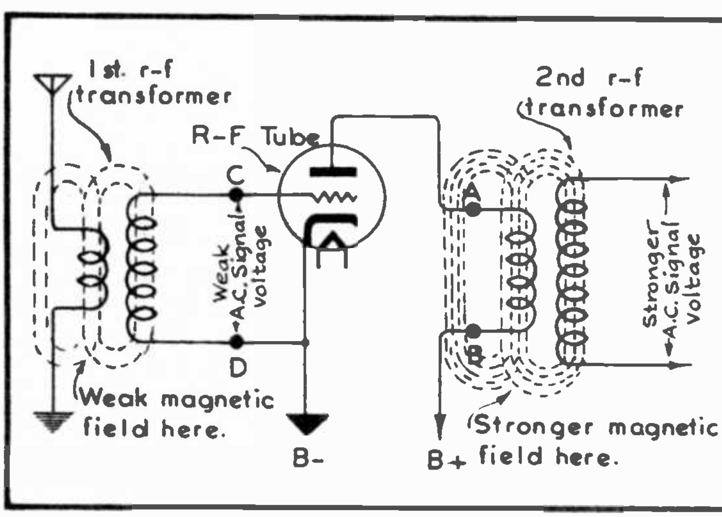


FIG. 6
BASIC R-F AMPLIFIER CIRCUIT

magnetic field produced thereby will build up to a much greater intensity than was the case when this same winding was connected in the antenna circuit.

And, since the fluctuation of this magnetic field is of greater magnitude than before, greater signal voltages will be induced into the secondary winding of the second r-f transformer. Thus, greater signal voltages are now available with which to operate the detector, and so this weak signal will be audible in the headphones.

The r-f transformer which is connected between the antenna circuit and the r-f tube is usually called an "antenna-stage r-f transformer" (and, sometimes, as "antenna coil") --- to distinguish it from the transformer which is used between the r-f tube and the detector circuit. The latter is then called an "r-f transformer", and sometimes, an "r-f coil". The antenna coil and r-f tube, together, constitute an "r-f stage".

If it is desired to amplify the signal still more than is possible with the r-f stage just described, we place a similar stage ahead of it, as has been done in Fig. 7. Here, then, we have two stages of r-f amplification preceding the detector. The various r-f stages, together, are spoken of as the "r-f amplifier".

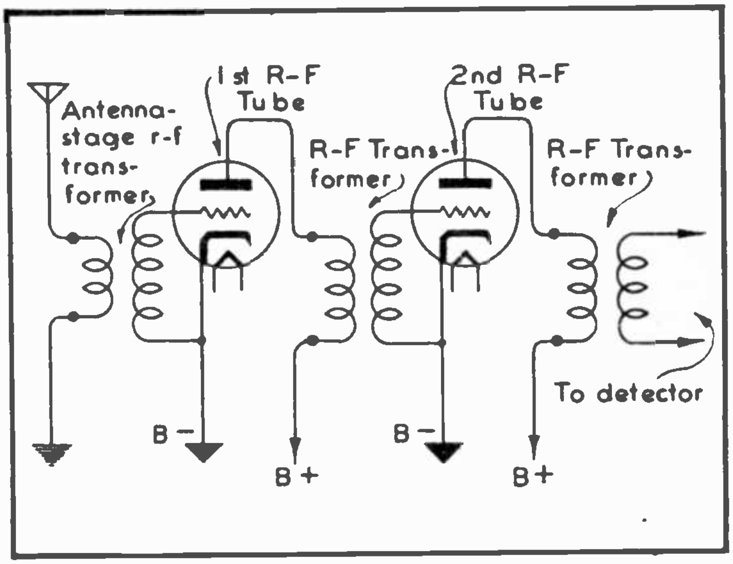


FIG. 7
ADDING ANOTHER STAGE OF R-F AMPLIFICATION

SEQUENCE OF AMPLIFICATION

The manner in which an r-f signal voltage is amplified is illustrated step by step in Fig. 8. The relative values of amplification or "gain" shown are purely imaginary for the purpose of illustration.

With an r-f signal impressed on the antenna, this signal is transferred by induction from the primary (position No. 1) to the secondary (position No. 2) of the antenna-stage r-f transformer. No step-up in voltage occurs in this transformer even though more turns may be used on its secondary winding than on its primary, because of the transformer's inefficiency when operating at high frequencies. Actually, somewhat of a loss occurs here, for the reason just given; and which will be further explained later in the course. So, to simplify matters for the present, we are considering this transformer as serving only as a coupling device for transferring electrical energy from one circuit to another. The same applies to the other r-f transformers in this circuit.

The signal strength in the primary and secondary circuits of the antenna transformer are represented by small white rectangles at the bottom of this drawing.

The 1st r-f tube amplifies the signal appreciably. Therefore, the strength of the signal appearing in the plate circuit of the tube (position No. 3) is much greater than that in its grid circuit. At the

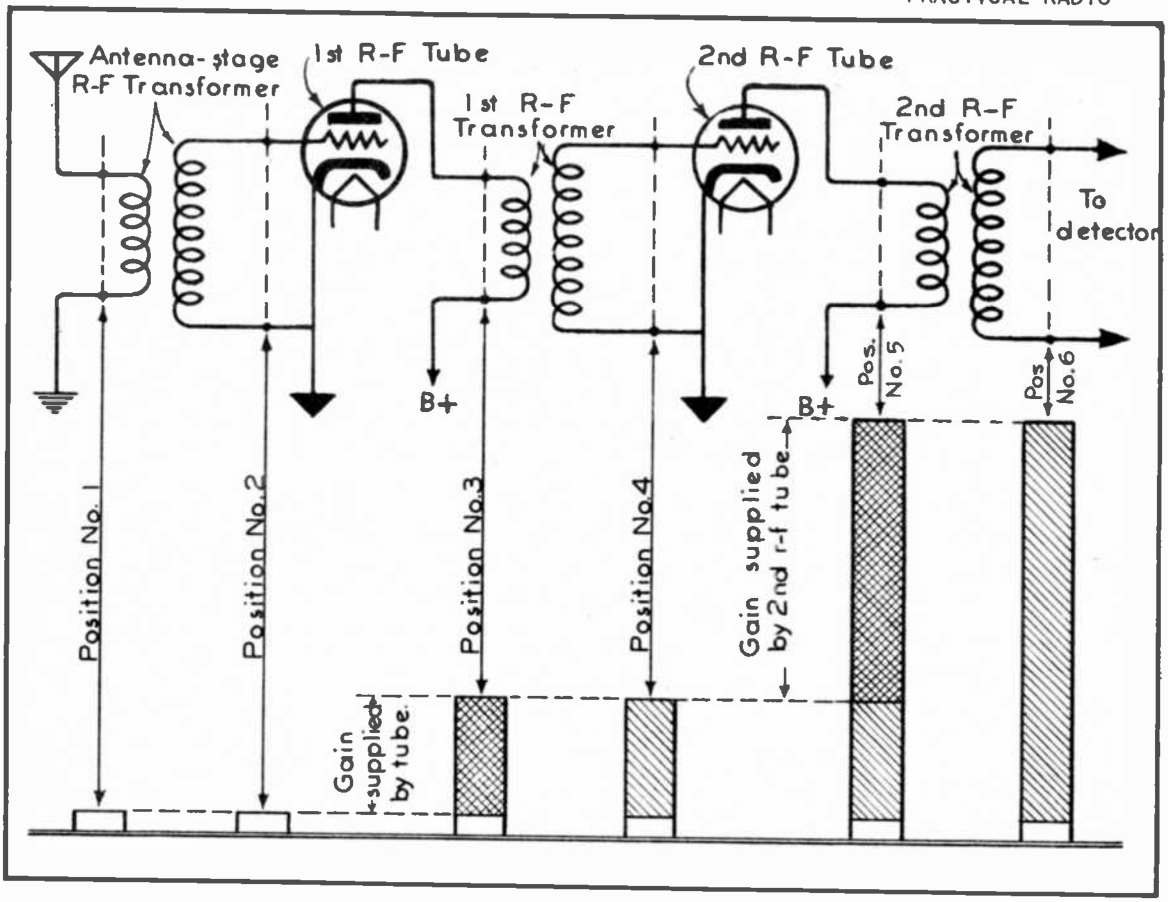


FIG. 8
HOW THE R-F AMPLIFIER INCREASES SIGNAL INTENSITY

1st r-f transformer, we have a transfer of energy from the plate circuit of the 1st r-f tube to the grid circuit of the 2nd r-f tube, with no gain (for reasons previously given). An additional gain is experienced through use of the 2nd r-f tube, and is illustrated in Fig. 8 by the cross-hatched portion of the graph at position No. 5 as compared to the diagonally-shaded portion in the same graph which represents the signal strength in the preceding circuit.

THE NEED FOR TUNED R-F STAGES

In our analysis of Fig. 8, we assumed that a single r-f signal existed in the antenna circuit of the amplifier. Actually, this is not true.

In Fig. 9, seven arbitrary frequencies have been chosen (10 kc. apart) as representing signals of equal intensity received from various transmitters, and applied to the untuned amplifier just described. Note, especially, the reference line marked "Audible Level". This indicates an arbitrary minimum r-f signal intensity, sufficient to produce an "audible signal" in the headphones after detection.

Before these signals have become amplified (position No. 1 of Fig. 9), all of them are observed to be below the "audible level" reference line; that is, none of them is of sufficient intensity to produce an audible signal after detection. At position No. 2, however,

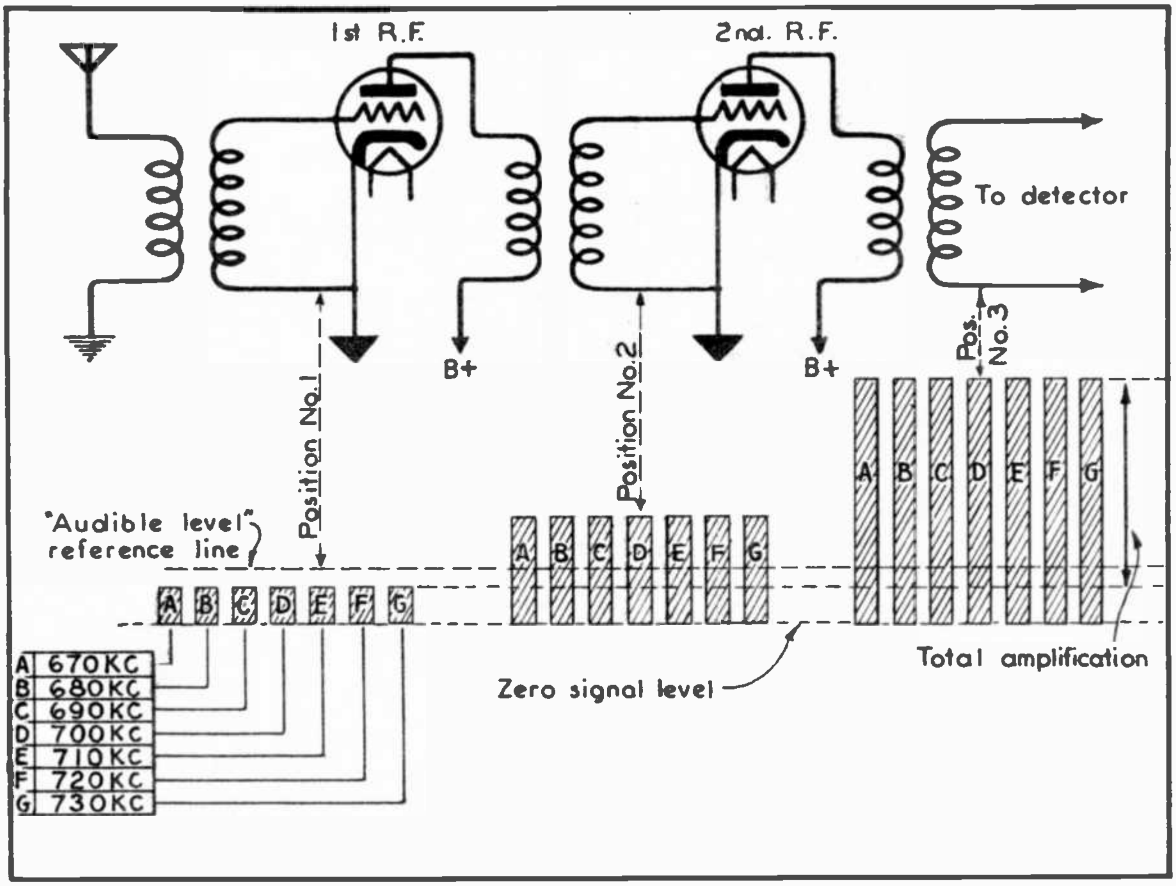


FIG. 9
UNTUNED R-F AMPLIFIER AMPLIFIES ALL SIGNALS EQUALLY WELL

the amplification furnished by the 1st r-f stage has raised all of the signals an equal amount above the reference line, so that they can be detected and produce an audible signal in the "phones". But, since the amplifier stages are untuned, no selection or discrimination of any one particular frequency has been achieved. Therefore, all of the signals would be heard simultaneously in jumbled confusion. Upon being amplified by the following r-f stage, the resultant stronger r-f signal at position No. 3 would still be of no use, as the same jumbled confusion of signals would then be heard in the headphones with greater intensity.

It becomes increasingly evident that amplifying the r-f signals, as we have done in the untuned r-f amplifier, does give us a greater audible signal in the headphones, but in an unusuable form, as we do not wish to listen to all signals at the same time.

The obvious solution to the problem, then, is to TUNE the r-f amplifier stages individually, applying the same principles to tuning as previously described for the simple crystal receiver.

As you already know, tuning enables us to select one particular frequency (out of many existing in a circuit), and so cause it to predominate. At the same time, it reduces in intensity, or suppresses, all other frequencies above or below that to which our circuit is tuned. The frequency to which the circuit is tuned is called the RESONANT FREQUENCY; or, we say that the circuit is TUNED TO RESONANCE. All frequencies above or below resonance (the resonant frequency) are said to be OFF-RESONANCE.

FIRST STAGE OF TUNING

Let us now take the untuned r-f amplifier illustrated in Fig. 9, and place a tuning condenser across the secondary of each transformer in the manner illustrated in Fig. 10. Still assuming that the r-f signals in the antenna circuit are all of equal intensity, note the relative change in signal level that has occurred between the signals of the seven different stations as they are passed through the successive stages of amplification.

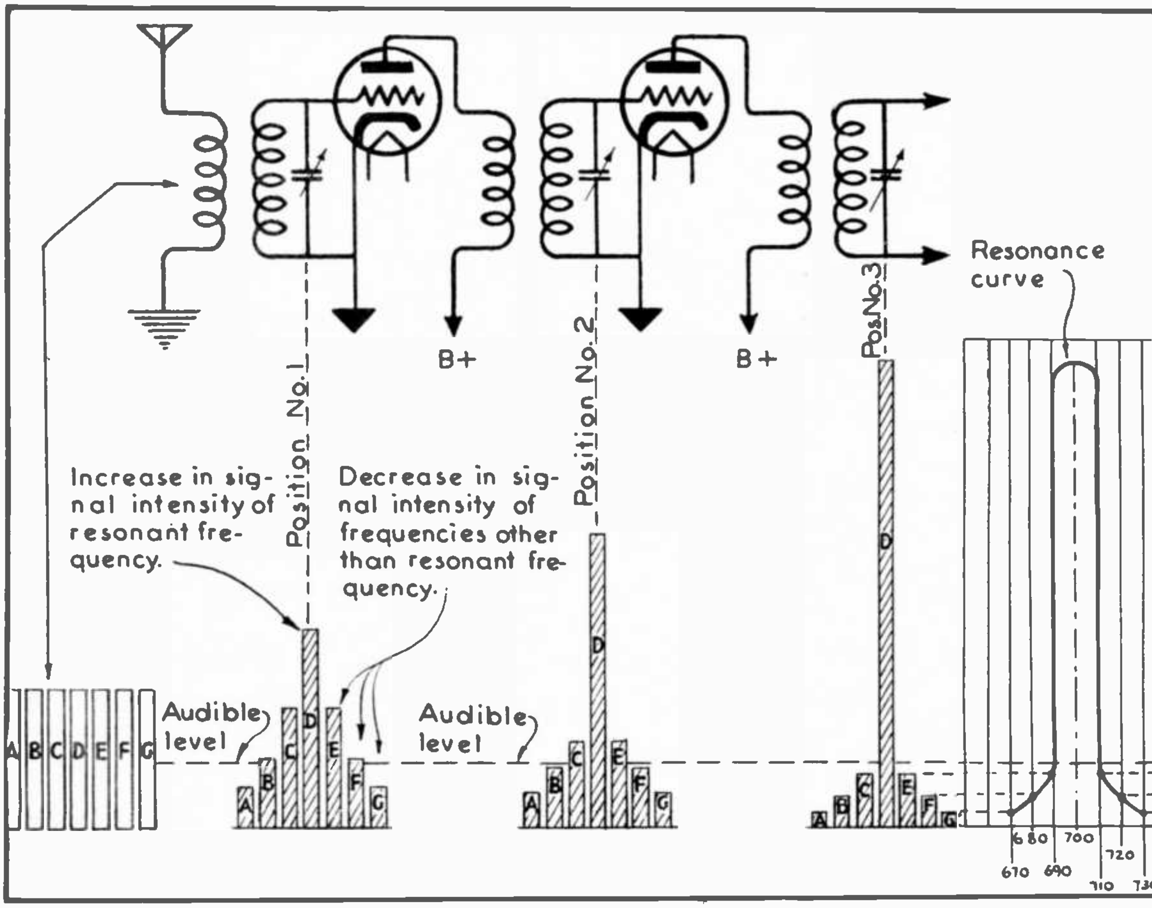


FIG. 10
TUNED R-F AMPLIFIER "SELECTS" THE DESIRED SIGNAL

At position No. 1 in Fig. 10, for instance, the condenser has been adjusted so as to tune the circuit to a frequency of 700 kc. Note that this has caused the signal intensity of Station D, to which we are tuned, to increase.

It should be remembered that a tuned circuit offers minimum opposition to the frequency to which it is tuned, and greater opposition to all other frequencies. It is for this reason that the intensity of the signal from station "D" (the resonant frequency) has increased, while the intensities of signals from the other stations ("A"-"B"-"C" and "E"-"F"-"G") have been reduced; and the farther away they are from the resonant frequency, the greater is the reduction. Hence, stations "A" and "G", being farthest "removed" from resonance, their signals have been reduced the most by tuning. Stations "C" and "E", being immediately adjacent to station "D" (the resonant frequency), their signals are not so greatly reduced in strength.

Let us now analyze the relative signal strengths of the various stations in relation to the "reference line" representing "Audible Level", at position No. 1 in Fig. 10. Station "D", of course, will predominate and produce the loudest signal in the headphones. Stations "C" and "E", although weaker, would nevertheless still be quite audible; while stations "B" and "F" are just within audibility. The signals of stations "A" and "G" are inaudibile.

SECOND STAGE OF TUNING

In this first tuned stage, we have accomplished some "selectivity". However, greater separation of the interfering signals ("B"- "C"- "E"- "F"), than has been attained in the first tuned stage, is generally desirable. Continuing to the next tuned stage, in Fig. 10, we see at position No. 2 that the "selectivity" has been materially improved.

In relation to the other signal frequencies, that of station "D" now predominates to a much greater degree; whereas those of stations "C" and "E" are very close to the inaudible point on the "reference line". All of the other signal frequencies have been reduced materially below audibility. Thus, through the use of successive stages of tuned circuits, we are approaching ideal selectivity, where only one frequency --- the RESONANT FREQUENCY --- will be outstanding; and all others will have been reduced to the point of inaudibility. If the listener is satisfied with a slight amount of interference from stations on adjacent "channels", or frequencies, we could very well limit tuning to these two stages. In fact, we could then eliminate the second r-f amplifier tube, and feed the signal into the detector at this point --- provided, of course, that only a small amount of r-f amplification is desired. This is illustrated in Fig. 11, where one stage of tuned r-f amplification precedes the detector. This is done in many low-cost receivers that are known for their lack of selectivity.

THIRD STAGE OF TUNING

Returning to Fig. 10, we have at position No. 3 reduced to complete inaudibility all frequencies other than the resonant frequency (700 kc.). Station "D" alone remains audibile, whereas the signals from station "A"-"B"-"C" and "E"-"F"-"G" have been so reduced by the opposition offered to them by the three tuned circuits that they are no longer detectable and able to produce an audible signal in the headphones. We then say that they are incapable of causing "interference". Station "D", in contrast, has increased considerably,

Observe that selectivity or separation of the interfering (unwanted) frequencies is accomplished by the opposition offered to the non-resonant signals as they reach each tuned circuit. Whereas, the resonant signal receives minimum opposition from the tuned circuit. Thus, the strength of the resonant signal increases in each tuned stage.

At the extreme right of Fig. 10, we have projected over to a standard graph, the signal intensity values

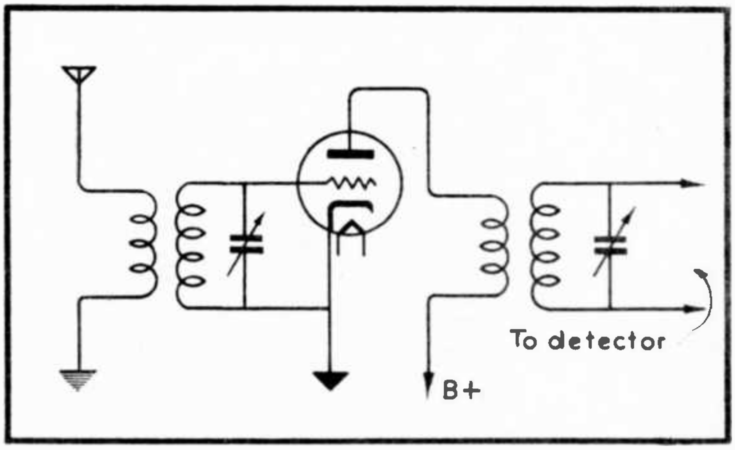


FIG. 11
ONE STAGE OF R-F AMPLIFICATION
PRECEDING THE DETECTOR

as they appear just before entering the detector. In this manner, we are able to "draw a picture" that illustrates the efficiency of the tuned circuits. This is called a "selectivity curve". This curve shows us at a glance the opposition offered to the "off resonance" frequencies, and how "sharp" the tuning is.

SELECTIVITY CURVES

When a tuned r-f amplifier circuit provides a high degree of acceptance at RESONANCE and a high degree of rejection to all frequencies removed from resonance, it is said to be very selective or "sharp tuning". One that does not do this is said to be "broad tuning". Thus, the selectivity curve at (A) of Fig. 12, illustrates broad tuning or poor selectivity; and that at (B), sharp tuning or good selectivity.

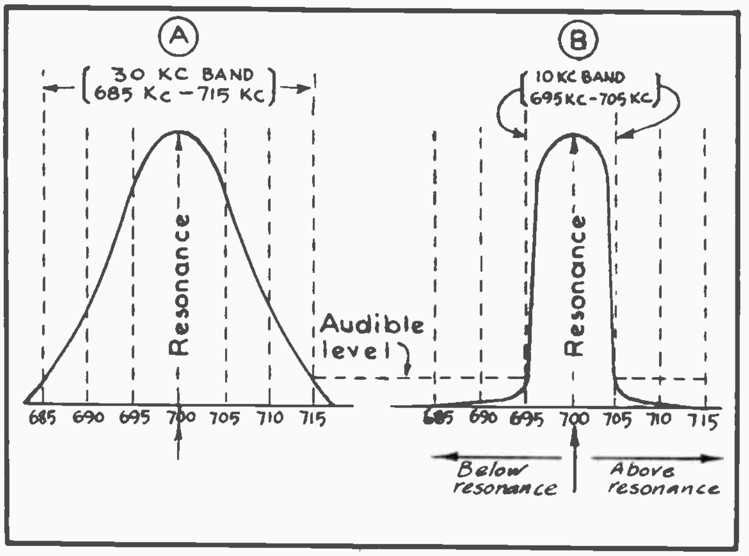


FIG. 12
SELECTIVITY CURVES

Note that the curve at (A) of Fig. 12 is considerably broadened out at the base, showing that the circuit which it represents does not reject the frequencies immediately adjacent to the resonant frequency (700 kc.) enough to reduce their intensity to a value below the audible level. In fact, station signals ranging all the way from 685 kc. to 715 kc. would be accepted with sufficient strength to be detectable. We would then say that the frequency band passed by this tuning circuit is 30 kc. (Note: 715 - 685 = 30.) Many tuned stages would be necessary to accomplish anywhere near ideal selectivity with such an inefficient tuning circuit in each stage.

Observe at (B) of Fig. 12, that the tuning circuit represented by this curve will reject any frequency 5 kc. above or 5 kc. below the point of resonance --- a band-width of 10 kc.

If the selectivity of a tuned r-f amplifier is carried to extremes, whereby the band-width --- or "channel-width", as it is sometimes called --- is less than 10 kc. wide, the higher audio frequencies (sounds) will not be audible.

Thus, it is seen that the band of frequencies passed by the complete r-f tuning system determines the "range" of the audio frequencies that will be heard, as well as how effectively the desired station signal is separated from the unwanted ones. That is, if the selectivity curve is only 5 kc. wide at the resonant point, then the upper limit of the audio frequencies that will be heard is 2.5 kc. or 2,500 cycles. If the selectivity curve is 10 kc. wide at the resonant point, the upper limit of the audio frequencies that will be heard is 5 kc. or 5,000 cycles.

Although the audio frequency scale is considered to extend up to about 20,000 cycles, sounds having frequencies higher than around 5,000 cycles are seldom transmitted by ordinary broadcast stations. For this reason, a tuning circuit that passes a 10 kc. band is satisfactory for receiver use.

In review, the advantages of the tuned r-f amplifier are:

FIRST: Ability to bring to a level of practical audibility feeble r-f signals received from distant transmitters.

SECOND: Increased selectivity, or reduction and elimination of interference from r-f signals other than the desired signal.

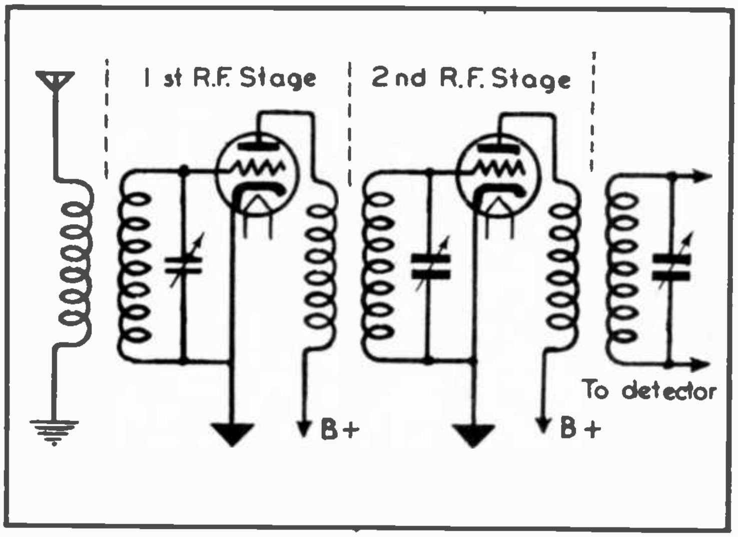


FIG. 13
TWO STAGES OF R-F AMPLIFICATION PRECEDING DETECTOR

GANG TUNING CONDENSERS

In early receivers employing tuned r-f amplifiers, a separate tuning condenser was employed in each r-f stage, as well as in the detector circuit. For this reason, a receiver consisting of two stages of tuned r-f amplification and a tuned detector circuit, as illustrated in Fig. 13, required three separate, individual tuning condensers. Many disadvantages were encountered in receivers of this type, both in construction and operation. Obviously, a great amount of patience was required on the part of the operator in tuning each stage to resonance with one specific frequency. Fig. 14 illustrates a typical receiver with individual tuning controls.

Observation revealed that in the majority of cases, the dial settings of the individual tuning condensers were very nearly alike, provided that the secondary windings of the various r-f transformers used in the receiver possessed the same inductance. Naturally, this would be the case, because in order for each tuned r-f stage to tune to the same frequency, the inductance and capacity of each tuned stage must be identical

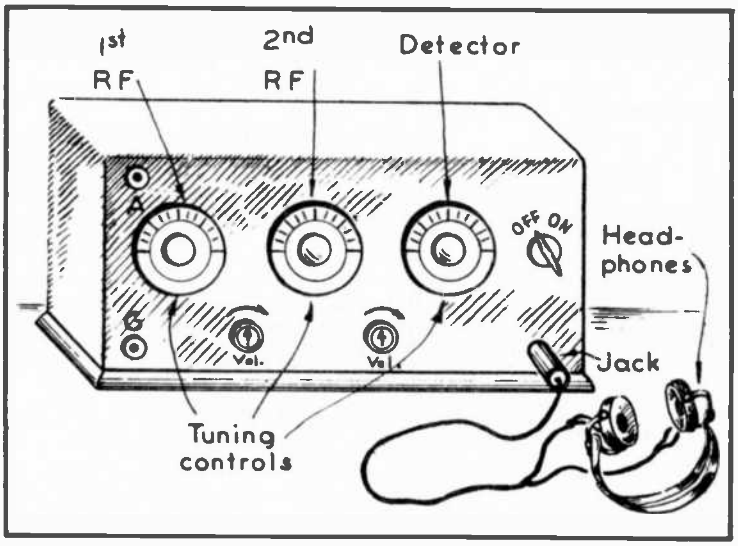


FIG. 14
EARLY MODEL RECEIVER WITH INDIVIDUAL TUNING CONTROLS

In Fig. 15, illustrating a typical three stage r-f amplifier, and detector, four tuning condensers are employed. Suppose, now, that we were to place these variable tuning condensers end to end, extend their shafts, and then couple the shafts together. It would then be possible to rotate the rotor plates of all four condensers simultaneously by means of a single control.

To conserve space, the present practice is to consolidate these four individual condenser sections into a compact unit, as illustrated

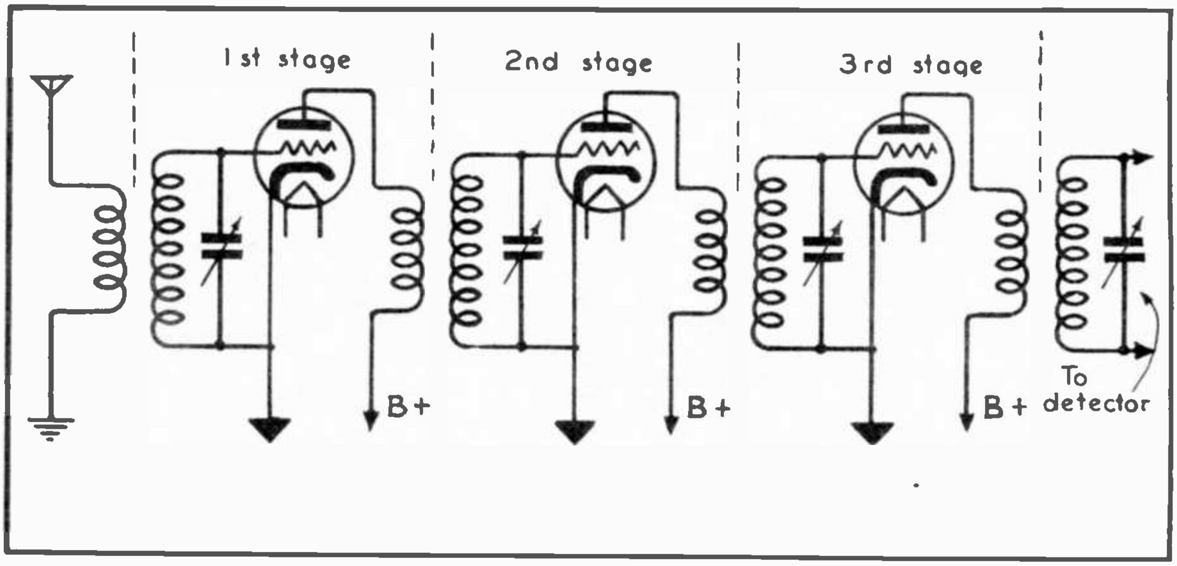


FIG. 15
THREE STAGES OF R-F AMPLIFICATION PRECEDING DETECTOR

in Fig. 16. We call this a gang condenser; and since four condenser sections are employed in this particular unit, we speak of it as being a four-gang condenser.

Notice in Fig. 16 that the rotor or movable plates of each condenser section are mounted on a common shaft, and must therefore move as one whenever the shaft is turned. The shaft is electrically connected to the frame.

The condenser in Fig. 16 is designed especially for mounting on a metal receiver chassis base. The condenser frame will therefore be in direct contact with the base which serves as the "ground" side of all circuits in the receiver; and the entire condenser frame, as well as all rotor plates, will be grounded in common. The stator plates are insulated from the frame, and each stator section is insulated from the other stator sections.

The metal plates which are placed between each condenser section of the assembly serve as shields to prevent electrostatic coupling between the various sections.

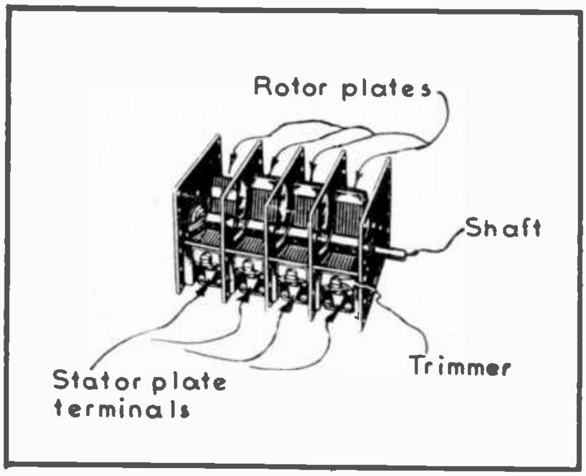


FIG. 16
FOUR-GANG CONDENSER

The terminals which are mounted on the side of the condenser are connected to the stator plates. In wiring a receiver, we fasten the grid circuit leads to them.

The rotor plates are all automatically connected to the chassis (ground) through the metal frame of the condenser. Therefore, by grounding one end of the r-f transformer secondary windings, and the cathodes of the various tubes, this side of the circuit is completed through ground as illustrated in Fig. 17. This diagram shows, also, how the tuning condenser symbols on a diagram are connected together with dotted lines to show that the

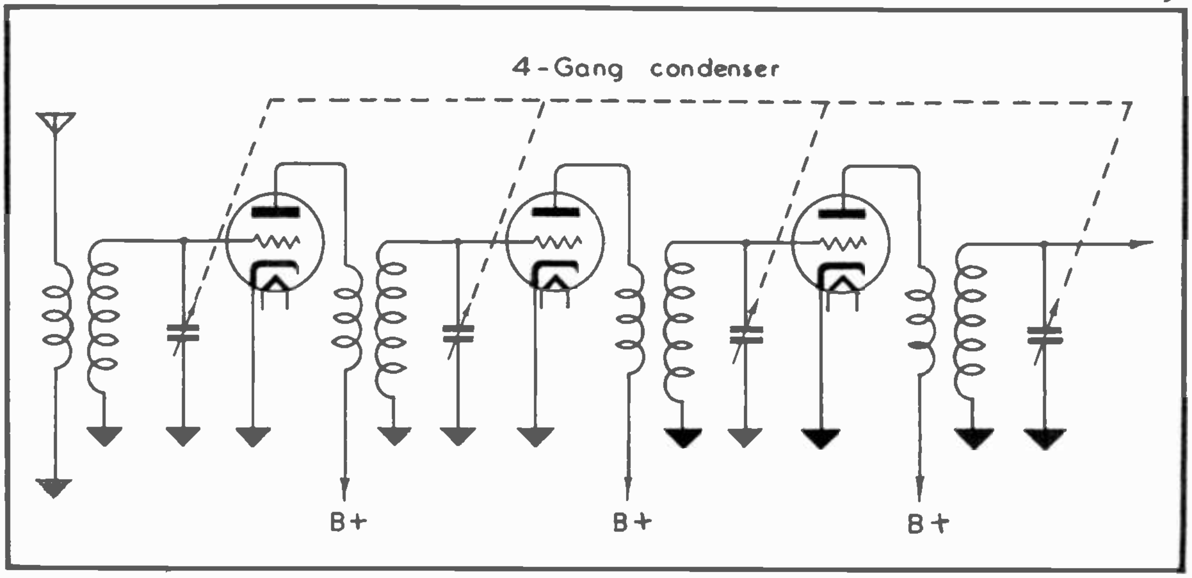


FIG. 17
USING CHASSIS GROUND CONNECTIONS TO COMPLETE CIRCUITS

condensers which they represent are ganged and adjusted by a single control.

If three condenser sections are combined into a single unit, as in Fig. 18, we have what is known as a three-gang condenser. Two such units (Fig. 19) constitute a two-gang condenser.

The mounting of a two-gang condenser on a metal chassis base, and the dial mechanism for operating the condenser, is illustrated in Fig. 20. Observe how turning the knob rotates the small pulley which transmits motion to the large disc through a friction drive. Rotation of the latter is then transferred to the dial needle through a short shaft, and to the condenser shaft through the locking collar.

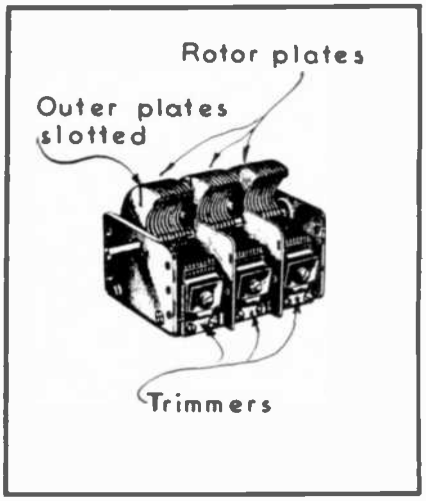


FIG. 18
THREE-GANG CONDENSER

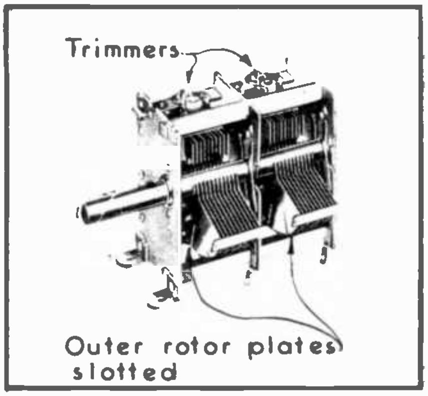


FIG. 19
TWO-GANG CONDENSER

TRIMMER CONDENSERS

In order to operate separate tuning condensers as this together, and yet have all stages tuned to the same frequency at any given condenser setting, the inductance values of the tuning circuits in these stages must be exactly alike, as also must be the capacity values. However, due to slight variations in electrical values that occur in the mass production of tuning condensers and r-f transformers, in addition to differences in the distributed capacity of the circuit wiring, the inductance and capacity values in the different tuning circuits are not always properly matched. To cor-

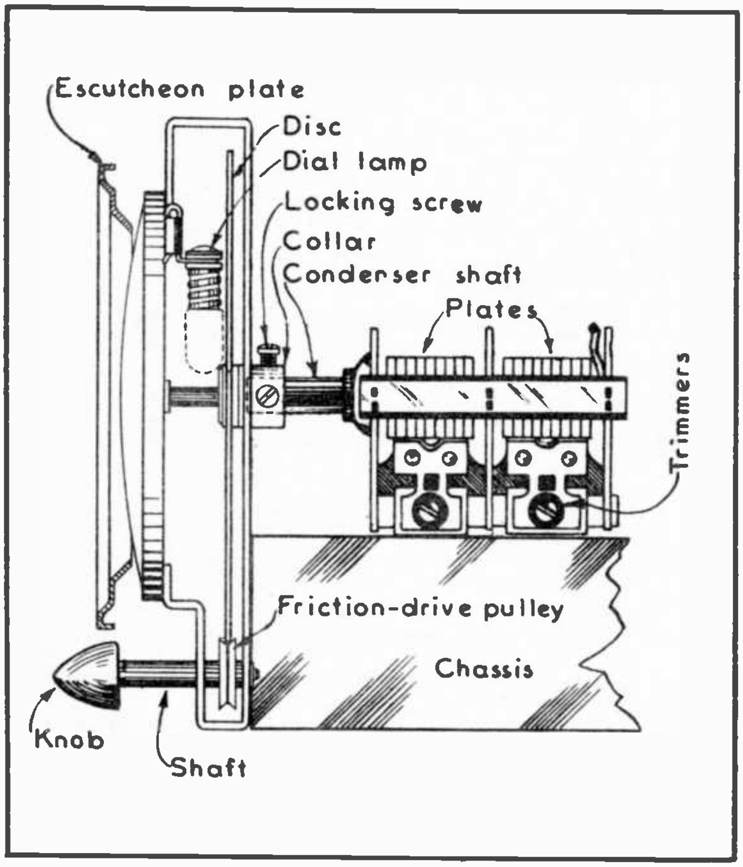


FIG. 20
TWO-GANG CONDENSER MOUNTING AND DIAL ASSEMBLY

rect this condition, small trimmer condensers are mounted on the gang condenser, as shown in Figs. 18, 19 and 20.

These trimmer, or "compensating" condensers, are connected in parallel with the tuning condenser section on which they are mounted, by the manufacturer. Thus, they are automatically installed in the receiver circuit as shown in Fig. 21, at the time the receiver is wired. Then, when the receiver is completed, the trimmers are adjusted with a screw driver or special wrench until the circuits are tuned precisely to the same frequency whenever the gang condenser is set in a certain position. We then say that the tuning circuits are "aligned".

On some gang condensers, the outer rotor plates are slotted (see Fig. 19) so that they can be bent either closer to or farther away from the adjacent stator plate. As the rotor plates are bent in this way, the capacity of that particular tuning section will be altered. That is, bending an outer rotor plate toward its adjacent stator plate will increase the capacity of that section, while bending it farther away from the stator plate will decrease the capacity of that section.

The step by step procedure for making this adjustment is described elsewhere in the course, and will be brought to your attention at the proper time. This is strictly a service adjustment, and should therefore never be disturbed by the owner of the receiver.

TYPES OF TUNING CONDENSERS

Variable condensers are divided into the following four main types: (1) Straight line capacity; (2) Straight line wave length; (3) Straight line frequency; and (4) Straight line tuning.

STRAIGHT LINE CAPACITY

The rotor plates of the straight line capacity condensers are shaped in the form of semi-circles, with the shaft running through their center. (See "A" of Fig. 22.) With this arrangement, the capacity varies directly with changes in the position of the plates. That

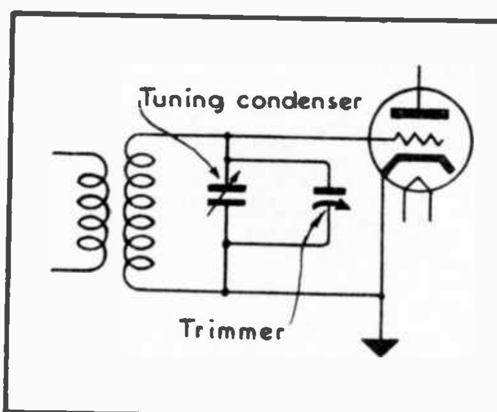


FIG. 21
CONNECTION OF TRIMMER IN CIRCUIT

is, with the plates meshed exactly half-way, the capacity will be just one-half the maximum or rated capacity of the condenser. With the plates one-fourth meshed, the capacity will be one-fourth of the maximum capacity, etc.

This condenser is mainly suitable for radio testing equipment, where accurate capacity measurements are to be made. The straight line capacity condenser is not suitable for use in present-day receivers because the lower wave length stations will be crowded closely together on the dial, whereas the upper wave length stations will be widely separated on the dial.

STRAIGHT LINE WAVE LENGTH

The rotor plates of straight line wave length condensers ("B" of Fig. 22) are shaped so that when used in conjunction with a given coil to form a tuned circuit, the wave length to which the circuit is tuned will vary directly with changes in the position of the rotor plates. For instance, if a straight line wave length condenser is used in conjunction with a certain coil so that the circuit will tune over a range of from 200 to 600 meters, then with the plates meshed half-way, the circuit will be tuned to 400 meters, etc. This condenser was commonly used a few years ago while broadcast stations were rated according to wave length instead of frequency.

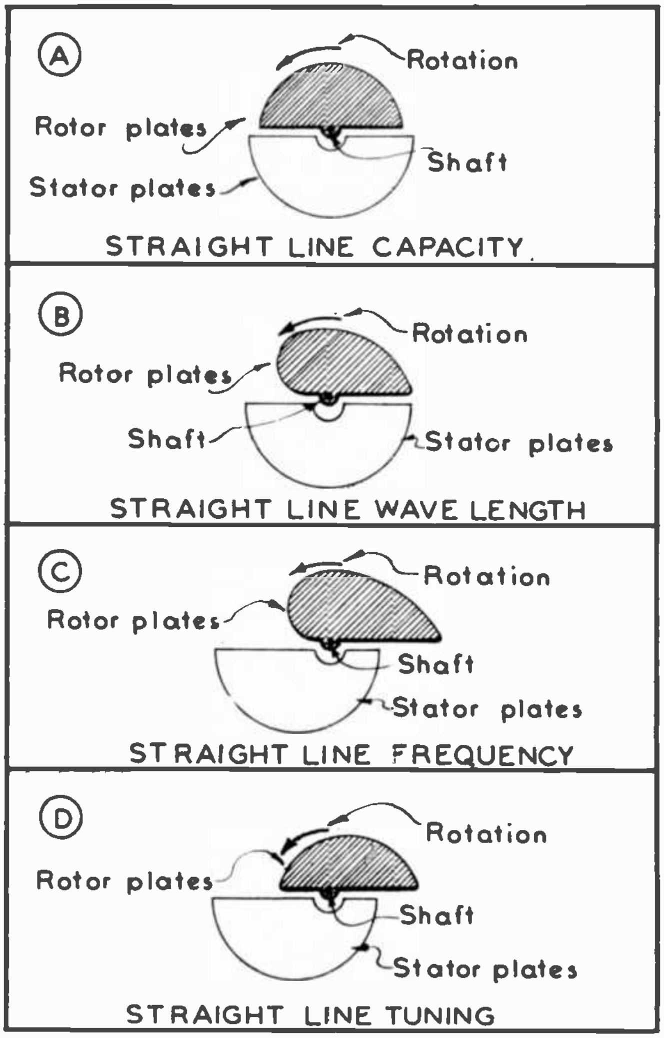


FIG. 22
TYPES OF VARIABLE CONDENSERS

STRAIGHT LINE FREQUENCY

Later, when broadcast stations were separated from each other by 10 kilocycles, the straight line frequency condenser came into prominence. The shape of plates used is shown at (C) of Fig. 22.

This condenser differs from the one previously described, in that instead of the wave length being altered in proportion to changes in the position of the rotor plates, the frequency is affected in this manner. The main disadvantage of this condenser, however, is that the condenser must have considerable maximum capacity in order to cover the broadcast band, thus making it quite large in physical size. Furthermore, stations at the high-frequency end of the band are quite close together on that position of the dial scale.

STRAIGHT LINE TUNING

The straight line tuning, or modified straight line frequency condenser, is now most used in receivers. Generally speaking, it is a combination of a straight line wave length and a straight line frequency condenser. With this condenser installed in a tuning circuit, the high frequency stations will be separated considerably on the dial scale, whereas the low frequency stations will be closer together on the scale. This condition is not objectionable, because present-day receivers are by nature more selective at the lower frequencies. The shape of the plates used in this type of condenser is illustrated at (D) of Fig. 22.

Tuning condensers are generally rated according to their maximum capacity. The minimum capacity of the unit will then be about one-tenth of the maximum capacity. That is, if a certain condenser is rated as having a maximum capacity of .0005 mfd., you can expect its minimum capacity to be approximately 1/10 of this amount, or .00005 mfd.

R-F TRANSFORMERS

The transformers used as means of coupling between r-f tubes and those employed in the antenna stage of receivers, differ but little in basic form and construction; the chief difference being the degree of coupling between their primary and secondary windings.

A transformer is said to be "CLOSE COUPLED" when the primary and secondary windings are placed close to each other, and on the same axis. This arrangement permits a large transfer of energy (by mutual induction) between these windings. "LOOSE COUPLING" is attained by placing the primary and secondary windings farther apart. The coupling between these two windings can also be decreased by altering the position of either one so that its axis is more nearly at right angles to that of the other. Increasing the number of primary turns, will also result in closer coupling between the two windings.

Two solenoid type r-f transformers are shown in Fig. 23. On the one appearing at (A), the primary winding is located farther from the secondary than is the case on the transformer shown at (B). Hence, transformer (A) provides loose coupling between its primary and secondary winding, while that at (B) provides close coupling between its two windings. Design (A) is most used in the antenna stage of receivers, because loose coupling aids in obtaining better selectivity. Design (B) is most used in the circuits following the antenna, or 1st r-f stage, because it makes greater gain (amplification) possible.

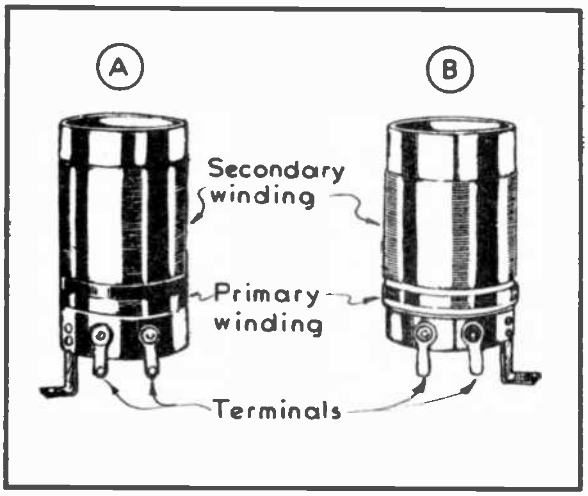


FIG. 23
R-F TRANSFORMERS

PLACEMENT OF COILS

In the construction of any radionic device employing an r-f amplifier, stability of operation is of great importance. To maintain this condition, it is important that all of the r-f energy in every part of the circuit be confined to that region where it belongs. If any of this energy is allowed to "stray" or "wander about" to other portions of the circuit, several undesirable effects will be experienced; the most noticeable and irritable of these being loud, shrill whistles and chirping sounds emanating from the headphones or loudspeaker.

Such unwanted transfer of r-f energy from one circuit to another --- as, for instance, from the plate or output circuit of the LAST r-f stage to the grid or input circuit of the FIRST r-f stage would create an undue amount of trouble of this nature. This condition is commonly known as "feedback", and can occur between r-f transformers of different stages; between various cables and wires that are placed parallel to each other in the circuit; or anywhere that an "ELECTRO-MAGNETIC" or "ELECTRO-STATIC" field (created around one part) reacts upon some nearby part.

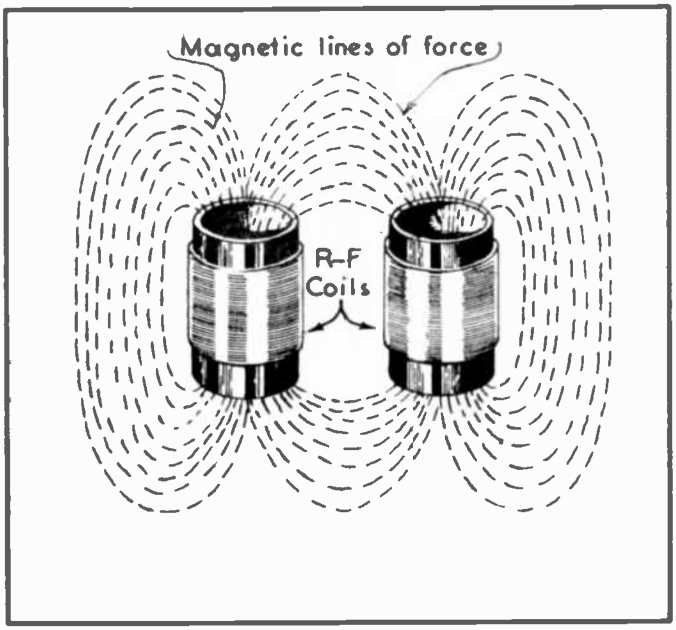


FIG. 24
MAGNETIC COUPLING BETWEEN COILS

It should be remembered that "INTERCOUPLING" between r-f stages, as well as between certain other parts in a circuit, must be kept at a minumum to ensure stable operation. For this reason, the various coils or transformers in radio receivers should be so located that coupling between them is at a minumum.

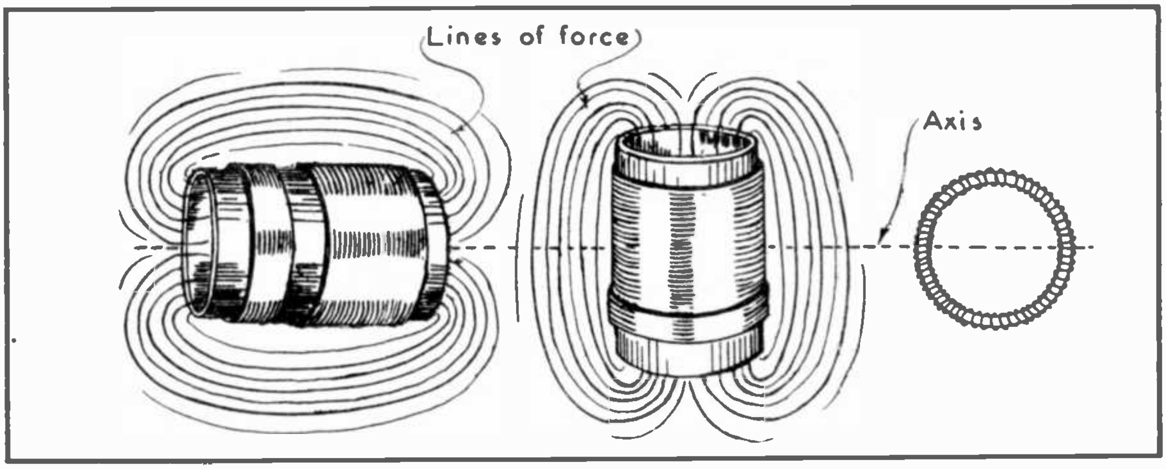


FIG. 25
PLACEMENT OF THREE COILS TO PREVENT INDUCTIVE COUPLING

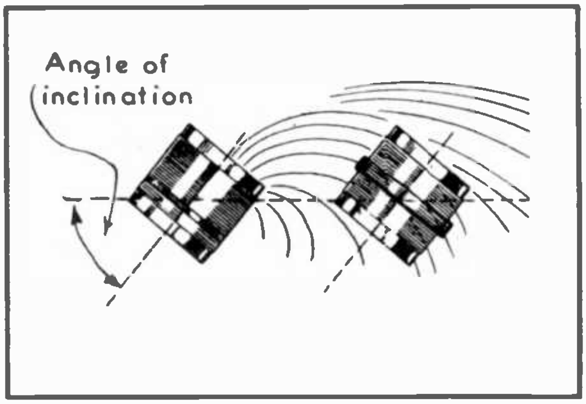


FIG. 26
PLACEMENT OF NEUTROFORMERS

In Fig. 24, two r-f coils have been placed near, and parallel to each other. Under such conditions, the magnetic field created by each coil completely surrounds the other. We therefore say that these two coils are inductively coupled.

In Fig. 25, the most desirable placement for three nearby coils is illustrated. Here, the axis of each coil is at right angles to that of the

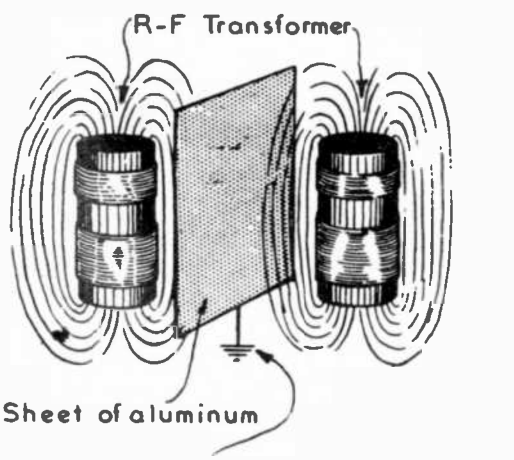


FIG. 27
PRINCIPLE OF SHIELDING

other two. The magnetic fields produced by each coil will therefore not interlink with those of the others; and so we have practically no coupling between them. Of course, besides utilization of this angular relationship between the coils, coupling between them can be reduced still more by mounting them farther apart; however, limitation of space does not always permit this to be done.

Another placement of r-f coils that has been used to reduce coupling between them is illustrated in Fig. 26. Here, the axis of each coil forms a 56° angle with the horizontal plane. Such an arrangement of coils was employed in early receivers known as "neutrodynes", and the r-f transformers used in this case were called "neutroformers".

MAGNETIC AND ELECTROSTATIC SHIELDING

The method which is now most used to prevent electromagnetic and electrostatic coupling between parts of a circuit is illustrated in Fig. 27. This method employs the principle of shielding.

In Fig. 27, two r-f transformers are placed close, and parallel to each other, but with a grounded metal plate between them. A plate so used is call a "shield".

Without the shield, strong inductive coupling would exist between the coils. However, by placing the shield in the position shown, we form a barrier for the magnetic lines of force emanating from the two coils. But, in order for this shield to be effective, it must be grounded, as shown in Fig. 27. In practice, the method of shielding a coil is as shown in Fig. 28, where the coil is completely enclosed in a grounded metal can. Sheet aluminum is most used for this purpose, although copper is sometimes employed.

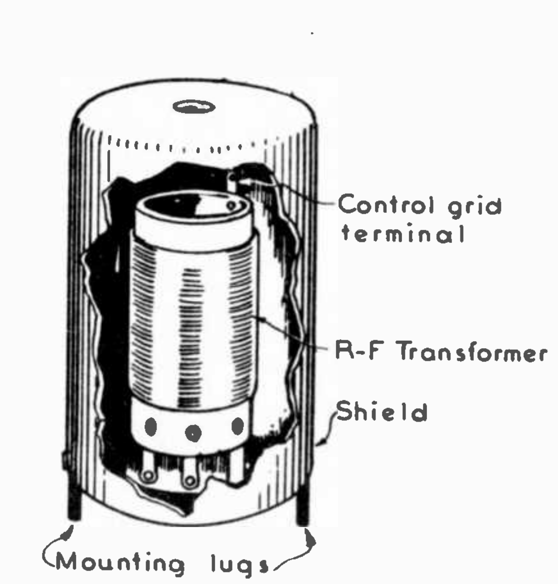


FIG. 28
SHIELDED R-F TRANSFORMER

Metallic shields are also placed around glass electron tubes to eliminate electrostatic or "capacitive" coupling between them and parts of different circuits. A typical example of the application of shielding on a commercial receiver is shown in Fig. 29. Here, the antenna coil, r-f transformers, r-f tubes and the detector tube are all enclosed in metal shield cans ---

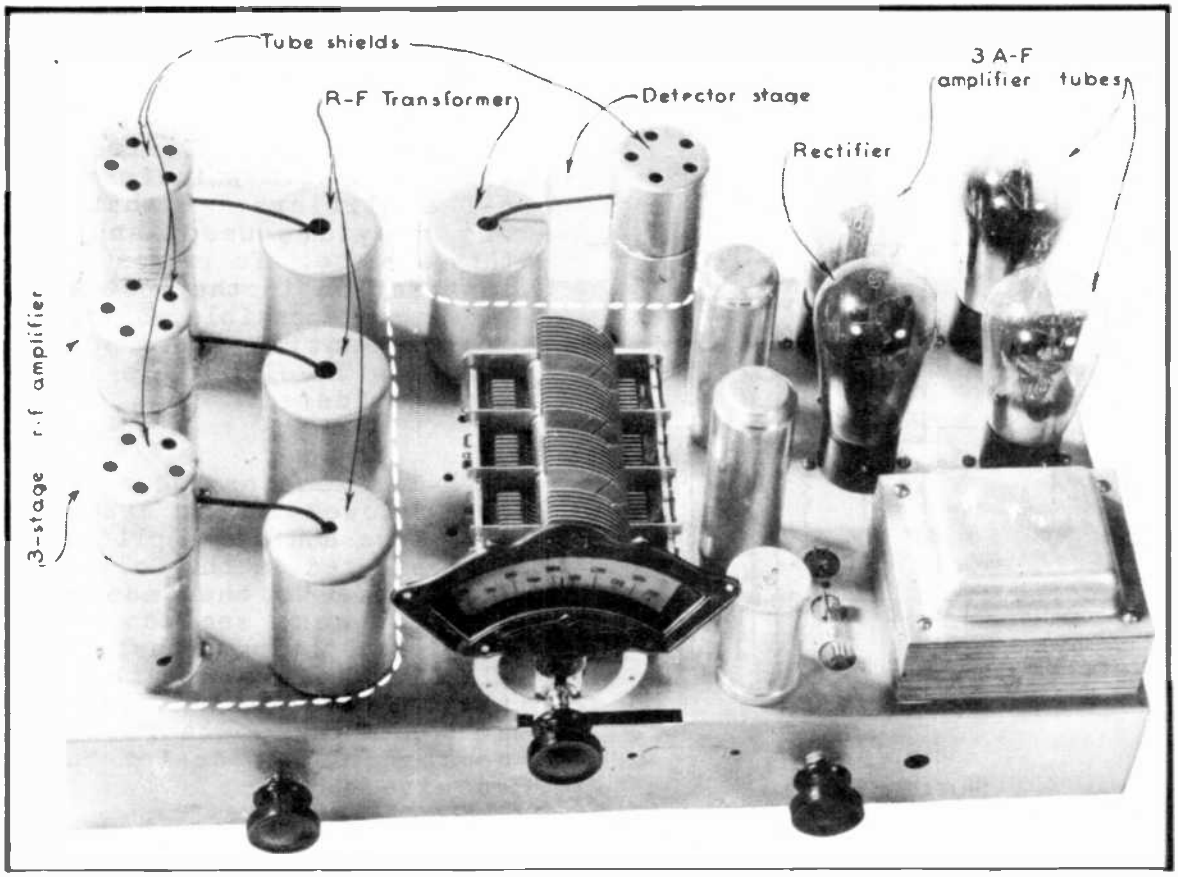


FIG. 29
APPLICATION OF TUBE AND R-F TRANSFORMER SHIELDS

thus, confining their respective magnetic and electrostatic fields to themselves. The three shielded r-f transformers and tubes, bounded by the white dotted line at the left in Fig. 29, comprise the three r-f amplifier stages used in this receiver. The shielded r-f transformer and tube bounded by the white dotted line at the rear-center of this same illustration comprise the detector stage.

Since the shield cans and the chassis base of this receiver are all made of metal, the shields are automatically grounded through physical contact with the chassis. Therefore, no wires are needed to make this connection.

Notice how these three stages of r-f amplification, in conjunction with the detector stage, require the use of a four-gang condenser. The general circuit arrangement for this r-f amplifier and detector corresponds to Fig. 15 of this lesson.

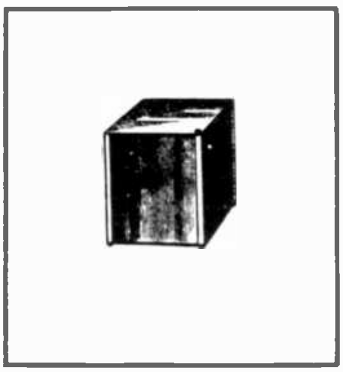


FIG. 30
STAGE SHIELD CAN

Frequently, a complete r-f amplifier stage is shielded in its entirety by a single metal container. The type of shield used for this purpose is shown in Fig. 30, while Fig. 31 illustrates in diagram form how dotted lines are used to indicate the portion of the cicruit so shielded.

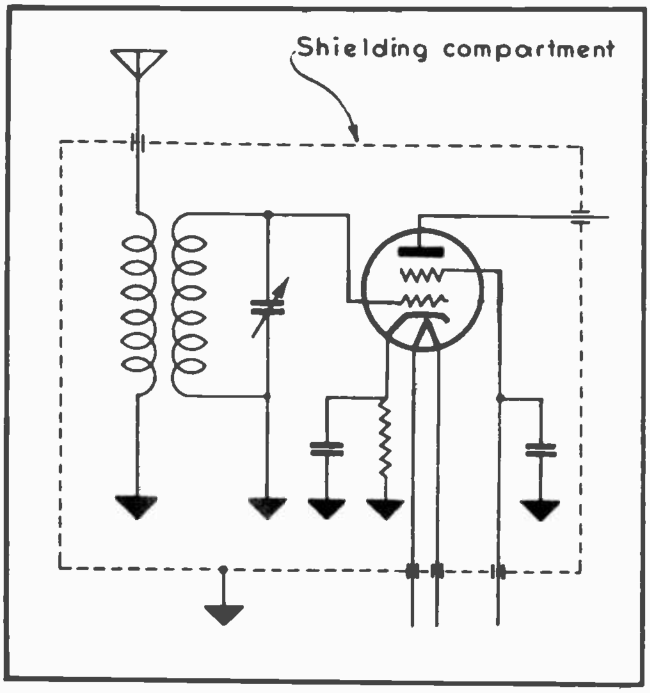


FIG. 31
SHIELDED R-F STAGE

A WORD ABOUT R-F AMPLIFIER CIRCUITS

In this lesson, our chief aim was to familiarize you with the basic principles of r-f amplifiers --- that is, why they are used; and how they operate. To present this instruction in the most simple manner possible, only the most essential parts of the circuits involved were shown and considered.

The same procedure will be followed in our study of detectors and a-f amplifiers, as presented in the following lessons. We then assemble all of these sections into complete systems, showing you all of the wiring details; and the many variations in circuit arrangements found in commercial and custom-built receivers.

EXAMINATION QUESTIONS

1. - What two important advantages are offered by the r-f amplifier in a radio receiver?

2. - Why are trimmer condensers supplied on ganged tuning condensers?

3. - What does a selectivity curve tell us about a radio receiver?

4. - What should be taken into consideration with respect to mounting unshielded r-f transformers close to each other?

5. - What do we mean by the expression "loose coupling" as applied to the windings on an r-f transformer?

6. - Why is shielding employed in r-f amplifiers?

7. - Name four main types of variable condensers (not including gang condensers).

8. - Why is it that a three-stage r-f amplifier is more selective than a two-stage amplifier, assuming that all tuning circuits are equally selective?

9. - What basic parts constitute an r-f amplifier stage?

10.- How is effective shielding accomplished in r-f amplifiers?

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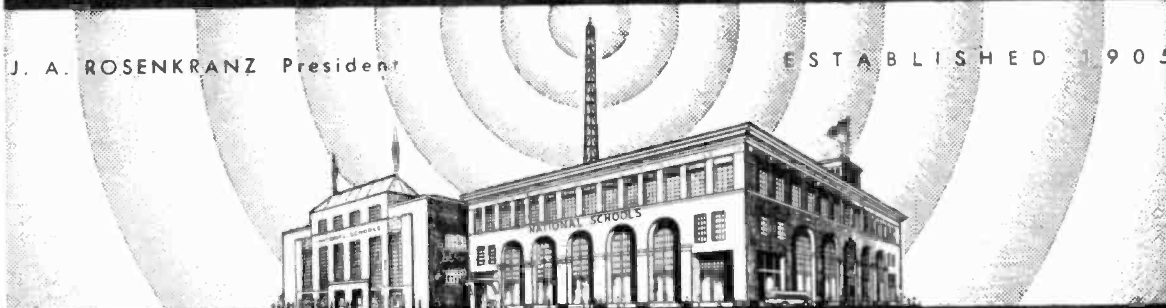

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LESSON NO. 14

VACUUM-TUBE DETECTORS

Earlier in the course, you learned how crystal detectors separate the audio component from the modulated carrier wave, which process is known as "detection." In this lesson, you are shown how detection is accomplished through the use of electron tubes.

Basically, the action of all detectors --- whether they be of the crystal or vacuum tube type --- is that of a rectifier. By this we mean that it is in rectifying the incoming signal that the detector "detects," and changes the output current in such manner so that proper operation of the sound reproducer (headphones) is possible. Certain tubes (triodes, tetrodes, pentodes) have the ability to rectify the incoming signal.

FIG. 1
PARTIAL VIEW OF NATIONAL'S RECEIVER CONSTRUCTION AND SERVICE LABORATORY

and also to amplify it; thus furnishing a louder audible signal. Because of these aforementioned features, we can classify vacuum-tube detectors into two distinct groups; namely, as non-amplifying detectors and as amplifying detectors. Both types are used in modern receivers; each having certain characteristics that make it desirable in specific circuit arrangements.

NON-AMPLIFYING DETECTORS

In the non-amplifying class, we have the diode vacuum-tube detector. Incidentally, the crystal detector is also a non-amplifying device, but its use is confined almost entirely to receivers built for instructional or experimental purposes. The diode vacuum tube, therefore, is the only non-amplifying detector that is being used in present-day commercial type receivers.

Since a diode acts as a rectifier only, and does not amplify, a one-tube receiver using a diode as a detector would obviously provide low volume and limited sensitivity. However, the diode has two important features --- notably good tone quality, and the ability to operate without distortion when comparatively strong signal voltages are applied to its input. For these reasons, it is popular in modern high-fidelity receivers, where the detector is preceded by several stages of high-gain r-f amplification, and followed by one or more stages of a-f amplification. (Note: A "high-fidelity" receiver is one that furnishes high-quality sound reproduction.)

AMPLIFYING DETECTORS

The only amplifying detector that has ever been used satisfactorily in radio receivers is that utilizing a multi-electrode vacuum tube; such as a triode, tetrode, or pentode. The triode (three-element tube), which is the basic tube of all multi-electrode types, has the ability to pass comparatively heavy currents through its plate circuit, controlled by feeble signal voltages applied to its grid.

Because of its amplifying ability, the triode is a more sensitive detector than is the diode; but does not provide the same faithfulness of sound reproduction.

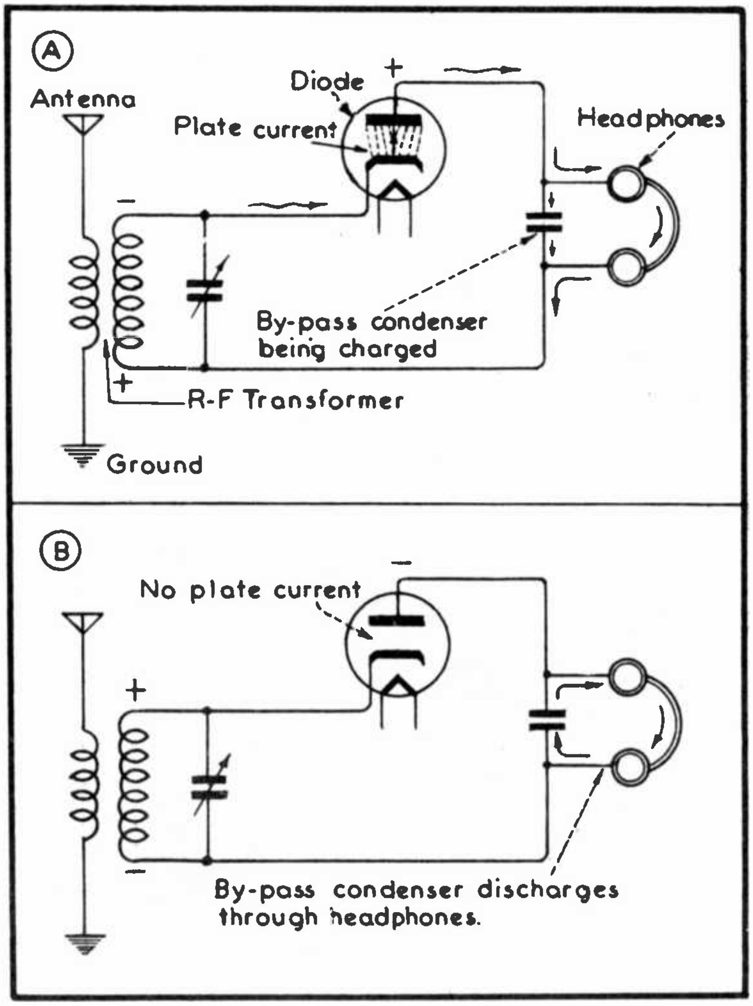

FIG. 2
HOW A DIODE DETECTOR RECTIFIES SIGNAL

This lesson covers thoroughly the theory and operation of both non-amplifying and amplifying types of detectors, so that you will fully understand their functions in modern receivers.

THE DIODE DETECTOR

The basic circuit of a diode detector is shown in Fig. 2, where you will observe the tube to be incorporated in a circuit similar to that described in a previous lesson pertaining to crystal detectors. It operates in the following manner:

Signal voltages induced in the antenna by the passing radio wave cause an alternating voltage of corresponding frequency to appear across the ends of the r-f transformer's secondary winding and the condenser. These same voltages will therefore be impressed across the cathode and plate of the diode, through the windings of the headphones. The hot cathode emits electrons that are attracted to the plate whenever the a-c signal voltage places a positive charge on the plate; so permitting a surge of current to flow through the headphones, as at (A) of Fig. 2 --- at the same time charging the condenser that is connected across the headphones. (Note: The filament circuit has been omitted in Fig. 2, for simplicity.)

No current flows through the headphones when the signal places a negative voltage on the plate, because the plate opposes the flow of electrons through the tube at this time. This is illustrated at (B) of Fig. 2. And, since the charging voltage has been removed from the "phone condenser," the latter discharges through the headphone windings.

The curve at (A) of Fig. 3 illustrates the modulated signal in the receiver's tuning circuit; that at (B) represents the rectified signal current resulting from the action of the diode; and that at (C) illustrates the audio frequency to which the headphones respond.

From the explanation just given, it is quite apparent that the diode performs the same function as does the crystal detector in circuits described earlier in the course. That is to say, when an a-c signal voltage is applied to the diode, a rectified (pulsating, direct) current flows through the headphones the same as in a circuit containing a crystal detector. And, this flow of rectified current through the

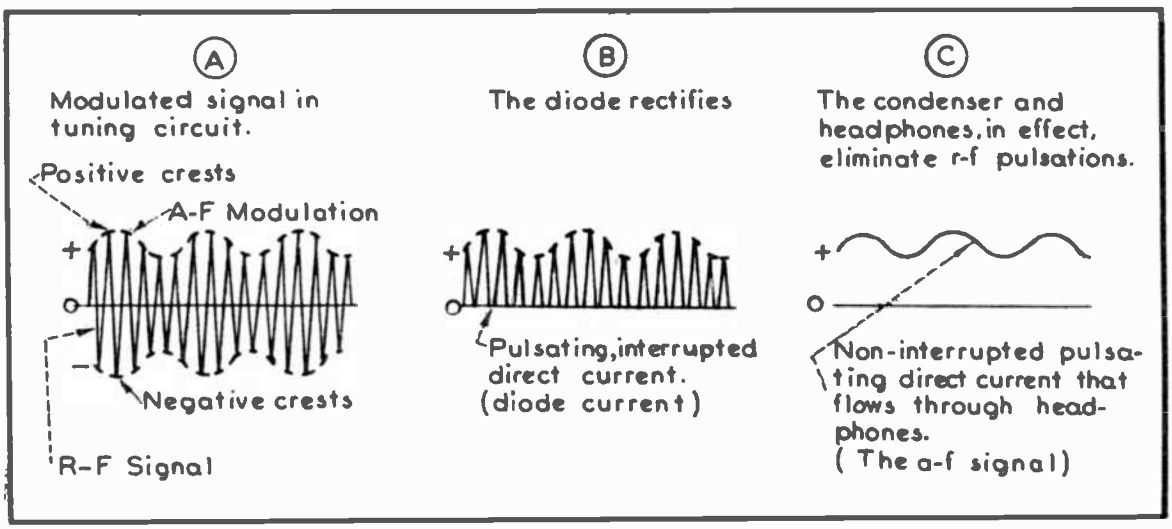

FIG. 3
DEMODULATION (DETECTION) OF THE BROADCAST SIGNAL

headphones produces an audible signal for the same reasons as given previously relative to crystal-detector receivers. The action of the "phone condenser" in smoothing out the r-f ripples in the output current was explained in detail at that time; and therefore need not be repeated now.

You will note from the input and output curves in Fig. 3 that this device functions only as a rectifier, and that no amplification of the signal takes place. This is true of all diode detectors.

Due to the lack of amplification, this receiver will not operate a loudspeaker, and will be capable of receiving signals only from nearby transmitting stations. This is characteristic of all one-tube sets using diode detection. However, the incoming signal will be reproduced by the headphones with excellent fidelity,and with a minimum of distortion.

The arrangement of the parts and wiring of a circuit of this type is shown in Fig. 4

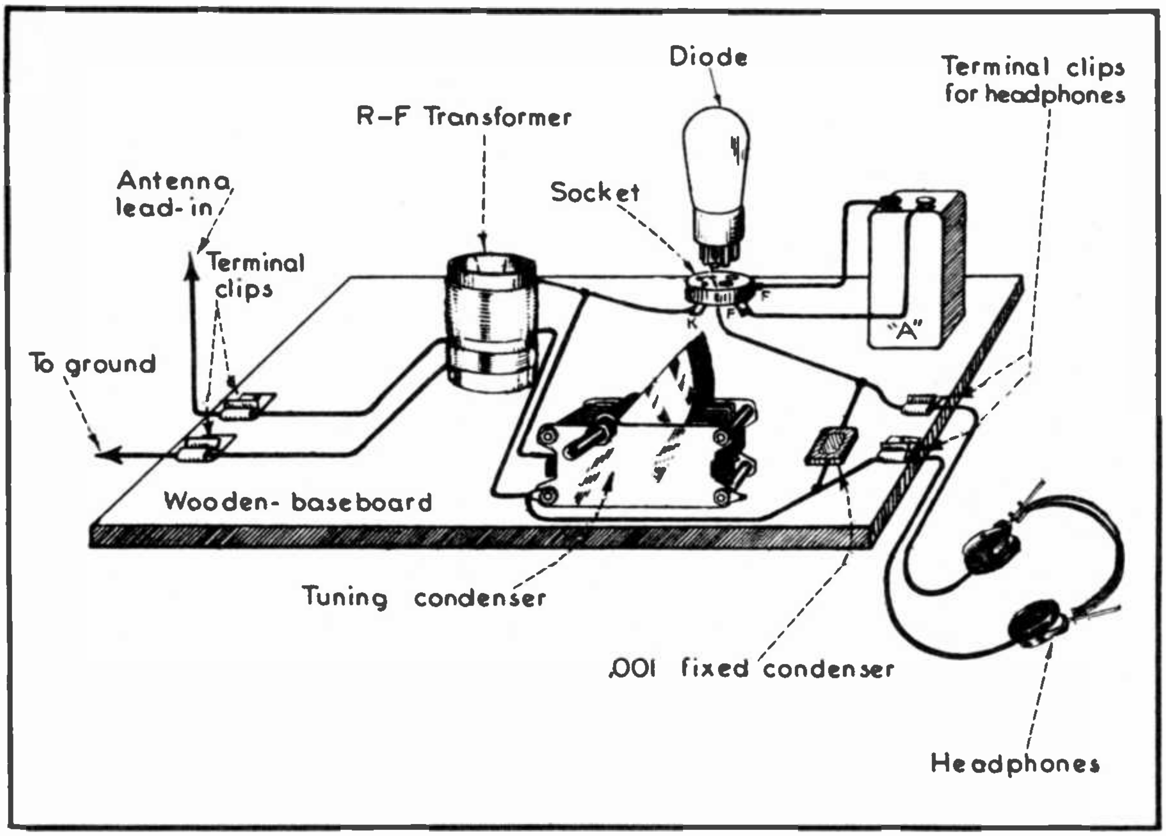

FIG. 4
PHYSICAL APPEARANCE OF DIODE DETECTOR

DIODE DETECTOR COMBINED WITH R-F AMPLIFICATION

When the diode detector is placed in a receiver containing one or more stages of r-f amplification, its lack of sensitivity is compensated for by the gain of the amplifier; and good reception of distant stations is then possible. But yet, the diode detector retains the desirable features of fidelity and stability. This is shown in Fig. 5, where a two-stage r-f amplifier precedes the detector and so feeds amplified r-f voltages to it.

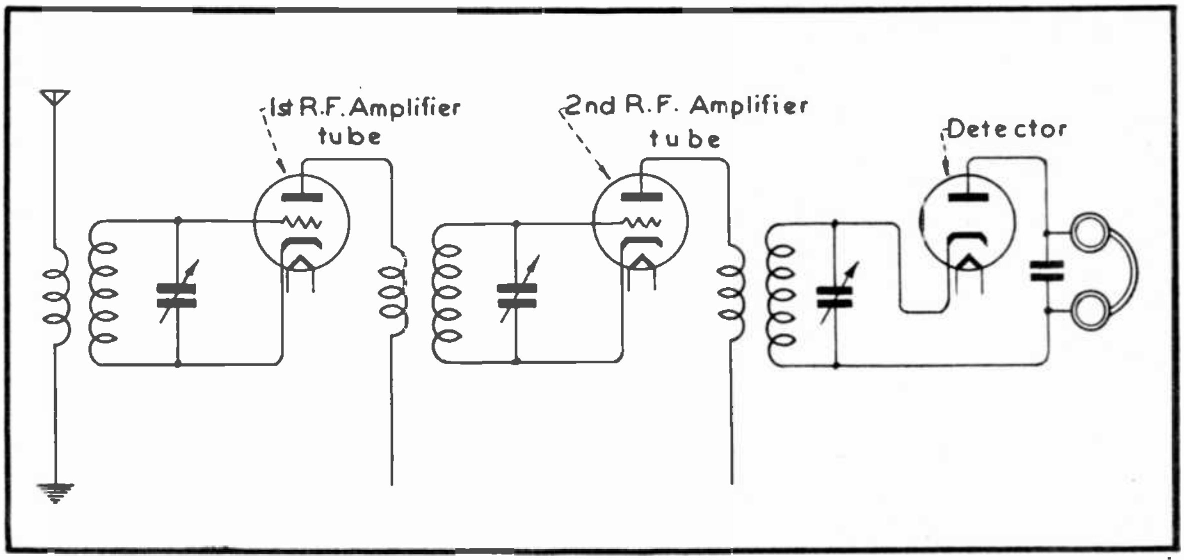

FIG. 5
TWO STAGES OF R-F AMPLIFICATION PRECEDING THE DETECTOR

You will note that an r-f coupling transformer has been substituted in the detector circuit for the antenna-stage r-f coil of our simple one-tube receiver. A concise analysis of the action taking place in this arrangement follows:

Amplified r-f signal current variations that are present in the plate circuit of the tube in the second stage of the r-f amplifier flow through the primary winding of the r-f transformer installed at this point --- causing r-f voltages to be induced into the secondary winding. Signal currents of like frequency therefore flow in the tuning circuit of the detector --- producing an r-f emf across the tuning condenser which sends current through the detector and headphones. But, since the diode functions as a rectifier (one-way electrical valve), the current that passes through the headphones is a direct current, pulsating or varying at an audio frequency rate --- and so producing sound.

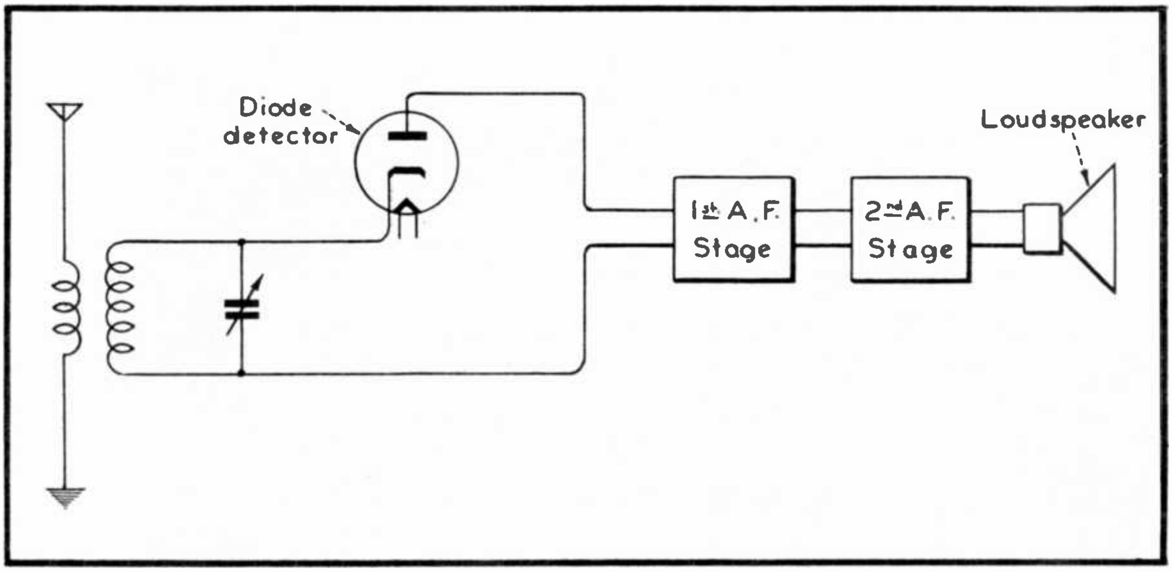

FIG. 6
DIODE DETECTOR COUPLED TO A-F AMPLIFIER

DIODE DETECTOR COMBINED WITH A-F AMPLIFICATION

When the diode detector precedes one or more stages of a-f amplification, the lack of amplification on the part of the detector is compensated for by the gain of the a-f amplifier. By referring to the diagram in Fig. 6, you will see that this combination will operate a loudspeaker satisfactorily. The desirable features of the diode --- namely, fidelity and stability --- are retained in this case also.

As a-f amplifying circuits are explained in detail in the next lesson, the a-f stages in Fig. 6 are shown in block form only, the output of the detector being fed into the first stage.

DIODE DETECTION COMBINED WITH R-F AND A-F AMPLIFICATION

A complete receiver, employing diode detection with two stages of r-f amplification preceding the detector and two stages of a-f amplification following the detector is shown in Fig. 7. As in Fig. 6, the a-f stages are represented in block form. You will note that with this combination, the three basic actions enumerated below take place:

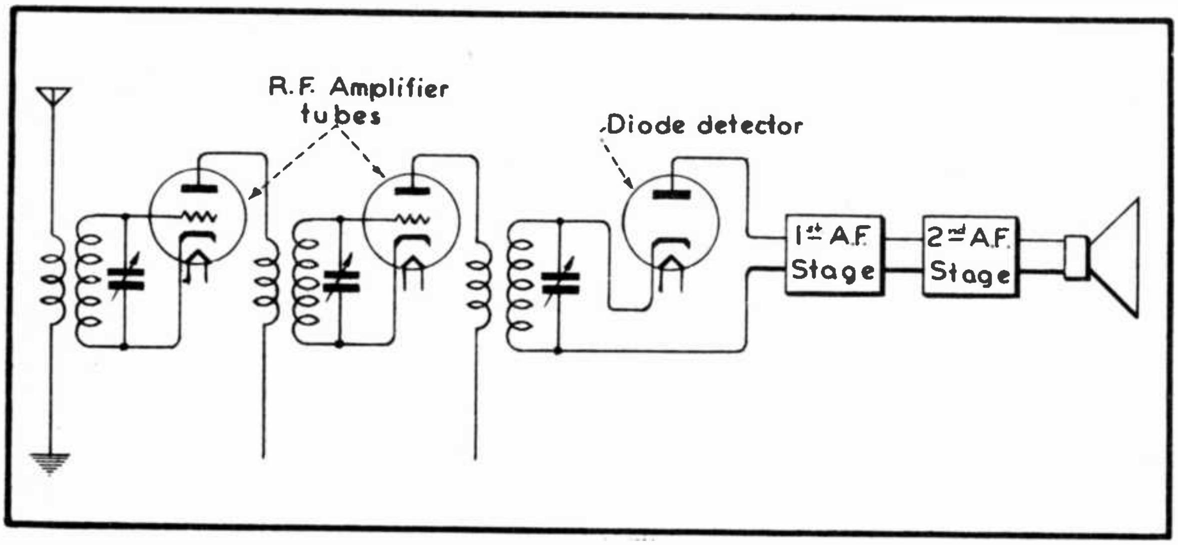

FIG. 7
COMPLETE RECEIVER COMPRISING R-F AMPLIFIER, DETECTOR AND A-F AMPLFIER

1. Adequate sensitivity and selectivity secured by the r-f amplifying stages; thus providing reception of distant, or weak, signals -- and proper selection of the desired station signal.

2. Good tone quality and stability --- both of which are characteristic of the diode detector.

3. Satisfactory operation of a loudspeaker, made possible by the a-f amplifier stages.

With slight variation as to certain circuit details, this arrangement is used in many of our present-day radio receivers.

TYPES OF DIODE TUBES USED FOR DETECTION

You have probably noticed that the diode employed in Fig. 7 is similar to the cathode-type diode used as a half-wave rectifier in power supply circuits. Present practice is to use a duo-diode as a detector instead of a tube having but a single diode section.

The use of a duo-diode as a detector is shown in Fig. 8. You will note that both plates are connected together; as also are the cathodes. This makes the duo-diode tube perform in every way as though it were a single-diode type. So far as detection is concerned, there is no advantage in using a duo-diode instead of a single diode; but since the single diode is applied in very few instances other than for detection, and since the duo-diode employed as in Fig. 8 will perform as well as would a single diode, needless duplication of tube types is avoided by making tubes which may be used as single diodes in certain detector circuits, and as duo-diodes in other applications.

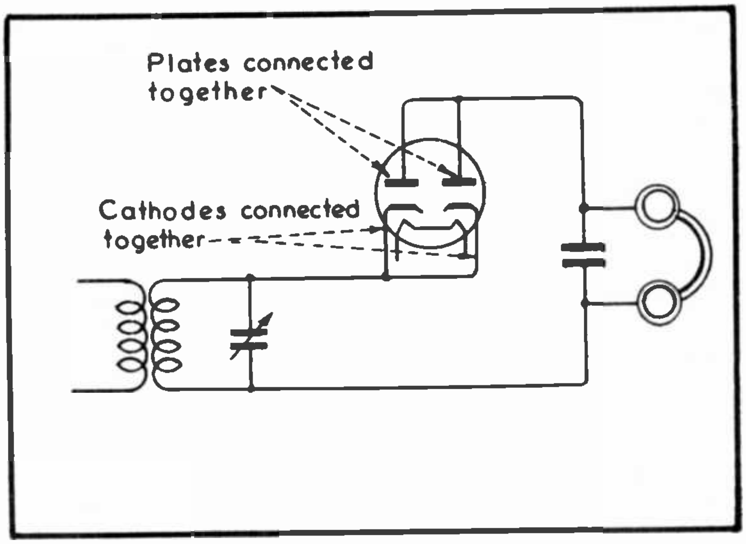

Fig. 8
Duo-Diode Tube Applied as Detector

TRIODE USED AS A DIODE

If all the electrodes of a multi-electrode tube, except the cathode, be connected together, the tube will function in all respects as a diode. This is shown in Fig. 9, where a triode is being used as a diode in a detector circuit. Here, the control grid of the triode has been connected to the plate, and so no longer functions as a control grid --- but rather, as part of the plate.

In the same manner, a tetrode or pentode could be so connected that it would function as a diode for detection. This is shown in Fig. 10, where the various grids will be seen connected to the plate.

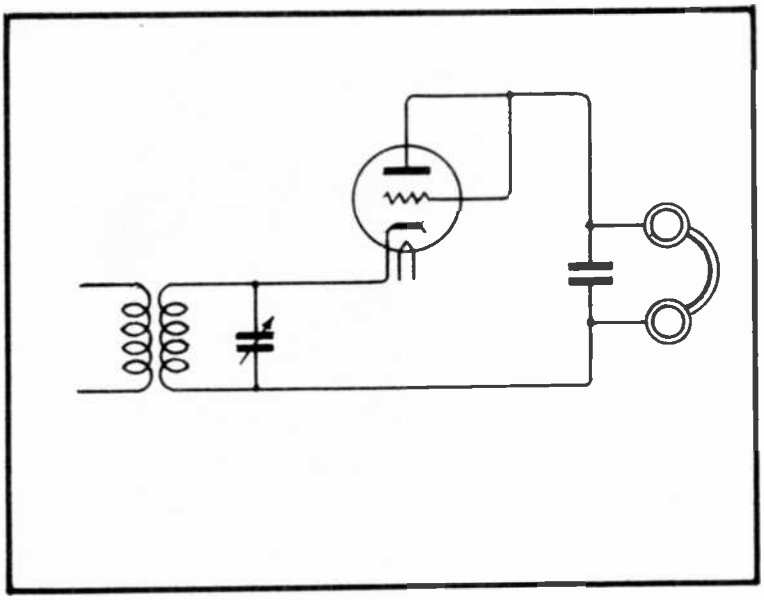

Fig. 9
Triode Connected to Function as Diode Detector

DIODE DETECTION USING DUO-DIODE TRIODE

Space is saved in many modern receivers by the use of a duo-diode-triode. This tube contains a duo-diode section comprising two small diode plates and the cathode which performs the functions of detection; and a triode section comprising a grid, large plate and cathode that serves as the first a-f amplifying tube --- all contained within one envelope. Note that the single cathode and heater are common to both sections of the tube. As we are at this time concerned only with

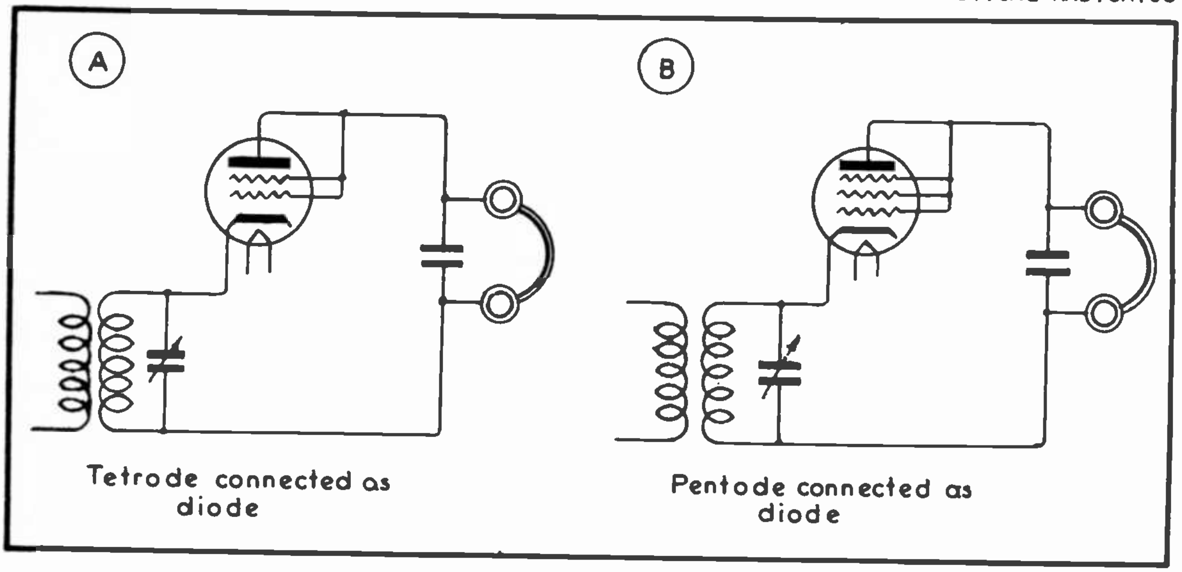

Fig. 10
Tetrode and Pentode Connected to Function as Diode Detector

the diode, or detector section of this tube, our present discussion will be so limited.

A diode detector circuit in which a tube of this kind is employed is shown in Fig. 11. The two small diode plates are in this case connected together to serve as a single diode plate. As far as the diode section of the tube is concerned, its action differs in no way from that of the simple diodes previously described. The triode section of the tube does not affect the operation of the diode section, and will therefore be discussed later.

AMPLIFYING DETECTORS

Two types of amplifying detectors are commonly used. They are known as the grid-bias detector and the grid-leak detector.

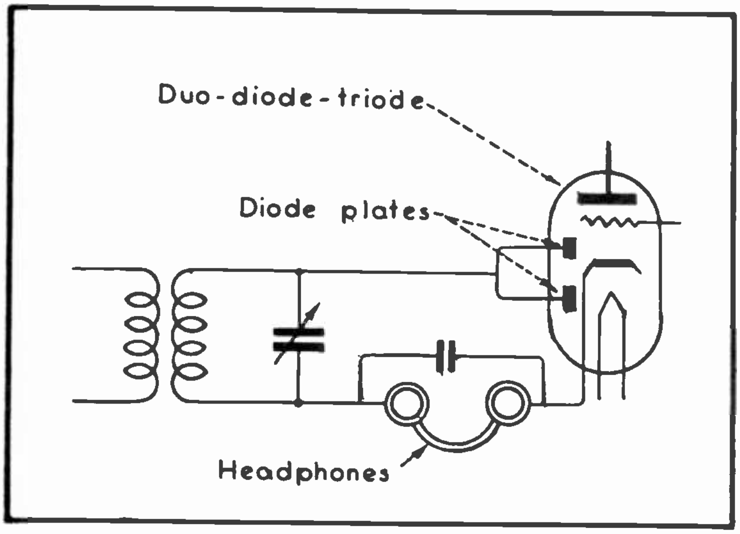

Fig. 11
Application of Duo-Diode-Triode As a Detector

GRID-BIAS DETECTOR: This type of amplifying detector is not the most sensitive, but it combines a reasonable degree of sensitivity with amplification, fidelity and stability. It works well on the large signal voltages supplied by modern high-gain r-f amplifiers. The majority of receivers which employ amplifying detectors utilize this type.

GRID-LEAK DETECTOR: The grid-leak detector is the most sensitive of all amplifying detectors; but it is somewhat unstable, and tends to distort strong signals. It is easily overloaded, and will therefore not operate satisfactorily when connected to the output of high-gain r-f amplifiers. Once very popular, it is now little used except in certain small shortwave receivers as built by experimenters.

As mentioned earlier in this lesson, all amplifying detectors utilize multi-electrode tubes --- such as triodes, tetrodes, or pentodes. Their theory of operation is quite simple, and there is little difference between the operation of a triode, a tetrode, or a pentode, when used for the same type of detection. Since the triode is the basic tube of all the multi-electrode types, we will confine our discussion of detectors to triodes except when it becomes necessary to refer specifically to a tetrode or pentode.

GRID-BIAS DETECTOR

In Fig. 12, we have a simple circuit containing a triode. Notice how one end of the tuning circuit is connected to the grid of the tube, and the other end to the cathode. This is called the "grid circuit."

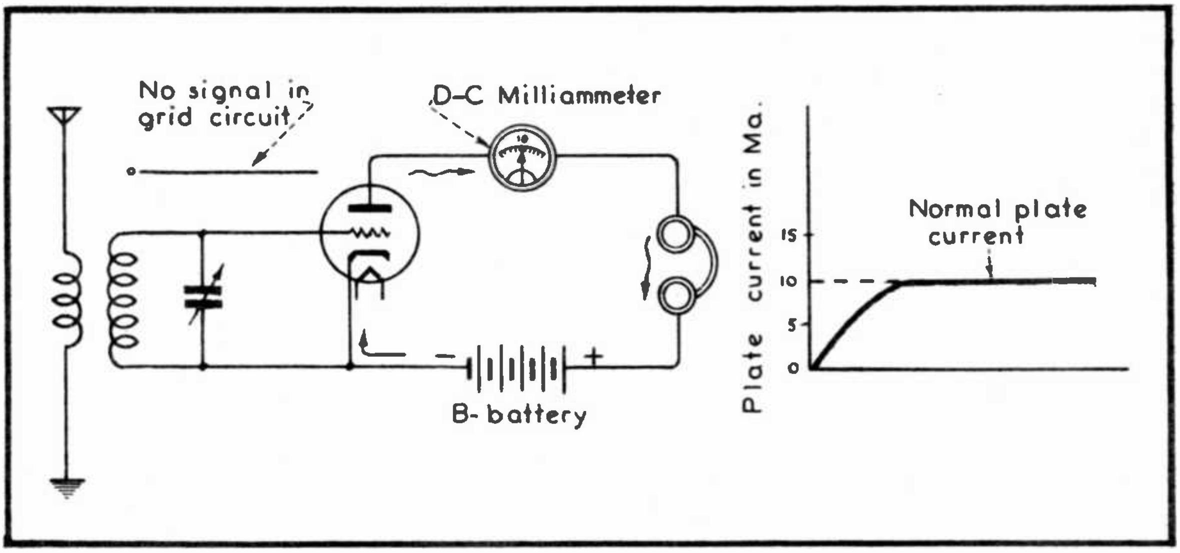

FIG. 12
OPERATION OF TRIODE CIRCUIT WHEN NO SIGNAL IS APPLIED TO GRID

The headphones, a d-c milliammeter and a B-battery are connected in series between the plate and cathode to form the plate circuit.

A positive voltage, furnished by the B-battery, is applied continuously to the plate of the triode. Therefore, electrons are attracted from the hot cathode to the plate, causing current to flow through the plate circuit in the direction of the arrows. We call this the "plate current."

CONDITION WITH NO SIGNAL ON GRID

In Fig. 12, signal current is considered to be flowing in the antenna coil; but we are assuming that the tuning circuit is not in resonance with the signal frequency, so no signal emf is being impressed on the grid. Under these conditions, the plate current is of a steady non-varying value, as illustrated by the curve at the right.

The current which flows in the plate circuit of any triode, or other multi-electrode tube, when no signal is being applied to the grid, is called the normal plate current. In Fig. 12, the milliammeter shows us that a normal current of 10 milliamperes flows in the plate circuit when no signal is applied to the grid of this tube. You should note,

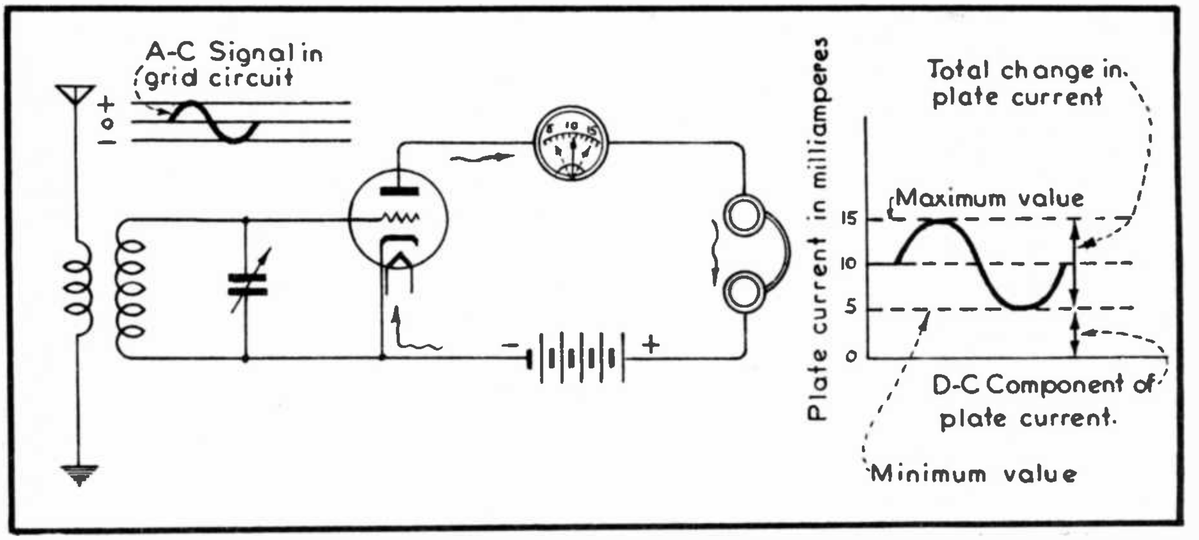

FIG. 13
OPERATION OF TRIODE CIRCUIT WHEN SIGNAL IS APPLIED TO GRID

however, that 10 ma. is not always the normal value of plate current, and that it is not the same for all tubes in all circuits.

But, since a pulsating or varying current is required for the operation of headphones or some other sound-reproducing device, this normal plate current will not produce sound.

CONDITIONS WITH SIGNAL APPLIED TO GRID

In Fig. 13, the tuning circuit has been brought to resonance with an incoming signal, and therefore a signal voltage is impressed on the grid. This is an r-f alternating voltage; which means that it is varying in both polarity and intensity. At one instant, the grid will be neutral --- then it will swing strongly negative --- come back to neutral --- then swing strongly positive. Remembering that plate current increases when the control grid is positive, and decreases when the control grid is negative, it is obvious that when an alternating signal voltage is applied to the grid, the plate current will rise and fall in exact step with the grid voltage.

This is illustrated in Fig. 13, where a cycle of signal voltage has just been impressed upon the grid, and the corresponding plate current (I_p) change is shown in the plate current (I_p) curve at the right. You will observe that as the grid swings positive, the plate current increases to a higher than normal value (15 ma., instead of 10 ma.).

The signal current in the antenna and tuning circuits is but a few microamperes; but we have a comparatively large current in the plate circuit. The plate current varies in intensity in exact step with the original signal current; but it is many, many times stronger --- and the changes in intensity are of greater magnitude than are those in the antenna and tuning circuits. It is therefore apparent that the triode has definitely provided amplification, or intensification of the received signal.

It is important to note that three values of current must be considered in the plate circuit of Fig. 13. They are:

1. The normal plate current, which is 10 ma.
2. The maximum plate current, which is 15 ma.
3. The minimum plate current, which is 5 ma.

PLATE CURRENT CHANGE

The total change in plate current is equal to the arithmetical difference between the minimum plate current and the maximum plate current (15 ma minus 5 ma. or 10 ma., in this case), the difference between zero and minimum plate current (5ma. in our example) is often called the "d-c component" of the plate current. These terms are illustrated on the plate current graph in Fig.13.

It should be brought sharply to your attention at this point that while we have achieved amplification of the signal in Fig. 13, detection has not taken plate, and no sound will be produced by the headphones. This is because the plate current changes are equal; that is, in the circuit of Fig. 13, the increase in plate current is the same as the decrease in plate current --- each being 5 ma. But, in order for the headphones to produce sound, there must be a difference between the plate current increases and the plate current decreases.

WHY EQUAL PLATE CURRENT INCREASES AND DECREASES WILL NOT PRODUCE SOUND

In connection with crystal and diode-detection receivers, you learned that in order to actuate the headphones, the received signal current must be rectified, or converted from alternating to pulsating current. Now, upon studying the plate current curve in Fig. 14-A, which shows the current existing in the plate circuit of the triode in Fig. 13, you will find that this curve resembles very much the curve for alternating current appearing in Fig. 14-B. The latter is a signal current curve before that current has been rectified.

It is quite true that the current in the plate circuit of any vacuum tube is always "direct" in the sense that it flows through the circuit in one direction only; but if we consider the line of normal current flow in Fig. 14-A as corresponding with the line of zero current flow in Fig. 14-B, there is no difference in the general appearance of the two current curves. When making such a comparison, we often call the line of normal current flow, as well as the line of zero current flow, the reference line.

We know, of course, that these two currents are not exactly alike, because one of them (the a-c) is constantly reversing its direction of

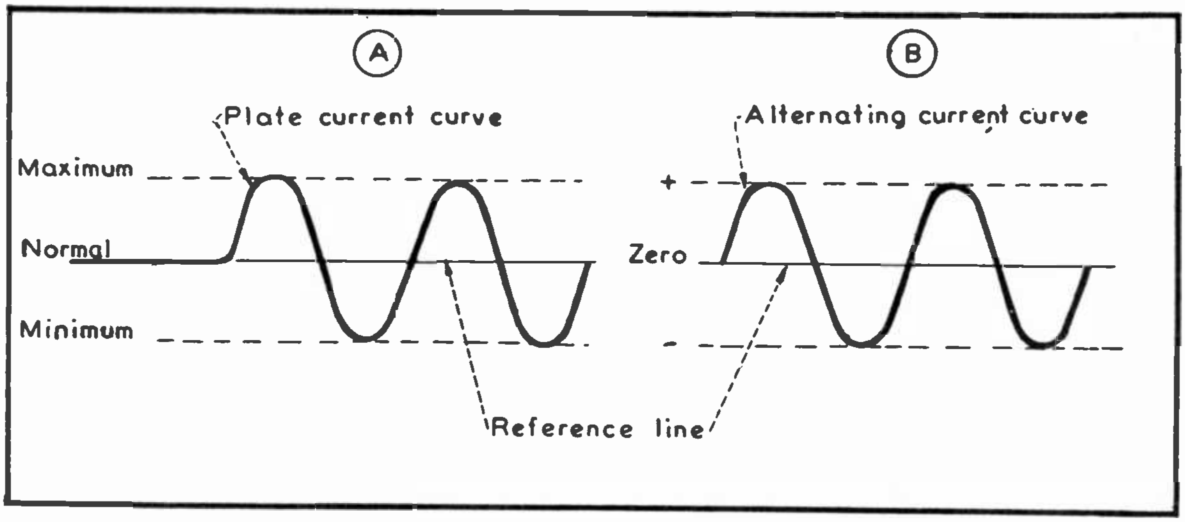

FIG. 14
COMPARISON OF PLATE CURRENT VARIATION WITH ALTERNATING CURRENT

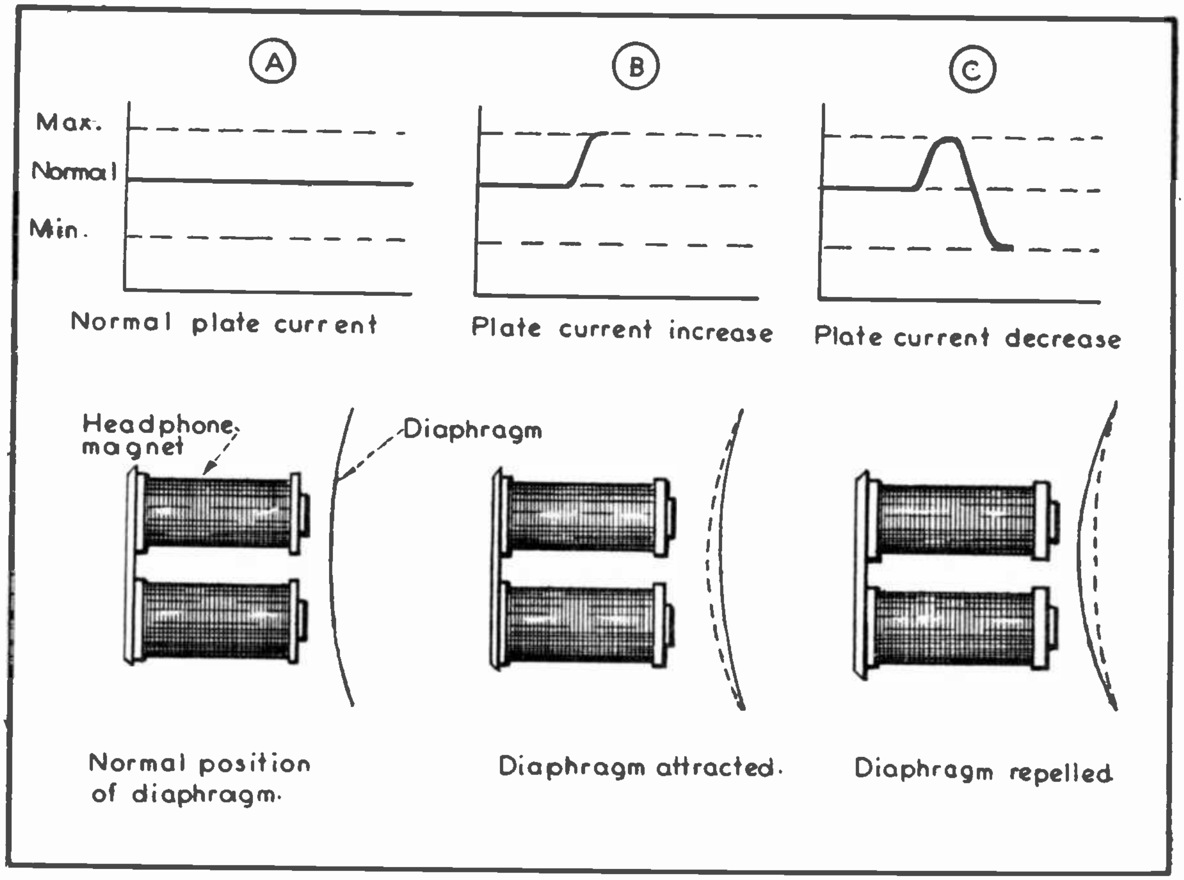

FIG. 15
EFFECT OF VARYING PLATE CURRENT ON HEADPHONE

flow, while the other (the plate current) is merely varying its intensity so that it rises above and falls below the reference line; but with that one exception, the general shape of the two curves is very much alike. Let us now see how this varying plate current would act if permitted to flow through a pair of headphones.

A sectional view of a headphone is shown in Fig. 15. When normal (no signal) plate current is flowing, the diaphragm will be pulled toward the poles of the phone as shown at (A). With an a-c signal voltage impressed on the grid of the tube, the plate current will rise above and drop below the normal reference line. This means that when the current is increasing, the diaphragm will be pulled still closer to the magnet, tending to approach the position represented by the dotted line at (B) of Fig. 15. When the plate current is decreasing to a value below normal, the pull on the diaphragm will be lessened, and the diaphragm will tend to move toward the position represented by the dotted line at (C) of Fig. 15. However, the diaphragm is physically too inert to respond to these very rapid plate current increases and decreases, which occur at radio frequencies. The final result is that instead of vibrating and producing sound, the diaphragm remains in the approximate position first assumed when normal plate current was flowing --- and, consequently, there is no sound.

In order for the headphones to respond to the current changes in the plate circuit, it is necessary that this current be rectified. Rectified, not in the sense that it will be flowing through the circuit in one direction only --- as it is already doing that --- but rectified in the sense that the plate current increases are greater than the plate current decreases. This is done by applying a negative voltage --- called a "biasing voltage" --- to the grid of the tube.

GRID-BIAS

Triodes, or other multi-electrode tubes which are being operated as so-called bias-detectors, require that a negative voltage be applied continuously to their control grid. A negative voltage so used is called a "bias voltage," or simply "bias." A simple way of securing this bias voltage is by means of a small battery; often called a C-battery.

The addition of a C-battery to furnish a bias for this circuit is shown in Fig. 16. You will note that the positive terminal of the C-battery is connected to the cathode, and that the negative terminal is connected to the grid through the coil. The grid will therefore now be at a negative potential with respect to the cathode. The grid of the tube is then said to be negatively biased.

In Fig. 16, a 15 volt C-battery has been inserted in the grid circuit. Consequently, there is now a voltage-difference of 15 volts between the cathode and the grid. And, since the grid is connected to the negative terminal of the battery, we can say that the grid is 15 volts negative with respect to the cathode. Another way of stating the same fact would be to say that the cathode is 15 volts positive with respect to the grid.

HOW BIAS AFFECTS NORMAL PLATE CURRENT

Now let's see what happens to the normal plate current when the C-battery is connected in the grid circuit. The plate current curve of Fig. 16 shows the change that has taken place. You will see that the plate current has been reduced greatly, by the negative potential applied to the grid. In fact, so great has been this decrease in normal plate current, that its value is but slightly above zero. Obviously, the greater the negative voltage (bias) applied to the grid, the less will be the plate current.

CUT-OFF: When a biasing voltage sufficient to completely stop the flow of plate current has been applied to the grid of a tube, the tube is said to be biased to cut-off. In other words, the plate current has then been cut off by the high bias.

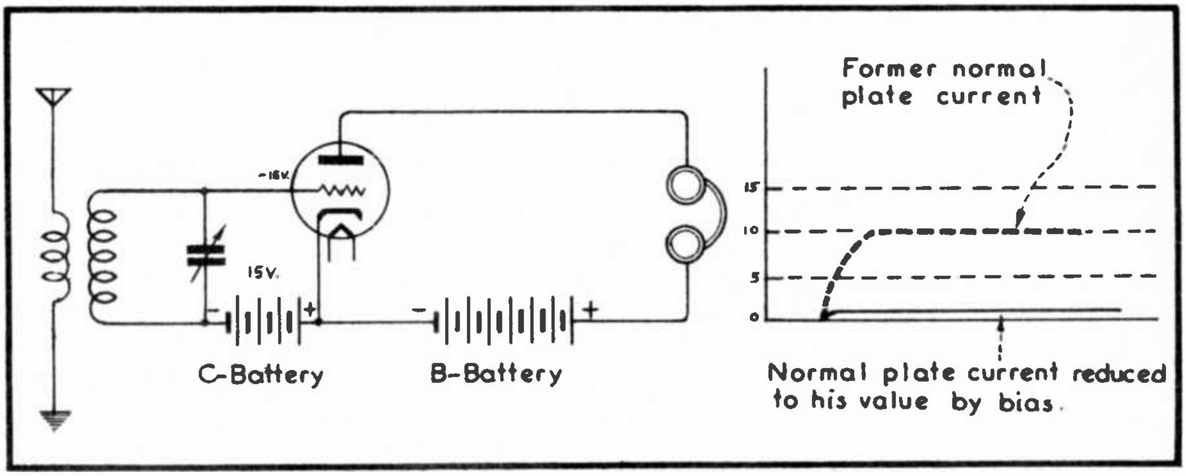

FIG. 16
C-BATTERY VOLTAGE REDUCES NORMAL PLATE CURRENT VERY NEARLY TO CUT-OFF IN BIAS-DETECTOR CIRCUIT

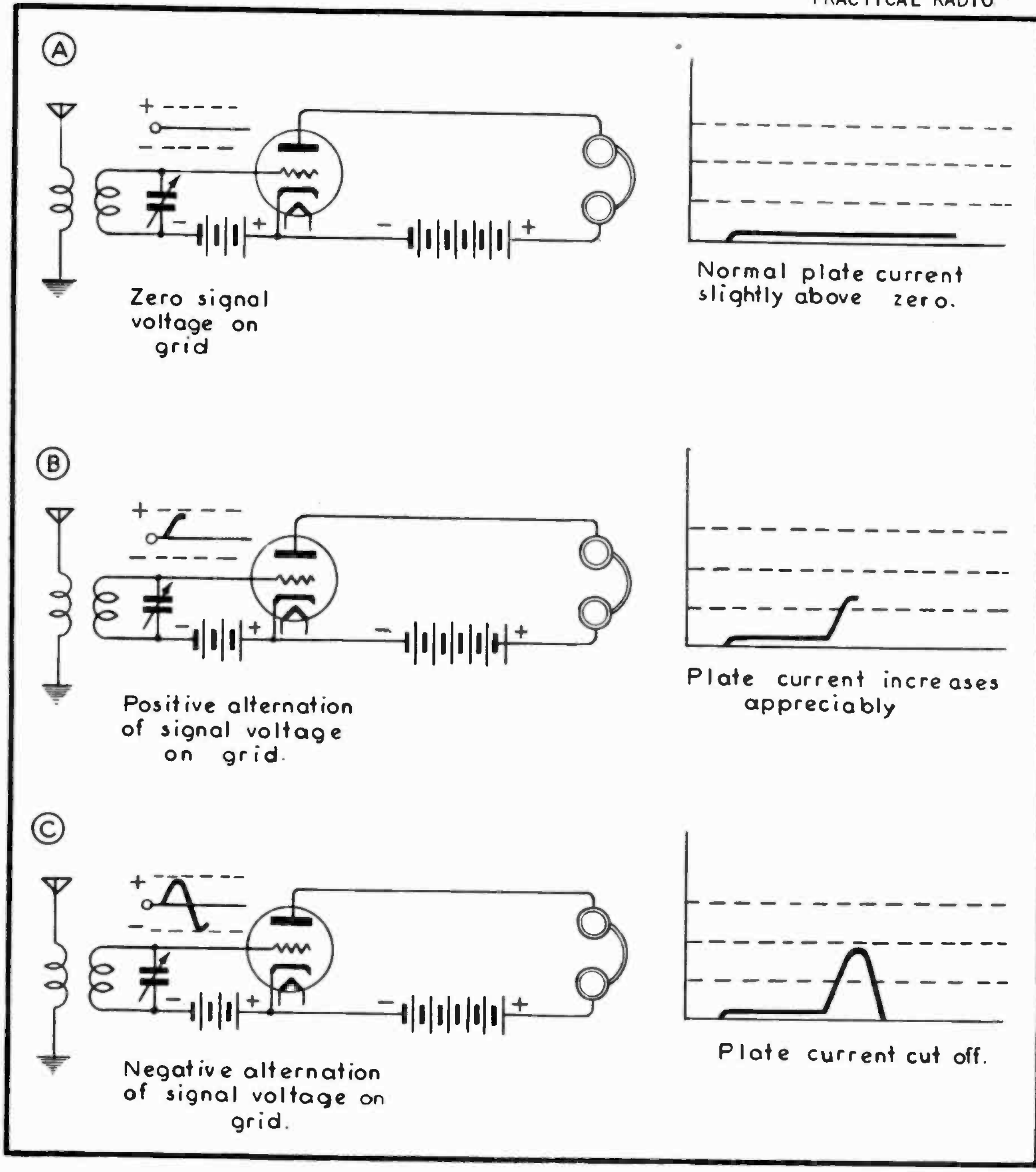

FIG. 17
HOW A-C SIGNAL VOLTAGE AFFECTS PLATE CURRENT OF BIAS-DETECTOR

AMOUNT OF BIAS REQUIRED FOR CUT-OFF: The value of the voltage necessary to achieve complete cut-off varies with different tubes, and with the plate voltage. Manufacturer's specifications give these values for most tubes which require biasing. You will find them to vary from about 3 volts to as high as a hundred volts or more. In the circuit of Fig. 16, we are assuming that a bias of 15 volts is reducing plate current to,or very near, cut-off.

PLATE CURRENT CHANGES OF BIAS-DETECTOR

Now, let us assume that a signal voltage is being induced into the tuning coil, and that this signal voltage, together with the constant d-c voltage of the C-battery, is applied to the grid. When the signal voltage is zero, the grid will still have the 15 volt bias of the C-battery applied to it, and very little current will be present in the plate circuit. This is illustrated at (A) in Fig. 17.

When the a-c signal voltage rises on the positive alternation, it applies a positive voltage to the grid. This positive signal voltage is opposite in polarity to, and therefore opposes the negative emf of the C-battery. Thus, the grid is made less negative (or more positive) than it was when the C-battery voltage alone was applied to it. Under such conditions, more current will flow through the plate circuit; and the tube will thus not be operating so close to cut-off as before. This is shown by the change in the plate current curve at the right of Fig. 17-B, where a plate current increase of 5 ma. is illustrated.

When the a-c signal voltage changes so that a negative alternation is being applied to the grid, this negative voltage aids the voltage of the C-battery --- tending to make the grid even more negative than does the C-battery alone.

Now, since the 15 volts of the C-battery was sufficient to very nearly stop the flow of plate current altogether and so bring about cut-off, the additional negative voltage of the signal will reduce the plate current but a slight amount until absolute cut-off takes place. In other words, if the plate current drops to zero as soon as the signal voltage barely commences to increase in a negative direction, there can be no further decrease in plate current regardless of the amount of negative signal voltage applied to the grid. (See Fig. 17-C.) When the next positive alternation reaches the grid, the plate current will again increase from zero toward maximum as it did in Fig. 17-B. Thus, we have found that a positive signal voltage increases the plate current appreciably, while a negative signal voltage has practically no effect at all upon the normal plate current.

In Fig. 18, you are shown a grid voltage curve comprising several cycles, and the corresponding plate current curve that would be formed thereby. Notice, especially, that current flows in the plate circuit only when a positive alternation is reaching the grid, and that a series of "gaps" represent the interruption in plate current during negative alternations of the grid voltage. The condenser which is connected across the headphones discharges during the "gaps" in plate current, causing the average current flow through the headphones to vary uniformly at an audio

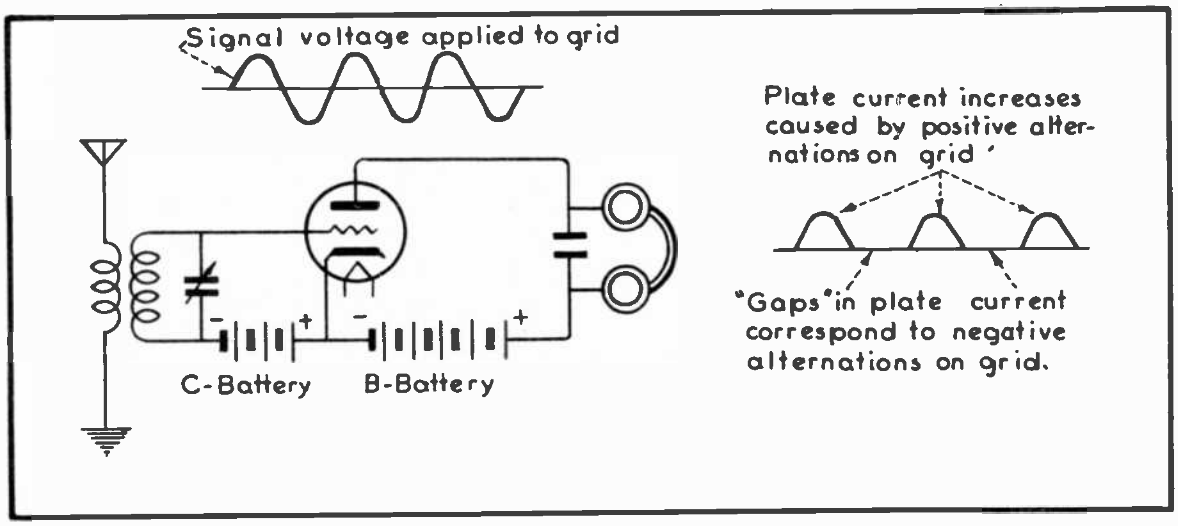

FIG. 18
HOW BIAS-DETECTOR RECTIFIES SIGNAL

frequency rate. This action is the same as that described relative to crystal detectors in an earlier lesson, and again illustrated in Fig. 3 of our present lesson.

METHODS OF SECURING BIAS

In the examples just given, you have been shown how the proper bias was secured through the use of a C-battery. This works very well, but the extra battery is not always desirable. A biasing voltage is often obtained by inserting a resistor between the tube's cathode and the negative terminal of the B-voltage supply, as shown in Fig. 19. You will note that current, in flowing from the negative terminal of the battery to the cathode of the tube, must pass through this resistor. In doing so, a voltage is developed across the resistor, the value of this voltage (voltage drop) being equal to the B-current (expressed in amperes) that passes through the resistor multiplied by the value of the resistor. This is in accord with Ohm's Law in the form E = I x R.

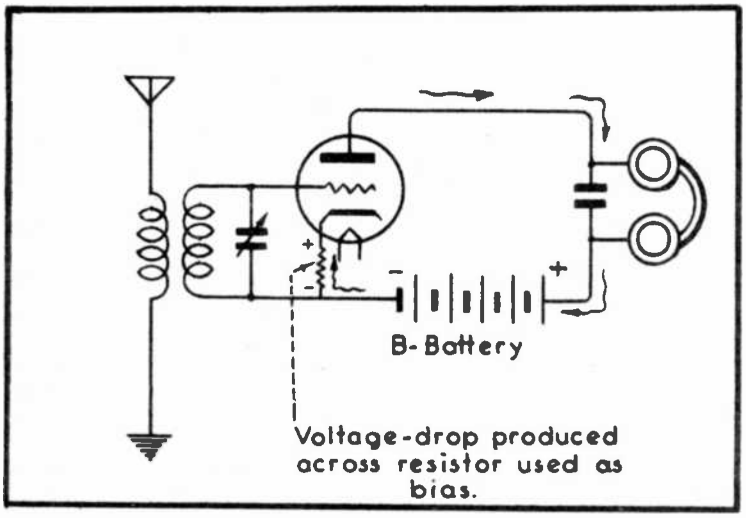

FIG. 19
SECURING BIAS VOLTAGE BY MEANS OF RESISTOR

It is to be noted further in Fig. 19, that the plate current flows through the bias resistor from its lower end toward its upper end, thus causing the lower end to be at a negative potential with respect to the upper end. Then, since the upper (positive) end of this resistor is connected to the cathode of the tube, and the lower (negative) end to the grid through the secondary winding of the r-f transformer, the grid will be at a negative potential with respect to the cathode. We therefore say that the grid of this tube is being operated with a negative bias applied to it, the bias in this case being furnished by the voltage drop appearing across the bias resistor because of the flow of plate current through it. The bias resistor thus takes the place of the C-battery used in the circuit of the bias-detector previously described. Sometimes, the bias resistor is spoken of as a "cathode resistor" because of being connected in the cathode circuit.

SECURING BIAS IN A-C RECEIVERS

In a-c receivers which derive their operating currents from a power supply system, it is particularly desirable that the bias be secured by means other than a C-battery. The most common method of doing this is by inserting a resistor between the cathode of the detector tube and the chassis. Almost all commercially manufactured receivers have a metal chassis that serves as the common connection for the negative side of the B-power supply.

In Fig. 20 is shown a diagram of a bias-detector circuit as commonly used in a-c receivers. Here, the negative side of the B-circuit is completed through the chassis (ground). Thus, by grounding the lower end of the bias resistor, this resistor is effectively connected in series with the B-circuit so that plate current must flow through it. By also grounding the lower end of the r-f transformer's secondary winding, the grid of the tube is electrically connected to the lower end of the resistor. Therefore, the difference in potential between the cathode and grid is equal to the voltage drop appearing across the bias resistor the same as in Fig. 19 --- the grid being negative with respect to the cathode because of the plate current flowing through the bias resistor in the direction indicated.

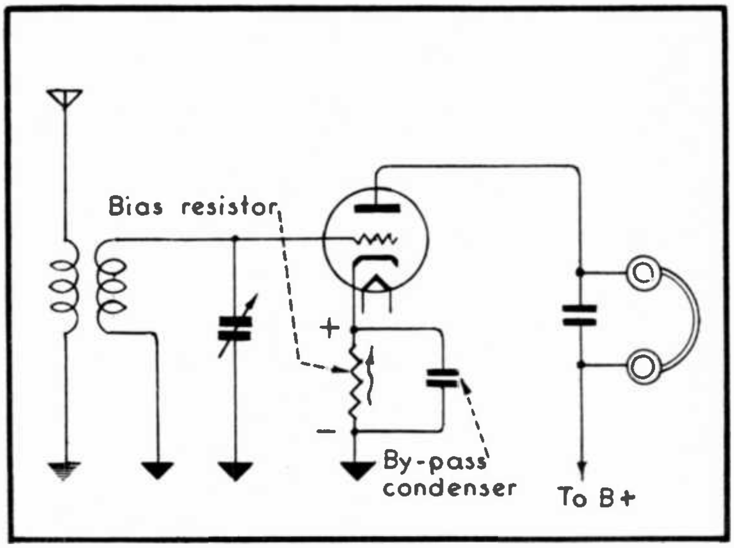

FIG. 20
BIAS-DETECTOR CIRCUIT WITH B-MINUS SIDE OF CIRCUIT GROUNDED

BY-PASS CONDENSER ACROSS BIAS RESISTOR

When bias is secured be means of a cathode resistor, a by-pass condenser is nearly always connected across it as in Fig. 20. Such a condenser opposes any direct current that may tend to flow through it, and therefore compels the d-c plate current to be confined strictly to the bias resistor. However, this same condenser offers a low-reactance path to the signal component of the plate current which varies in value in accordance with the frequencies being handled by the circuit. For this latter reason, these variable-current components react through the condenser rather than through the resistor; and therefore only a d-c voltage is developed across the resistor with which to bias the tube.

If the condenser were not placed across the bias resistor, fluctuating voltages as well as a d-c voltage would exist across the ends of the bias resistor; and if these fluctuating voltages were to be applied to the grid together with the d-c bias voltage, correct operation of the circuit could not take place, and the signals as reproduced by the headphones would be distorted. In detector circuits, the value of this by-pass condenser may be anywhere from about .1 mfd. to 10 mfd.

DETERMINING THE VALUE OF BIAS RESISTOR

The value of the bias resistor may be found in either one of two ways. The first of these, which consists of reference to the tube manufacturer's specifications, is the easier. All tube manufacturers specify the value of bias voltage required in order for a certain tube to function as a bias-detector, along with other data. Many of them also specify the value of the bias resistor to use for the purpose; but, if the latter information is not given, the bias resistor value may be computed by means of Ohm's Law.

COMPUTING VALUE OF BIAS RESISTOR FOR TRIODE: We will first show you how to compute the value of a bias resistor for a triode detector.

Knowing the required bias voltage from referring to the tube manufacturer's specifications, the value of the resistor is found by dividing the cathode current expressed in amperes into the bias voltage. (Note: In a triode, the cathode current is always equal to the plate current of the tube.)

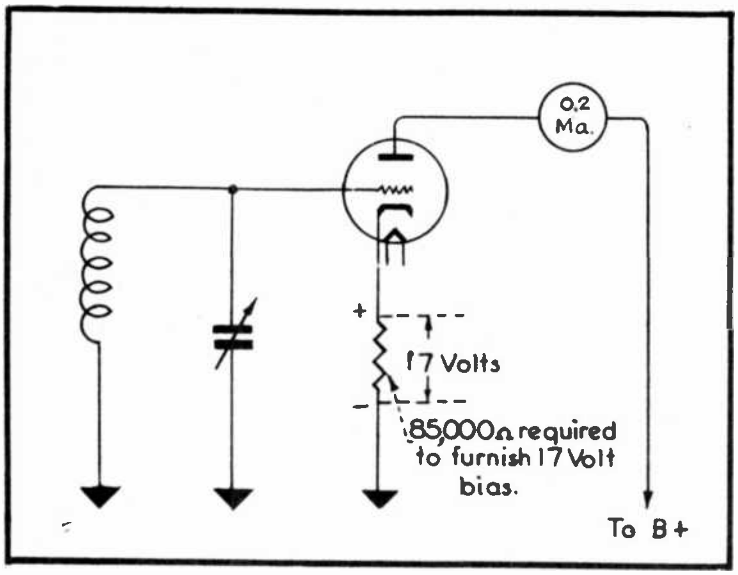

FIG. 21
COMPUTING BIAS RESISTOR FOR TRIODE

In Fig. 21, we present an example of this method. Here, the tube requires a grid bias of 17 volts. The plate current (I_p) is 0.2 ma. As the cathode current is equal to the plate current in all triodes, the cathode current is likewise equal to 0.2 ma. Converting the given plate current to amperes gives a value of 0.0002 ampere. Then, dividing the required bias by the cathode current, we have:

$$17 \div 0.0002 = 85,000$$

Therefore, a bias resistor of 85,000 ohms is needed. Notice that this is simply an application of Ohm's Law, (R = E ÷ I).

COMPUTING VALUE OF BIAS RESISTOR FOR TETRODES AND PENTODES: Bias resistors for tetrodes and pentodes are computed in the same manner, except that the cathode current of these tubes is equal to the combined plate and screen grid currents. An example of this is shown in Fig. 22, where the plate current is .3 ma., and the screen current .1 ma. The cathode current is therefore .3 + .1 or .4 ma. And, since a bias of 5 volts is required to operate this particular tube as a bias detector we determine the cathode resistor value by first changing the cathode current from .4 ma. to its equivalent of .0004 amperes and then substituting values in the formula R = E ÷ I, thus; 5 ÷ .0004 = 12,500 ohms. A bias resistor of 12,500 ohms must therefore be used in this case.

We wish to bring to your attention the fact that the bias resistor in series with the cathode is the most popular method of securing bias in modern receivers, and is therefore the method you will most often encounter in your work in this field. Bias is also required for certain types of r-f and a-f amplifier tubes, as well as in many electronic devices other than radio. So, what you learn about this subject now will be applicable to these other cases also.

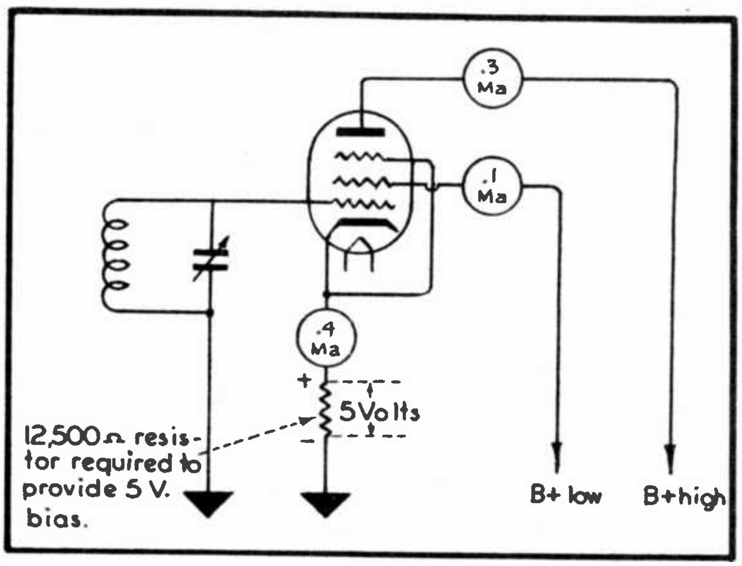

FIG. 22
COMPUTING BIAS RESISTOR FOR PENTODE

GRID-LEAK DETECTION

A grid-leak detector is so named because its grid circuit always contains a resistor of several million ohms that is called a "grid-leak." As mentioned earlier in this lesson, this too is an amplifying type detector.

The circuit of a grid leak detector is shown in Fig. 23, in diagram form. The distinguishing features of this detector circuit are the grid condenser that is connected between the grid of the tube and the tuning circuit, and the grid-leak resistor that is connected between the grid and cathode of the tube. No C-battery or bias resistor is used. The tuning and plate circuits are similar to these same circuits as employed in the bias-detector.

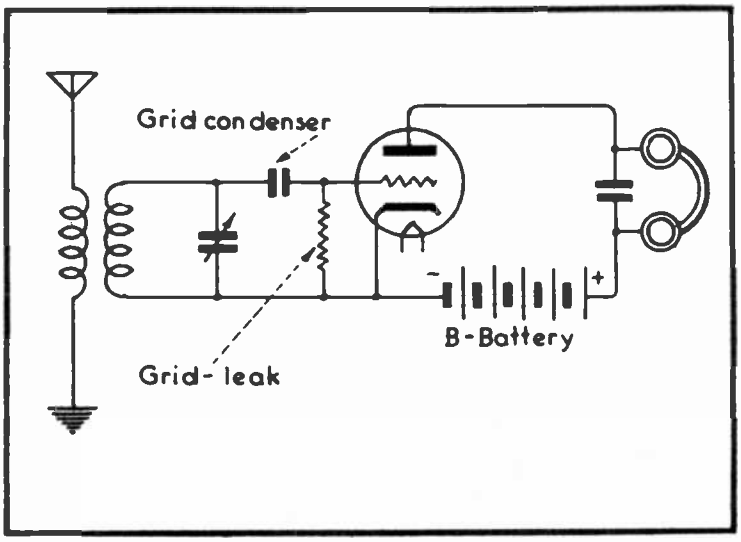

FIG. 23
GRID-LEAK DETECTOR

HOW THE GRID-LEAK DETECTOR WORKS

The illustrations appearing in Figs. 24 and 25, together with the following explanation, should give you a clear understanding of the theory involved.

With the receiver in operating condition, and no signals being received, plate current of constant value will flow through the plate circuit. This is the normal plate current flow.

Now, let us assume that the signal wave, striking the antenna at one particular instant, causes the elevated portion of the antenna to become negatively charged with respect to ground as shown in Fig. 24.

This condition will cause an electron-flow through the primary winding of the antenna coil in the direction indicated by the arrows.

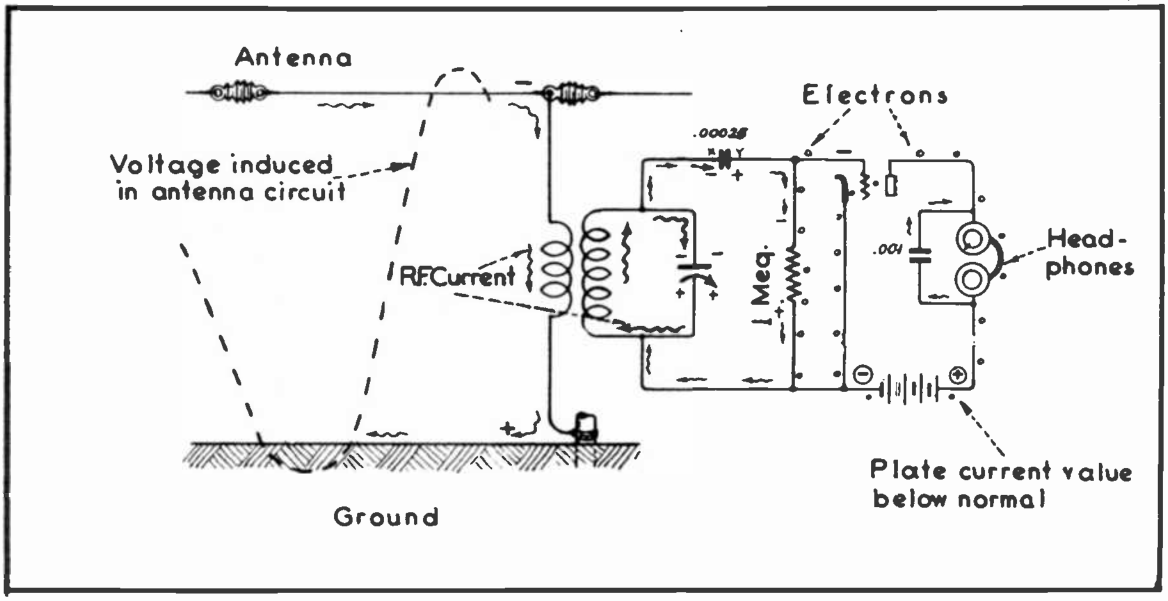

FIG. 24
CIRCUIT OPERATION DURING FIRST ALTERNATION OF SIGNAL VOLTAGE

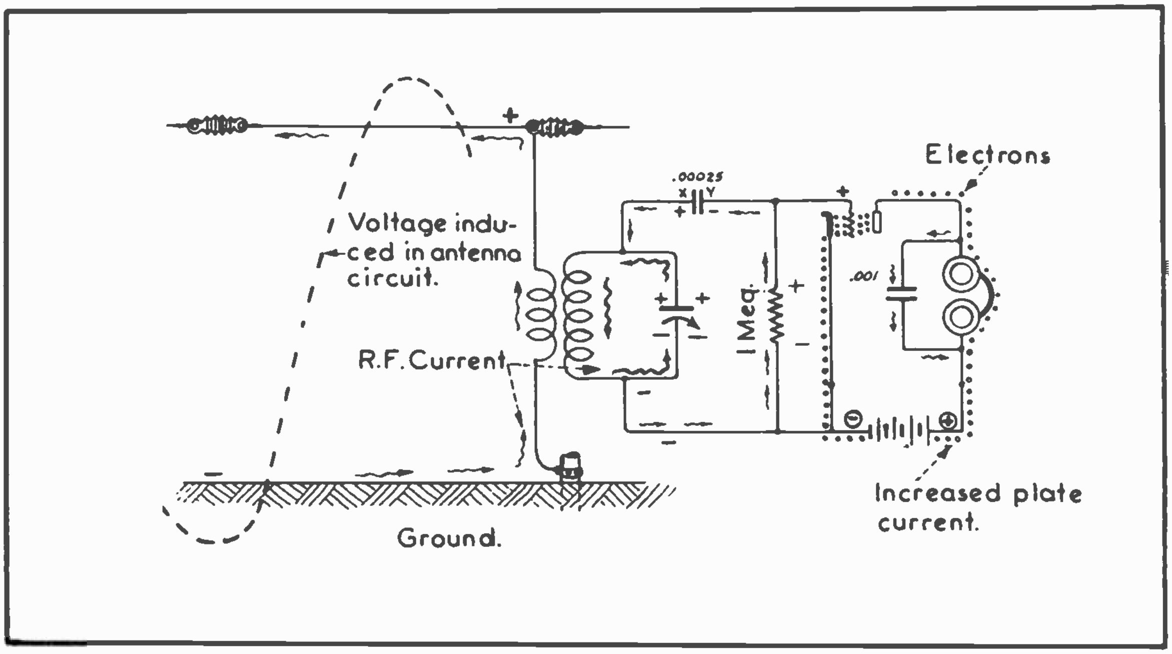

FIG. 25
CIRCUIT OPERATION DURING SECOND ALTERNATION OF SIGNAL VOLTAGE

This electron-flow, in turn, builds up a magnetic field around the primary winding which links the secondary and induces therein a voltage that causes electrons to flow into the plates of the tuning condenser in such manner that a negative potential is produced at the stator (upper) plates and a positive potential at the rotor (lower) plates, as shown in Fig. 24.

Since the .00025 mfd. grid condenser is connected in parallel with the tuning condenser through the leak resistor, some electrons will also flow into plate X of the grid condenser, charging it to a negative potential with respect to plate Y. As this charging action of the grid condenser takes place, some electrons leave plate Y, flow through the 1 megohm leak resistor in the direction indicated, and over toward plate X. The direction of electron flow being from the grid-end of the leak resistor toward its cathode-end causes its grid-end to become negative with respect to its cathode-end.

At radio frequencies, the capacitive reactance of the grid condenser is practically negligible in comparison to the resistance value of 1 megohm possessed by the leak resistor. Therefore, the voltage-drop produced across the leak resistor is far greater than that generated across the plates of the grid condenser. Such being the case, the net or effective voltage applied across the tube's grid and cathode terminals is practically equal to that produced across the ends of the leak resistor by the flow of electrons through it, and also of like polarity. Thus, during the instant illustrated in Fig. 24, the tube's grid is <u>negative</u> with respect to its cathode.

The grid of the tube, now being negative, decreases the flow of electrons between the cathode and plate, and in this way decreases the plate current below its normal value.

As the following alternation of signal-voltage occurs, the elevated portion of the antenna becomes electrically positive, and the grounding system, negative. The electrons through the antenna circuit will then reverse their direction of flow in accordance with the arrows appearing in Fig. 25. Similarly, the electron flow in the tuning circuit, caused by induction, will also reverse its direction in accordance with the arrows in Fig. 25. The upper tuning condenser plates will therefore now be charged to a positive potential and the lower ones to a negative potential.

This action causes plate X of the grid condenser to become positively charged with respect to plate Y. During this charging period of the grid condenser, the electron-flow through the leak resistor is in such direction that its cathode-end becomes negative with respect to its grid-end. Also, the voltage-drop across the leak resistor is again much greater than that across the plates of the grid condenser for the reason given previously. Therefore, the voltage that is effective across the tube's grid and cathode is again practically equal to, and of the same polarity as, that appearing across the ends of the leak resistor. In other words, the tube's grid is now positive with respect to its cathode, which condition accelerates the flow of electrons between the cathode and plate, causing the plate current to increase above its normal no-signal value.

However, it is also to be noted that each time the grid is positively charged (as in Fig. 25), it acts somewhat as a "plate" and attracts a few of the electrons emitted by the cathode. Assuming for the moment that the 1 megohm leak resistor is not included in the circuit, it is apparent that such electrons as are attracted by the grid, would become isolated because they cannot flow through the insulation of the grid condenser --- and, since they bear a negative electrical charge, they have a natural tendency to partially neutralize the positive signal potential and also to maintain a negative charge on plate Y of the condenser. Therefore, as the signal voltage reverses to re-establish conditions as shown in Fig. 24, causing the grid to become negatively charged, the condenser plate Y and the grid will already be slightly negative. (This is due to the accumulation of electrons that are trapped on those parts, on account of this portion of the circuit being isolated during the absence of the leak resistor.) Thus, it is apparent that whenever the control grid is "swung" negative by the signal-voltage, it will be slightly more negative than is made possible by the signal voltage alone, and the flow of plate current is therefore reduced accordingly.

Since electrons are accumulated by the grid during each positive alternation of signal-voltage, the average positive potential of the grid and its corresponding effect on the plate current will gradually become less during each successive cycle, for any given constant signal intensity. Also, the increasing effect of the negative grid potential during the negative alternation of each successive cycle will cause a steady decrease in the average plate current. Thus, these two factors, together, cause the average plate current to decrease in value during each successive cycle of the r-f wave train.

In the absence of the leak resistor, this action would continue for a number of cycles of the signal voltage until so many electrons have collected on plate Y of the grid condenser that their charge would cause the grid to become so much negative that the flow of plate current would be stopped entirely. The tube would then be "blocked," and the system paralyzed.

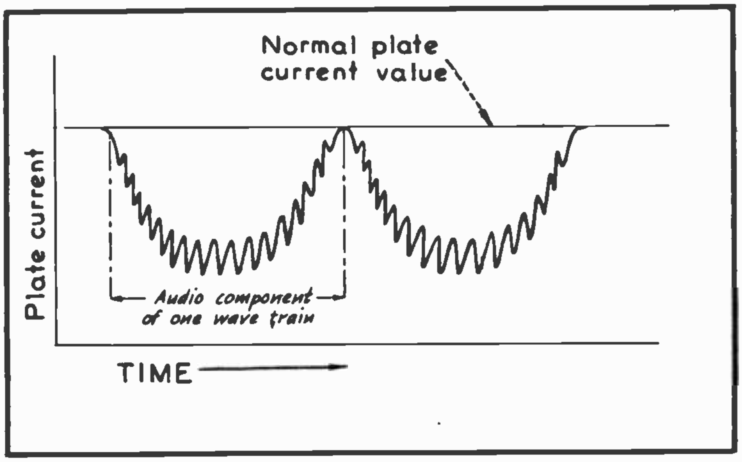

FIG. 26
AVERAGE CHANGE IN PLATE CURRENT

The leak resistor prevents the occurrence of conditions described in the preceding paragraph. It does this by offering a high-resistance path between the tube's grid and cathode so that the excess electrons may drain off the grid before the state of blocking occurs. In fact, the relation between the values of the grid condenser and the leak resistor is such as to allow the excess electrons, accumulated during the r-f cycles constituting one-half of the audio cycle, to drain off the grid at the time that the following half of the modulated signal comes in. This draining of electrons by the leak resistor is illustrated in Fig. 24 by means of the small circles spaced along this path.

The action of the grid condenser and leak being as described, the plate current will vary as shown by the curve in Fig. 26. Notice that the average change in plate current has little ripples incorporated in it, which represent remaining r-f variations.

The manner in which these r-f ripples are handled by the plate condensers is indicated by the small arrows in Figs. 24 and 25. It will be noted that the alternate charge and discharge of this condenser is such as to store electrons during the peaks of the plate current r-f pulses, and to deliver them to the plate circuit during the depressions; thereby acting as a filter and thus causing the flow of plate current through the headphone windings to more nearly conform with the curve appearing in Fig. 27. Thus, clear, audible sounds are produced by the headphones.

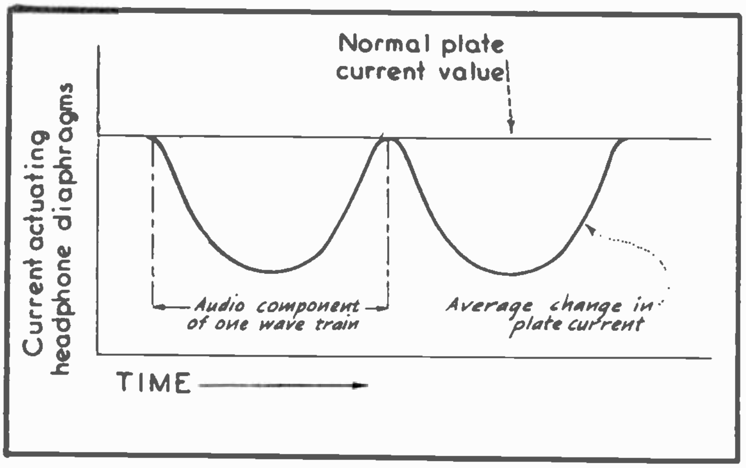

FIG. 27
HOW FILTERING AFFECTS PLATE CURRENT

OPTIONAL METHOD OF CONNECTING GRID-LEAK

In all diagrams of grid-leak type detectors shown thus far, the leak resistor has been placed between the grid and cathode of the tube. In many diagrams, however, it is shown as being connected directly across the grid condenser, as in Fig. 28. Either method will work. If the grid-leak resistor is connected as in Fig. 28, the electrons will return from the grid via the tuning coil as indicated by the arrows.

GRID-LEAK VALUE

The value of the grid-leak resistor used in this type of detection is important. It must be such that just exactly the right quantity of electrons will leak off the grid. If this leaking action occurs too rapidly, due to a leak of too low value, the grid will lose electrons so that there will be little or no opposition to the next positive alternation, and rectification will then not take place. On the other hand, if this leaking action be too slow, due to an excessively high resistance, the grid will soon become saturated with electrons, which condition will make it very negative and thereby block further tube action. Grid-leak resistor values range from about one million, to as high as ten million ohms; the exact value being dependent upon the characteristics of the tube used.

DIFFERENCE IN RECTIFYING ACTION OF DETECTORS

From the study of this lesson, you have learned that with bias-detection, the plate current increases are always much greater than the decreases; while for the grid-leak detector, the plate current decreases are always much greater than the increases. The two systems are therefore exactly opposite in this respect, but satisfactory detection is accomplished in either case.

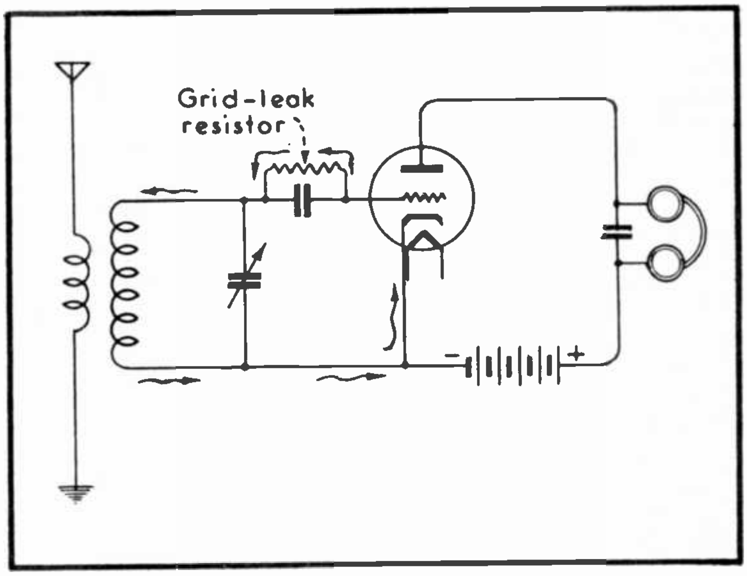

FIG. 28
LEAK RESISTOR CONNECTED ACROSS GRID CONDENSER

The important fact to remember is that each method eliminates one-half of the modulated signal wave form (either the positive or negative half) in the plate circuit, which action is the basis for signal rectification or detection.

REGENERATION

The principle known as "regeneration" is sometimes applied to grid-leak detectors employing either a triode, tetrode or pentode in order to increase the amplifying ability of the circuit above that made possible by the amplification factor of the tube alone. This is particularly true in small shortwave receivers, as used by amateur radio operators and experimenters.

The circuit diagram of a simple form of regenerative detector is presented in Fig. 29. You will observe the circuit as a whole to be quite similar to that of the grid-leak detector previously described. However, an important addition exists in the form of an extra winding --- called a "regeneration coil", "feed-back coil" or "tickler coil" --- which is included between the plate of the tube and the headphones.

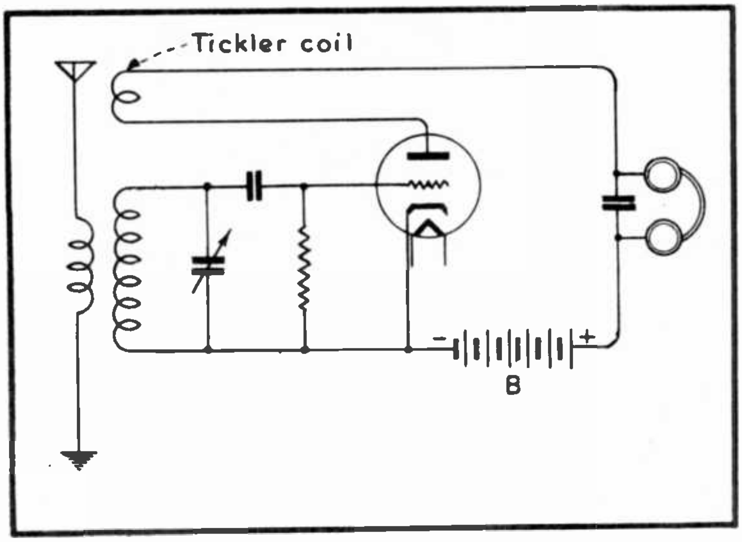

FIG. 29
REGENERATIVE DETECTOR CIRCUIT

The tickler coil consists of a relatively few turns of wire, of about the same size as that used for the tuned secondary winding of the r-f transformer; and is placed in an inductive relationship with the secondary winding. The circuit operates in the following manner:

Signal voltages are applied to the grid of the tube in the usual way, causing variations in plate current that are of both a radio frequency and audio frequency character, as explained earlier in this lesson. This varying plate current flows through the tickler coil, producing a correspondingly varying magnetic field that induces r-f voltages in the tuned winding.

The directions in which the various coils are wound are so related to each other with respect to polarity that the voltages induced in the tuned winding by the tickler coil are of the same polarity as the signal voltages appearing in the tuned winding by induction from the primary. The signal voltages induced in the tuned winding by the tickler coil will therefore be added to those induced in the tuned winding by the primary, with the result that the signal voltages applied to the grid of the tube will be appreciably greater than would be the case if the tickler coil were not employed. Consequently, signal current variations of greater amplitude will be avialable in the plate circuit with which to actuate the headphones, thereby resulting in a louder sound.

It is to be noted that the high degree of amplification made possible by this circuit is due to the fact that the signal has already been amplified at the time part of its energy is returned to the grid circuit for re-amplification.

You will hear more about the application of regeneration, and the methods for controlling it, later in the course as the circuits under discussion make use of it.

EXAMINATION QUESTIONS

LESSON NO. 14

1. - Does the diode type detector amplify the signal as well as rectify it?

2. - Is a grid-leak detector best suited to a receiver circuit wherein considerable or very little r-f amplification precedes it?

3. - What is the purpose of applying a negative bias voltage to the grid of the tube used in a grid-bias detector?

4. - How may the bias voltage be obtained, other than from a C battery, for biasing a cathode-type tube?

5. - What is the chief purpose of the leak resistor in a grid-leak detector circuit?

6. - Why is regeneration incorporated in some detector circuits?

7. - If a certain pentode detector tube draws .6 ma. of plate current, and .2 ma.of screen current, what value of resistor would you install in the cathode circuit to provide a bias of 10 volts for the tube?

8. - Why is it that the increases in plate current are very much greater than the decreases in a grid-bias detector circuit?

9. - What are the two most important features in favor of diode detectors?

10.- How is it possible to operate a tube having several grids as a diode?

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LESSON NO. 15

AUDIO-FREQUENCY AMPLIFICATION

You are now taking up the study of audio frequency amplifiers. This subject should be easier for you to master than were those covered in some of the earlier lessons, as the principles you learned in studying power supplies, r-f amplifiers and detectors will aid you in understanding the workings of a-f amplifiers.

The purpose of the a-f amplifier in a receiver is to take the received signal after it has been handled by the r-f amplifier and the detector, and "boost" or amplify it further until it has sufficient amplitude and power to operate a loudspeaker.

OTHER USES FOR A-F AMPLIFICATION

In addition to the valuable part it serves in radio receivers, a-f amplification is also used in many other electronic and radionic devices. Radio transmitters, for example, have one or more stages of a-f amplification between the microphone and the modulator. Television receivers employ similar amplification to increase the brilliance of the televised image. Electronic alarm systems; public address systems; hearing aids for the deaf; medical apparatus; submarine sounding devices; long-distance telephones; navigation equipment; certain air-

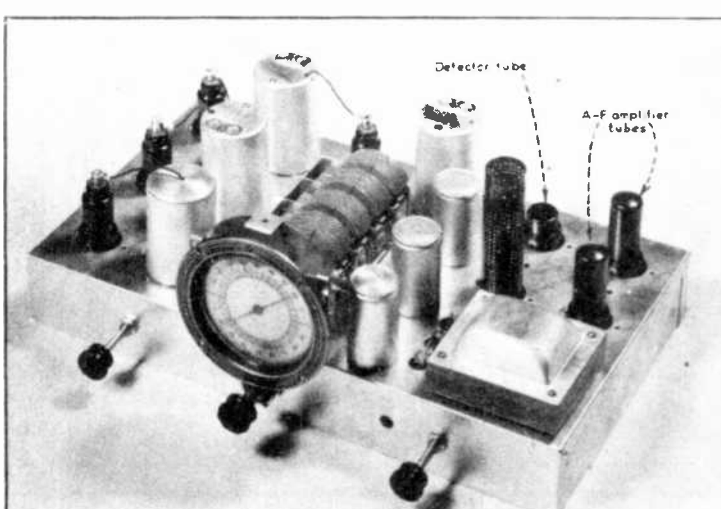

FIG. 1
RECEIVER WITH TWO A-F AMPLIFIER TUBES

craft instruments --- all these, and many more, utilize audio frequency amplifying circuits which are basically and electrically the same as those you will learn about in this lesson.

COUPLING METHODS

The various sections or stages of the a-f amplifier are always connected together in such manner that the incoming signal must pass through them in sequence after detection, and before it reaches the loud speaker. This is said to be a cascade arrangement, and to form a cascade type a-f amplifier. A cascade amplifier must have more than one stage.

The method used to couple a stage of a-f amplification to the detector, or to a preceding stage of amplification, is most important. In fact, it is the method of coupling which distinguishes one type of a-f amplifier from another.

The method of coupling has a great bearing on the amount of gain provided by each stage, as well as on the tone quality (fidelity of reproduction) of the signal. Modern practice has settled on the use of three possible coupling systems. They are:

1. Resistance-capacity coupling. (Usually called resistance coupling).

2. Impedance-capacity coupling. (Usually called impedance coupling).

3. Transformer coupling.

We will now discuss each of these three methods, in the order named.

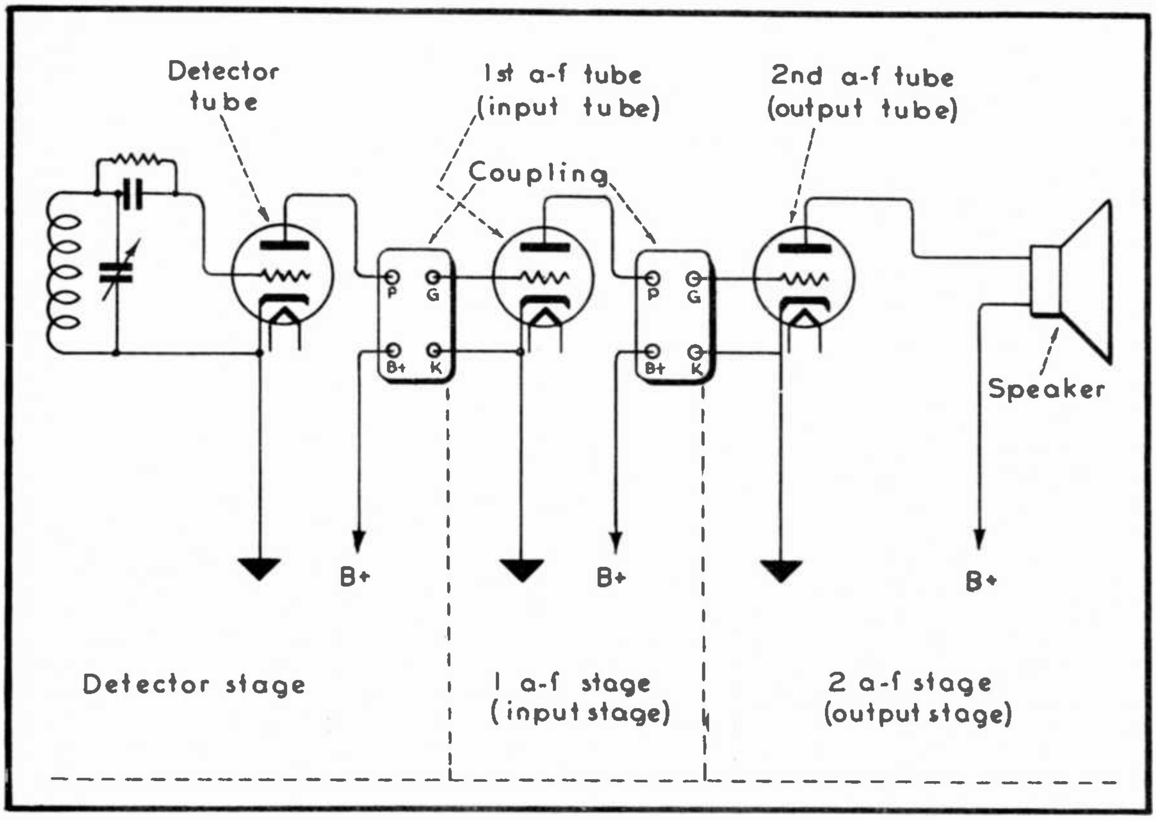

FIG. 2
HOW INTER-STAGE COUPLING IS USED IN A-F AMPLIFIER

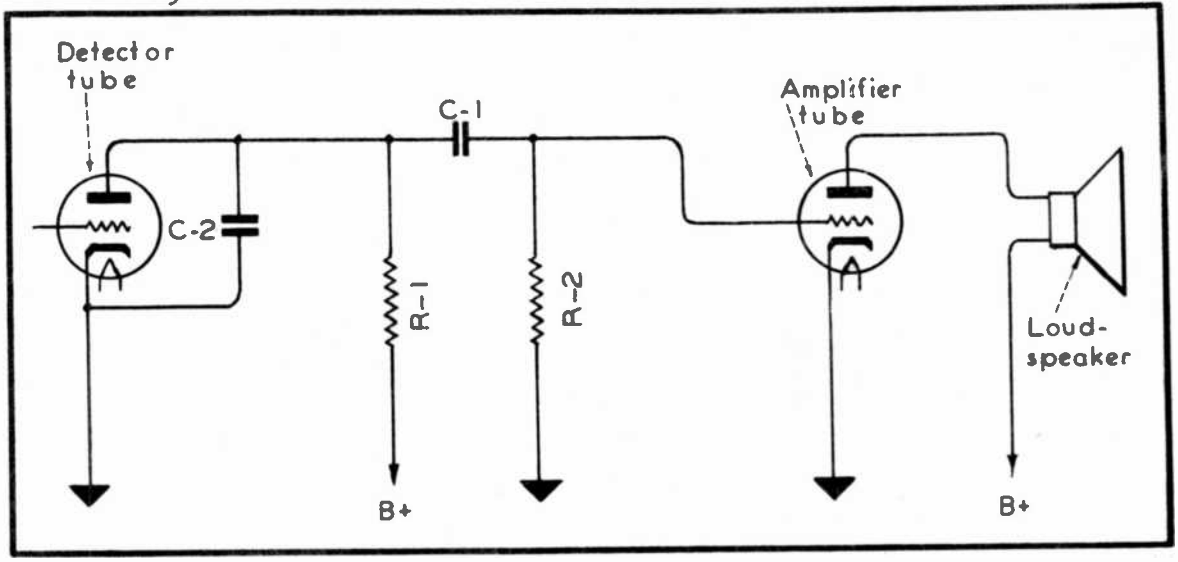

FIG. 3
RESISTANCE-COUPLED AMPLIFIER STAGE

WHAT WE MEAN BY COUPLING

Any amplifying stage consists of a tube which has its grid connected, or coupled, in some manner to the plate circuit of the preceding tube. In that way, the signal available in the plate circuit or "output" of one tube is fed to the grid of the following one.

In Fig. 2, you are shown the use of coupling in a two-stage amplifier. The coupling systems are illustrated in block form so that you will find it easy to understand their use in the circuit. Notice how the coupling system is connected in the plate circuit of one tube, and in the grid circuit of the next. The first stage of any amplifier is always called the input stage. The last stage is called the output stage. If the amplifier contains more than two stages, those which are located between the input and output stages are known as the intermediate stages. Thus, a two-stage amplifier would consist of an input and an output stage; while a three-stage amplifier would have an input stage, an intermediate stage and an output stage.

RESISTANCE-COUPLED AMPLIFIERS

A basic diagram of a resistance-coupled audio amplifier stage is presented in Fig. 3, connected to the output of the detector tube. The following are distinguishing features of this type of amplifier:

A resistor, called the "plate load resistor" (R-1), is connected between the plate of the detector tube and the positive terminal of the "B" voltage source. Another resistor, called the "grid leak" (R-2), is connected between the grid of the audio amplifier tube and the cathode of the same tube, through the chassis. A fixed condenser (C-1), called a "coupling condenser," is connected between the plate of the detector tube and the grid of the amplifier tube. Condenser C-2, called a "plate by-pass condenser," serves the same purpose as the condenser which was placed across the headphones in the simple receivers described in previous lessons.

A picture-drawing of such an amplifier stage, showing a typical arrangement of the parts and circuit wiring, is presented in Fig. 4.

For the present, we are showing only those parts of a-f amplifier circuits that are involved in our explanation of the basic principles. This will simplify matters for you at the beginning. Additional features, such as provisions for biasing the tubes, etc., will be injected into the description at the logical time as we progress through this discussion.

TRANSFER OF A-F SIGNAL THROUGH RESISTANCE COUPLING

You will recall that the detector tube, together with other components of the detector circuit, has changed the original modulated r-f signal to an audio-signal plate current which is identical in frequency to the current flowing through the microphone at the studio of the transmitting station.

This varying a-f current, flowing through the plate load resistor (R-1) in Fig. 3, produces a correspondingly varying voltage drop across it. Remembering that a coupling condenser of the proper capacity will offer but slight opposition to audio frequencies, you can readily see that the a-f voltage variations appearing across R-1 will be applied to the grid of the amplifying tube through condenser C-1. Thus, there is now being applied to the grid of the amplifying tube an alternating a-f voltage --- that is, a voltage which is varying in both, intensity and polarity at an audio-frequency rate.

It is to be noted further that although the coupling condenser permits the alternating a-f signal voltage to react through it and so be applied to the grid of the amplifying tube, it also serves to prevent the d-c plate voltage of the detector tube from being applied to the grid of the a-f tube.

A more detailed analysis of the transfer of the signal through this type of coupling follows.

DETAILED ANALYSIS: In Fig. 5, we have a diagram of a resistance-coupled amplifier stage, simplified for the purpose of analysis. That is, the sources of "B" voltage are represented in the form of blocks to com-

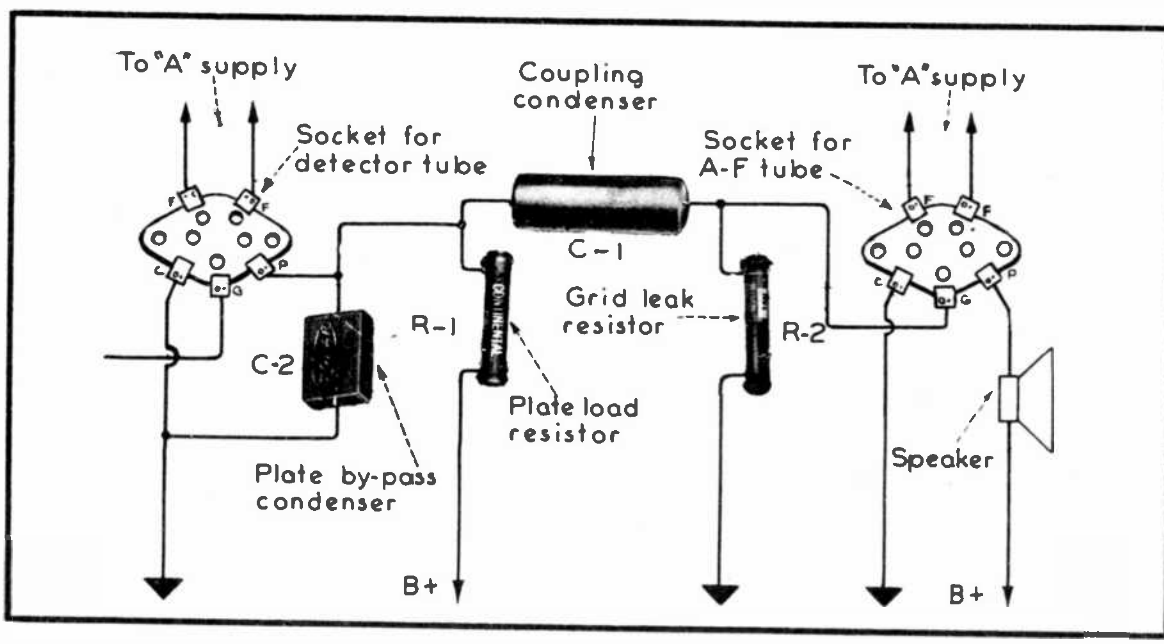

FIG. 4
PICTURE-DIAGRAM OF RESISTANCE-COUPLED AMPLIFIER

plete the circuits involved in our present discussion, and the source of "C" (bias) voltage has been omitted for the sake of simplicity.

At the time the receiver is first turned on and no signal is tuned in, the plate current gradually increases to its normal no-signal value. This current flows through the detector tube and its plate load resistor R-1, as indicated by the solid arrows in illustration (A) of Fig. 5. This rising current produces a voltage drop across R-1, causing end #1 to be less positive than end #2. Actually, the cathode-to-plate path within the tube and R-1 form a series combination --- the "B" voltage being divided between these two components, part of the voltage drop being across the tube and part across R-1.

Since plate "a" of the coupling condenser (C-1) is connected to the junction of the tube's plate and end #1 of R-1, a positive voltage somewhat lower than the "B" voltage will be applied to it. This induces a negative charge to build up on plate "b" of the condenser. During the time condenser C-1 is being charged, electrons flow upward through grid leak resistor R-2; causing a momentary voltage drop which makes its end #4 negative, and its end #3 positive. This will apply a slight positive voltage to the grid of the amplifier tube; but once the plate current reaches a steady value, the electron drift through R-2 stops and the voltage drop across it disappears.

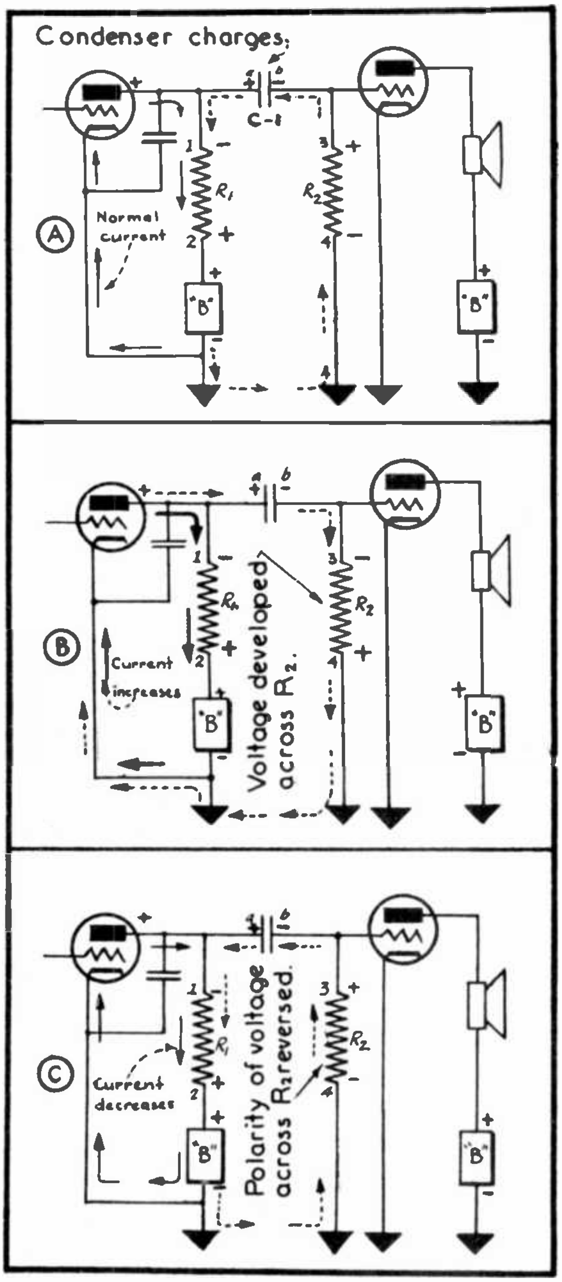

FIG. 5
TRANSFER OF SIGNAL THROUGH RESISTANCE-CAPACITY COUPLING

Now, when a signal is tuned in and rectified by the detector, the flow of current through plate load resistor R-1 will alternately increase and decrease at an audio frequency rate. When current through the plate circuit of the detector tube increases, as indicated by the heavy arrows in illustration "B" of Fig. 5, the voltage drop across R-1 also increases. Therefore, the positive potential at end #1 of R-1 and at plate "a" of condenser C-1 will decrease, and the condenser will lose some of its charge. Electrons will flow downward through R-2 during this process, and the resulting volt-drop will apply a negative voltage to the grid of the amplifier tube. Thus, the plate current through this tube decreases.

Then, as the signal causes the plate current through the detector tube and R-1 to decrease below the normal value (Fig. 5-C), the voltage drop across this resistor will be reduced correspondingly. This causes the voltage at end #1 of resistor R-1 and on plate "a" of condenser C-1 to become more positive. The condenser therefore receives an increased charge, with electrons flowing upward through resistor R-2, as indicated by the dotted arrows, until the potential across the condenser comes up the the applied positive voltage.

It is of special importance to observe that the direction of electron flow through R-2 at this time is reversed to what it was before. Thus, end #3 of resistor R-2 is now positive, and end #4 is negative. Then, since the grid of the amplifier tube is now positive, plate current through it will increase.

From the explanation just given, you will see that as the plate current through the detector tube increases, that through the amplifier decreases in step. However, the a-c (signal) component of the current in the plate circuit of both these tubes has the same shape or pattern, and will therefore produce the same sound when utilized by a headphone or loudspeaker.

NECESSITY OF A GRID-LEAK RESISTOR

Besides serving as a means for applying the signal voltage to the grid of the amplifier tube, resistor R-2 in Fig. 5 functions also as a grid leak, without which the amplifier would operate intermittently. This is due to the electrons which would collect on the grid every time a positive alternation of a-f signal voltage were applied to it.

You should recall that when a grid is positive, it will attract electrons from the electron stream which is passing between the cathode and the plate. If these electrons were not permitted to "leak-off" the grid, they would eventually collect in sufficient quantity to constitute a strong negative charge on it; thus making it so strongly negative as to completely block the passage of electrons through the tube. This would reduce the plate current so near to zero that no sound would be emitted by the speaker.

The value of this grid leak resistor is somewhat less than that required by the grid-leak detector described in the previous lesson. Values ranging from 50,000 to 500,000 ohms are typical in a-f amplifiers.

COMBINED GRID LEAK AND VOLUME CONTROL

In commercial receivers, the functions of a grid-leak resistor and volume control are often combined in one unit. This is shown at (A) in Fig. 6, where the regular grid-leak resistor has been replaced by a potentiometer which has the same value of resistance. The potentiometer, which is a variable resistor, has been discussed and illustrated in a previous lesson. You will remember that it has a contact, in the form of a slider, that may be moved along a resistance element by rotating a knob.

Notice in Fig. 6 that the coupling condenser C-1 is connected to one end of the potentiometer's resistance element instead of directly to the grid of the first a-f tube. And the slider is connected to the grid.

Now, if the potentiometer knob be rotated so that the slider contacts that end of the resistance element which is connected to the condenser as at (B) of Fig. 6, the stage will deliver maximum volume. As the slider is moved toward the grounded end of the resistor element, the volume will gradually decrease; reaching a minimum value when the slider contacts the grounded end of the resistor as at (C) of Fig. 6. While all volume control systems do not work according to this circuit, it is, nevertheless, a popular arrangement.

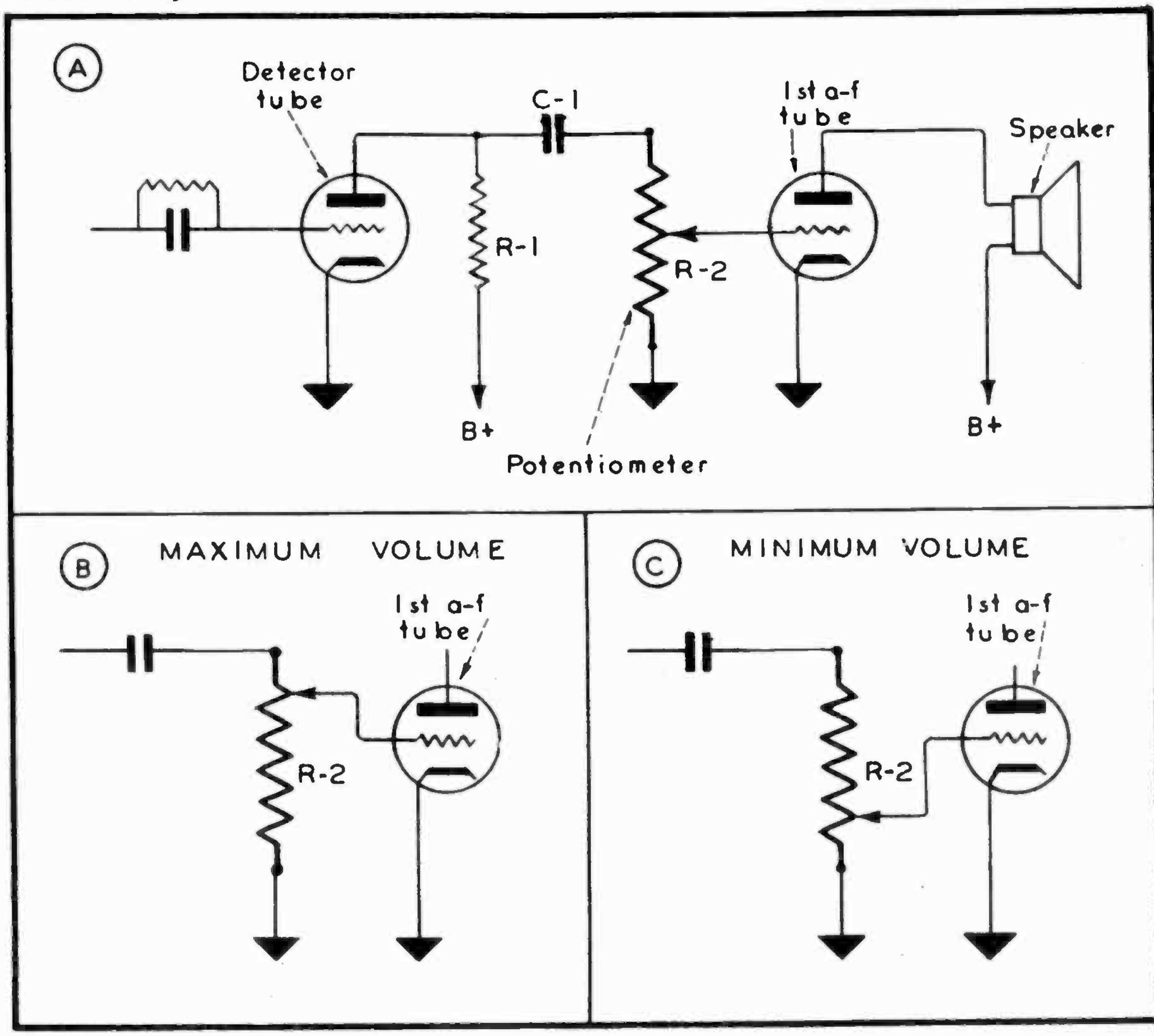

FIG. 6
POTENTIOMETER SERVING AS GRID-LEAK RESISTOR AND VOLUME CONTROL

HOW AMPLIFICATION IS ACHIEVED

The amplification or increase in signal intensity provided by this circuit can be demonstrated by the fact that a speaker connected in the plate circuit of the detector tube would produce a barely audible sound; while the same speaker inserted in the plate circuit of the amplifier tube would produce sound of sufficient volume to be heard several feet from the speaker.

This amplification, or gain, is secured by the ability of the tube to amplify. That is to say, the amplification factor of the tube determines the amount of gain or "boost" in signal strength available per stage of resistance coupled a-f amplification. No gain whatever is supplied by the coupling circuit.

GAIN SECURED FROM ONE STAGE OF RESISTANCE COUPLED A-F AMPLIFICATION

As was just mentioned, the amount of gain realized from one stage of resistance-coupled amplification is governed largely by the amplification factor of the tube. The average triode in such a circuit would give a gain of about fifteen; whereas a pentode, which has a much higher amplification factor, would make it possible for the amplifier stage to furnish a higher gain.

Another important factor in determining gain is the plate load resistor. The higher its value, the more closely will the actual amplification attained approach the amplification factor of the tube. For example, if the plate load resistor is twice the plate resistance of the tube, the gain will be two-thirds of the amplification factor; if the plate load resistor is three times the tube's plate resistance, the gain will be three-fourths of the amplification factor, etc. (Note: The plate resistance of a tube is the opposition it offers to the varying audio signal plate current mentioned on page four.)

In practice, the value of the plate load resistor seldom exceeds ten times the plate resistance because the resulting volt-drop would leave too little B-voltage applied to the plate of the tube. A value smaller than twice the plate resistance not only gives a very low gain, but also tends to distort the quality of the amplifier signal.

TWO-STAGE RESISTANCE COUPLED AMPLIFIER

When a single tube does not give adequate amplification, two or more stages may be employed.

The addition of another stage to the amplifier just described is shown in Fig. 7. A load resistor (R-3) is now placed in the plate circuit of the first amplifying tube, just as was done in the case of the detector tube's plate circuit; a coupling condenser (C-3) is connected between the plate end of R-3 and the grid of the second amplifying tube; a leak resistor (R-4) is placed between the grid of the second a-f tube and the chassis; and the plate circuit of the second amplifier tube is completed through the speaker.

An analysis of the gain secured by means of a two-stage amplifier is illustrated in Fig. 8. Here, a two-stage, resistance coupled a-f amplifier is connected to the output of a detector; and each of the amplifier tubes has a net amplification of 10. Assuming that the detector furnishes a signal emf of 0.5 volt to the input of the amplifier, this same voltage (neglecting a slight loss in the coupling circuit) will be applied to the grid of the first amplifier tube. Then,

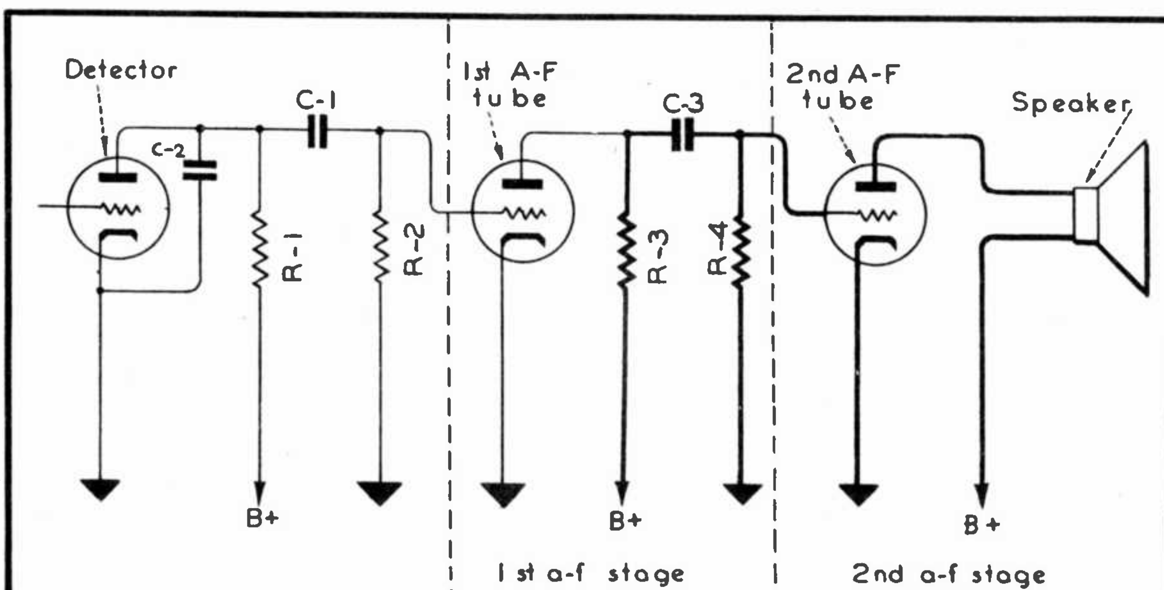

FIG. 7
TWO-STAGE A-F AMPLIFIER

since this tube has an amplification of 10, the signal voltage available at its output will be 10 times 0.5 or 5 volts. This 5-volt signal will react through the following coupling circuit and thus be applied to the grid of the next amplifier tube, where it is again amplified 10 times. Thus, a signal of 5 times 10 or 50 volts will be available at its output. (Note: Since no step-up in voltage is provided by the coupling circuit, we say that its voltage ratio is 1 to 1 --- the same as we do of a transformer in which the number of turns on the primary winding is equal to the number of turns on the secondary, and in which case the two voltages are equal.)

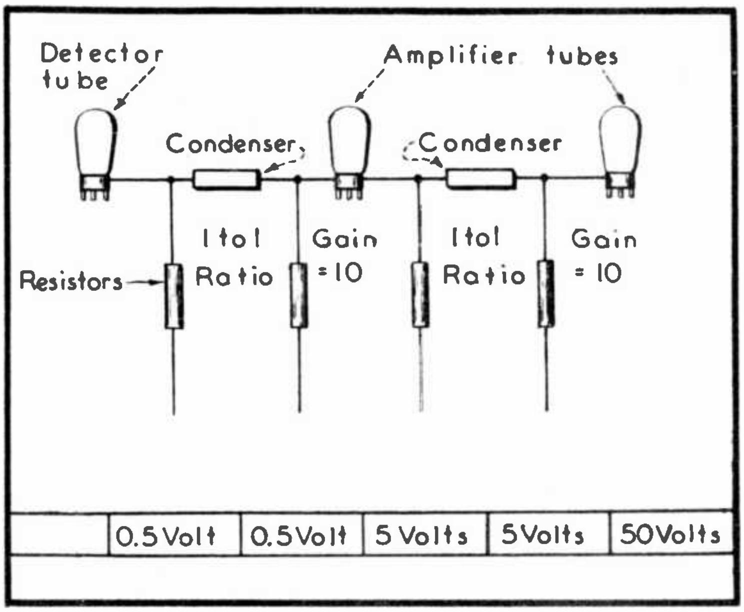

FIG. 8
EXAMPLE OF VOLTAGE GAIN IN RESISTANCE-COUPLED AMPLIFIER

THREE-STAGE RESISTANCE COUPLED AMPLIFIER

A third stage may be added to our amplifier of Fig. 7, by placing a load resistor in the plate circuit of the second stage; connecting the plate of the second a-f tube to the grid of a third a-f tube by means of a coupling condenser; and placing a grid-leak resistor between the grid of the third a-f tube and the chassis. The plate circuit of the final tube would then be completed through the speaker as before. Here, too, each tube amplifies the signal, in turn --- and since more tubes are employed than in Fig. 7, a greater over-all gain or total amplification is possible.

IMPEDANCE-COUPLED AMPLIFIERS

Impedance coupled a-f amplifiers are very similar to those employing resistance coupling. In fact, the only change necessary to convert a resistance-coupled amplifier to one using impedance coupling is to replace the plate load resistors with small iron-core chokes (called "a-f chokes"). This is shown in Fig. 9, where the flow of plate current through the chokes L-1 and L-2 is indicated by means of arrows. In general appearance, an a-f choke is very similar to a filter choke as used in power supply systems.

One of the disadvantages of resistance-coupling is that the high resistance of the plate load resistor opposes the normal d-c plate current to a very great extent --- thereby resulting in an appreciable d-c voltage drop across it. This d-c voltage drop is of no value in transferring the signal through the coupling; in fact, it is a disadvantage, in that a very high B voltage must be available at the source in order to have the voltage necessary at the plate of the tube. This calls for a B-power supply capable of furnishing a very high d-c voltage --- and which would be rather expensive.

The chief advantage of resistance-coupling is that it amplifies all audio frequencies equally well. That is, it does not amplify certain

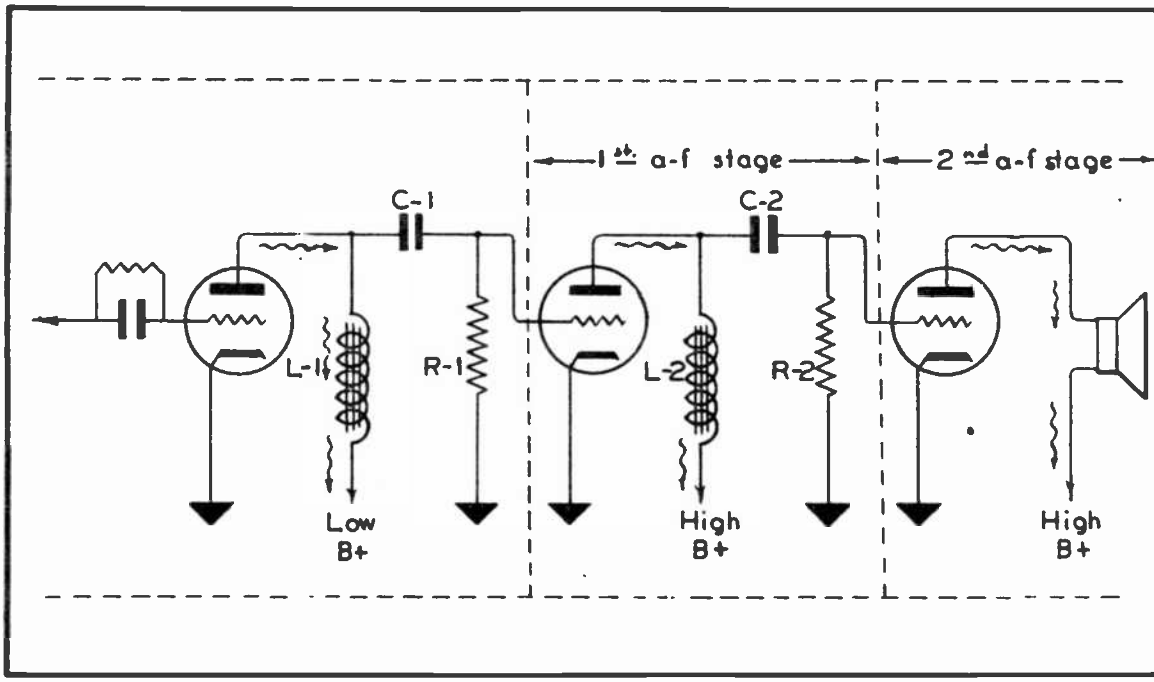

FIG. 9
IMPEDANCE-COUPLED A-F AMPLIFIER

frequencies more than others. In other words, it is capable of amplifying with good fidelity a broad audio frequency band --- ranging all the way from the lowest to the highest audio frequency which the radio receiver is expected to reproduce.

Chokes do not oppose the passage of the normal d-c plate current to the extent as do the plate load resistors in resistance-coupled circuits, and for this reason, less B voltage is wasted between the plate terminal of the tube and the B voltage source. However, the passage of varying (signal) current is greatly opposed by the reactance of the chokes, thereby permitting an appreciable a-f voltage to be developed across them.

For example, the d-c resistance of the winding in a typical a-f choke as used for this purpose might be 300 ohms; while the inductive reactance, or opposition to a varying current, offered by the same winding, could be as much as 60,000 ohms at the higher audio frequencies. Thus, the flow of normal plate current would be opposed only be the 300 ohms of resistance; while the flow of a-f signal current would be opposed by an inductive reactance which could be as high as 60,000 ohms --- the exact value depending on the frequency. Note that coupling condensers, as well as grid-leak resistors, are necessary in impedance-coupled systems, just as they are in resistance-coupled amplifiers --- and for the same reasons. Also, a combined grid leak and volume control, in the form of a potentiometer, may be used in one of the stages of an impedance coupled amplifier the same as in the resistance coupled circuit of Fig. 6.

Although impedance coupling reduces the d-c voltage loss in the plate circuit, an a-f choke costs more than a resistor, and requires more space for mounting. And, unless the choke is of very good quality, it will favor certain of the reproduced frequencies more than others.

TRANSFORMER-COUPLED AMPLIFIERS

An amplifier which utilizes transformer coupling will have more gain per stage, as well as a greater total gain, than will a resistance or impedance-coupled amplifier using the same number of stages, and the same tubes. Somewhat off-setting this increase in amplification is the fact that transformer coupling does not provide the same high degree of fidelity (tone quality) that is characteristic of resistance coupling, unless expensive transformers of very high quality are used.

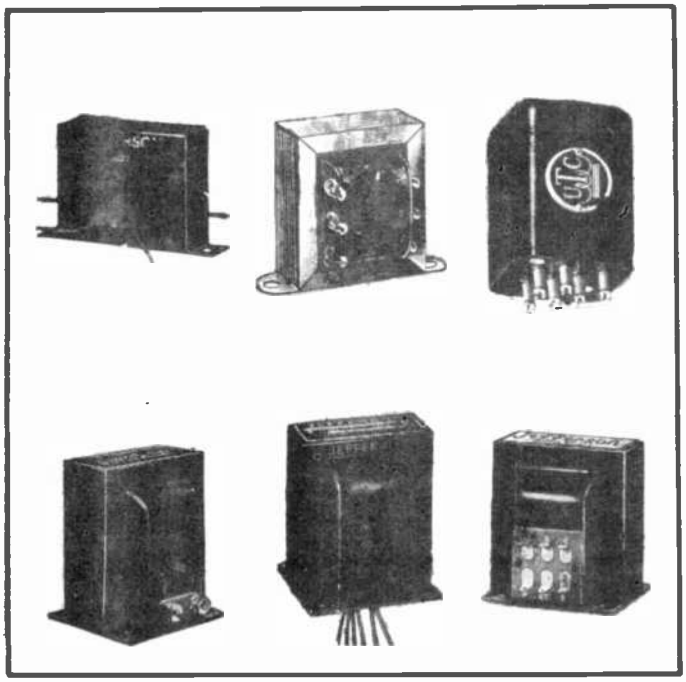
FIG. 10
TYPICAL A-F TRANSFORMERS

Inferior transformers have a natural tendency to amplify certain frequencies more than others. In general, they amplify the higher audio frequencies better than the lower ones; and may have a resonant condition which causes them to amplify one particular frequency so much more than the others that the tone corresponding to it is abnormally accentuated.

A-F TRANSFORMERS

Typical a-f (audio) transformers of different designs and styles of mounting are presented in Fig. 10. Such transformers have a primary and a secondary winding, and vary considerably as to turns-ratio --- a 2 to 1 or 3 to 1 ratio being most popular for inter-stage use.

Illustration (A) in Fig. 11 shows how the secondary winding is usually applied over the primary, while the shape of the silicon-steel core is shown at (B); and the placement of the windings on the core, at (C). The complete assembly, with mounting frame, appears at (D).

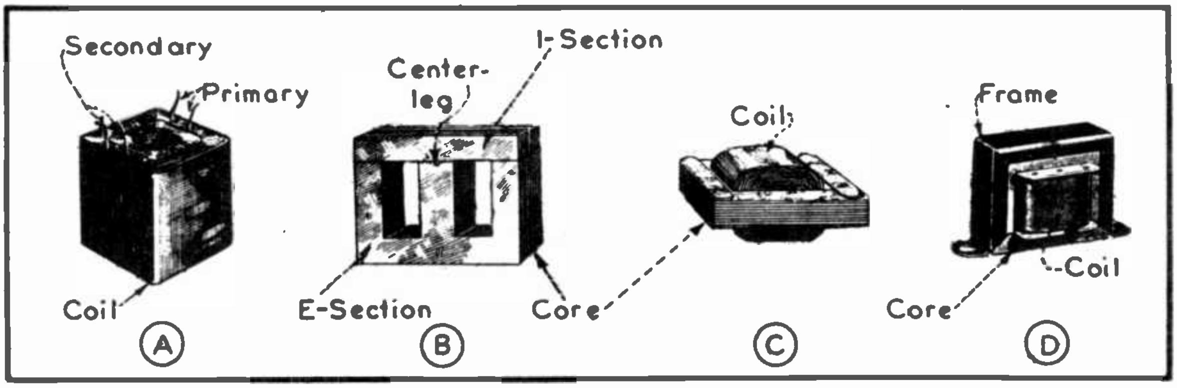

FIG. 11
STRUCTURAL DETAILS OF A-F TRANSFORMER

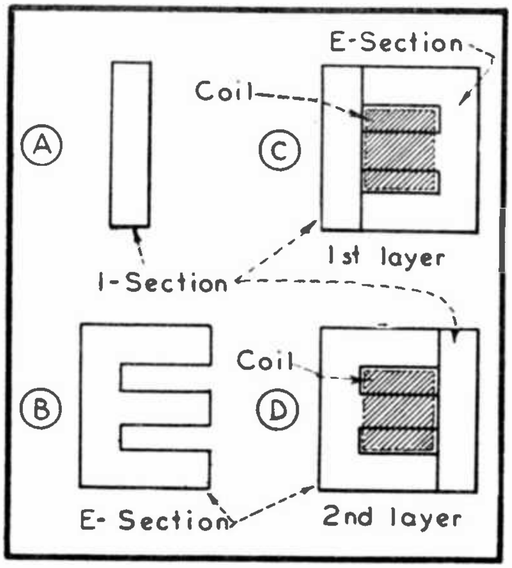

FIG. 12
CORE ASSEMBLY

The core is made up of soft-steel laminations, cut to the shape of an "I" and an "E", as shown in Fig. 12. These laminations are assembled about the completed winding to form the core, in the following manner:

First, the center leg of the E-shaped lamination is slipped through the opening of the winding from the right as at (C) of Fig. 12; an I-shaped lamination is then placed at the left, in the position indicated. Another E-shaped lamination is then laid on top of the first, but is inserted through the coil from the left as shown at (D) of Fig. 12; an I-shaped member is placed to the right of it as also here shown. This alternate placement of laminations is repeated until the core has been built up to the proper thickness, as shown in illustration (C) of Fig. 11. The laminations are held together by some form of bracket, as at (D) of Fig. 11. Of course, such details of manufacture vary somewhat, but the example presented will give you a general idea of the construction.

TRANSFORMER CONNECTIONS

An a-f transformer, connected between the detector and the first a-f tube, is shown in Fig. 13. Observe that the primary winding has been placed in the plate circuit of the detector tube, in the same manner as was the winding of the a-f choke in the impedance-coupled circuit. The secondary winding is connected between the grid and cathode of the first a-f tube by way of ground. No coupling condenser or grid-leak resistor is necessary.

A pictorial drawing of this same stage appears in Fig. 14.

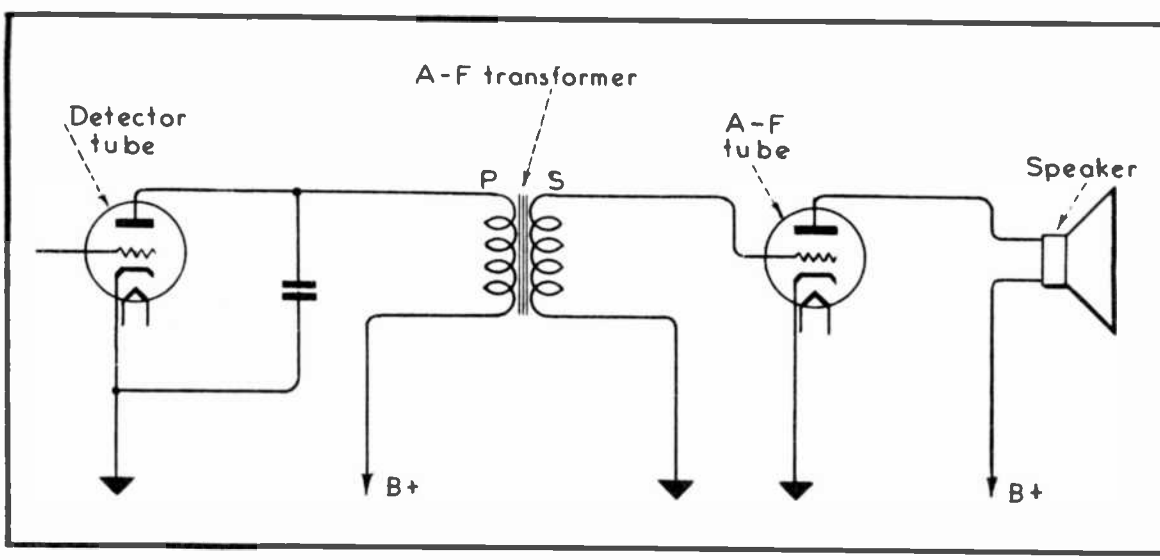

FIG. 13
TRANSFORMER-COUPLED A-F STAGE

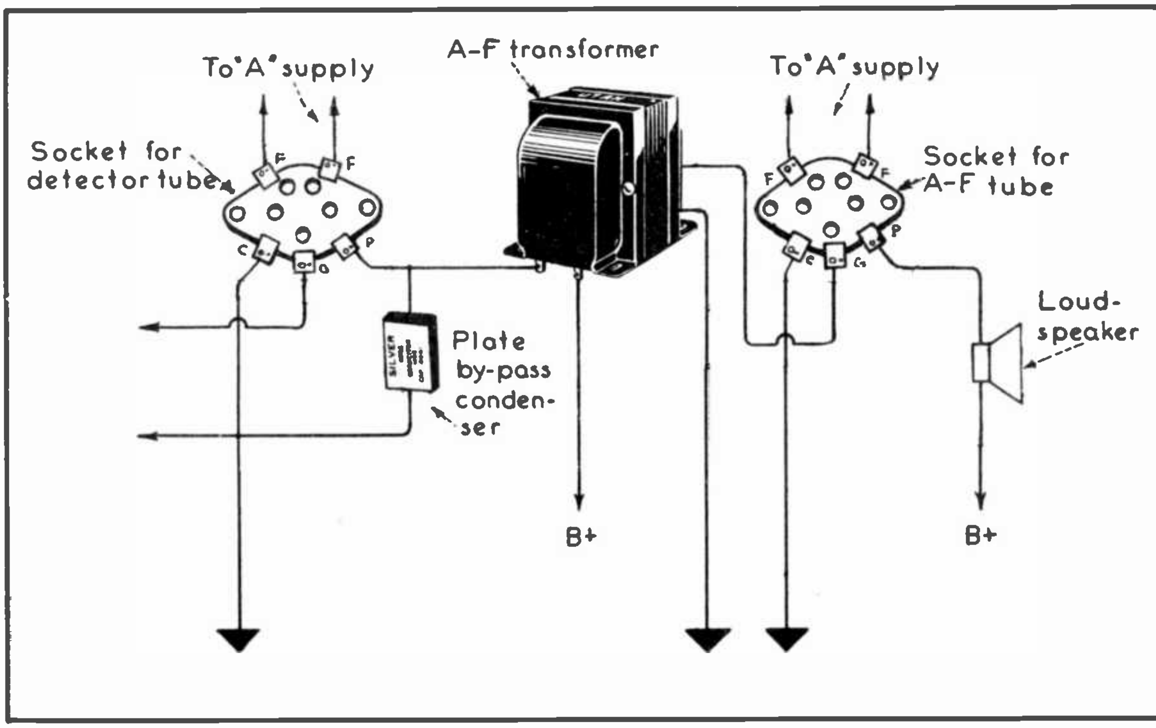

FIG. 14
PICTORIAL DRAWING OF TRANSFORMER-COUPLED A-F STAGE

ANALYSIS OF TRANSFORMER-COUPLED A-F AMPLIFICATION

In Fig. 15(A), a sensitive a-c voltmeter has been connected across the secondary winding of the a-f transformer. With detector plate current flowing through the primary winding of the transformer, any variation in this current will cause an emf to be induced into the secondary. Since the plate current is not varying in Fig. 15(A), no emf. is being induced into the secondary, and so the voltmeter indicates zero.

At (B) in Fig. 15, a signal is being received, causing the plate current to increase and decrease. This constitutes a flow of varying current through the primary winding of the a-f transformer. The voltmeter therefore now indicates the presence of an induced emf in the secondary.

At (C) in Fig. 15, the secondary of the transformer has been connected to the grid and cathode of the first a-f tube (through ground). Thus, the induced emf ,whose presence was previously indicated on the voltmeter, is now being applied across the grid and cathode of the amplifying tube. This causes the customary sound-producing increase and decrease of plate current through the amplifying tube and speaker.

STEP-UP ACTION OF A-F TRANSFORMER

If an a-f transformer having a step-up ratio is employed, the signal voltage across the secondary winding will be greater than that across the primary. This results in a "gain" or signal-voltage increase, taking place at the transformer. Thus, when the signal is fed to the grid of the first a-f tube, it has already been stepped-up by the transformer. It is because of this step-up in voltage that this type of amplification provides an over-all gain greater than that furnished by either resistance or impedance coupled amplification.

MULTI-STAGE, TRANSFORMER COUPLED A-F AMPLIFIER

By inserting an a-f transformer between each stage, a multi-stage amplifier may be produced. This is shown in Fig. 16, where a two-stage transformer coupled amplifier is illustrated. A third stage could be added to form a three-stage amplifier by repeating the procedure just outlined.

Fig. 17 has been prepared to further illustrate how the signal voltage is built up during the process of amplification, when transformer coupling is used between the stages. Here, each of the transformers has a turns-ratio of 3 to 1, and the intermediate amplifier tube has a net amplification of 10. Hence, if a 0.5-volt signal is available at the output of the detector, the first transformer will increase it to 3 times 0.5 or 1.5 volts, so that 1.5 volts will be applied to the grid of the first a-f tube. Since this tube also has an amplification of 10, it will boost the signal to 10 times 1.5 or 15 volts. The following transformer increases the signal to 3 times 15 or 45 volts, which voltage is applied to the grid of the second amplifier tube.

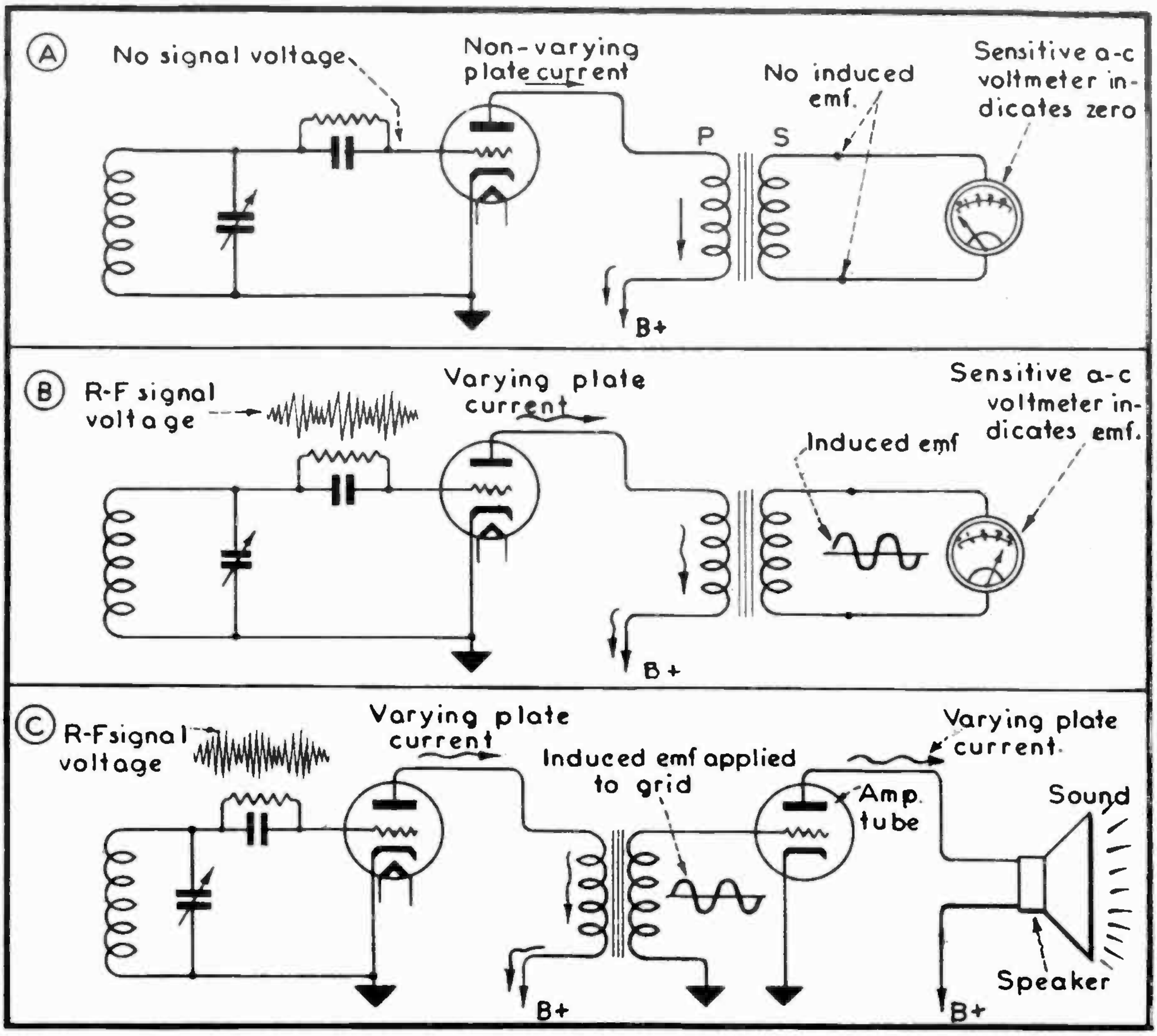

FIG. 15
OPERATING ANALYSIS OF TRANSFORMER COUPLED A-F AMPLIFIER

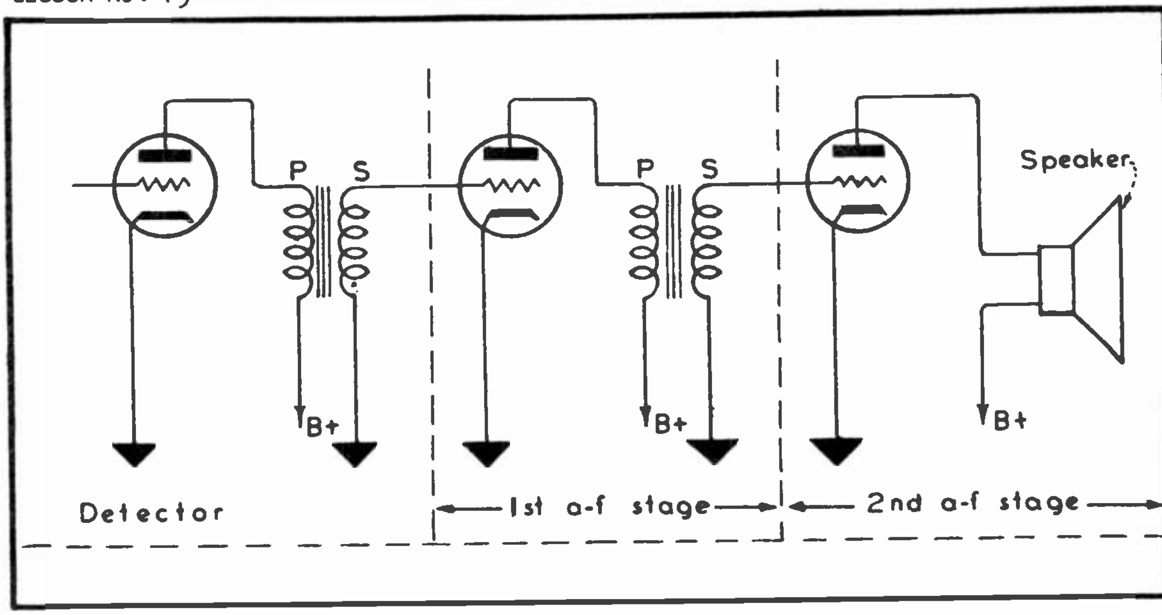

FIG. 16
TWO STAGES OF TRANSFORMER COUPLED A-F AMPLIFICATION

POWER AMPLIFIER STAGE

A so-called "power amplifier" tube is used in the last stage of commercial audio amplifiers. This type of tube is designed primarily to handle comparatively large amounts of power for the purpose of supplying the energy necessary to operate a speaker vigorously enough to produce a loud sound. It is characteristic for such tubes to pass a larger plate current than those used in the preceding stages. A tube of this type is therefore called a "power amplifier tube"; and the circuit in which it is used is referred to as the "power amplifier stage", but sometimes merely as the "output stage". The stages preceding the output stage are often called "voltage amplifier stages", and the tubes used therein are classed as "voltage amplifiers."

USE OF MORE THAN ONE TUBE PER STAGE OF AMPLIFICATION

It is sometimes desired to have a stage of amplification handle a higher signal current than can be controlled by one tube, and thus obtain a higher power output. This is often true of the output stage (last stage of the a-f amplifier). In that case, it is possible to utilize two tubes in a single stage of amplification.

These two tubes may be connected in parallel, as is shown in Fig. 18. You will note that the grid, plate, and cathode, of the additional tube are connected to like terminals on the other tube. This parallel

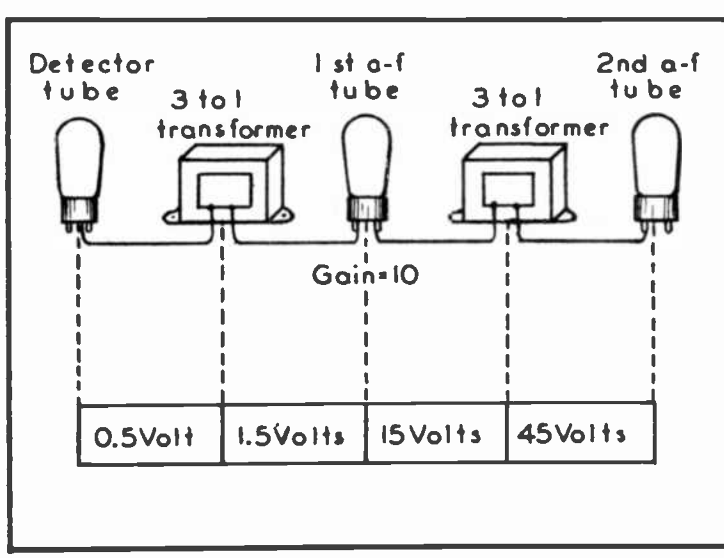

FIG. 17
EXAMPLE OF VOLTAGE-GAIN IN TRANSFORMER COUPLED AMPLIFIER

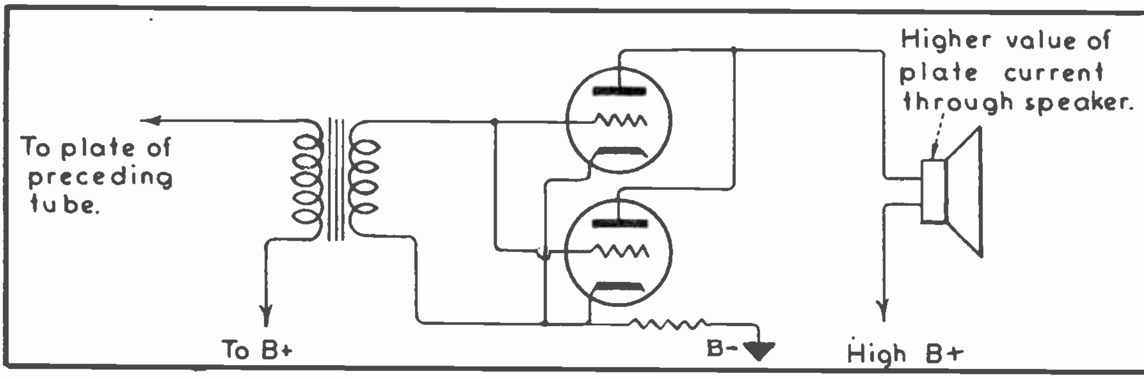

FIG. 18
PARALLEL-CONNECTED OUTPUT TUBES

arrangement enables the stage to handle twice the plate current than would be possible with only one tube.

A more satisfactory arrangement for using two tubes in one amplifying stage will now be described.

PUSH-PULL AMPLIFICATION

In Fig. 19, you are shown a stage in which push-pull amplification is employed. You will note that two a-f transformers are required. One of them is called the input transformer; and the other, the output transformer. Observe, also, that the secondary winding of the input transformer, and the primary winding of the output transformer, are center-tapped. That is, a connection is made to the mid-point of these windings so that there is the same number of turns from this point to each end of the winding.

Again referring to Fig. 19, notice that the cathodes of the two tubes are connected together. The grids are connected to the ends of the input transformer's secondary winding. The plates are connected to the ends of the output transformer's primary winding.

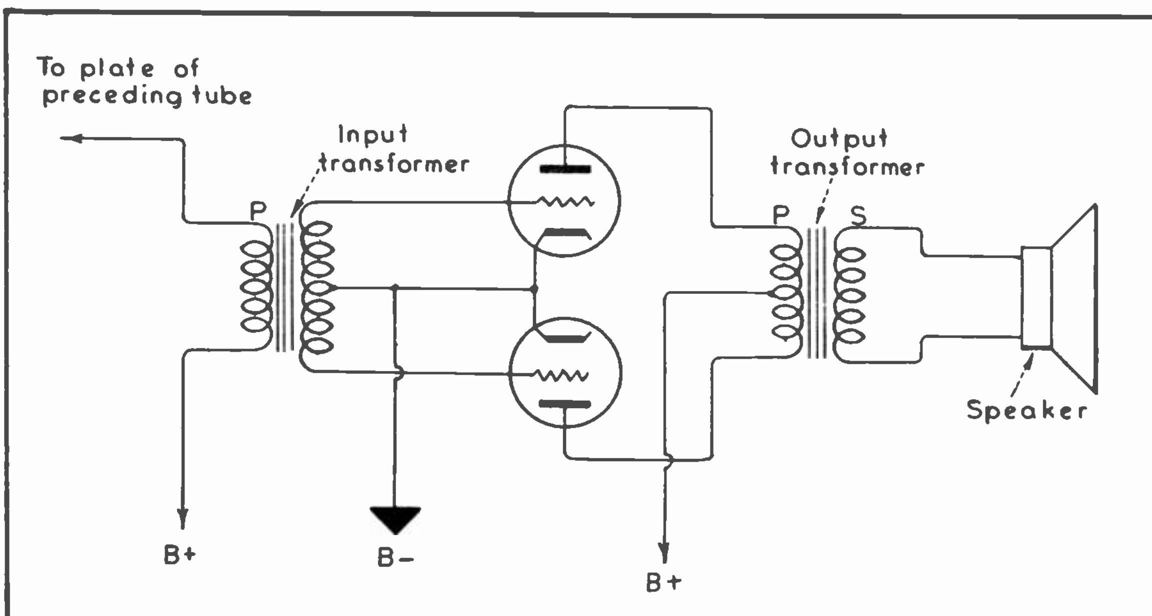

FIG. 19
PUSH-PULL A-F AMPLIFIER STAGE

The center tap of the secondary winding on the input transformer is connected to the cathode of both tubes, as well as to the chassis (B-). The center tap of the output transformer's primary winding is connected to B+. The secondary winding of the output transformer is connected to the speaker.

ANALYSIS OF PUSH-PULL OPERATION

A complete analysis of the operation of such a push-pull amplifying stage is given in the three drawings presented in Figs. 20, 21 and 22. It is customary to "feed" or "drive" a push-pull amplifier stage with a voltage amplifier stage. In the circuit of Fig. 20, it is assumed that the push-pull stage, which is functioning as the last or output stage of the amplifying system, is preceded by such a stage of amplification. The tube in the preceding stage is shown at the extreme left; and is referred to as the "input tube", with respect to the push-pull stage.

In Fig. 20, no signal is being applied to the grid of the input tube. Therefore, the plate current of this tube, which flows through the primary winding of the input transformer, is a non-varying, or steady direct current, as indicated by the straight arrows. With a non-varying current in the primary winding, no emf will be induced in the secondary --- and thus, the control grids of both push-pull tubes will be neutral. With the control grids of both tubes neutral (the no-signal condition), normal current flows in the plate circuit of both tubes, as indicated by the straight arrows.

Notice how these arrows show that plate current is reaching the cathodes of both tubes by way of the chassis. Passing through the tubes in the form of an electron stream, this same current leaves the plate of each tube and flows to the center tap on the primary winding of the output transformer. The plate current of tube #1 flows through the

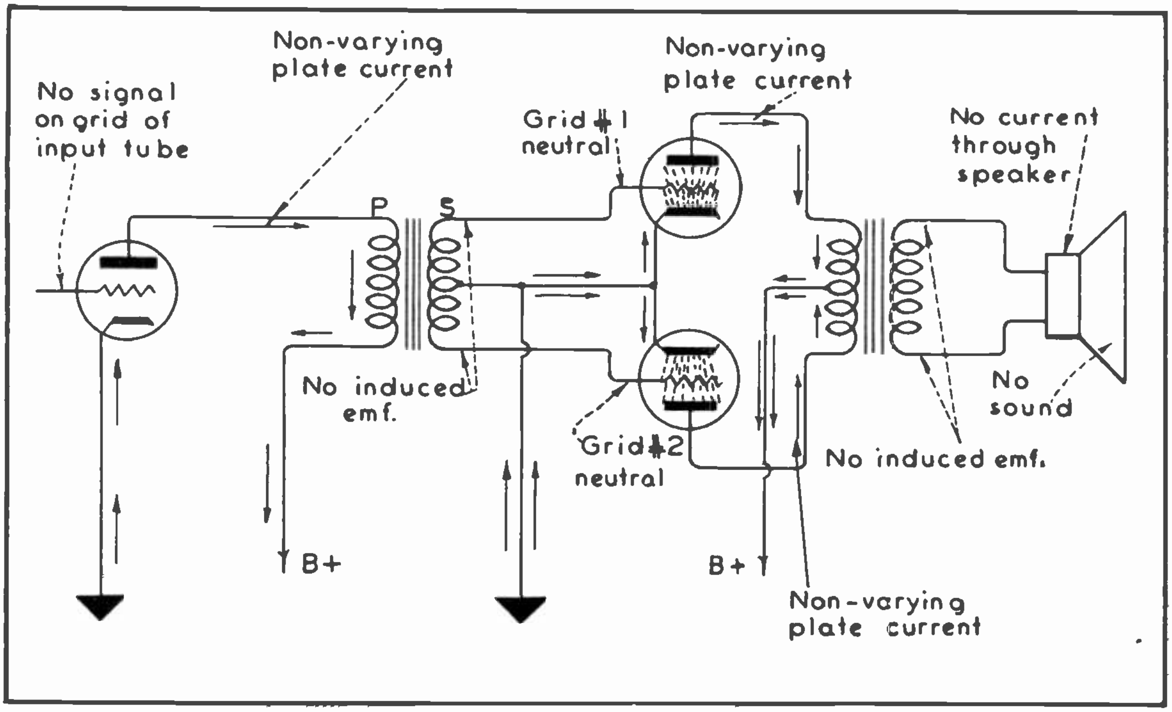

FIG. 20
OPERATION OF PUSH-PULL STAGE DURING NO-SIGNAL CONDITIONS

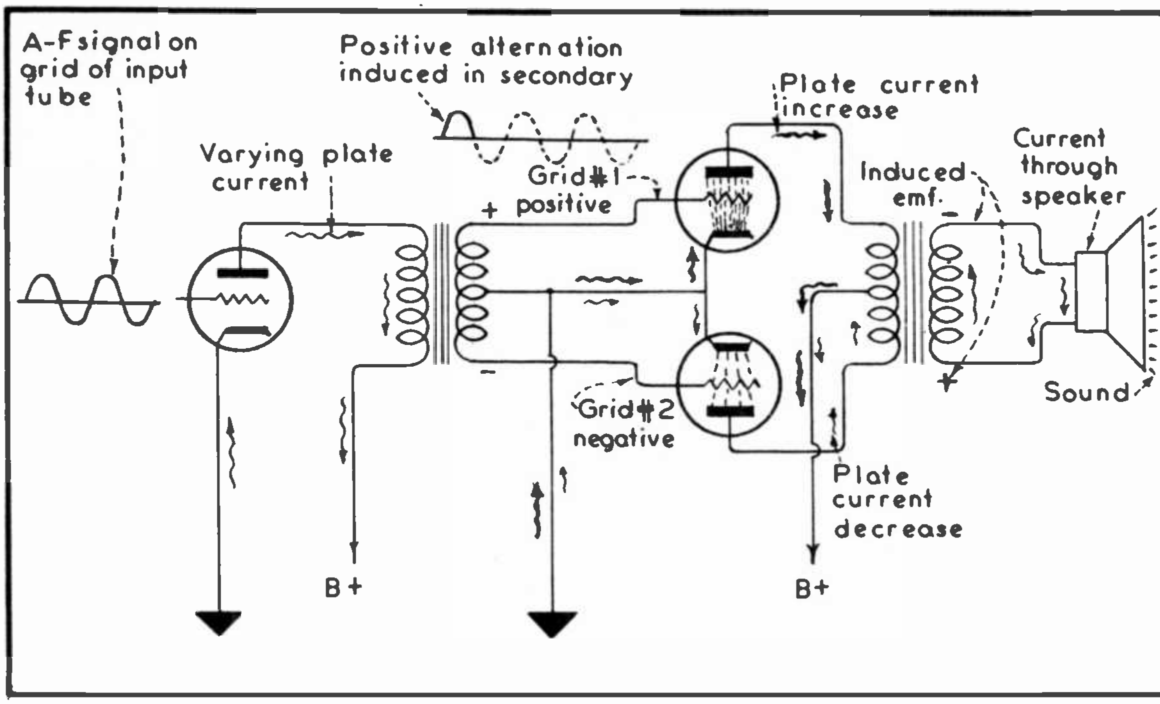

FIG. 21
OPERATION OF PUSH-PULL STAGE DURING FIRST ALTERNATION OF SIGNAL VOLTAGE

top-half of the output transformer's primary winding, while that of tube #2 flows through the bottom-half of the winding. The current from both tubes leaves the winding at the center tap, and returns to the power supply system through the B+ lead.

With a non-varying current flowing through both halves of the center-tapped primary winding on the output transformer, as in Fig. 20, there will be no induced emf in the secondary winding of this transformer; and therefore no current will flow through the windings of the speaker which is connected to the secondary. Thus, no sound is produced by the speaker.

In Fig. 21, an audio signal is being impressed upon the grid of the input tube. This causes the plate current of this tube, which is passing through the primary winding of the input transformer, to rise and fall in the form of a-f variations. This is shown by the wavy arrows which indicate the path of this current from the plate of the tube to the B+ lead of the input stage.

FIRST ALTERNATION:

With a varying current in the primary of the input transformer, an a-c emf will be induced into the secondary winding. This is shown by the voltage curve, and the polarity signs at the two ends of the secondary winding. In the case of Fig. 21, the top end of the secondary winding is, at this instant, positive; and the bottom end of the winding is, at this same instant, negative.

Thus, the control grid of tube #1, is positive; while the control grid of tube #2, is, at the same time, negative. There will therefore be an increased flow of electrons from the cathode to the plate of tube #1, and a corresponding increase in the plate current passing through the upper half of the output transformer's primary. Large, wavy arrows indicate this a-f current increase.

On the other hand, the control grid of tube #2 has a negative potential impressed upon it. This causes a decrease in the flow of electrons through this tube; and a corresponding decrease in plate current --- indicated in the drawing by the small wavy arrows in the plate circuit of tube #2. Since the plate current of tube #2 is passing through the bottom-half of the output transformer's primary winding, the decrease in plate current will reduce the flow of current through this half of the winding.

These current changes in the primary winding of the output transformer will set up an emf in the secondary, and cause current to flow through the speaker which is connected to this winding. Thus, sound will be produced at the speaker.

SECOND ALTERNATION:

In Fig. 22, the current in the primary of the input transformer has decreased below its normal value; and, as a consequence, the induced emf in the center-tapped secondary winding has undergone a reversal of polarity; the top end of the secondary winding now being negative, and the bottom end, positive. This is shown by the polarity symbols, and the grid voltage curve.

Under these conditions, the grid of tube #1 will be negative; and that of tube #2, positive. Electrons will therefore pass freely through tube #2, as shown by the large wavy arrows in the plate circuit of this tube; but their passage through tube #1 will be sharply reduced by the negatively charged grid, as indicated by the small wavy arrows in the plate circuit of this tube. Thus, current in the top half of the output transformer's primary winding decreases, while that in the bottom half of the winding increases. Again, these current changes in the primary cause an emf to be induced into the secondary of the output transformer so that an a-f current will energize the speaker and produce sound.

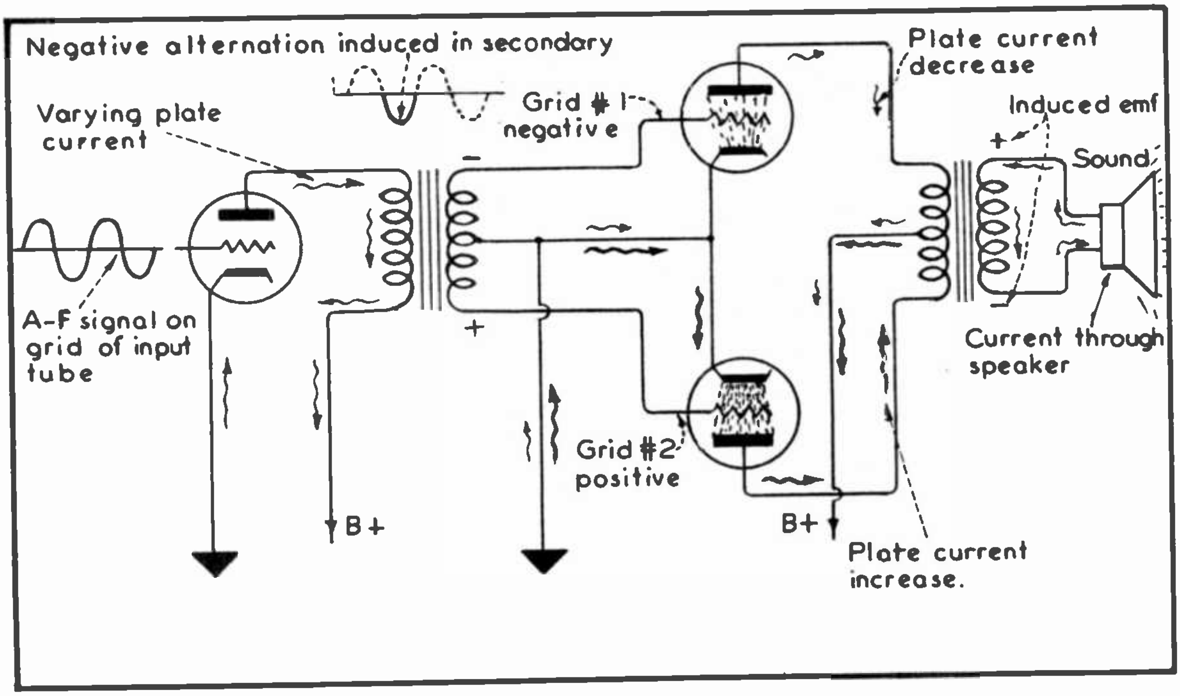

FIG. 22
OPERATION OF PUSH-PULL STAGE DURING SECOND ALTERNATION OF SIGNAL VOLTAGE

In summation, it should be borne in mind that when the plate current of one of the push-pull tubes is increasing, that of the other is decreasing. When one is at peak value, the other is at minimum value, etc. One of the tubes is thus considered as "pushing" while the other is "pulling" --- hence, the name "push-pull".

Also, the current in one half of the primary on the output transformer is decreasing while that in the other half is increasing. These current increases and decreases, which occur simultaneously in the primary, aid each other in inducing an emf into the secondary. That is, the combined effects of simultaneous current increases and decreases in the two halves of the primary winding result in the secondary emf being of much higher value than would be the case if the current changes of only one tube were being applied to the primary as done in ordinary transformer coupling.

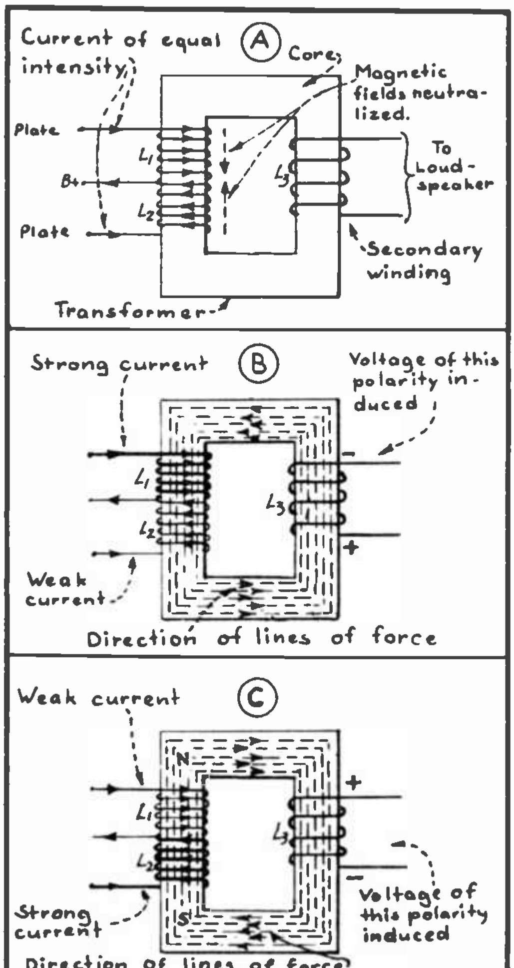

FIG. 23
HOW VOLTAGE IS INDUCED IN SECONDARY OF PUSH-PULL OUTPUT TRANSFORMER

The action that takes place within the output transformer of a push-pull amplifier stage is illustrated in detail in Fig. 23. At (A), conditions are illustrated at the time that the same amount of current is flowing through both halves of the primary winding. Since the current flows through these two halves of the winding in opposite directions, the polarities of the magnetic fields produced by them oppose each other. This neutralizes the field so that there is an absence of flux, as here shown; so no voltage appears across the secondary.

Then, when the signal causes the plate current to increase through the tube which is connected to winding-half L-1, and decrease through that which is connected to winding-half L-2, conditions will be as illustrated at (B) of Fig. 23. Notice, here, that since the current through L-1 is the stronger, the former neutralized condition will be overcome, and the effective or resultant field will have its polarity controlled by winding-half L-1. The direction of this resultant magnetic field is indicated by the arrows in this illustration.

During the other alternation of signal voltage, the plate current will increase through winding-half L-2, and decrease through L-1, as at (C) of Fig. 23. Therefore, L-2 now becomes the controlling factor in establishing the polarity of the resulting field; and the direction of the lines of force, as a consequence, is reversed to what it was at (B). Notice, particularly, that the reversal of the magnetic field as caused by the variation in current through the two halves of the primary winding, produces an alternating voltage in the secondary; which voltage is applied to the speaker.

AMPLIFIER GRID BIAS

Most amplifying tubes will operate more satisfactorily from the standpoint of fidelity if a certain value of bias (negative voltage) is applied to the grid.

Tube manufacturers specify what particular tubes require a bias for certain applications, and what the bias voltage should be. Corresponding plate voltage, screen voltage, tube current values, etc., are also given in such specifications to assure satisfactory performance of the tube as an amplifier.

You will recall that in the case of a bias-detector, a bias was impressed on the tube's grid to make the increases and decreases in plate current unequal. Such, however, is not the case in an amplifier. Bias is used in an amplifier for the purpose of placing a sufficient negative voltage on the control grid of the tube so that the grid will never actually become positive when the maximum positive alternation of the signal voltage is applied to it. If the grid were to become positive, due to a strong signal voltage being impressed on it, it would act as a plate and so attract electrons that would constitute a flow of current through the grid circuit. Such a condition would result in poor tone quality.

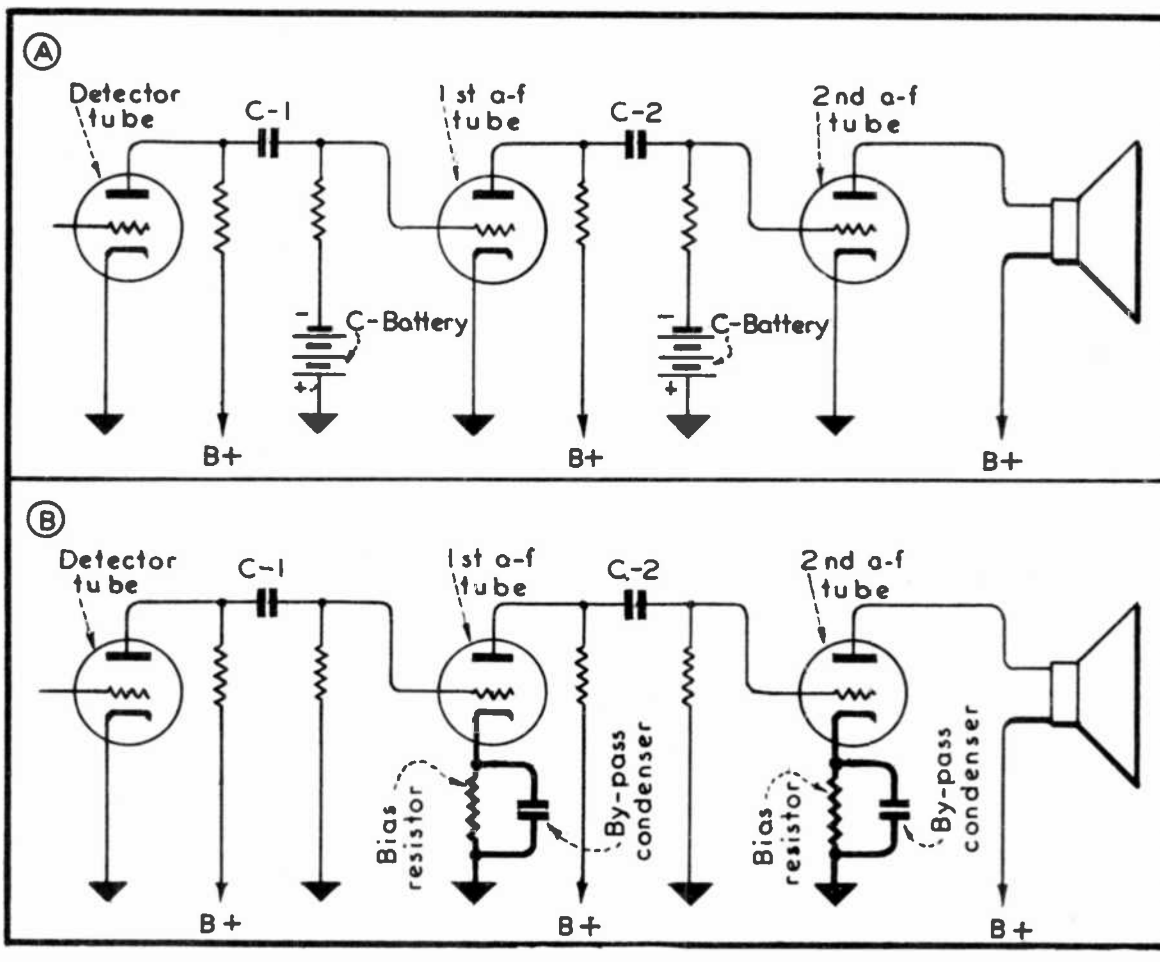

FIG. 24
SECURING BIAS FOR RESISTANCE-COUPLED STAGES

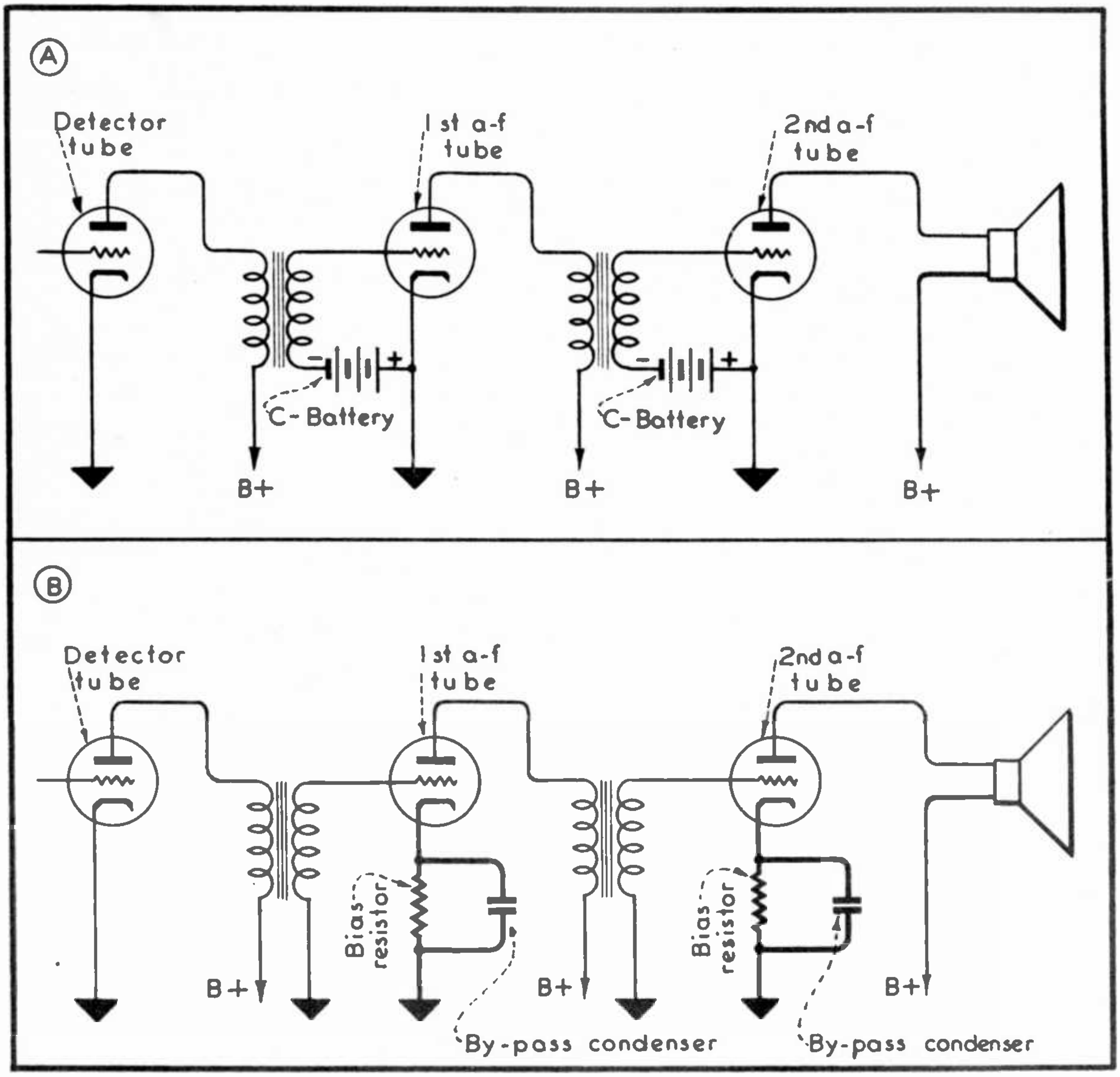

FIG. 25
SECURING BIAS FOR TRANSFORMER-COUPLED STAGES

It is to be noted, that the value of the bias selected for an amplifier tube is such that the increases and decreases in plate current produced by the signal voltage at the grid are equal to each other. In general, it can be said that where one particular tube is designed for use either as a bias-detector or as an amplifier, the bias voltage for the detector application is much greater than that used when operating this same tube as an amplifier. As you progress with your studies, this point will be made more clear.

BIAS FOR RESISTANCE-COUPLED STAGES: Bias for amplifiers may be secured, as in detector circuits, by the use of a C-battery, or a bias resistor. In Fig. 24, you are shown how bias is obtained for tubes used in resistance-coupled circuits by either of these two methods. At (A), bias is derived by a C-battery which has been inserted between the lower end of the grid-leak resistor and the chassis, to which the cathode is also connected. At (B), it is obtained by means of a bias resistor which has been inserted between the cathode and the chassis.

This bias resistor functions exactly as did that in the detector circuits which were previously explained. That is, the cathode current --- which is really the plate current (and sometimes the screen current as well) --- in returning to the tube from the chassis, passes through this resistor and causes a voltage drop to be developed across it. Due to the direction of current flow through this resistor, the upper end of the resistor is positive, and the lower end is negative. Then, since the cathode is connected to the upper end and the grid to the lower end (through the leak resistor), the grid will be at a negative potential with respect to the cathode. Thus, a bias is applied to the grid.

BIAS FOR IMPEDANCE-COUPLED STAGES: Bias is secured for impedance-coupled stages in exactly the same manner as described for resistance coupling; that is, by means of a C-battery, or bias resistor.

BIAS FOR TRANSFORMER-COUPLED STAGES: Transformer-coupled stages may be biased as shown in Fig. 25. At (A), a C-battery has been inserted between the lower end of the transformer's secondary winding and the cathode. At (B), the usual bias resistor has been placed in the cathode circuit,

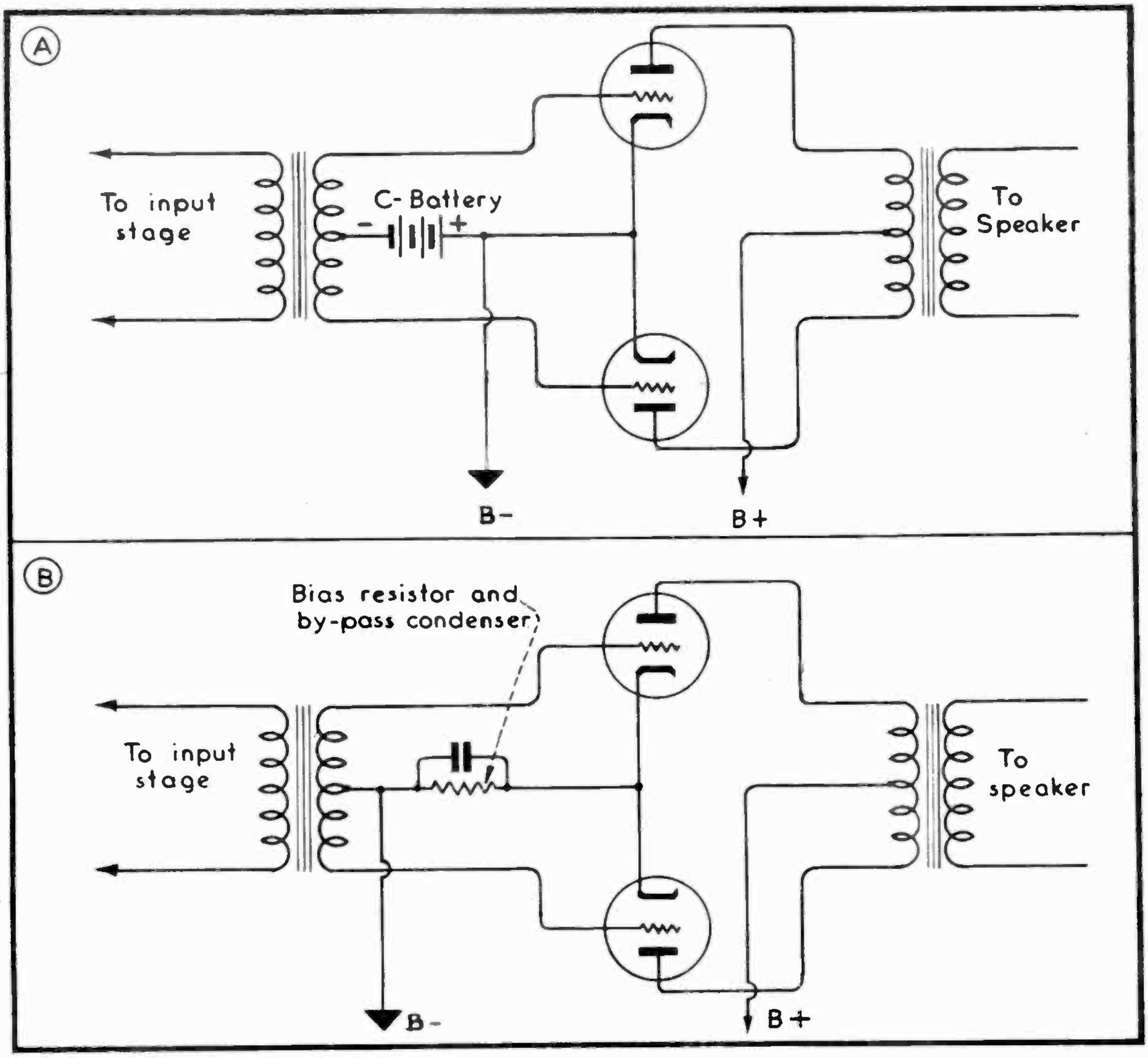

FIG. 26
SECURING BIAS FOR PUSH-PULL STAGE

and the secondary winding of the transformer completes the grid circuit and applies the bias voltage to the tube's grid.

BIAS FOR PUSH-PULL STAGES: Push-pull stages are biased by means of a C-battery inserted between the center tap of the input transformer's secondary winding and the cathodes of the tubes as is shown in Fig.26(A), or by means of a resistor placed between the chassis (B-) and the cathodes of the two tubes, as at (B). You should note that if a C-battery is used, the cathodes are connected directly to the chassis (B-); and that the center tap of the input transformer's secondary winding is connected to the chassis through the C-battery. When a bias resistor is used, the resistor is connected between the cathodes and chassis, while the center tap on the secondary winding of the input transformer is connected directly to the chassis.

BY-PASS CONDENSERS ACROSS BIAS RESISTORS: Where a bias resistor is used, a by-pass condenser should be connected across it, so that a-f signal currents will not have to pass through the resistance offered by the resistor. Since these currents are of an audio frequency, the capacities of such by-pass condensers must be greater than those used in r-f or detector stages. Capacities from 0.5 mfd , to as high as 20 mfd are often used for this purpose.

Sometimes there are exceptions to this rule. For example, you will frequently encounter cases where no such condenser is connected across the bias resistor in a push-pull amplifier circuit, as the use of the two tubes usually makes this unnecessary. However, there are times when the condenser is used in this circuit as a precautionary measure to assure peak performance, and where the cost of the condenser warrants its use.

EXAMINATION QUESTIONS

LESSON NO. 15

1. - Name the three basic coupling methods that are used in a-f amplifiers.

2. - What is the chief advantage of transformer coupling over the other coupling methods?

3. - What is the chief advantage of resistance-coupling in an a-f amplifier over the other coupling methods?

4. - What is the reason for using more than one tube in the power amplifier stage of some audio amplifiers?

5. - When a signal is being handled by a push-pull power amplifier stage does the plate current in the two tubes increase at the same time?

6. - Why is a negative bias applied to a-f amplifier tubes?

7. - Why is a by-pass condenser connected across a bias resistor in a-f amplifier circuits?

8. - How does impedance coupling differ from resistance coupling?

9. - In a push-pull power amplifier stage, is it the primary or secondary winding of the input transformer that has a center tap?

10.- Draw a circuit diagram of a two-stage resistance coupled audio amplifier.

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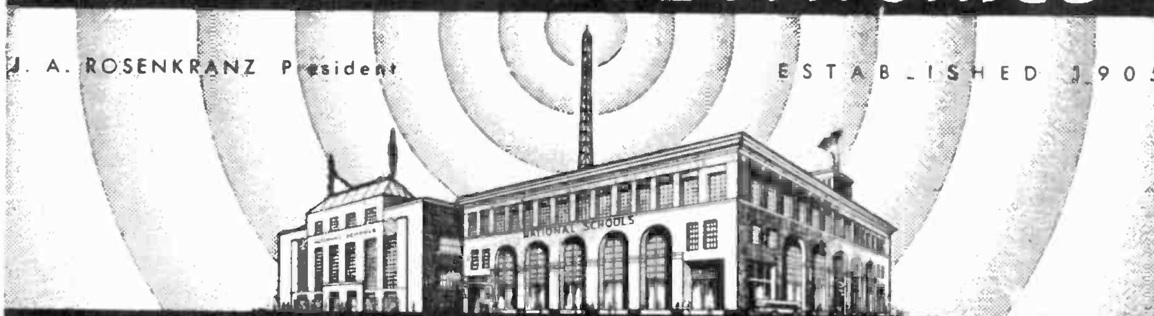

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LESSON NO. 16

HEADPHONES and LOUD SPEAKERS

We have learned how radio signals are tuned in, detected and amplified. Now, we are ready to convert the amplified audio signal energy into sound. The devices that do this are called "sound reproducers," or simply "reproducers"; and of which are two distinct types used in radio --- headphones and loud speakers.

In this lesson, you will become acquainted with the structural features and operating principles of the basic forms of reproducers in each class, and the method of connecting them to radio receivers.

HEADPHONES

Earlier in the course, you were introduced to the headphone, and the principle whereby it produced sound. This device is used extensively in connection with communication type receivers in commercial radio-telegraph and radio-telephone work, as well as in various other fields of the radionic industry. It is therefore necessary that you become thoroughly familiar with it. Also, by acquainting yourself with its principles, you will be better able to understand the operation of the loud speakers that are covered later in this lesson.

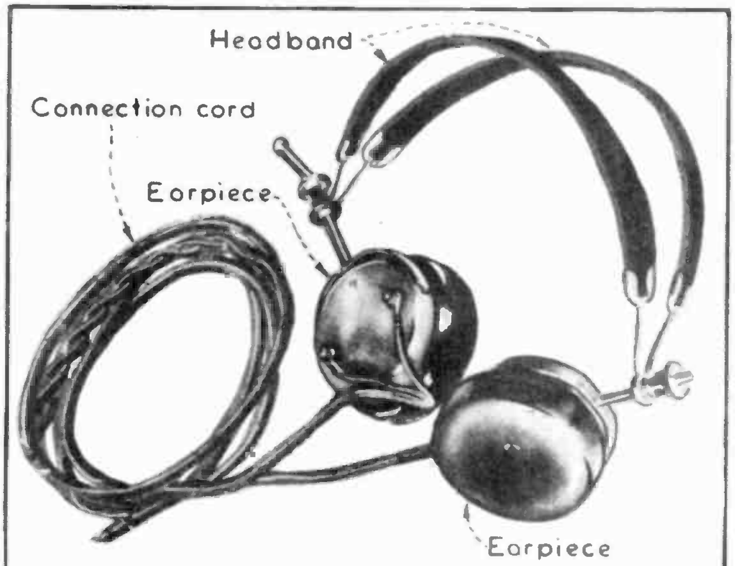


FIG. I
HEADPHONE SET

A typical headphone set appears in Fig. 1. You will observe that it comprises two earpieces, fastened to a headband in such manner as to be held securely over the ears. The cord (cable) which is attached to the headset is connected to the output of the receiver. Although the headset illustrated in Fig. 1 is equipped with two earpieces, some headsets comprise only one earpiece.

A sectional view of an earpiece, or headphone unit, is presented in Fig. 2. You will no doubt recall from a description previously given that it consists of a small permanent magnet, resting at the bottom of the case. Two pole pieces are attached to the magnet in such manner as to extend the magnetic poles upward, near the diaphragm. (See detail of magnet assembly at right of Fig. 2). On these pole pieces, are mounted the coils through which the a-f current supplied by the receiver flows.

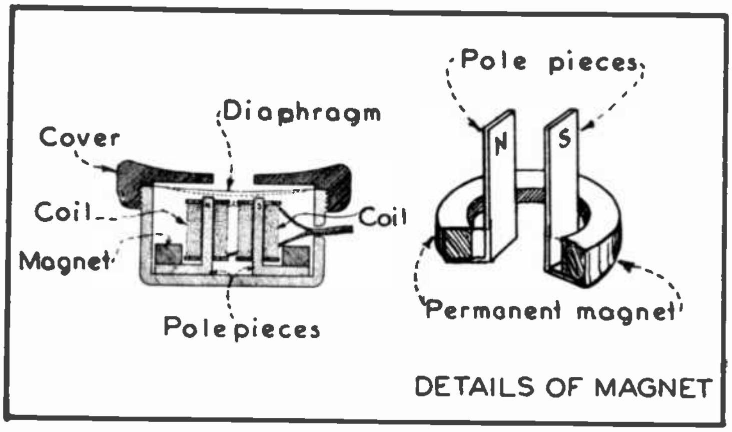


FIG. 2
STRUCTURAL DETAILS OF HEADPHONE

Notice in Fig. 2 how the disc-shaped, flexible metal diaphragm is placed close to the ends of the pole pieces, in which region the attractive force of the magnet is concentrated. For this reason, the center portion of the diaphragm is attracted somewhat toward the pole pieces at the time no signal current flows through the windings.

ANALYSIS OF HEADPHONE OPERATION

A detailed analysis of the operation of a headphone unit is given in Fig. 3. At (A), we have a simplified diagram of a diode detector, and the windings of a headphone unit connected in series with its output. This diagram illustrates conditions as they are at the time no signal is being handled by the detector. Notice, that no current is flowing through the windings, but that the center of the diaphragm is nevertheless attracted slightly toward the pole pieces by the permanent magnet.

When a signal is tuned in, and the audio frequency current increases to value "a", as shown by the graph at the left of illustration (B) in Fig. 3, this increasing current (electron) flow through the windings of the headphone causes the latter to set up a magnetic field of correspondingly increasing intensity. And, since the field established by this electromagnetic action is of the same polarity as that produced by the permanent magnet, the total or effective field is now stronger than was that produced by the magnet alone. Therefore, the center of the diaphragm is attracted more than during the no-signal condition illustrated at (A).

As the diaphragm bends inward, it exerts a "sucking" effect upon the air that bears upon it through the opening in the cover. This movement of the diaphragm, and the resulting displacement of the surrounding air, is also illustrated at (B) of Fig. 3. Since the molecules of air directly in front of the diaphragm are now less dense than normal, we say that the air in this region is "rarefied".

Now, if the flow of audio frequency current through the headphone windings should decrease to a value represented by point "b" in Fig. 3-C, the electromagnetic effect upon the diaphragm will be reduced. The diaphragm will then straighten out more, pushing the air ahead of it, as also shown in this illustration. This crowds the molecules of air together, so we say that the air is being "compressed."

Then, when the current through the headphone windings increases to a higher value than at (B), as represented by point "c" in Fig. 3-D, the electromagnet will attract the center of the diaphragm to a greater extent than was the case in illustration (B); thus causing the air to be rarefied more than formerly.

As the current through the headphone windings varies constantly at an audio frequency rate, the diaphragm will bend inward and outward in step with the variations; and will affect the surrounding air accordingly. All such motion of the air in the immediate vicinity of the diaphragm is transmitted by conduction to the surrounding air, spreading outward until the energy imparted by the diaphragm is dissipated. We call this movement of the air "sound waves."

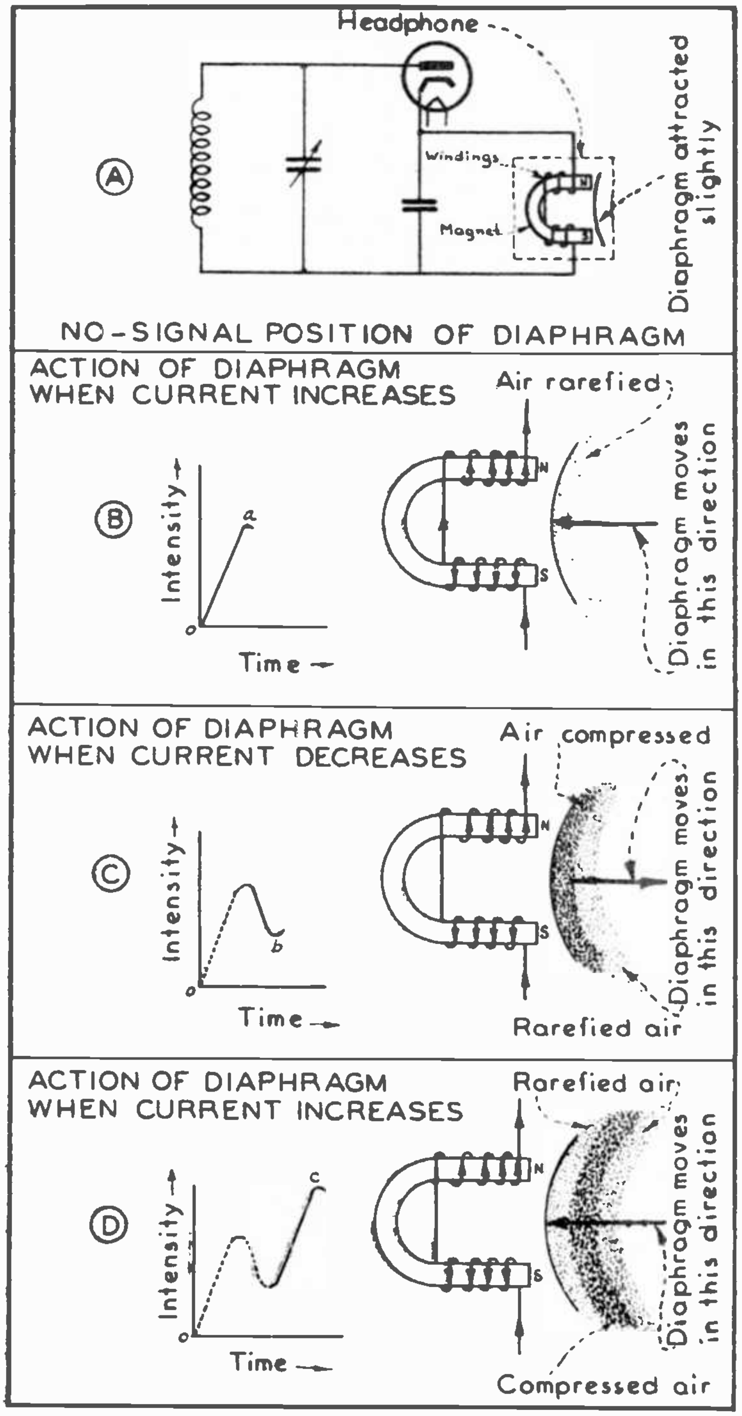


FIG. 3
ANALYSIS OF HEADPHONE OPERATION

SENSE OF HEARING

While discussing the manner in which sound waves are produced, it is well to also consider how these waves act upon our ears to produce the sensation of sound.

The human ear consists of three basic parts --- the external, middle and internal portions. This is illustrated in Fig. 4.

The so-called external portion consists of the flap (P) which acts as a collector of sound waves; and the duct or channel (C) that leads from the flap to the middle section. The inner end of channel (C) is sealed by a thin membrane or diaphragm (D), which we generally speak of as the "ear drum."

Sound waves enter the external opening of the ear channel (C), thereby permitting the air-pressure vibrations to act upon the thin, elastic ear drum.

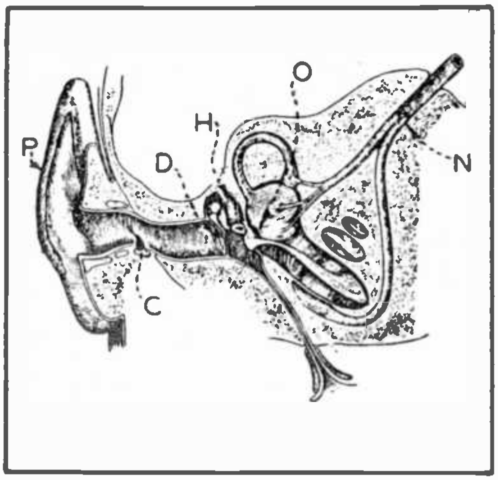


FIG. 4
SECTIONAL VIEW OF HUMAN EAR

This causes the ear drum to vibrate in step with the sound-producing device that set up these waves.

Vibration of the ear drum is transmitted to a group of three bones which form a mechanical lever system, shown at (H) in Fig. 4. These bones transmit the motion of the ear drum to a second diaphragm (O), located in the inner ear. The vibration of this second diaphragm is impressed upon a fluid contained in a spiral-shaped chamber in the bony structure of the head.

The auditory nerve, labeled (N) in Fig. 4, branches off into minute nerve fibers, each of which is attached to one of thousands of tiny, flexible hairs of various sizes and lengths that project into the fluid. The vibration of the liquid in the inner ear acts upon the hairs, so stimulating the nerve fibers that they transmit impressions to the brain which we sense as "sound."

HEADPHONE SENSITIVITY

The term "sensitivity" is often used in connection with headphones. By this is meant the ability of the phones to operate satisfactorily on very small signal currents.

Since the strength of an electromagnet is governed by the ampere-turns rating of its winding, it is apparent that the more turns of wire there are on a headphone winding, the less current will be required to operate the headphone. Therefore, the windings in headphones which are to be used for radio purposes contain several thousand turns of wire. This requires that the wire be very small, so that the proper number of turns may be contained in the small space available. The combination of small wire and many turns results in the windings of such headphones having high values of electrical impedance.

Headphones intended for radio and similar uses have impedances of from 500 to as high as 12,000 ohms per phone. And, since a pair of headphones is always series-connected, the set may have a total impedance of from 1000 to 24,000 ohms. Headphones having an impedance of 2000 ohms per set are the most popular for general radio use.

From the explanation just given, you can see that the impedance of a headphone, or headphones, is usually an indication of its sensitivity. It should be remembered, however, that the impedance is not an indication of the loudness of sound produced --- but tells us only whether or not small values of current will produce a hearable sound.

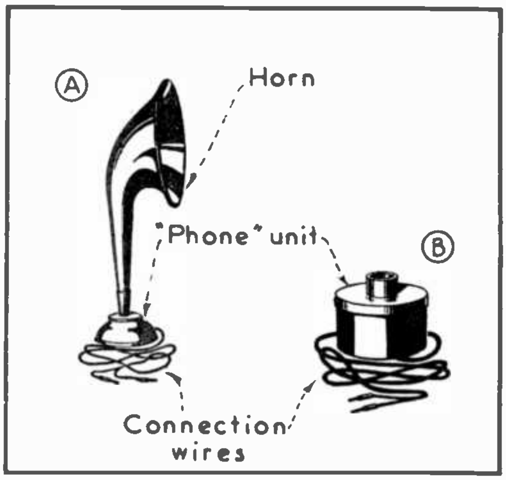


FIG. 5
EARLY METAL-DIAPHRAGM SPEAKER

VOLUME OF SOUND

The maximum volume of sound which headphones are capable of producing is limited by several factors to the extent that it is generally necessary to place them quite close to the ear. These factors are:

1. The amount of signal current available.
2. The maximum amount of signal current which may be passed through their windings without damaging them.
3. The maximum amount of signal current which may be passed through the phones without creating an undue amount of distortion.
4. The limited area of the vibrating surface (diaphragm) in contact with the surrounding air.

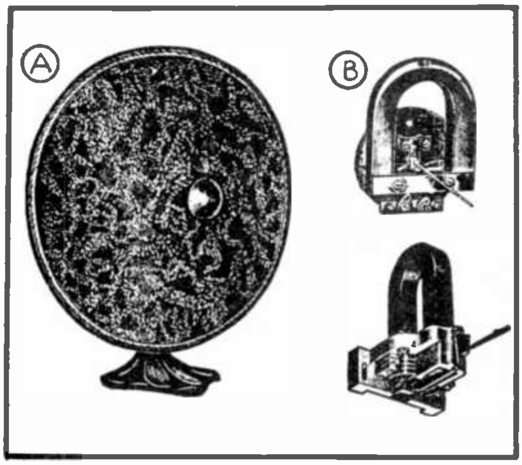


FIG. 6
EARLY PAPER-CONE SPEAKER

You have previously learned that the value of the signal current present in a crystal detector, diode detector, or even in a triode detector circuit is limited; and therefore not always capable of actuating headphones to the extent necessary for producing sounds that can be heard comfortably. However, by using one or more stages of a-f amplification, stronger headphone currents can be secured, and greater vibration of the diaphragms achieved. This will produce somewhat louder sounds at the phones, but there is danger of the heavy currents burning the fine wire of their windings, unless special precautions are taken.

Also, even though the windings might be able to withstand the increased current, the diaphragms would be limited as to their amplitude of vibration by the small distance available between them and the poles of the magnets. If the amount of vibration becomes excessive, the diaphragms will strike the poles, thereby producing an objectionable rattling sound.

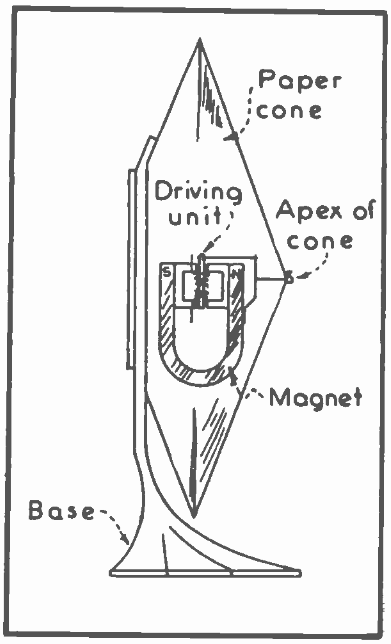


FIG. 7
DRIVE UNIT MOUNTED INSIDE OF CONE

One of the main reasons for lack of volume is the small area of the headphone diaphragm. Obviously, with only a very small diaphragm contacting air, there is a limit to the amount of air which can be set in motion, even with considerable diaphragm movement.

LOUD SPEAKERS

Basically, loud speakers serve the same purpose as do headphones, with the exception that they set larger volumes of air in motion, and with greater vigor. In this way, the reproduced sound can be heard by many listeners at one time, and without the need for any one of them having listening devices clamped over their ears. This adds considerably to the comfort of listening.

The first attempts at constructing loud speakers consisted of combining the headphone with the then popular phonograph horn, as shown at (A) in Fig. 5. Later, an oversize, or heavy-duty type of "headphone" unit ("B" of Fig. 5) was designed for use in conjunction with a horn. However, the performance of such devices was rather mediocre; the volume and tone quality seldom being equal to that of a good phonograph.

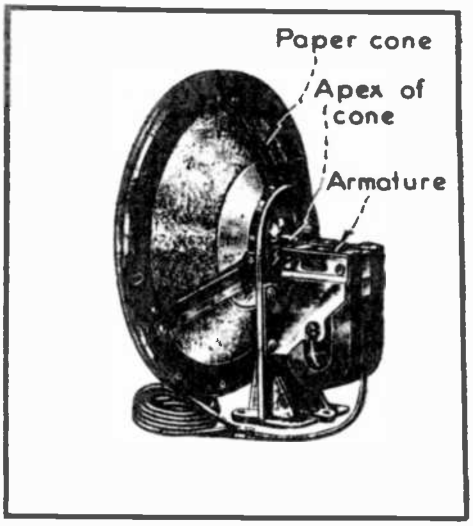


FIG. 8
DRIVE UNIT MOUNTED
OUTSIDE OF CONE

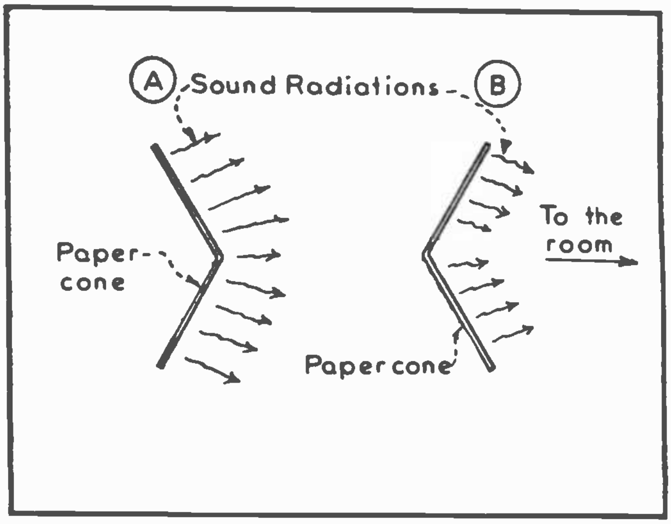


FIG. 9
RADIATION OF SOUND WAVES
FROM CONE

It is to be noted that the expression "loud speaker" has been simplified to "speaker", and that the latter word is now most used.

CONE SPEAKERS

The next big step in speaker design was the development of the cone speaker --- an example of which is shown in Fig. 6, together with two forms of driving unit. Here, the metal diaphragm used up to this time was replaced by a good grade of paper resembling parchment, formed into the shape of a cone. This paper had a tendency to vibrate naturally at a low frequency; for which reason this speaker was capable of reproducing the low notes much better than could metal diaphragm speakers of that day.

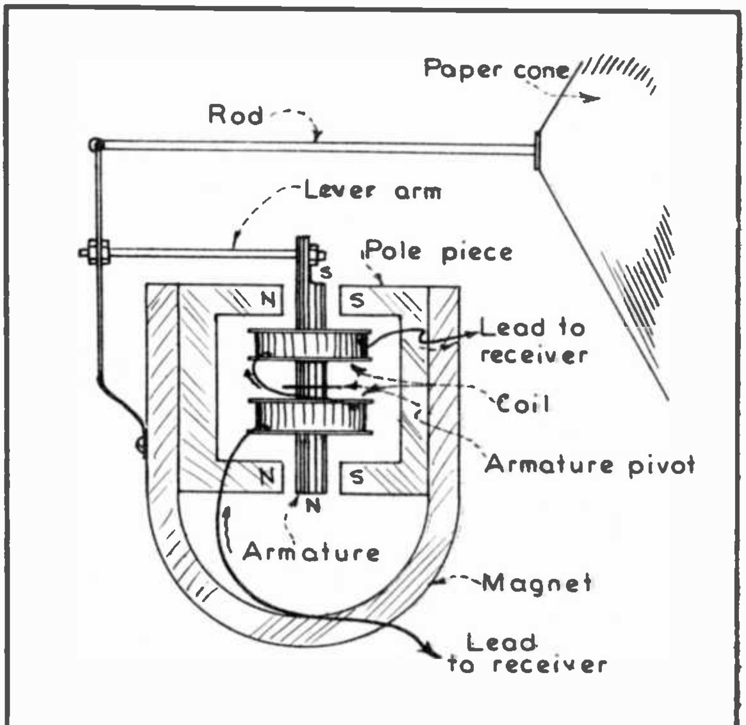


FIG. 10
BALANCED ARMATURE DRIVING UNIT

The cone speaker in Fig. 6 is not intended to be used inside of a receiver cabinet; but rather, is to be placed in some conspicuous and convenient location, such as on top of the receiver cabinet, on a table, etc.

An internal view of this same speaker appears in Fig. 7, where you will see how the driving unit is mounted inside of it. The driving unit is thus concealed within the speaker, and is therefore not visible from the outside. Speakers of this type that are designed for mounting within the receiver cabinet, have the cone inverted; and the driving unit placed behind the apex, as in Fig. 8.

The cone arrangement at (A) in Fig. 9 radiates sound waves outward from the center of the cone; while arrangement (B) radiates them toward the center-line of the cone. However, in both cases, the back side of the cone also radiates sound waves.

It is customary to support the cone at its rim by a metal ring. Flexible paper, cloth, or soft leather is used as the means for connection between the cone and ring; thus supporting the edge of the cone, but yet permitting adequate movement of the cone to produce sound.

BALANCED ARMATURE DRIVING UNIT

The two cone speakers just shown are operated by what is known as a "balanced armature" type driving unit. Such speakers are therefore properly called "balanced armature speakers"; but more often, "magnetic speakers." The principle of this driving unit is shown in Fig. 10.

By studying Fig. 10, you will observe that a soft iron, bar-shaped armature is pivoted at its center between the pole pieces of a horseshoe-type, permanent magnet. Two series-connected coils surround the armature. Assuming that these coils are connected in the plate circuit of the receiver's final a-f tube, the following action takes place:

When no plate current is flowing through the speaker winding, the armature will be in a straight up and down position, because the attractive force of the magnet poles will be equal on both sides of it. Now, if plate current should flow through the speaker coil in the direction indicated in Fig. 10, the armature will be magnetized in such a direction that its upper end will become a south pole. Therefore, this end of the armature will be repelled by the south pole piece and attracted by the north pole piece; and consequently, the upper end of the armature will tilt toward the left.

At the same instant, the lower end of the armature will become a north pole; causing it to be attracted to the south pole piece and repelled by the north pole piece. This assists in tilting the armature on its pivot, which motion is transmitted to the apex of the cone by the levers and connecting rod. The apex of the cone is thus pulled toward the left.

From this explanation, it will be seen that as the current through the speaker coils varies at an audio frequency rate, the armature will move correspondingly, and the apex of the cone will be pushed and pulled in step with it. This movement of the cone varies the pressure on the air that contacts its surface, and thus radiates sound waves as illustrated in Fig. 11.

ELECTRODYNAMIC SPEAKERS

The electrodynamic speaker --- more often called a "dynamic" speaker ---- is the most popular type of sound reproducer in use today. It is manufactured in many different sizes, and for many different applications. In the medium sizes, it is to be found in practically all receivers built since 1930. In larger sizes, it is used in public address systems. Very small models are used in portable and midget receivers, as well as in inter-office communication systems.

In reality, the dynamic speaker is a cone speaker, similar to the one just described, but with an improved type of driving unit. Thus, it combines the good qualities of the paper cone with

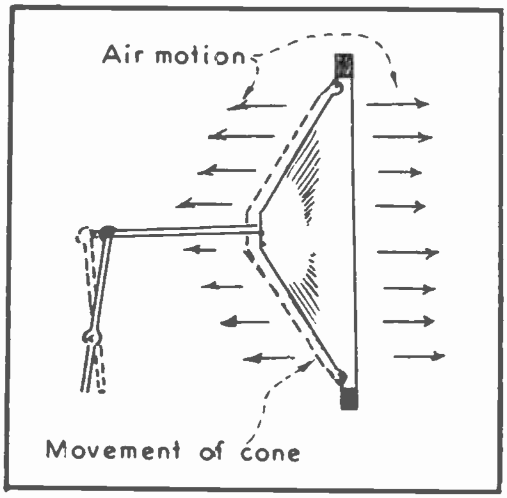


FIG. 11
ACTION OF CONE

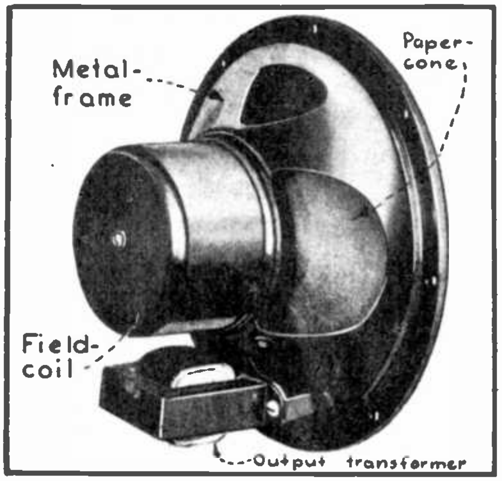


FIG. 12
DYNAMIC SPEAKER --- REAR VIEW

a driving unit which has very few of the drawbacks of speakers patterned after headphone units.

DRIVING UNIT

A typical dynamic speaker appears in Fig. 12. Details of the driving unit are shown in Fig. 13. To better illustrate the individual parts, the voice coil form is shown detached from the cone; but in the actual assembly, the voice coil form is cemented to the cone as indicated. The driving unit consists essentially of a powerful electromagnet called the field magnet; and a small coil of wire, called the voice coil.

The winding of the field magnet is called the field coil. It consists of many turns of rather small wire, and is placed on an iron core. This core, and the frame of which it is a part, is shown in detail in Fig. 14. Observe in this illustration that the frame is shaped in the form of the letter "E", and that the core is the center-leg of the assembly. Thus, the core and frame all serve as part of the magnetic circuit, which circuit is indicated by the dotted arrows in Fig. 13.

The frame has an air gap, at which point magnetic poles will be formed (See Fig. 13). The central portion of the air gap is enlarged to accommodate one end of the core. Adequate clearance is provided between the ends of the frame and the core so that the voice coil can move back and forth freely over the core without touching it or the frame. In Fig. 14, the left end of the core is attached rigidly to the frame.

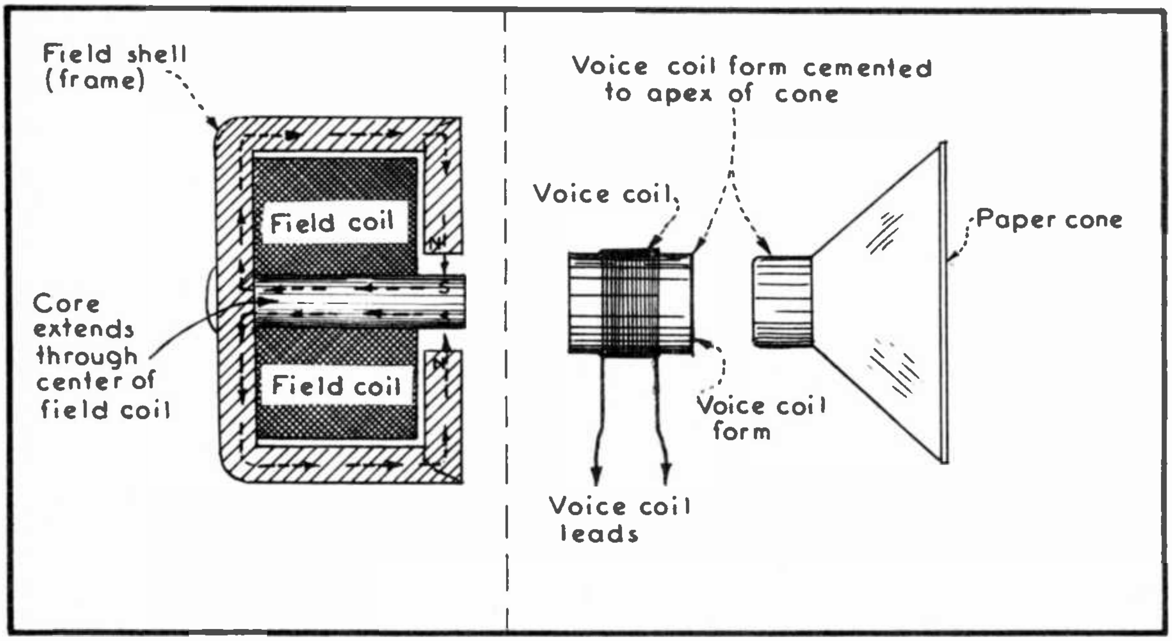


FIG. 13
DYNAMIC SPEAKER DRIVING UNIT AND PAPER CONE

The voice coil consists of a few turns of very small wire, wound on a short length of insulating tubing which is cemented to the apex of the speaker cone. This is shown in Fig. 13.

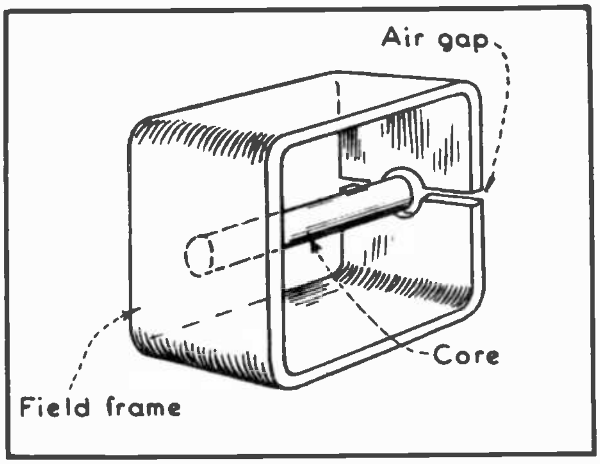


FIG. 14
FIELD CORE ASSEMBLY

HOW THE DYNAMIC SPEAKER OPERATES

An analysis of the operating principle of a dynamic speaker is given in Fig. 15. Here, the field coil assembly is illustrated diagrammatically, viewed from the side. At (A), the field assembly is shown without the voice coil. You will note that the field coil is connected to a source of d-c voltage, which is usually the power supply system in a-c receivers. With direct current passing through the field coil, a strong magnetic field is set up.

Since the coil is wound on an iron core, and as there is a path through the frame for the lines of force to pass from the north to the south pole of this core, the magnetic flux, thus generated, has a practically continuous path through iron. However, there is one small portion of the magnetic path where the lines of force must traverse air rather than iron. This is the air gap, shown in Fig. 15-A. When the lines of force cross this gap, they form a very strong magnet that would attract the blade of a screw driver, or other magnetizable metal, if held close to the end of the core.

At (B), the voice coil is shown with the field. Note that the voice coil is placed so that it projects into the gap, and almost fills this space. Since the wire on the voice coil is copper, and therefore non-magnetic, it will not be influenced by the lines of force extending across this gap. However, if the voice coil also be connected to a source of emf, the flow of current through the voice coil will set-up a magnetic field around it. Thus, we now have two magnetic fields:

1. The very strong field which is set up by the field coil.

2. A weaker field which is set up by the voice coil.

If the polarity of the emf applied to the voice coil is such that the direction of the resulting current flow through it causes the end of the voice coil nearest the field core to be of the same polarity as that end of the field core, then the two fields will repel each other; and the voice coil will be pushed farther out of the gap. Such is the case in illustration (B) of Fig. 15, where the voice coil moves from the position shown by solid lines to that represented by dotted lines.

If the polarity of the field established around the voice coil is such that the end of the voice coil nearest the field core has a polarity opposite to that of the core, the two fields will exert an attracting force upon each other. The voice coil will then move farther into the gap. This is demonstrated at "C", where symbols show the polarity of the emf applied to the voice coil as having been reversed. The voice coil is illustrated at "C" as having moved from the position it previously occupied at "B" to the position represented by dotted lines.

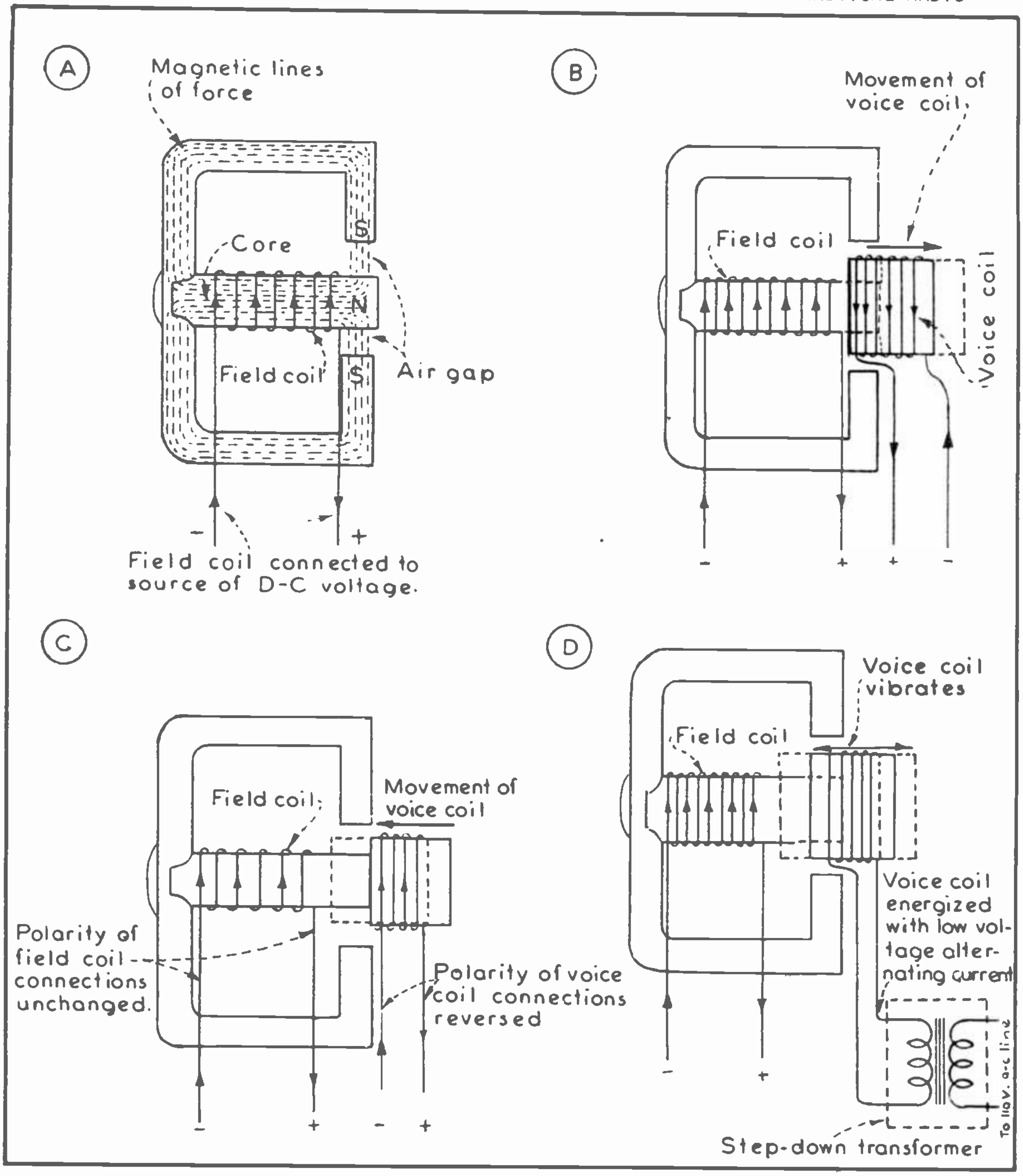


Fig. 15
Operating Principle of Dynamic Driving Unit

As further illustration of dynamic speaker action, refer to (D) of Fig. 15. Here, 60-cycle alternating current supplied by the low-voltage secondary winding of a step-down transformer is energizing the voice coil. The field winding remains connected to a d-c voltage source as previously specified. With a 60-cycle a-c emf applied to the voice coil, the field which surrounds this coil would be undergoing reversals of polarity at the rate of 120 times per second. This would cause the voice coil to move into the gap 60 times per second, and out of the gap 60 times per second.

In Fig. 16, the field remains connected to the d-c power supply, and the voice coil to the source of 60-cycle alternating currènt. A paper cone, very much like that described under "Cone Speakers," has been attached to the outer end of the voice coil. This cone is supported by a metal ring at its rim. A flexible connection of felt, cloth, or leather, permits movement of the cone just as in our example of the cone speaker.

Since the apex of the cone is cemented to the form upon which the voice coil is wound, the previously described movement of the voice coil is transmitted to the cone, thus imparting a pumping action on the surrounding air and so producing a 60-cycle sound. In fact, under the conditions shown, the speaker would be producing a "60-cycle hum."

Now, if instead of the 60-cycle lighting circuit being connected to the voice coil through the step-down transformer, let us suppose that the output of an a-f amplifier be connected to the voice coil through a transformer. The current which flows in the secondary winding of a transformer so connected to the output circuit of an a-f amplifier is an alternating current of audio frequency. Such an a-f current passing through the voice coil will cause the latter to move back and forth in the gap at the same frequency and in accordance with the amplitude of the amplifier's output current.

You should note that neither the polarity nor the intensity of the field coil current has been changed in any of the examples just given. This is always true, as the field requires that direct current of non-varying value pass through its winding merely for the purpose of energizing the electromagnet which establishes the field.

The voice coil, on the other hand, requires that an alternating current, or a pulsating current of audio frequency, pass through it in order to produce sound.

STRUCTURAL DETAILS OF DYNAMIC SPEAKERS

In Fig. 17, you are shown the structural details of a typical dynamic speaker. Here, you are shown clearly the physical relationship between the field coil, field core and frame, cone, voice coil, and the speaker frame. A front view of the cone appears in Fig. 18. Notice, how the end of the field core can be seen through the sleeve on which the voice coil is mounted.

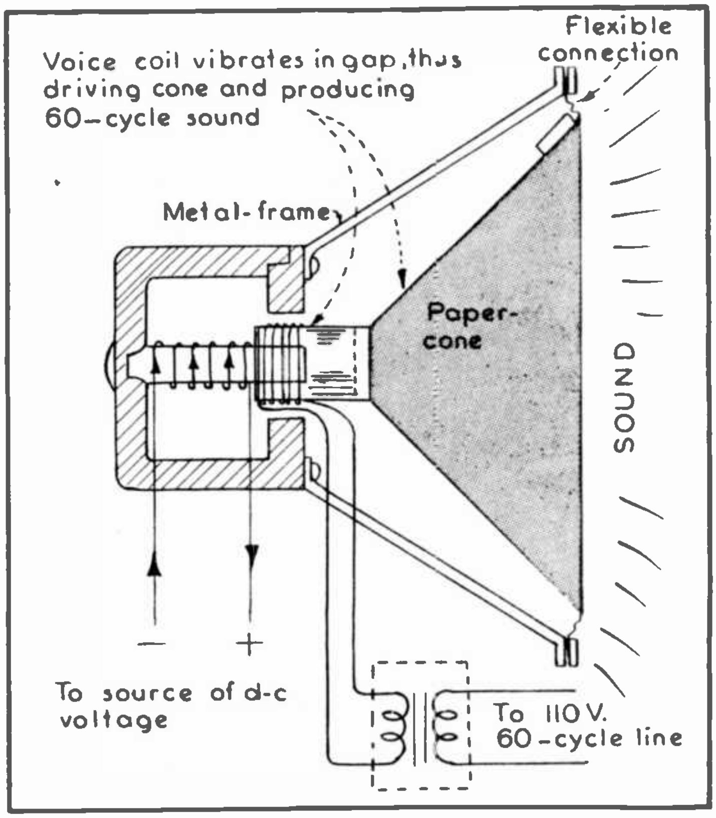


FIG. 16
DYNAMIC SPEAKER PRODUCING 60-CYCLE HUM

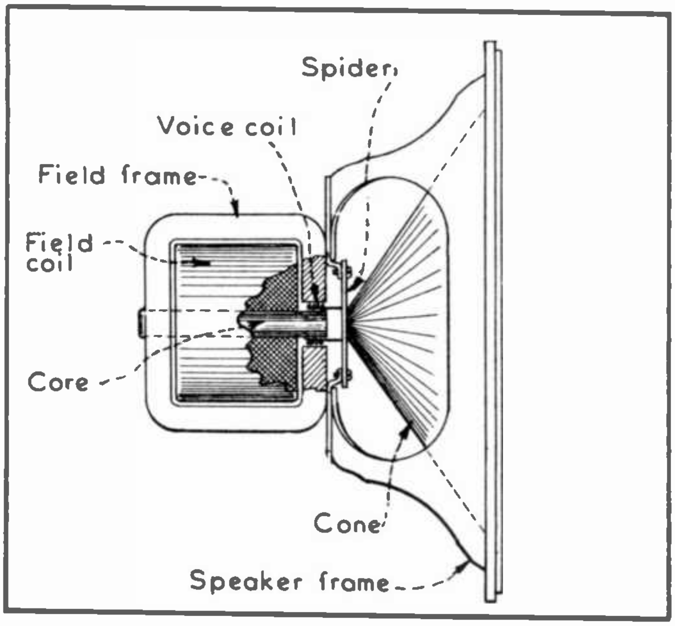


FIG. 17
SECTIONAL VIEW OF DYNAMIC DRIVING UNIT

Fig. 18 shows also how the cone is supported by the frame at its large end by means of a felt, cloth, paper, or leather suspension. A flexible suspension permits free backward and forward movement of the cone within the frame of the speaker, while at the same time supporting the cone against stresses in any other direction.

The voice coil sleeve (form) must be able to slide back and forth in the gap of the field magnet, without touching the poles at the gap. If it were to touch or scrape on the field magnet, the emitted sound would be distorted, and rattles or buzzing sounds would be heard.

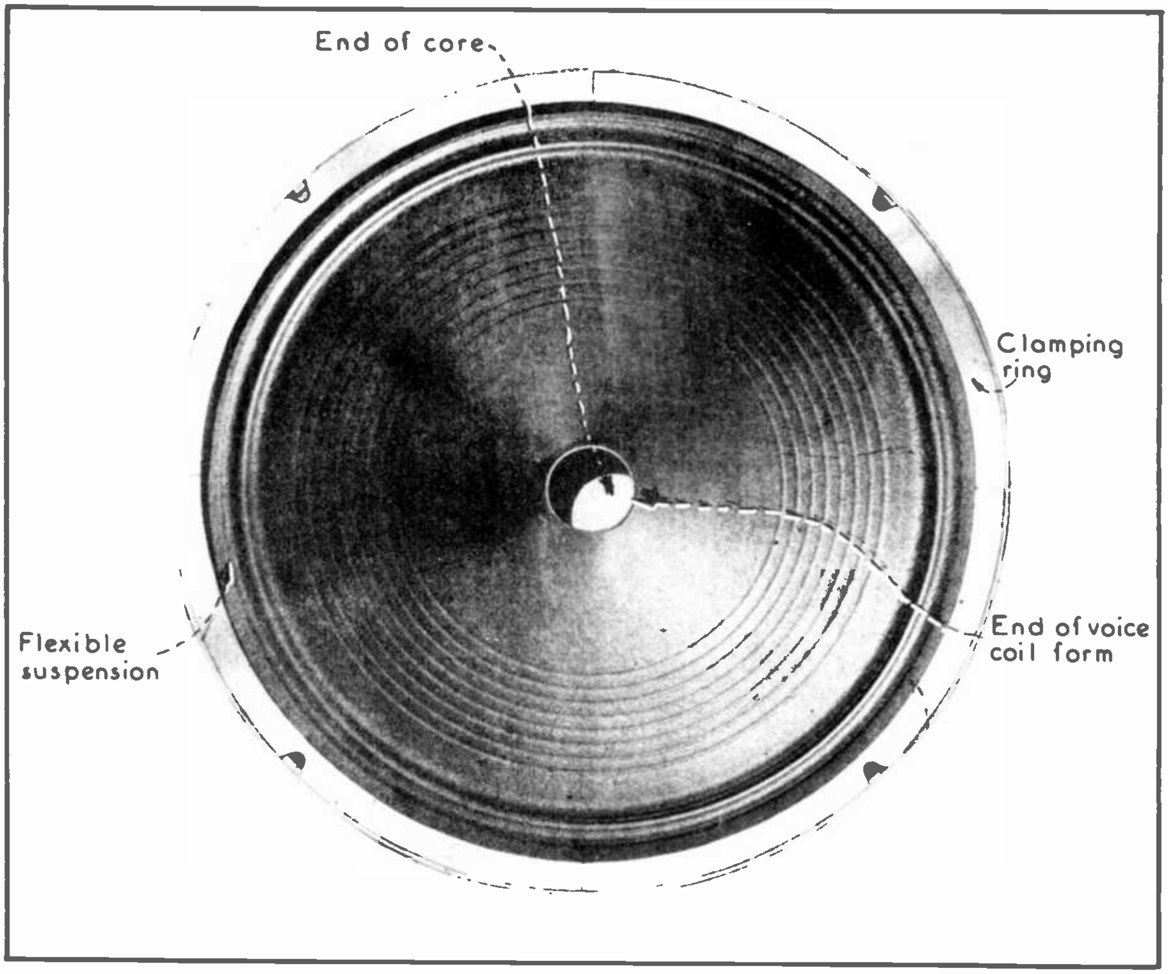


FIG. 18
DYNAMIC SPEAKER --- FRONT VIEW

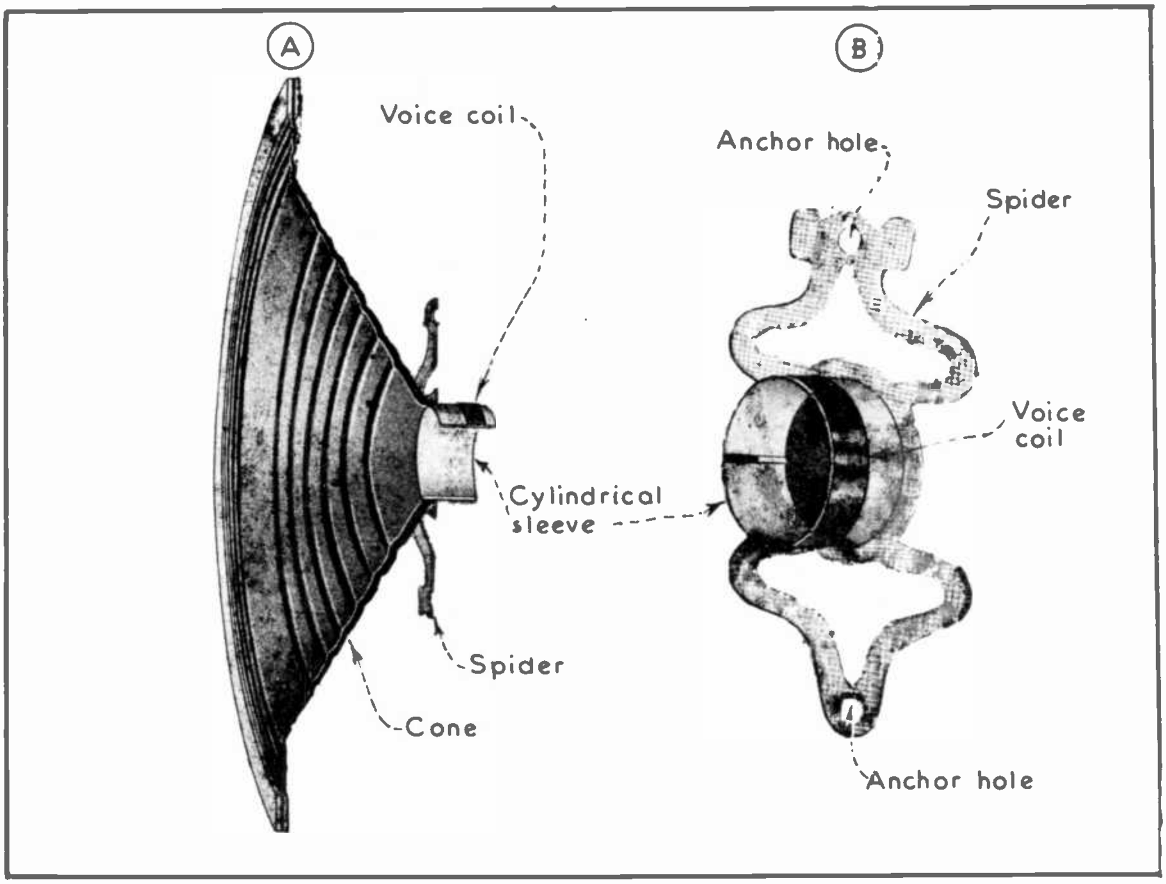


FIG. 19
DETAILS OF SPEAKER CONE ASSEMBLY

SUPPORTING SPIDERS

Most dynamic speakers have a flexible support at the voice-coil end of the cone. Such a support is known as a spider. The purpose of the spider is to keep the voice coil centered in the gap. That is, it will permit the voice coil to move in and out of the gap, but will resist any sidewise motion.

A common form of spider is employed in the speaker shown in Fig. 17. It is made of flexible fiber, attached to the point where the voice coil joins the small end of the cone. The outer edge or rim of the spider is fastened to the speaker frame by means of screws.

A speaker cone is illustrated in section at (A) in Fig. 19, as also is the voice coil and spider; while the voice coil and spider are shown in detail at (B). The spider in this case is also made of thin fiber, cut to such shape as to be light in weight and flexible enough to permit the voice coil to have freedom of motion in a forward and backward direction over the core, but preventing the voice coil moving from side to side. The central portion of the spider at (B) in Fig. 19 is cemented to the voice-coil form (sleeve). The outer ends of the spider are fastened to the speaker frame with screws inserted through the holes indicated in this illustration.

Some spiders are made in the form of thin, disc-shaped flexible leather diaphragms; or thin, disc-shaped paper diaphragms that have corrugations or concentric rings molded in them for flexibility. An example illustrating the application of such a corrugated paper diaphragm spider appears in Fig. 20-A; and a detail of same at (B) of the same illustration.

ELECTRICAL CHARACTERISTICS OF FIELD COILS

The field winding, or field coil, consists of many turns of insulated copper wire, wound to fill the space between the central core and the outer frame of the field magnet. This is shown in Figs. 17 and 20. The resistance of field coils ranges from as little as 8 ohms for speakers designed to operate on the low voltage furnished by the battery in automobiles, to as much as 5,000 ohms for speakers whose field is energized from the high voltage output of the power supply system employed in a-c receivers.

Besides resistance, speaker field coils are also rated as to the current that they are capable of passing without burning out.

ELECTRICAL CHARACTERISTICS OF VOICE COILS

Voice coils are generally wound with rather small wire, and with not more than 100 turns. Therefore, voice-coil resistances are quite low; ranging from about 1.2 ohm to as high as 10 ohms. Because of the small number of turns used on a voice coil, the inductance of such coils is very low. So low, in fact, that the total impedance (combined effect of resistance and reactance) of voice coils is usually considered to be equal to the pure ohmic resistance of the winding.

Voice coil windings are cemented in place on the outside of a short, bakelite or fiber tube, which, in turn, is cemented to the small end of the speaker cone (see Fig. 19). Two flexible, braided wire leads connect the voice coil to suitable insulated soldering lugs on the speaker frame. Connections to the external circuit are made through these terminals.

PERMANENT MAGNET DYNAMIC SPEAKERS

In recent years, new magnetic alloys have been developed. These alloys have a high degree of permeability and retentivity. This makes

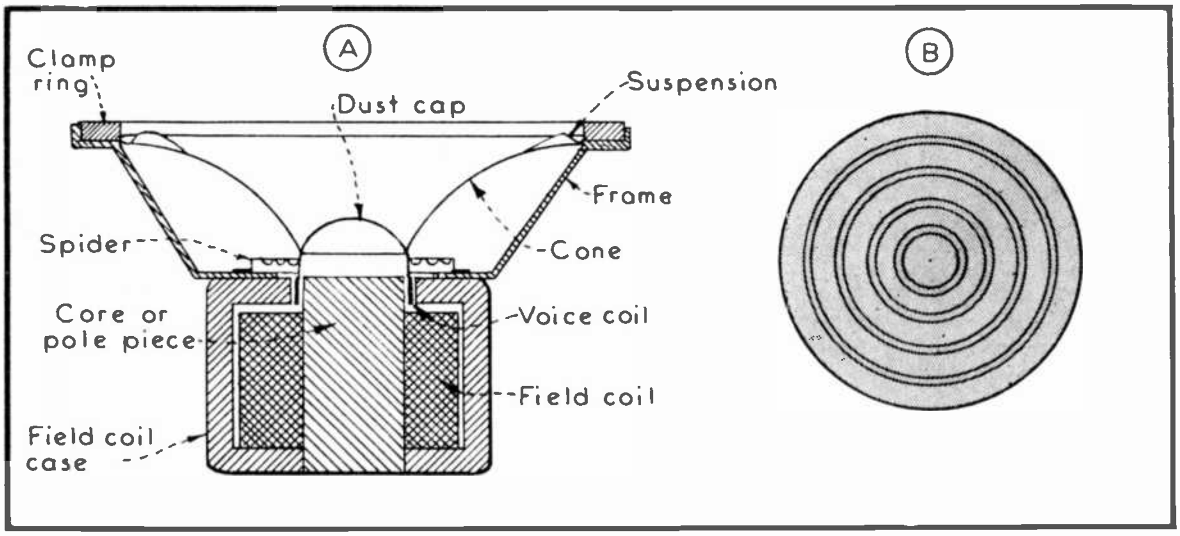


FIG. 20
CORRUGATED SPIDER SUSPENSION

it possible to manufacture permanent magnets that have a flux density almost as great as that of a good electromagnet. In loud speakers, these new alloys are being used in the construction of permanent magnets to furnish fields which function as satisfactorily as do those provided by electromagnets.

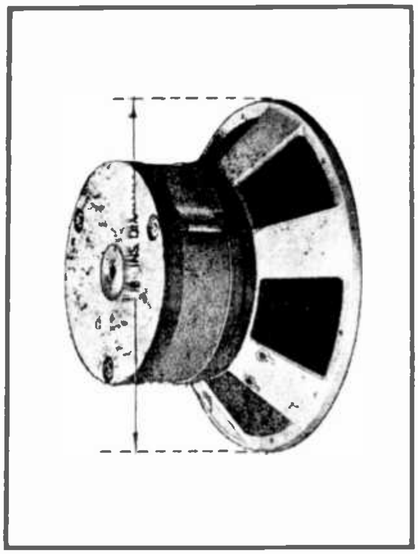


FIG. 21
PM DYNAMIC SPEAKER

Speakers which have permanent magnet fields require no field coil and, of course, no field current. This is of particular value in the case of speakers which are to be used in portable and midget receivers; or even in public address work and other high-power sound systems where several speakers are used and located at considerable distance from the amplifier.

A permanent magnet type dynamic speaker --- usually called a PM speaker --- is shown in Fig. 21. A sectional view of this same speaker appears in Fig. 22. You will observe in Fig. 22, that with the exception of the absence of a field winding, this speaker is practically identical to the electrodynamic speaker previously described. In other words, the voice coil, cone, and frame, are the same as in any other dynamic speaker. (It is to be noted that dynamic speakers having a field coil are often called "Electrodynamic speakers" to distinguish them from the PM dynamic Speakers.)

Upon studying Fig. 22 more closely, you will see that the magnet of the PM speaker is constructed in the form of a ring, closed at one end by a disc-shaped member, and fitted with a doughnut-shaped pole piece at the other end. A core is attached by one end to the solid disc. The other end of the core protrudes through the hole in the pole piece. Thus, we have in effect an arrangement similar to the E-shaped core assembly as used in the electrodynamic speaker. This design was adopted for the magnet of the PM speaker because it provides the means whereby the lines of force are concentrated at the air gap, in which space the voice coil must move.

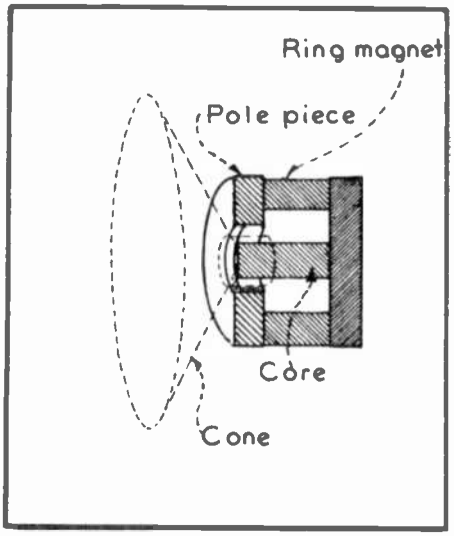


FIG. 22
MAGNET DETAIL OF PM SPEAKER

Fig. 23 will serve to better acquaint you with the manner in which the lines of force are set up in a magnet of this form. At (A) of Fig. 23, the speaker drive unit is shown as viewed from the side, with the center leg or core of the magnet pointing upward. Observe that the upper end of the core is a south pole. The ring-shaped pole piece will then be a north pole all the way around, as shown in illustration (A) of Fig. 23; and also at (B) of Fig. 23, where the magnet assembly is being viewed from the end --- with the core projecting outward from the paper.

Remembering that magnetic lines of force follow a north-to-south direction, you will see from this explanation that they exert themselves in a downward direction in the center leg, or core, as designated by the arrows in Fig. 23-A. Then they pass through the rear disc, upward through

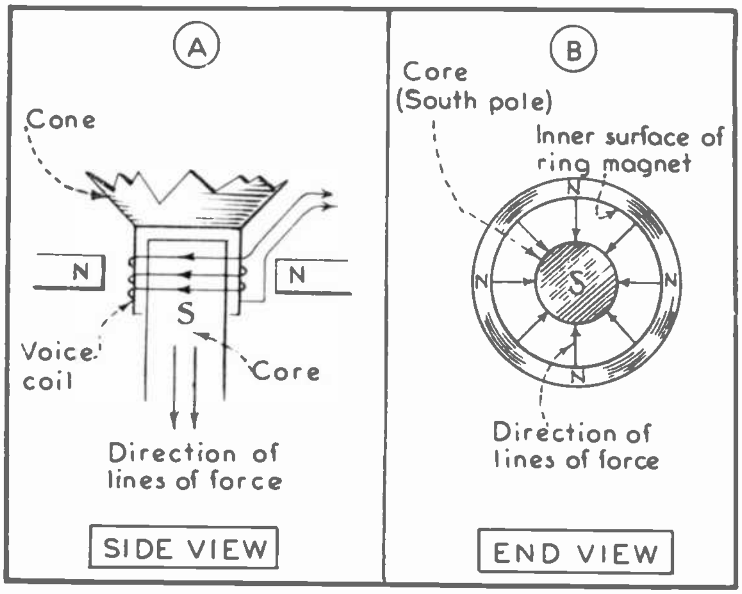


FIG. 23
FLUX ARRANGEMENT IN PM SPEAKER

the ring-shaped member, through the pole piece, and by way of the air gap back to the core.

CRYSTAL SPEAKERS

The operating principle of the crystal speaker is quite unique, in that this speaker does not employ a permanent magnet, nor field coil for polarization. In fact, all of the parts found in the driving unit of the conventional electrodynamic speaker are replaced by a small crystal unit that actuates a paper-cone diaphragm through a system of levers.

A front and rear view of a crystal speaker is shown in Fig. 24.

In Fig. 25, we have a drawing of the operating machanism of this speaker. The heart of the driving unit consists of Rochelle-salt crystals. In the particular model being described, two slabs of Rochelle-salt crystals measuring 2-1/2 inches square and 1/8 inch thick are covered with a metal foil on each surface and cemented together.

This crystal element is held in place by soft rubber supports at three of its corners. The fourth corner is connected to the center (apex) of the cone diaphragm through the lever system.

Upon applying signal voltages across the crystal element, the corner of the crystal assembly which is connected to the cone will vibrate in a direction vertical to the flat surface of the crystals. This causes the cone to undergo a corresponding vibrating motion; thus radiating sound waves.

This moving action of the crystal element is similar to that found in thermostats, where the expansion of one metal and the contraction of another produces a "wiggling motion." In the case of the crystal speaker element, however, this motion is due to an electrical phenomena which is brought about by what is known as the "Piezo-Electrical" characteristic of Rochelle-salt crystals.

Piezo-electrical properties are demonstrated in quartz and other crystals, and have been employed in Radio transmitter circuits for some time to keep the oscillator on the assigned frequency. The theory of this crystal's operation is therefore explained in greater detail in one of your more advanced lessons.

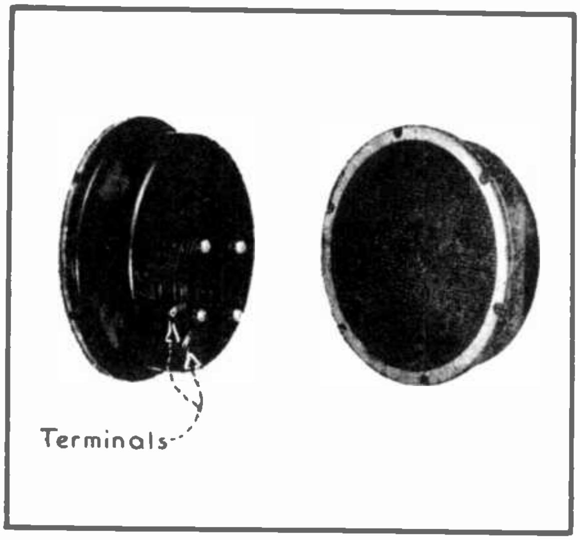


FIG. 24
TWO VIEWS OF CRYSTAL SPEAKER

SPEAKER SIZE

Paper-cone speakers are rated according to the diameter of the large end of their cone. Thus, a speaker which has a cone of 4-inch diameter would be called a "4-inch speaker." An "eight-inch speaker" has a cone that measures 8 inches across the large end, etc. Typical radio speakers range from the small 2-inch size which is intended for use in midget receivers, to 15-inch speakers which are for use in large console receivers.

The size of the cone determines, to a certain extent, the amount of audio signal power that the speaker will handle without distortion. Thus, an 8-inch speaker will handle greater audio power (produce louder sounds) than will a 4-inch speaker.

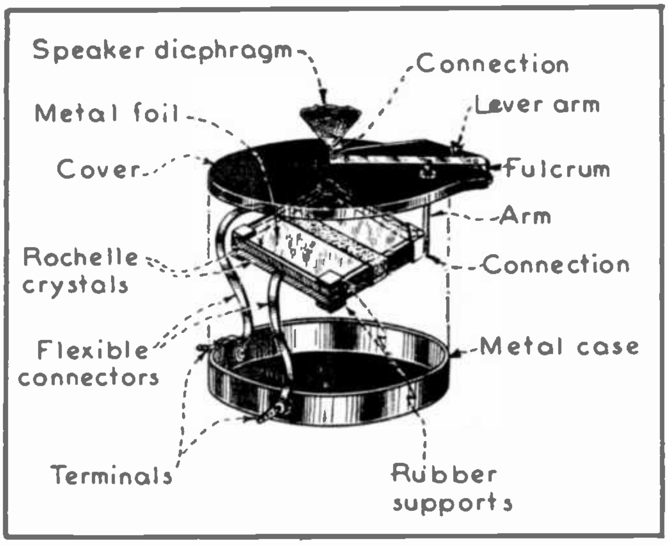


FIG. 25
DRIVE MECHANISM OF CRYSTAL SPEAKER

The size of the cone and the amount of audio power fed to the speaker, together, govern the loudness of the sound produced. For maximum efficiency, the speaker should be of the proper size to handle the maximum power that the audio amplifier of the receiver is capable of delivering.

EFFECT OF SOUND WAVES ON BOTH SIDES OF CONE

When the cone of a loudspeaker is vibrating in air, sound waves are set in motion in the air. Both sides of the cone produce these sound waves; and there is little difference between the amplitude of the sound waves set in motion at the back of the cone, and those set in motion at the front.

An analysis of this action is given in Fig. 26. At (A), the cone is in its normal or neutral position, and no sound waves are being produced. At (B), the cone is moving away from its neutral position, in the direction shown. Note that the air in front of the cone is now being compressed; while that at the rear of the cone is being decompressed, forming a partial vacuum on this side. At (C), the cone has moved from the normal or neutral position in a direction opposite to that at (B). Again, there is a compression of air on one side of the cone, and a decompression or rarefaction on the opposite side --- but just the reverse to the conditions illustrated at (B).

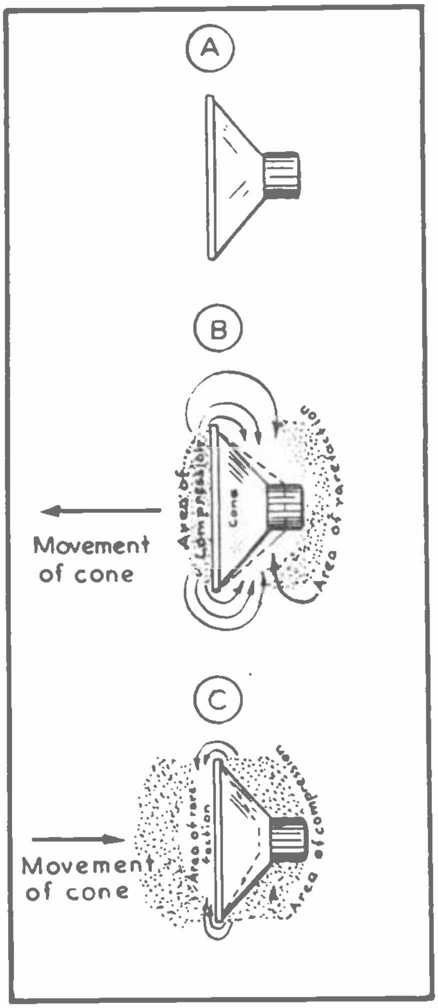


FIG. 26
AIR LEAKAGE AROUND EDGE OF CONE

Observe in illustrations (B) and (C) of Fig. 26, that at the instant a compression exists on one side of the cone and a rarefaction on the other side, the air is swiftly flowing around the edge of the cone from the compression side toward the rarefied side.

Air rushes around the cone in this manner until the pressure on both sides is equal. Thus, there is a tendency for the sound waves which are set in motion on the compression side of the cone to cancel those produced on the rarefied side. At high frequencies, the cone is vibrating so rapidly that this movement of air does not have time to take place during any one cycle, until the next cycle begins; but at the lower frequencies, the cone is vibrating so slowly that air will have time to move from the compression side, around the edge of the cone, and into the partial vacuum on the other side before the cone has a chance to start its stroke in the reverse direction. In fact, this movement, or leakage of air around the edge of the cone is so great as to cancel out most of the low frequency sound waves before they have time to leave the vicinity of the cone. This condition is objectionable, as it results in poor tone reproduction.

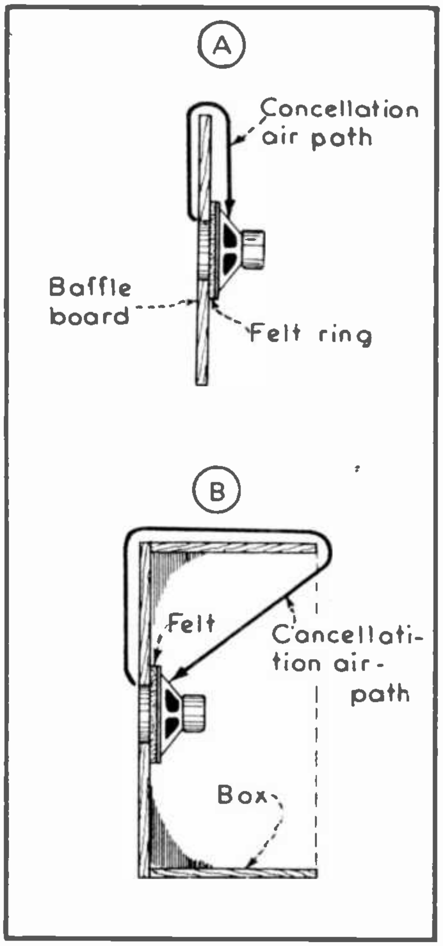


FIG. 27
SPEAKER BAFFLES

SPEAKER BAFFLES

To prevent the action just described, it is customary to use speaker baffles. A baffle, in its simplest form, is shown at (A) in Fig. 27. Note that it consists of a large, flat board, with a round hole equal to the diameter of the speaker cone cut in its center. The speaker is mounted so that the cone is centered over this opening. Celotex, felt, heavy cloth, cork, and soft wood are used for baffling materials because they are non-resonant; that is, they do not vibrate so readily as do sheet metals and other more rigid materials.

With a baffle board, such as described, it is necessary for the air to travel a much greater distance in attempting to leak from one side of the cone to the other. That is, the air must travel around the baffle board in order to pass from the compression side of the cone to the rarefied side. Because of the increased distance, it will require more time for such leakage to take place; and therefore sound waves will have left the cone before any cancellation due to leakage can take place. If the area of the baffle board is large enough, the harmful effects of such leakage will be almost entirely eliminated.

BOX-TYPE BAFFLES

Another form of baffling is shown at (B) in Fig. 27. This is known as a box-type baffle. Note that it is still necessary for air to traverse a comparatively great distance in order to flow from the compression side to the rarefied side of the cone.

It is customary to design receiver cabinets so that they will serve as a baffle for the speaker. Obviously, the baffling effect furnished by a small table model receiver is not as great as that of a large console (floor model) receiver. This is one of the reasons why receivers with large cabinets have better tone quality than do those with small cabinets. In the latter case, most of the low notes will not be heard due to insufficient baffling; and the reproduced sound will therefore appear to be "tinny." The large cabinet model, on the other hand, will have a deeper tone which is more pleasing to the listener --- assuming, of course, that the same size and quality of speaker is used in both cases.

When box-type baffles are used, either in the form of radio cabinets, or as individual speaker baffles, the box, or cabinet, should always be left open at the rear. If completely enclosed, the sound waves which are emitted from the back of the cone will be muffled or lost. Also, enclosing the back of the cabinet will cause a pressure to build-up behind the cone, and thereby make the action of the speaker sluggish.

MAGNETIC SPEAKER CONNECTIONS

The windings of magnetic speakers sometimes have sufficient resistance to permit connecting them in series with the plate circuit of the final a-f tube. However, if the tube being used in the last audio stage passes plate current of such value that the speaker winding would be burned out thereby, it is necessary to use the method of connection shown at (A) or (B) of Fig. 28.

At (A) of Fig. 28, an a-f choke, capable of passing the current required, is connected in series with the plate circuit of the last audio amplifier tube (power amplifier tube). The speaker winding is then connected across the choke through a condenser. Usually, a 1 mfd or 2 mfd condenser is used for the purpose.

In this circuit, all of the plate current drawn by the tube flows through the choke --- none passes through the speaker. However, the a-f voltages developed across the ends of the choke because of the varying current flow through it, react through the condenser and thus permit a current of corresponding frequency to pass through the speaker winding. Sound is therefore produced by the speaker.

Circuit arrangement (B) is somewhat similar, with the exception that one of the speaker terminals is connected to the cathode (filament) of the tube instead of to the positive

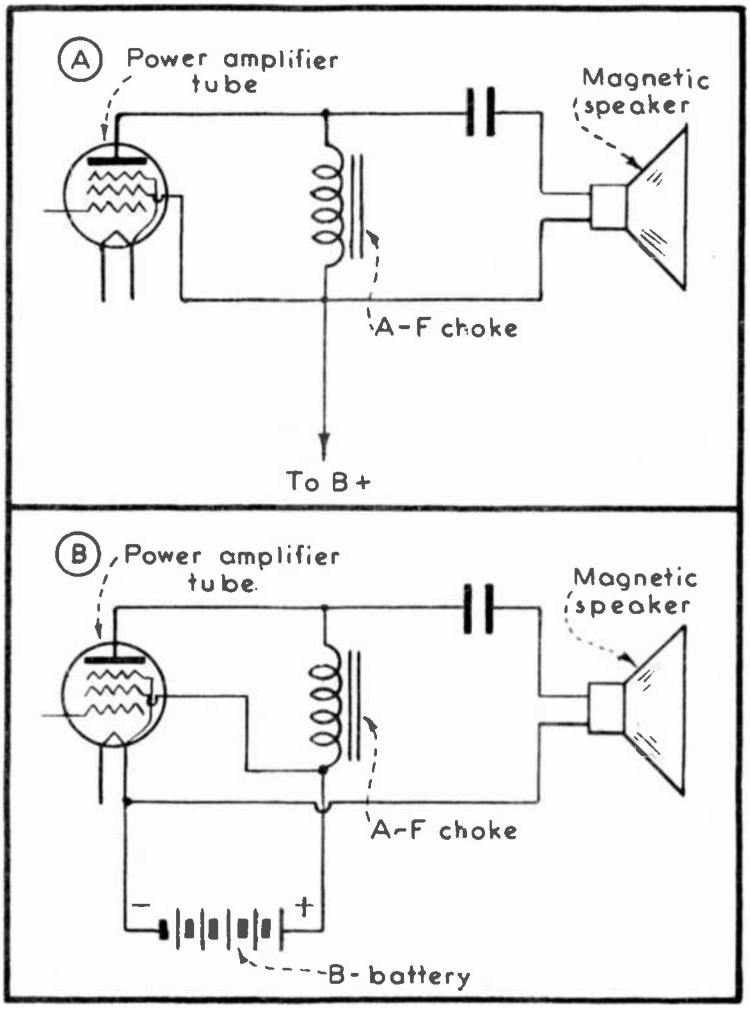


FIG. 28
CONNECTIONS FOR MAGNETIC SPEAKER

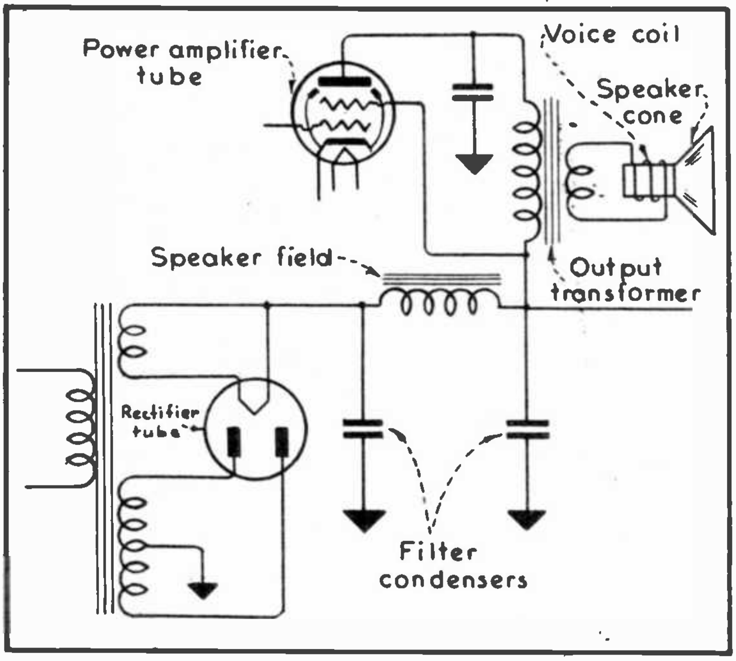


FIG. 29
CONNECTIONS FOR DYNAMIC SPEAKER, USING FIELD AS FILTER CHOKE

end of the choke. Hence, the speaker is connected across the choke through the B voltage source as well as through the condenser, and the signal is transferred to the speaker by the same means as already explained for circuit (A) in Fig. 28.

The methods illustrated in Fig. 28 may also be used for connecting headphones to the output of an amplifier where the plate current of the tube would burn out the headphone windings if they were connected directly in series with the plate circuit.

DYNAMIC SPEAKER CONNECTIONS

In connecting a dynamic speaker to a receiver, one -- and often two -- requirements must be met.

1. If the speaker is an electrodynamic type, and does not use a permanent magnet to supply the field, the field coil must be excited. That is, provisions must be made for passing a direct current through it.

2. The voice coil of the speaker must be coupled to the output of the a-f amplifier through a transformer.

FIELD COIL CONNECTIONS

The field coil of an electrodynamic speaker must be connected to an appropriate source of direct current. In a-c receivers, the high-voltage d-c output of the power supply system generally serves this purpose. Because of the rather high inductance of speaker field windings, it is generally possible for them to furnish the main magnetic field for the speaker, and at the same time act as a filter choke in the power supply system. This is illustrated in Fig. 29. Observe in this diagram how the field and voice coil are represented by symbols.

By combining the functions of filter choke and speaker field in this manner, a saving in cost, weight and space is made possible.

VOICE COIL CONNECTIONS

Dynamic speakers, either of the electromagnetic or the P-M type, require that a transformer be used between the last stage of a-f amplification and the voice coil. A transformer, so used, is called an "output transformer" or "speaker coupling transformer."

It is never permissible to connect the voice coil directly in the plate circuit, because its resistance is so small (10 ohms or less), as also is the wire-size, that the plate current would burn it out.

Besides illustrating the field coil connection, Fig. 29 shows also how the voice coil is coupled to the plate circuit of the power amplifier tube by means of a transformer.

In addition to reducing the flow of plate current through the voice coil to a safe value, the transformer serves also to properly match the impedance of the speaker's voice coil to the plate circuit of the final amplifier tube so that maximum transfer of signal energy can take place with minimum distortion.

Tube manufacturers specify a certain load impedance which should be placed in series with the plate circuit of the power amplifier tube in order to ensure best performance. In Fig. 29, it will be seen that this load is supplied by the primary winding of the output transformer --- the loading effect being the combined opposition of the inductive reactance, resistance and distributed capacity of this winding to the varying plate current that flows through it while a signal is being handled. This electrical characteristic of the transformer's primary winding is called impedance. It is measured in ohms; and in the particular case illustrated, may be several thousand ohms for a 1,000 cycle a-f current.

The speaker's voice coil, on the other hand, has a low impedance --- usually, about 8 ohms. For maximum transfer of signal energy from the output of the amplifier to the speaker voice coil, it is necessary that the impedance of the output transformer's secondary winding be equal to the impedance of the voice coil. We then say that these impedances are matched.

This matter of impedance matching is so important that replacement output transformers are ordered on this bases. That is, we order such transformers by specifying the type-number of the power amplifier tube, and the voice coil impedance of the speaker. We then know that the manufacturer of the transformer will have provided the transformer with the correct number of turns on the primary winding to furnish the proper load in that particular tube's plate circuit, and the correct number of turns on the secondary winding so that the impedance of this winding will be equal to that of the voice coil to which it is to be connected.

This information on output transformers applies to PM speakers, as well as to dynamic speakers that have a field coil.

The output transformer is generally mounted on the frame of the dynamic speaker as in Fig. 12. This eliminates the need for long leads between the secondary terminals of the output transformer and the voice coil. However, there are times when you may find the output transformer mounted on the chassis of the receiver or amplifier, and connected to the speaker voice coil with leads.

In circuit diagrams of receivers using electrodynamic speakers, the field coil is often shown as though it were located at some distance from the other parts of the speaker. This is done only for convenience in drawing; but, in reality, the field coil is always an integral part of the speaker.

For example, the diagram in Fig. 29 makes it appear as though the speaker field occupied a position in the filter circuit of the power supply. The truth of the matter is that it is connected in the power supply circuit to serve as a filter choke, but actually is located within the speaker assembly which may be mounted at some distance from the power supply.

A-C DYNAMIC SPEAKERS

Some electrodynamic speakers are equipped with a rectifier so that the d-c voltage necessary to excite their field can be obtained directly from the a-c lighting circuit, without depending upon the power supply system of the receiver for this. Copper-oxide and vacuum tube rectifiers are used for the purpose. Dynamic speakers equipped with a rectifier are called "A-C Dynamic Speakers" to distinguish them from the "DC type" which receive their exciting current from the receiver's power supply, and from PM speakers which receive their field from a permanent magnet.

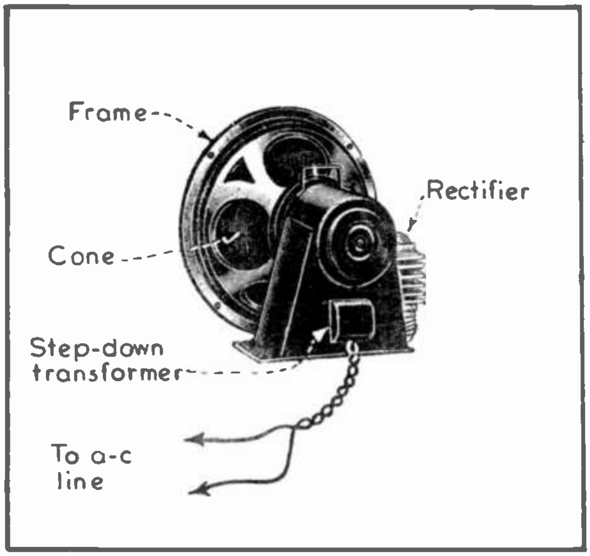


FIG. 30
A-C DYNAMIC SPEAKER

A speaker with a copper-oxide rectifier, and its associated step-down transformer, is shown in Fig. 30. Three such rectifiers of different design appear in Fig. 31.

The unit at the left of Fig. 31, for example, is rated at 3 amps. That at the center can be obtained in several different sizes --- such as 1 amp at 6 volts, 2.5 amps at 4 volts, 2 amps at 6 volts and 1 amp at 8 volts. Units with a screw base, such as illustrated at the right of Fig. 31, are available in current ratings from 0.6 amp to 2.5 amps. Besides these examples, similar rectifiers are available with other shapes and ratings.

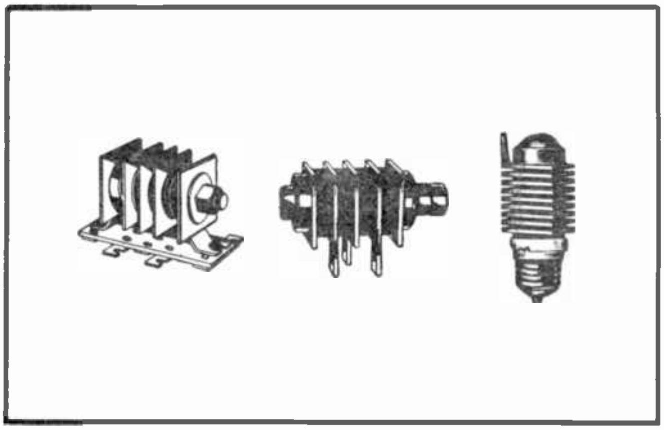


FIG. 31
COPPER-OXIDE RECTIFIERS

HOW THE COPPER-OXIDE RECTIFIER WORKS

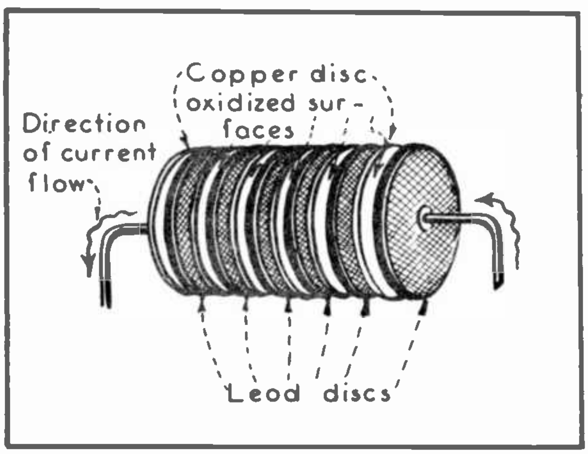


FIG. 32
PRINCIPLE OF COPPER-OXIDE RECTIFIER

The detailed illustration in Fig. 32 will enable you to more clearly visualize the construction and operation of one of these units. In this particular case, copper discs are "sandwiched" between lead discs; the entire group being clamped together tightly.

One surface of each of the copper discs is oxidized; that is, it is covered with a tarnishing film (cuprous oxide) much as rust would coat a piece of iron. The other surface of each copper disc is completely free from oxide.

A copper disc in this condition possesses a very valuable property. Namely, if a voltage be applied across the two surfaces of the disc, current will flow through the disc from the oxidized surface towards the clean (pure) copper surface much more easily than in the reverse direction. In other words, the disc acts as a rectifier.

The purpose of the lead discs in Fig. 32 is to provide a separation between adjacent copper discs, while at the same time serving as an electrical conductor between them. If an alternating voltage be applied across the entire unit of Fig. 32, the current will only flow through it in the direction indicated; and thus bring about rectification. This is generally classified as a copper-oxide rectifier, dry-disc rectifier, or contact rectifier.

It is also possible to obtain rectification by this same method through the use of copper sulphide discs in conjunction with aluminum or magnesium discs. These discs are stacked alternately and clamped together firmly so that the unit will have the same appearance as the one shown in Fig. 32; only that copper sulphide discs will replace the copper discs, and aluminum or magnesium will replace the lead discs. Current will then pass through this assembly from the copper sulphide discs towards the aluminum or magnesium discs. Rectifiers of this type are generally called "copper-sulphide rectifiers."

Besides their application on speakers, rectifiers of this type are used on meters to permit the measurement of alternating current and voltage, and in miscellaneous electronic apparatus where rectification at low voltage is required. It is to be noted that this rectifier is suitable only in low-voltage circuits.

RECTIFIER FOR FIELD EXCITATION

In Fig. 33, we have a half-wave rectifier circuit in which a copper-oxide rectifier is used. Notice that a transformer is employed to step down the voltage to the value required by the load --- which voltage must be of a sufficiently low value so that it can be handled by this type of rectifier without the latter breaking down. Observe that since electrons flow through the rectifier and load in the direction indicated, half-wave rectification is obtained.

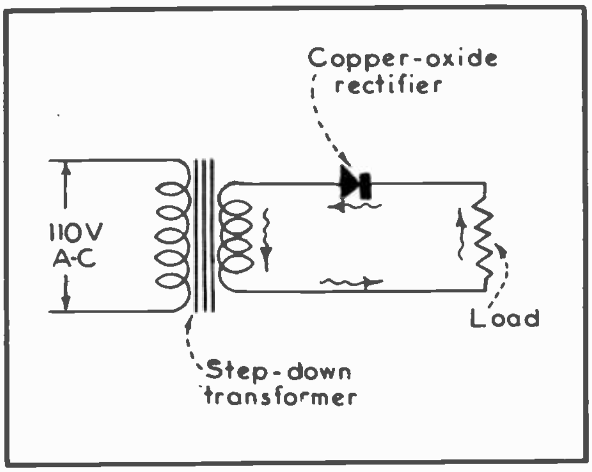


FIG. 33
HALF-WAVE COPPER-OXIDE RECTIFIER

In Fig. 34, four similar rectifying units are connected in what is known as a "bridge circuit" to furnish full-wave rectification. During the alternation of line voltage when point "W" is positive, and point "X" negative, electrons will move from point "X" through rectifier unit #4, the load, rectifier unit #1, and to point "W", as at (A). Then, when point "X" becomes positive and "W" negative, electrons will move from point "W", through rectifier unit #2, the load, rectifier unit #3, and to point "X" as at (B) of Fig. 34.

Thus, point Y is at all times positive and point "Z" is at all times negative, with respect to the load.

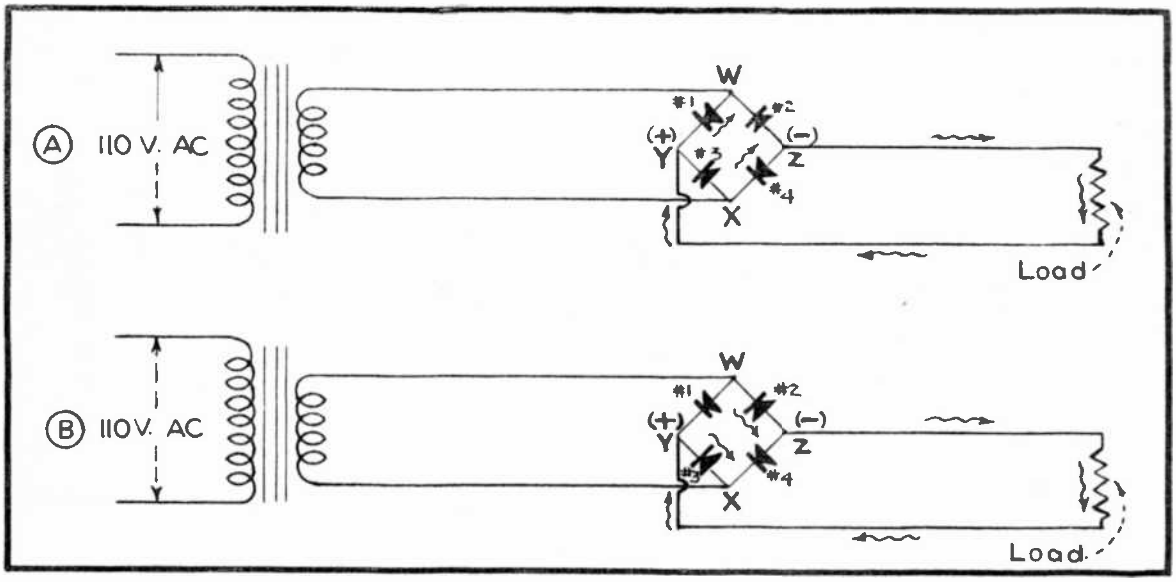


FIG. 34
FULL-WAVE COPPER OXIDE RECTIFIER

The circuit for connecting a full-wave copper-oxide rectifier to a speaker field coil for excitation purposes is shown in Fig. 35. Connection of the voice coil to the output of the receiver's a-f amplifier through a transformer is also shown.

VACUUM-TUBE RECTIFIER FOR SPEAKER FIELD EXCITATION

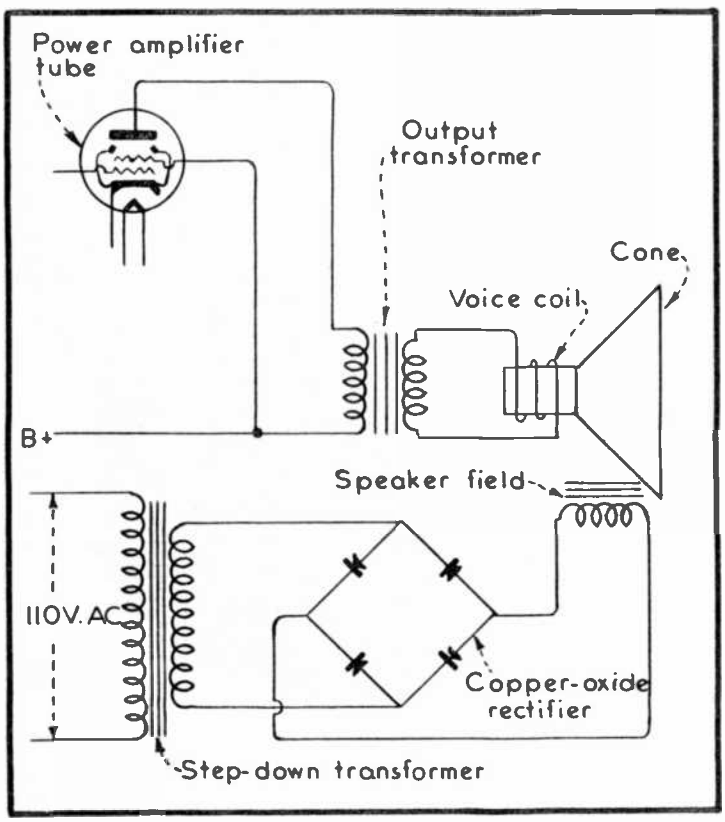


FIG. 35
A-C DYNAMIC SPEAKER WITH COPPER-OXIDE RECTIFIER

In Fig. 36, we have a vacuum tube connected in a half-wave rectifier circuit to excite a speaker field. For this, a step-down transformer may be used. The two plates are connected together and to one side of the 110 volt a-c circuit.. Whenever the plates of the tube are positive, electrons emitted by the hot filament are attracted to them, and pass through the primary winding of the transformer and speaker field, back to the filament. The speaker field serves as a choke, functioning in conjunction with the condenser as a filter.

A full-wave tube rectifier for speaker field excitation is diagrammed in Fig. 37. Here, a transformer similar to that used in receiver power supplies is employed, and the speaker

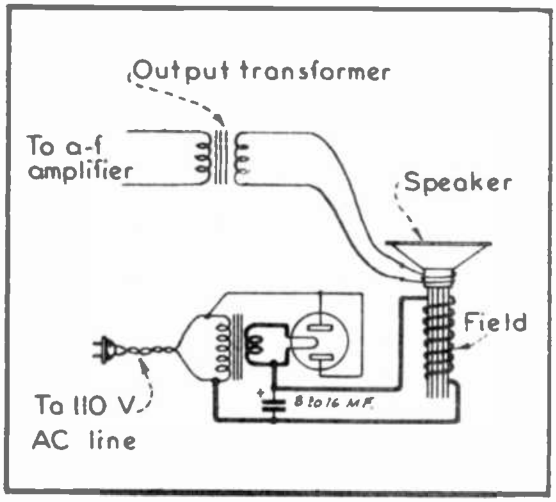


FIG. 36
HALF-WAVE TUBE RECTIFIER FOR FIELD EXCITATION

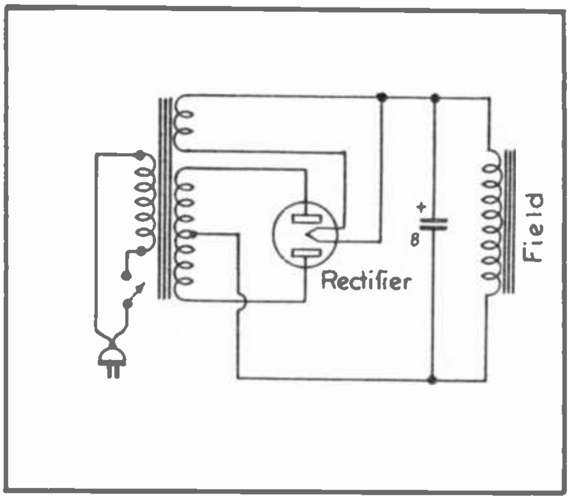


FIG. 37
FULL-WAVE TUBE RECTIFIER FOR FIELD EXCITATION

field is connected across the output terminals of the rectifier circuit. The field, in conjunction with the condenser, serves as a filter.

The transformer, condenser and rectifier tube are mounted on the speaker frame to form a self-contained assembly. This is shown in Fig. 38. The tube is in this case housed in a metal guard to protect it against breakage.

HUM-BUCKING COIL

In cases where the speaker field coil is used as a choke in the filtering system of the receiver's power supply, there may be a slight pulsation in the direct current flowing through it. This would induce a small a-c voltage in the voice coil and so cause a steady hum to be produced by the speaker.

The effects of this condition are minimized by incorporating a hum-bucking coil in the speaker as shown in Fig. 39. The hum-bucking coil consists of a few turns of wire that are wound in a direction opposite to that of the voice coil. It is connected in series with the voice coil and secondary winding of the output transformer, and placed at one end of the field coil as shown in Fig. 39.

If any ripple exists in the field coil, the hum-bucking coil will have induced in it an a-c voltage of the same value as is induced in the voice coil. But, since the hum-bucking coil is wound in a direction opposite to that of the voice coil, the voltage induced in the hum-bucking coil will oppose and therefore

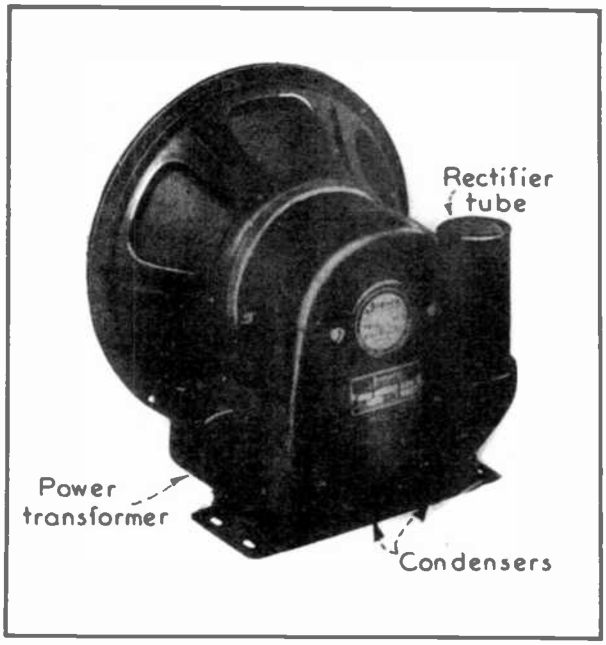


FIG. 38
A-C DYNAMIC SPEAKER WITH TUBE RECTIFIER

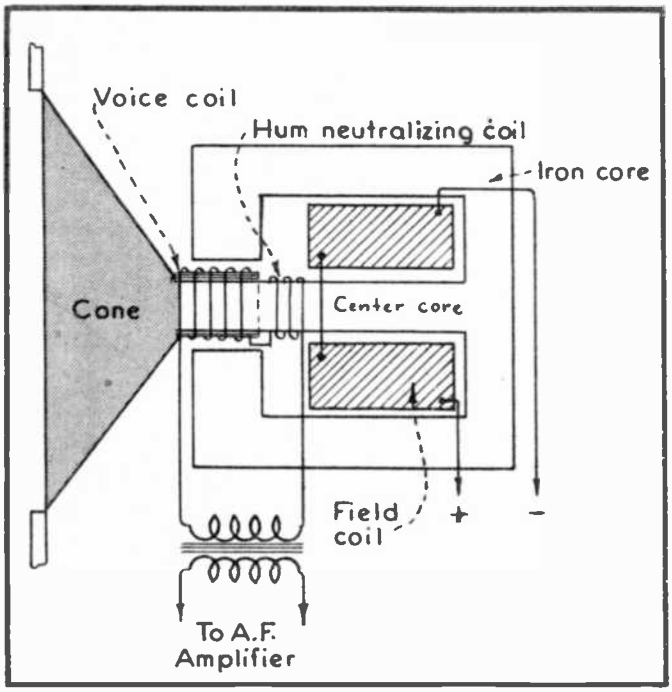


FIG. 39
APPLICATION OF HUM-BUCKING COIL

buck out or neutralize that in the voice coil. Hence, speaker hum is eliminated.

Another method of bucking out the hum voltage is to use a so-called "shading ring" as shown in Fig. 40. This ring consists of a thick copper disc, permanently fixed to the center pole of the field core. The ring acts as a single-turn coil which has strong circulating currents (called "eddy currents") induced in it. These eddy currents buck the flux movement and tend to keep the field stationary. Thus, the relative motion between the voice coil and the field at the hum frequency is reduced, and the ability of the field coil to induce a hum voltage in the voice coil is minimized.

CRYSTAL SPEAKER CONNECTIONS

A common method of connecting a crystal speaker to an audio amplifier is illustrated in Fig. 41. Here, the primary winding of an output transformer is connected in series with the plate circuit of the power amplifier tube. The secondary winding of the same transformer is connected across the crystal element of the speaker.

However, since the crystal element has a much higher impedance than does the voice coil of a dynamic speaker, the secondary winding of the output transformer used therewith must have an equally high impedance. Of course, no field coil circuit is used in connection with crystal speakers.

In the event that the power amplifier stage comprises two push-pull connected tubes, the connection of the crystal speaker remains as shown in Fig. 41 --- with the exception that the primary winding of the output transformer is then center-tapped.

VARIATIONS IN SPEAKER CONNECTIONS

As you progress through the course, you will receive additional information on loud

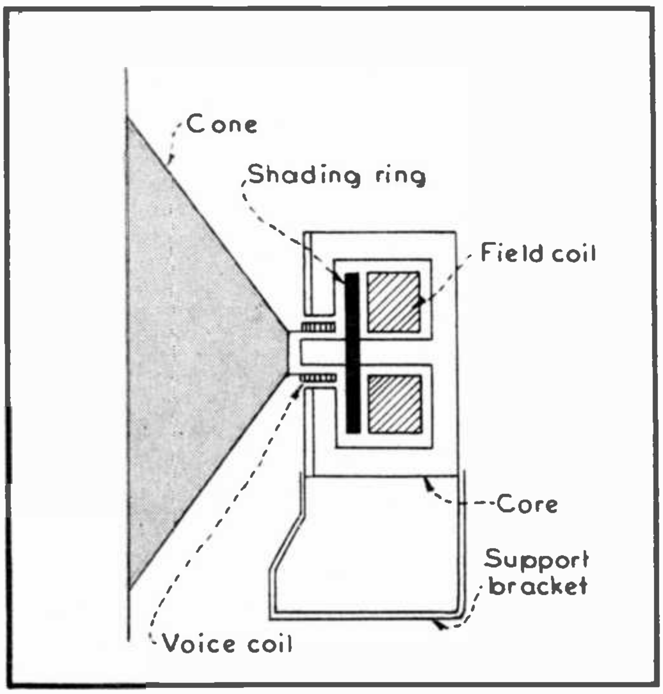


FIG. 40
APPLICATION OF SHADING RING

speakers and their application. For instance, you will learn about the variations in field coil connections of electrodynamic speakers as employed in commercial receivers; and how several speakers may be connected together, and operated from the same receiver or sound amplifier.

You will also be made acquainted with the structural features of speakers designed especially for sound installations where large amounts of audio power are handled. Horn designs for high-power speakers will be covered, as also will special baffle designs and acoustic chambers for high-fidelity sound reproduction; testing and repairing of speakers, etc.

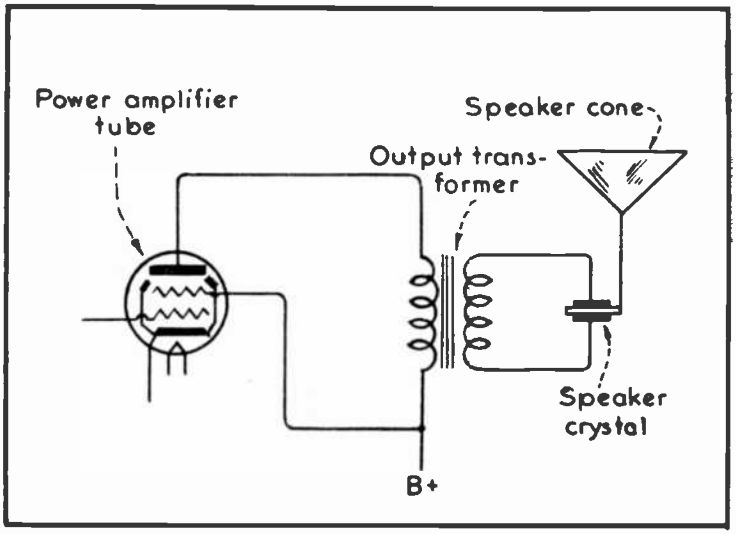


FIG. 41
CONNECTIONS OF CRYSTAL SPEAKER

As part of your advanced training, you will take up the study of acoustics, and learn how proper acoustic treatment of the location where speakers are employed makes faithful sound reproduction possible.

PRACTICAL Training means the acquisition of Technical information and facts, and the learning how to apply them in a useful manner.

In order to acquire knowledge we must use our brain. Our brain, like our body, only grows and develops when properly used.

When we stop using any part of our body it starves and dies. When we fail to use our brain cells they decay and die of starvation.

Let's learn how to use intelligently our natural abilities, talents, and gifts, and apply them efficiently to our task at hand.

J. A. ROSENKRANZ

EXAMINATION QUESTIONS

LESSON NO. 16

1. - Is the voice coil of a dynamic speaker supplied with a direct current or audio-frequency current?

2. - Briefly describe a p-m dynamic speaker.

3. - What is the purpose of the "spider", as used in dynamic speakers?

4. - Explain the basic operating principle of the crystal speaker.

5. - Why is a baffle used in connection with a loud speaker?

6. - What is the essential difference between a d-c and an a-c type dynamic speaker?

7. - (a) What is a hum-bucking coil?

   (b) How is it employed in a dynamic speaker?

8. - Draw a diagram, showing how the field coil and voice coil of a d-c type dynamic speaker are connected to a receiver circuit.

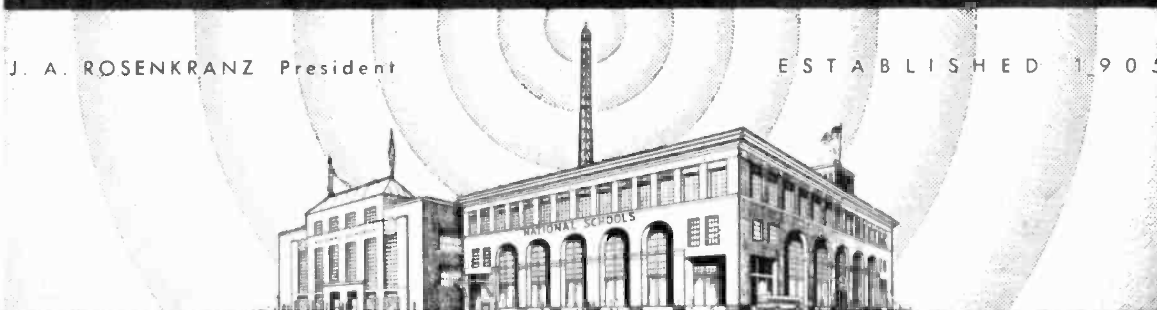
9. - How is the sensitivity of radio headphones generally expressed?

10. - On what principle do the so-called "magnetic speakers" operate?

Practical Technical Training In
RADIO·TELEVISION
AND ALLIED ELECTRONICS

J. A. ROSENKRANZ President

ESTABLISHED 1905



NATIONAL SCHOOLS ★ LOS ANGELES 37, CALIF.

LESSON NO. 17

T-R-F RECEIVERS

Although you have completed only sixteen lessons, you have learned quite a lot about radio. You are familiar with many of the basic principles, tubes, power supplies, r-f amplifiers, detectors, a-f amplifiers and loud speakers.

Now, we are going to consolidate this information, so that you can see just exactly how all of the various parts are connected together to produce a complete receiver. You will at this time also be shown several circuit features that help to improve the performance of receivers, and which are therefore employed in commercial models.

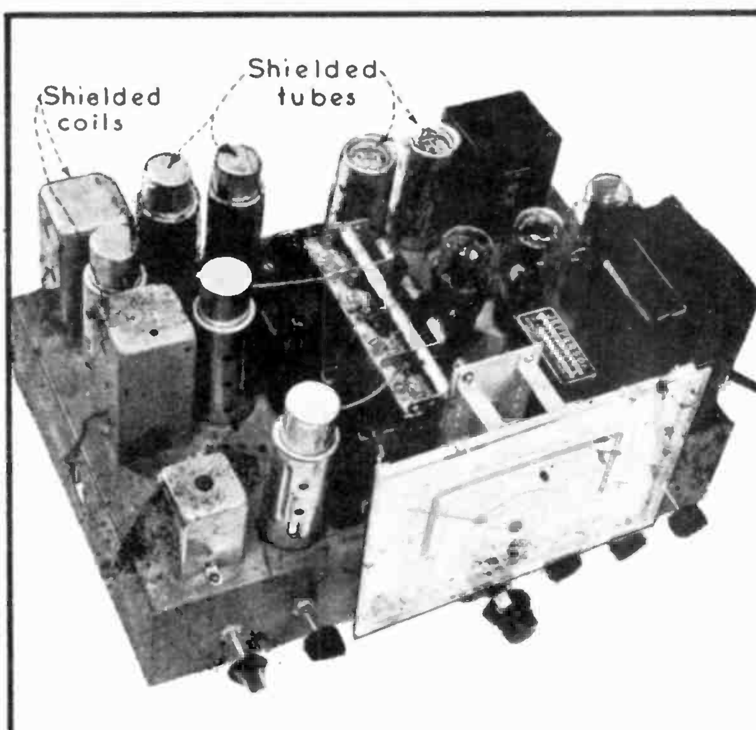


FIG. 1
TEN-TUBE RECEIVER, SHOWING USE OF METAL CHASSIS, COIL SHIELDS AND TUBE SHIELDS

THE R-F SECTION

The logical order in which to study a complete receiver is to begin with the input circuit and gradually advance, step by step, through the various circuits toward the output. In this way, you will be better able to see how the incoming signal is handled by each section as it passes through the receiver. This means, then, that r-f amplifier circuits are the first to be considered.

WHY PENTODES ARE PREFERRED TO TRIODES IN R-F AMPLIFIERS

In Fig. 2, we have an r-f amplifier stage in which a triode is used. In a tube as this, the plate and grid are so close together that when a difference of potential exists between them, they act as plates of a condenser of small capacity, just as would any two metal surfaces that are separated from each other by a slight distance. Thus, we have a capacity effect between the grid and plate, as indicated by the dotted condenser in the tube symbol. This is known as the "grid-plate capacitance."

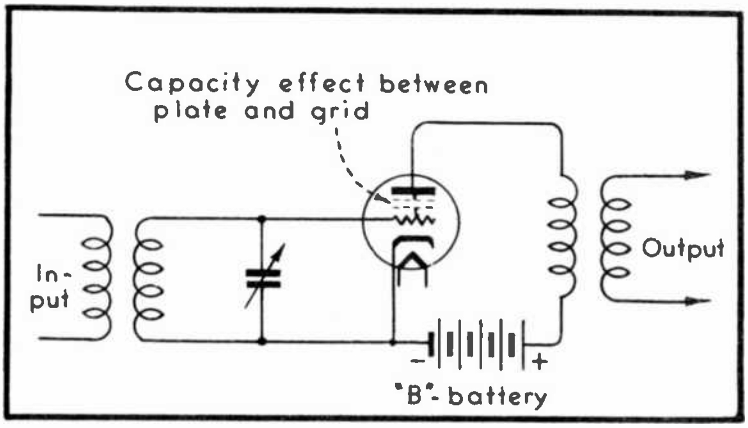


FIG. 2
CAPACITY EFFECT OF TRIODE IN R-F AMPLIFIER

Now, the primary winding of the r-f transformer which is connected in the plate circuit of this tube offers appreciable reactance to the r-f variations in plate current, causing r-f voltages to appear across its ends. These r-f voltages will react through the grid-plate capacitance just as though a regular condenser of small capacity were connected at this point. Thus, a certain amount of the <u>amplified</u> signal energy that exists in the plate circuit is returned to the grid circuit, causing the r-f voltages which are applied to the grid to be greater than would be the case if only the signal emf furnished by the preceding r-f stage should reach it. We call this phenomena "regeneration," or "feed-back."

Obviously, since it increases the intensity (amplification) of the signal being handled by the stage, a certain amount of regeneration can be used to advantage. But, since in a circuit such as illustrated in Fig. 2, no means is provided for <u>controlling</u> the degree of regeneration, the r-f energy which appears amplified in the plate circuit and is continually being returned in part to the grid circuit, eventually causes the stage to function as a <u>generator</u> of r-f energy --- meaning that more r-f energy is being built up in the circuit itself than is being supplied to it by an external source (the transmitter). When this happens, we say that the circuit is "oscillating," or that the stage is functioning as an "oscillator."

Whenever oscillation occurs in the r-f amplifier of a radio receiver, loud squeals and howls are emitted by the speaker; and the desired station signal may be blocked out.

Tetrodes and pentodes were developed for use in r-f amplifiers to correct this condition. This was done by placing the control grid and plate farther apart so as to reduce the grid-plate capacitance, and thereby minimize the feed back of r-f energy from the plate circuit to the grid circuit. The screen grid was then installed to accelerate the flow of electrons through the greater distance between the grid and plate, and the suppressor grid was included to reduce secondary emission.

All of these features concerning multi-grid tubes were covered thoroughly in an earlier lesson --- so without further delay, let us see how such tubes are connected in r-f amplifier circuits to accomplish their intended purpose.

CIRCUIT CONNECTION FOR FILAMENT-TYPE R-F PENTODES

In Fig. 3, we have a diagram that shows a filament-type pentode connected in a conventional r-f amplifier stage of a battery-operated receiver. You will observe that with the exception of the two additional grids (the screen grid and suppressor grid). the circuit is quite similar to that wherein a triode is employed.

Pentodes are preferred to triodes as r-f amplifiers because they provide greater amplification and permit the design of circuits that are more stable in operation --- that is, less susceptible to oscillation. Observe, particularly, how the screen grid is connected to a B-plus terminal of lesser voltage than is the plate. The suppressor grid is connected to the negative side of the filament within the tube structure at the time of manufacture. The control grid serves the same purpose as does the control grid of a triode, and is therefore connected to the tuned circuit in the usual manner.

Since the positive terminal of the "C" battery and the rotor plates of condenser C-1 are both grounded to the chassis, condenser C-2 has been placed at the point designated to prevent the "C" battery from being short circuited through ground. Thus, the negative terminal of the "C" battery is connected to the control grid through the secondary winding of the r-f transformer; and its positive terminal to the filament, through ground. A small negative bias is applied to the r-f amplifier tubes to prevent the signal voltage from causing the control grid of such tubes to become positive and draw grid current --- which condition would produce distortion, the same as explained for a-f amplifiers in a previous lesson.

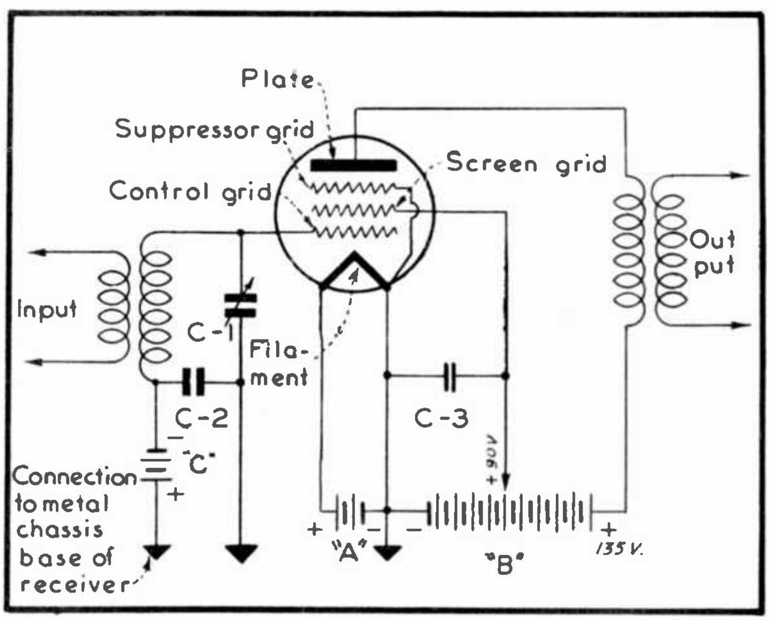


FIG. 3
BASIC CIRCUIT CONNECTIONS FOR FILAMENT-TYPE PENTODE

It is to be noted further that condenser C-2 is connected in series with the tuning circuit. In actual practice, C-2 would have a capacity of about 0.01 mfd., which is sufficient capacity so that the reactive effect of this condenser is practically negligible insofar as the high frequency (r-f) alternating current in this circuit is concerned. Briefly, then, we can say that condenser C-2 "blocks" the d-c current of the "C" battery, but "completes" the tuning circuit so that r-f currents can flow through it.

It is especially important to notice the connection of condenser C-3, between the screen grid and the negative side of the filament. This is called a "screen grid by-pass condenser." Its use is characteristic of all circuits containing a tetrode or pentode r-f amplifier tube. The purpose of this condenser is to by-pass to ground any r-f energy that finds its way into the screen grid circuit. The value of capacity generally used for this purpose ranges from about 0.01 mfd., to 0.5 mfd., which capacity is very much greater than the filament-to-screen grid capacity within the tube. Therefore, any r-f voltages that may develop between the filament and the screen grid will react through C-3 before they have a chance to build up to any appreciable strength. In this way, they are ineffective between the screen grid and control grid (or filament) within the tube, and the tendency toward oscillation is thus reduced to an absolute minimum.

In r-f amplifiers employing either tetrodes or pentodes, the tubes and r-f transformers are shielded, as described in your lesson on "R-F Amplifiers," to guard still further against oscillation. Such shielding prevents feed-back between the plate and control grid circuits through the capacitive and inductive coupling provided by certain parts, as well as by the circuit wiring; which conditions, if not corrected, might still permit oscillation to occur even if pentodes be used.

A circuit employing a tetrode r-f amplifier would be identical to that appearing in Fig. 3, with the exception that the suppressor grid would be omitted.

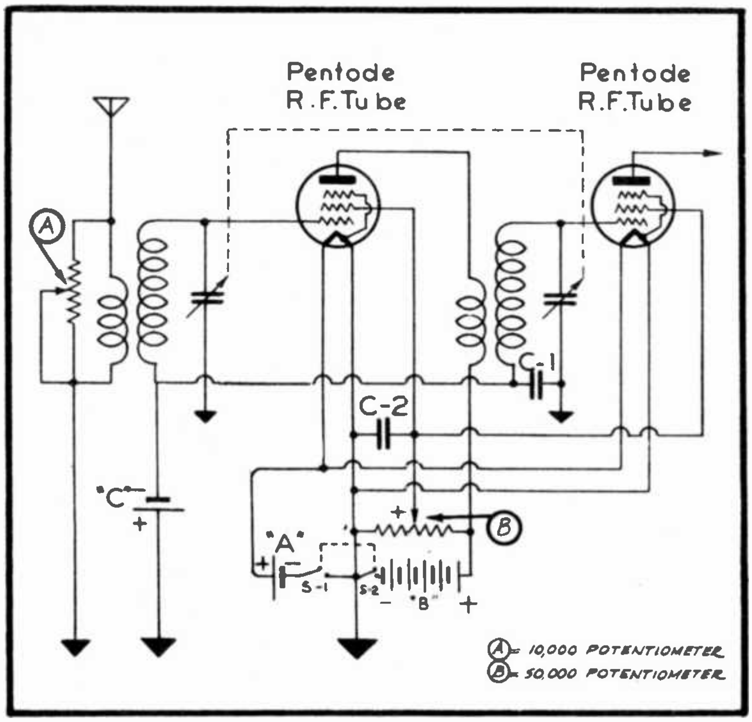


FIG. 4
TWO-STAGE R-F AMPLIFIER

TWO-STAGE BATTERY-OPERATED R-F AMPLIFIER

In Fig. 4, is shown a two-stage battery operated r-f amplifier, containing most of the features presented in Fig. 3. Notice, for instance, how a single condenser (C-1) is connected between the lower end of the secondary winding of both r-f transformers and ground; thus serving to complete both tuning circuits, while at the same time preventing the "C" battery from being short circuited through ground. Observe, too, how the single "C" battery supplies a bias voltage for the two r-f tubes. Condenser C-2 is connected between the negative side of the filament of each of the tubes and their screen grids; thus the screen grid of both of these tubes is by-passed to ground (A-) by a single condenser.

As you progress with your study of multi-stage receiver circuits, you will find that it is common practice for a single by-pass condenser to serve the same purpose in two or more stages, as is the case of condensers C-1 and C-2 in Fig. 4. By this means, the cost of the receiver is kept down, and wiring of the circuit is simplified.

Another interesting feature of the circuit presented in Fig. 4 is the use of the two switches, S-1 and S-2; both operated simultaneously by a single control, as indicated by the dotted line connecting them together. When the radio is turned "off," switch S-1 interrupts the filament circuit that is supplied by the "A" battery ; and, at the same time, switch S-2 interrupts the "B" battery circuit so that this battery will not continue discharging through potentiometer "B" when the receiver is not in use. Closing switches S-1 and S-2 completes the "A" and "B" circuits.

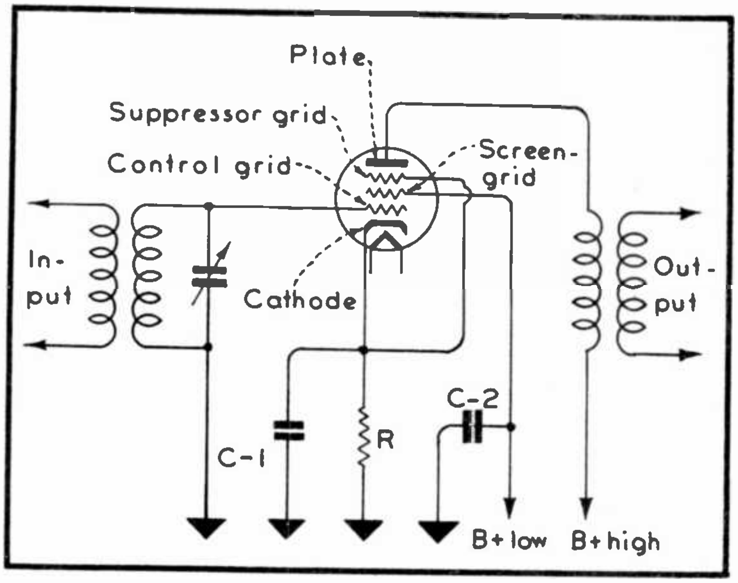


FIG. 5
CIRCUIT CONNECTIONS FOR CATHODE-TYPE PENTODE

INPUT VOLUME CONTROL

Two distinct volume control circuits are illustrated in Fig. 4, although they are seldom both used in the same receiver.

Control (A) takes the form of a potentiometer, connected across the ends of the antenna stage coil's primary winding. Moving the potentiometer arm upward shorts out a portion of the potentiometer's resistance element and thereby reduces the effective resistance of this path. This results in a greater percentage of the signal energy dissipating itself to ground through the potentiometer. Less signal energy will then reach the r-f tube's grid through the antenna stage transformer, and the volume will be reduced accordingly.

Moving the potentiometer arm downward decreases the shorting effect so that the resistance of the path offered by the potentiometer is increased, thereby permitting a greater percentage of the signal energy to be transferred through the antenna coil. The volume therefore increases.

SCREEN GRID VOLUME CONTROL

Volume control (B) of Fig. 4 controls the voltage which is applied to the screen grid of the two tubes. This is accomplished in the following manner:

The total potentiometer resistance, being connected across the B-plus and B-minus terminals, permits a small current to flow through it in such direction as to make the potentiometer arm positive with respect to the grounded B-minus side of the circuit. Therefore, whatever voltage drop is produced between the ground-end of this resistance and the potentiometer arm will be applied to the screen grid of both tubes; the screen grids being positive with respect to the filaments of these tubes. Moving the potentiometer arm toward the right increases the screen voltage and the volume; moving it toward the left, decreases the screen voltage and the volume.

CIRCUIT CONNECTIONS FOR CATHODE-TYPE R-F PENTODE

Connections for using a cathode-type pentode in an r-f amplifier stage are shown in Fig. 5. This circuit is essentially the same as that presented in Fig. 3, with the exception that bias is furnished by resistor R instead of by a "C" battery; and the suppressor grid is connected to the cathode outside of the tube, at the time the circuit is being wired.

C-1 in Fig. 5, is the usual by-pass condenser which is connected across a cathode resistor that is being used to furnish the bias voltage. Condenser C-2 is connected between the screen grid terminal and the cathode (through ground) for the same reason already given in this lesson relative to the screen grid by-pass condenser in Fig. 3. Ground symbols show that the metal chassis of the receiver serves to complete the grid-return and B-minus side of this circuit.

BIASING CATHODE-TYPE TUBES

The matter of bias has already been discussed to some extent, and will be brought up repeatedly in connection with circuits studied throughout the balance of this course. Being of such importance, it is advisable that we take time now to present sufficient additional facts concerning this subject to meet our immediate requirements.

To begin with, it is to be remembered that bias is nothing more than a negative voltage which is applied to the control grid of a tube. This voltage is measured between the tube's control grid and cathode (or between the control grid and filament in filament-type tubes). The value of the bias voltage is specified by the tube manufacturer for each particular type of tube, and the service to which it is being put in the receiver. Some tube manufacturers specify the bias under the heading of "control grid voltage," or simply "grid voltage."

In practically all cases, some bias voltage is applied to r-f and a-f amplifier tubes in accordance with tube manufacturers specifications. Its purpose is to prevent the control grid from ever actually becoming positive, even when the strongest signal is being handled. If the control grid were to become positive, it would attract electrons much the same as would a positively-charged plate and so permit a variable d-c current to flow through the grid circuit. Such a condition would cause the signal, as reproduced by the speaker, to be distorted.

In the case of grid-bias detectors, so much bias voltage is employed that the grid is maintained negative to such an extent that plate current is reduced to zero whenever a negative signal voltage is applied to the grid. Thus, by this means, we obtain a form of rectification that provides detection of a modulated radio signal, as was explained in a previous lesson on Detectors. The amount of bias required for this purpose is also specified by tube manufacturers in connection with tubes suited to this use.

Two terms, "fixed bias" and "self bias," are employed extensively in connection with the biasing of radio tubes. It is necessary that you become familiar with them.

FIXED BIAS

When employing the fixed bias method in connection with a cathode-type tube, the cathode is grounded directly; and a voltage, furnished by some external source, is applied between the grid of the tube and B-minus (ground). This is similar to the practice employed with filament-type tubes.

Such an arrangement is shown at (A) in Fig. 6, where you will observe that a "C" battery is connected between the cathode and grid of the tube through the secondary winding of the transformer. With the

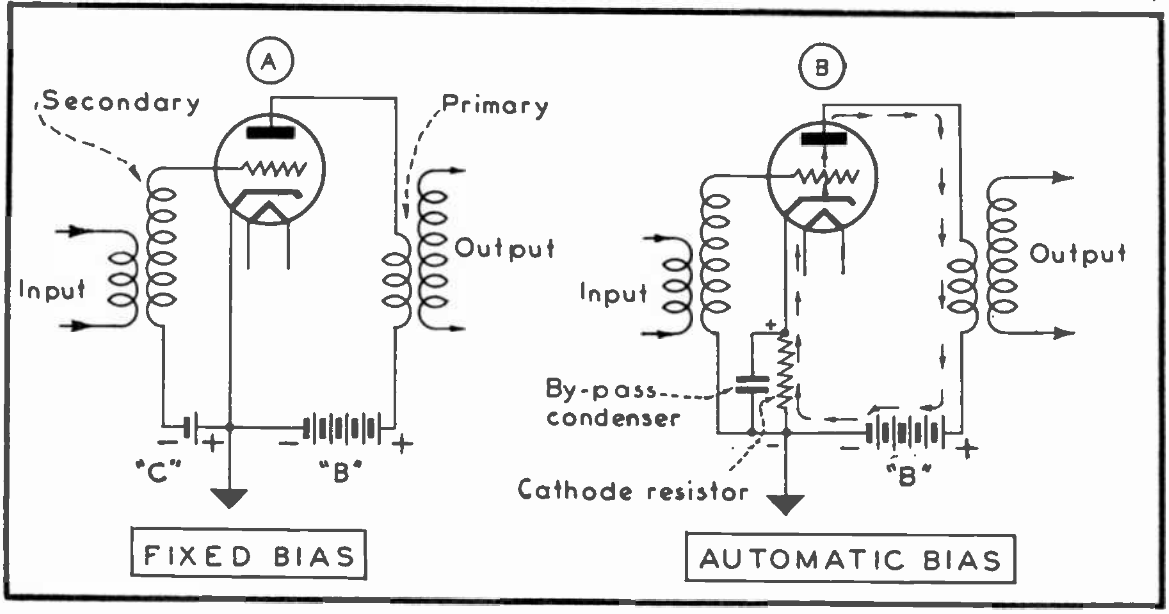


FIG. 6
FIXED AND AUTOMATIC BIAS METHODS APPLIED TO CATHODE-TYPE TUBES

polarity connections thus made, the grid will be at a negative potential with respect to the cathode --- by an amount equal to the "C" battery voltage. We call this the "bias voltage."

AUTOMATIC BIAS

The automatic bias arrangement, shown at (B) in Fig. 6, is used more than is the fixed bias method. Here, you will observe that a resistor is connected between the cathode and B-minus, instead of grounding the cathode directly. This is known as a cathode resistor or bias resistor; the purpose of which is to furnish the necessary bias voltage for the tube. The function of the cathode resistor will become clear upon studying the diagram appearing at (B).

Observe in this illustration that we consider the electron-flow (plate current) through the tube as being from the cathode toward the plate. From the plate, this current travels through the primary winding of the r-f transformer, B battery, cathode resistor, and back to the cathode --- as illustrated by the arrows. It is important to note that since the resistor is connected between the cathode and the B-minus side of the circuit, all of this tube's plate current must also flow through the resistor.

From your study of Ohm's Law, you learned that whenever a direct current flows through a resistance, a voltage will be developed across that resistance. This is exactly what happens at the cathode resistor in illustration (B) of Fig. 6. That is, the d-c plate current which flows through the tube and resistor produces a difference of potential (voltage) across the resistor --- the lower end of the resistor becoming negative with respect to its upper end for the reason that electrons always move through a load circuit in a negative-to-positive direction.

Then, by connecting the grid-return circuit of this tube to the ground or negative end of the cathode resistor, the grid will be maintained at a negative potential with respect to the cathode; thereby providing the required bias voltage without using a "C" battery. This method of obtaining bias is therefore logically called the SELF-BIAS or AUTOMATIC-BIAS method.

When this method of biasing a tube is used, the bias voltage furnished by this means is dependent upon the value of the plate current, and the ohmic value of the cathode resistor. That is, bias voltage will be increased as the plate current and cathode resistance (or both) are increased.

As mentioned before, it is common practice to connect a by-pass condenser across the bias resistor. This is done so that any r-f or a-f ripple which may be present in the plate current will react through, or be by-passed by the condenser, instead of flowing through the resistor. Thus, only pure d-c flows through the bias resistor, producing a d-c voltage suitable for biasing purposes across it; while the by-pass condenser virtually short circuits the a-f or r-f around the resistor, thereby making them ineffective so that voltages corresponding to them will not be applied to the grid circuit together with the d-c bias voltage. If this matter were not taken care of, the sounds reproduced by the speaker would be distorted and indistinct.

In r-f circuits, this by-pass condenser may have a value ranging from about .01 mfd. to .5 mfd.; while in a-f circuits, it may range from 1 mfd. to 10 mfd., or more. Later lessons explain how these values are determined when designing a receiver or amplifier.

CALCULATING THE VALUE OF THE BIAS RESISTOR

It is a simple matter to determine the value of the bias resistor required to obtain a certain bias voltage. All that must be done is to apply Ohm's Law in the manner explained in the following paragraphs.

For example, let us suppose that a certain triode is being used in a circuit for which the tube manufacturer recommends a plate voltage of 250 and a bias of 8 volts. Let us further assume that the tube manufacturer's data tells us that this particular tube draws a plate current of 8 milliamperes when operated under the conditions prescribed.

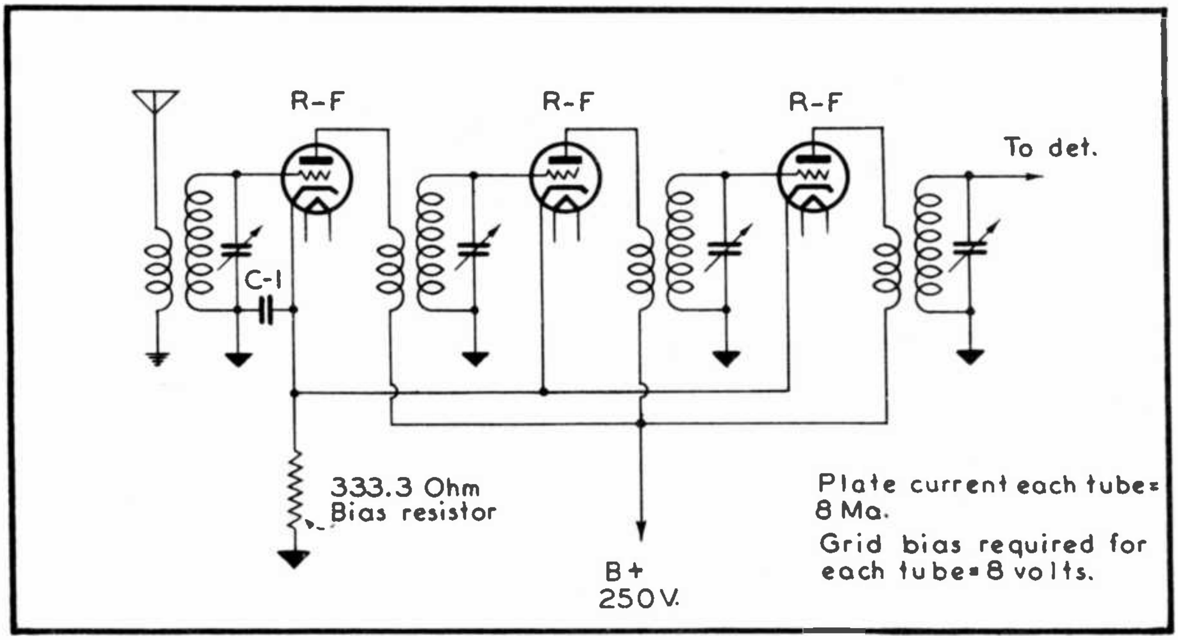


FIG. 7
BIASING THREE CATHODE-TYPE TUBES WITH A SINGLE BIAS RESISTOR

Notice, especially, when calculating the value of bias resistors, that the total current passing through the cathode (cathode current) is also considered as being the current that passes through the bias resistor. Thus, for a triode, the cathode current is equal to the plate current drawn by the tube.

Our problem, now, is to determine the value of the cathode resistor required to furnish a bias of 8 volts by the self-bias method, when 8 ma. flows through the cathode resistor. We do this by applying Ohm's Law as follows:

R = E ÷ I. However, since "I" must be expressed in AMPERES, we convert the 8 ma. of plate current (now considered as the cathode current) to its equivalent, .008 ampere. The value for "E" is, of course, the bias voltage required, or 8. Then, substituting these values in our formula, we have: R = 8 ÷ .008, which equals 1000 ohms. In other words, the bias resistor for this particular circuit must have a value of 1000 ohms.

Very often, a single bias resistor is used for more than one tube. In such cases, the cathode current flowing through the resistor will be equal to the sum of several cathode currents. For instance, if three tubes of the same type as used in our previous example are connected as shown in Fig. 7, the cathode current of all three tubes must flow through the single bias resistor which is common to all three cathode circuits. Therefore, 3 times 8 milliamperes or 24 milliamperes (or .024 ampere) will flow through this bias resistor. So, to produce the required 8-volt bias, a resistor having a value of 333.3 ohms must be used. (Note: R = E ÷ I = 8 ÷ .024 = 333.3 ohms.)

Since commercial resistors cannot be obtained in such odd values as 333.3 ohms, unless by special order,we would in practice use the nearest standard value --- preferably slightly higher than the value required. In other words, we would use a standard 350-ohm resistor in place of the 333.3 ohms actually required. This slight difference is not sufficient to produce any noticeable effect upon the performance of the receiver.

From this explanation, you will be able to deduce that the value of a bias resistor which is common to two tubes of the same type is one-half the value required for one of these tubes operating under the same conditions; for three similar tubes, the bias resistor value is one-third that required for a single tube, etc.

The same procedure, as just explained, is followed when calculating the value of bias resistors required for tetrodes and pentodes. However, the total cathode current to be considered in the calculation is then equal to the plate current plus the screen current drawn by the tubes in whose cathode circuit the bias resistor is connected. C-1 in Fig. 7 is the conventional by-pass condenser for the bias resistor.

SELF-BIASING FILAMENT-TYPE TUBES

You will also find cases where filament-type tubes are self-biasing in a-c receivers. This is accomplished by connecting the bias resistor between the center-tap of the filament winding on the power transformer and ground (chassis or B-minus), as shown in Fig. 8. The circuit connections being such, plate current will divide through the tube's filament circuit as indicated in this illustration.

The negative-end of the bias resistor and the grid-return circuit of the tube are both grounded, while the filament's center-tap

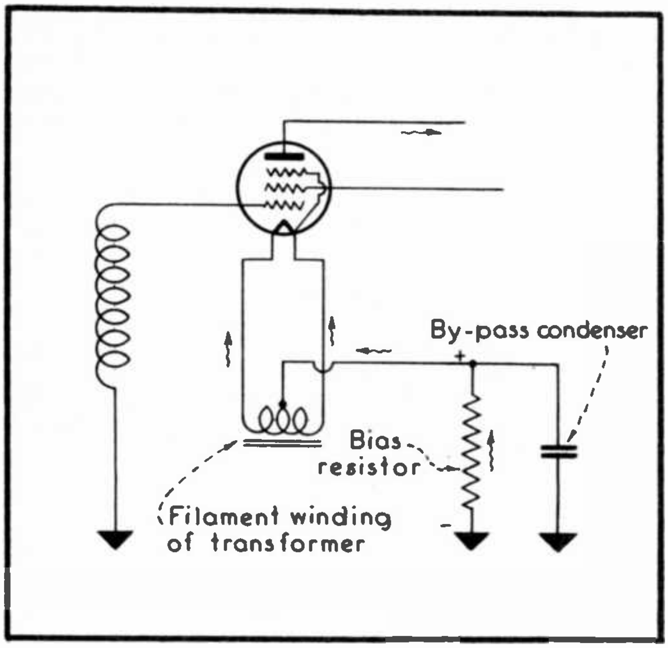


FIG. 8
AUTOMATIC-BIAS APPLIED TO FILAMENT-TYPE TUBE

is connected to the positive end of the bias resistor. Therefore, a negative bias will be applied to the grid of the tube.

The value for this bias resistor is calculated in exactly the same way as already explained for cathode-type tubes. If the tube in question is a triode, the current flow through the bias resistor is equal to the plate current. For tetrodes or pentodes, the current through the bias resistor is equal to the plate current plus the screen current.

THREE-STAGE R-F AMPLIFIER

The circuit diagram of a three-stage r-f amplifier, preceding a detector, is presented in Fig. 9. Cathode-type pentodes are used in all stages.

Dotted lines show that condensers C-1, C-2, C-3 and C-4 are all sections of a four-gang condenser, operated by a single control. Dotted lines also show that each of the r-f transformers is contained in an individual, metal shield can which is grounded to the chassis.

Resistor R-2 is connected in the circuit in such manner that the cathode current (combined plate and screen current) of all three of the

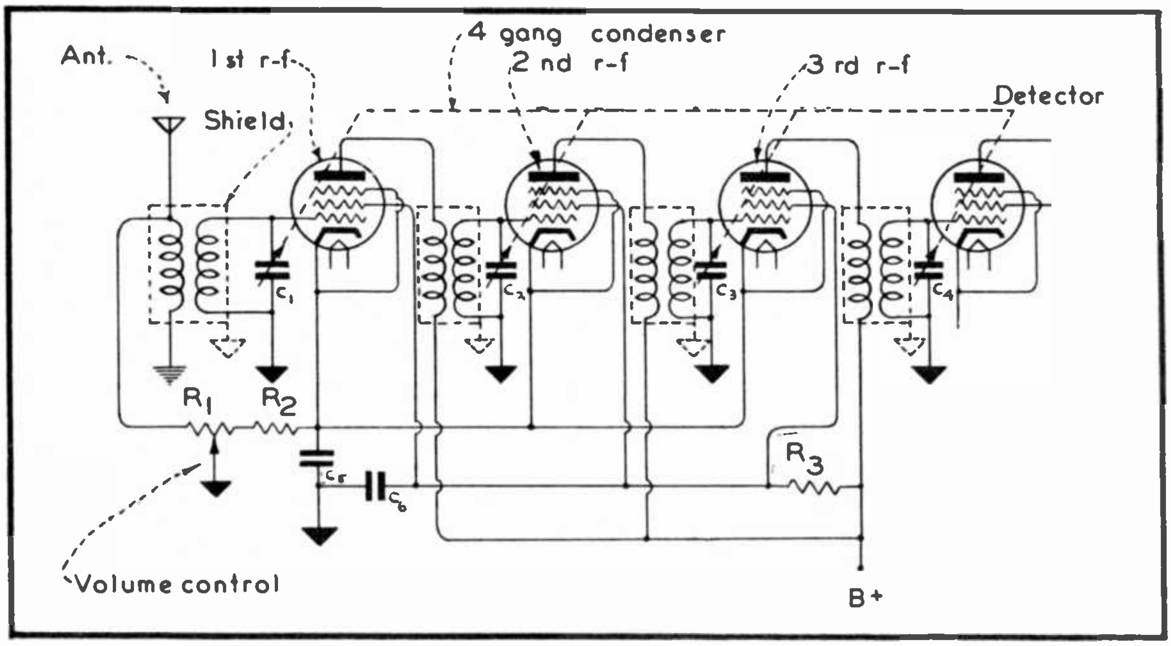


FIG. 9
THREE-STAGE R-F AMPLIFIER

r-f amplifier tubes must flow through it. When the arm of the potentiometer being used here as a volume control is moved all the way to the right end of resistance R-1, only resistance R-2 will be connected between the cathodes of these tubes and ground. Therefore, the voltage drop appearing across R-2, alone, will be applied as a bias to these three tubes.

As the arm of the potentiometer is moved toward the left end of R-1, more resistance will be inserted in series with R-2 and ground --- thereby increasing the value of the bias resistor actually effective in the circuit, and so increasing the bias voltage. Then, as we move the arm toward the right again, less of the resistance of R-1 will be connected in series with R-2 and ground; thus decreasing the bias voltage.

The pentodes that are used in the r-f amplifier of Fig. 9 have what is known as a "variable-mu" or "super-control" feature. By this is meant that the amplification factor of the tube increases when the bias is decreased, and decreases when the bias is increased. Thus, by varying the bias, we have a means for controlling the volume.

In other words, by moving the arm of the potentiometer R-1 toward the right, the bias voltage in each r-f stage is reduced --- thus bringing about an increase in the amplification factor of each of these tubes; and, as a consequence, an increase in volume. Then, by moving the arm of potentiometer R-1 toward the left, the bias voltage in each r-f stage is increased --- thus bringing about a decrease in the amplification factor of each of these tubes; and, a corresponding decrease in volume. This method of controlling the volume is used extensively in receivers.

You will also observe that the left end of the resistance element of potentiometer R-1 is connected to the antenna terminal. Therefore, when the arm of this potentiometer is moved toward the left so as to increase the bias voltage and decrease the amplifying ability of the r-f tubes, it will, at the same time, more nearly short circuit the primary winding of the antenna-stage r-f transformer. This will reduce the transfer of signal energy through the transformer, and thereby decrease the volume by this means as well as by the variable-bias method.

Moving the arm of potentiometer R-1 toward the right will place more resistance in parallel with the primary winding of the antenna-stage r-f transformer. The resistance of this winding is then less than that amount R-1 which is included between the antenna terminal and ground at this time; so more signal current flows through the winding, and less through R-1. Therefore, the transfer of signal energy through the transformer increases, causing an increase in volume by this means; while the movement of the arm in this direction, at the same time, decreases the bias and increases the volume by raising the amplification factor of the tubes. Thus, we have, here, two ways for regulating the volume --- affected by a single control. Since the volume is in this case controlled by varying the sensitivity of the r-f amplifier, we sometimes refer to this potentiometer as being a "<u>sensitivity control</u>."

C-5 is the usual by-pass condenser for the cathode resistor, while C-6 is the screen grid by-pass condenser for all tubes. Notice, further, that resistor R-3 is used for the purpose of reducing the B voltage supplied to the plates of all tubes to a lower value required by the screen grids of these same tubes. The total screen current drawn by all three tubes flows through R-3 to produce the necessary voltage drop. Plate current flows through the primary windings of the various r-f transformers, direct to the B-plus terminal, <u>without</u> passing through R-3.

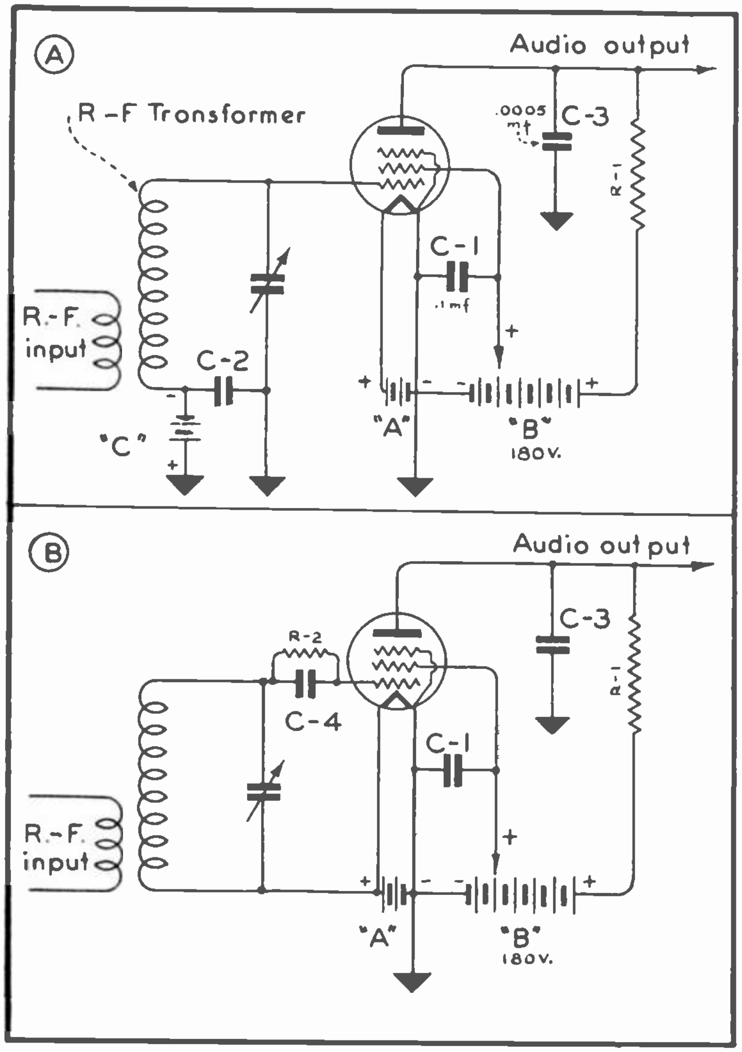


FIG. 10
DETECTOR CIRCUITS USING FILAMENT-TYPE PENTODES

PENTODE DETECTORS

USING FILAMENT TYPE TUBES: In a previous lesson dealing with detectors, you were shown how triodes are used as detectors. In Fig. 10(A), we have a filament-type pentode in a bias-detector circuit; and at (B), a similar tube in a grid-leak detector circuit.

You will observe that these circuits are similar to corresponding circuits, using triodes; and that the only essential difference is in the addition of the screen-grid voltage connection, and the by-pass condenser (C-1) associated therewith. Condenser C-2 has been placed in the control grid circuit at (A) to permit the use of a tuning condenser with a grounded rotor plate-group, without short-circuiting the C battery.

C-3 is a plate by-pass condenser, the use of which is explained later in this lesson.

Another important point to be noted relative to the use of pentodes is that for best efficiency they should be connected to the a-f amplifier through resistance coupling instead of through an audio transformer. The reason for this is that pentodes have a much higher plate resistance than do triodes; therefore, their load circuit (the plate circuit resistor R-1 in Fig. 10) must also be much greater. (Note: By the "plate resistance" of a tube is meant the opposition offered to the a-c component of the plate current by the path between the plate and cathode inside of the tube.)

A plate load resistance ranging from about 100,000 to 500,000 ohms is required for operating pentode detectors efficiently. Conventional audio transformers will not provide such a high impedance (total opposition of inductance, resistance and distributed capacity) at audio frequencies; therefore, a resistance in the plate circuit is the logical solution.

Triodes, on the other hand, having a comparatively low plate resistance, make the use of transformers in the output circuit of the detector practical. And, while it is true that resistance coupling provides no amplification of the audio signal, the high gain of the pentode compensates for this.

Illustration (B) of Fig. 10 shows how the grid-return circuit can be connected directly to the "A" battery in the event that the rotor section of the variable condenser is not grounded.

USING CATHODE TYPE TUBES: Grid-bias and grid-leak detector circuits using cathode-type pentodes, are presented in Fig. 11. Notice how the detector circuits here shown resemble triode detector circuits of similar type, described in an earlier lesson; and differ only in the connection of the suppressor and screen grid.

In circuit (A), the value of the bias resistor is much higher than would be the case in an amplifier stage --- thus causing detection (rectification) to occur.

R-F FILTER AT DETECTOR OUTPUT

To increase the efficiency and improve the stability of detector circuits, it is common practice to incorporate in the plate circuit of the tube some form of r-f filter. The majority of these schemes consist of a by-pass condenser of small capacity, as in the detector circuits shown thus far; or a small r-f choke coil used in conjunction with one or more by-pass condensers to form a filter.

The more typical of these arrangements are shown in Fig. 12, where the filter at (A) takes the form of a small fixed by-pass condenser connected in shunt, or across the plate circuit of the tube. The system operates as follows:

After rectification by the detector, small r-f ripples or variations still remain in each audio cycle of the incoming signal, as at (A) in Fig. 13. It is evident that since these r-f ripples are still incorporated in the plate current, the by-pass condenser at (A) of Fig. 12 will permit them to react through it to ground, without building up r-f voltage variations across the plate load resistor. You see, the capacity of this condenser is large enough so that it will offer less opposition to r-f currents than will the plate load resistor, thus virtually short circuiting them around the resistor. However, its capacity is small enough to offer considerable opposition to the passage of audio signals which are of a comparatively low frequency, thus forcing them through the load resistor, and so building up a-f voltages across it --- which voltages react through the

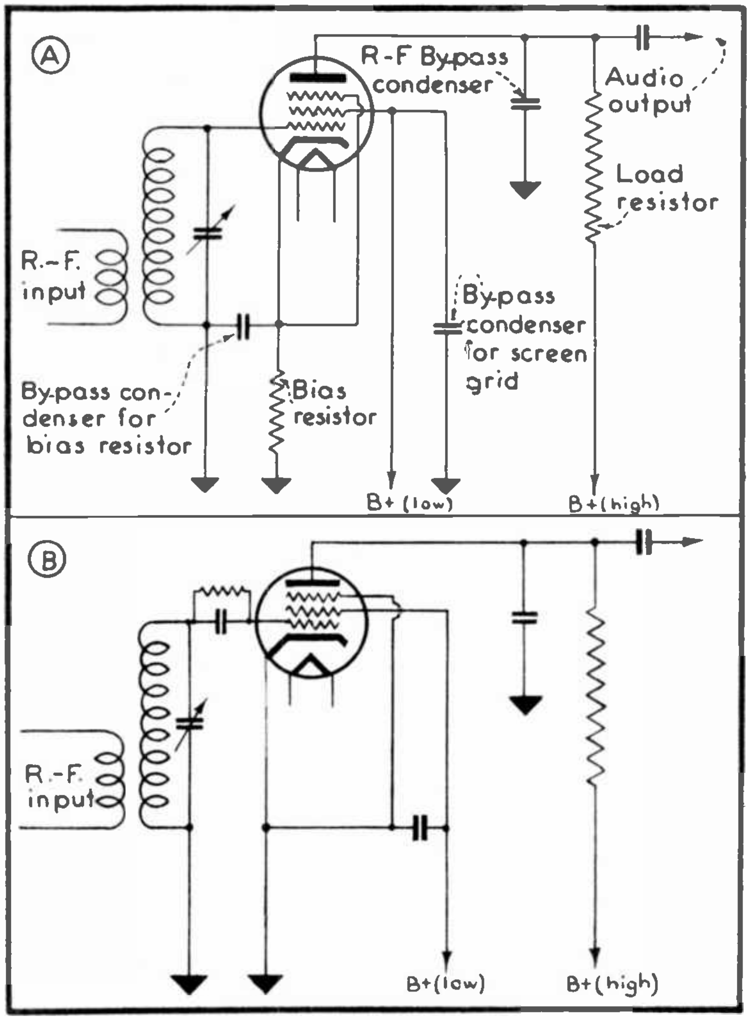


Fig. 11
Detector Circuits Using Cathode-Type Pentodes

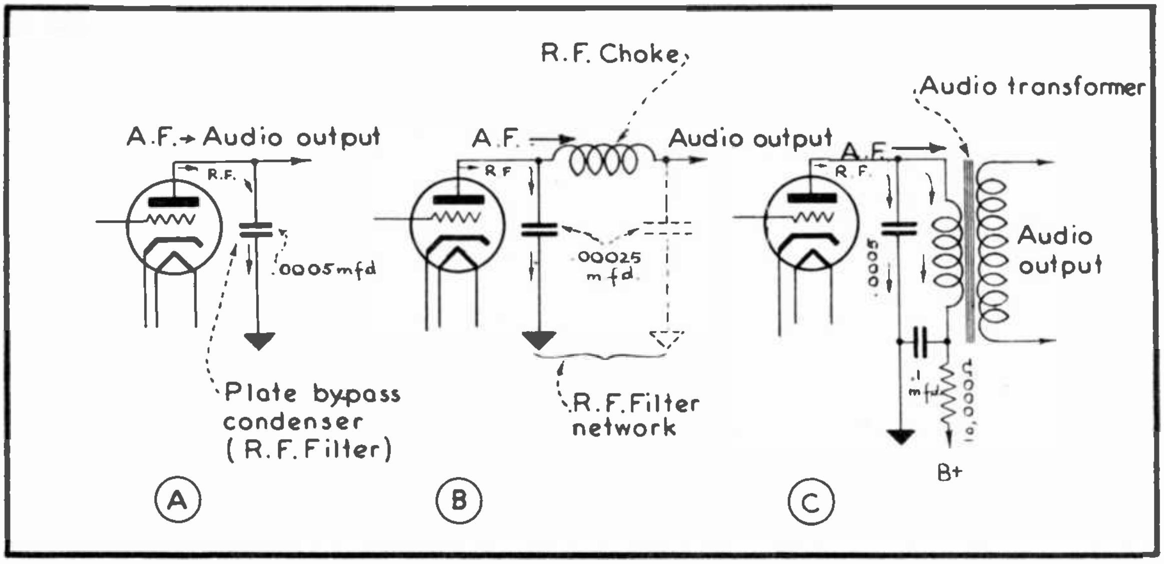


FIG. 12
DETECTOR OUTPUT FILTERS

coupling device being used in the detector's output circuit and are passed on to the audio amplifier. By rejecting the r-f ripples from the plate current in this way, the latter will vary uniformly as illustrated at (B) in Fig. 13.

You will no doubt realize by now, that this by-pass condenser serves the same purpose as does the condenser which is connected across the headphones of the simple detector circuits described in an earlier lesson.

The circuit shown at (B) of Fig. 12 operates on the same principle as that appearing at (A) of the same illustration, with the exception that an r-f choke is used to still further assist in rejecting the flow of r-f current variations from the audio section of the receiver by offering so much opposition to them that they are forced to react to ground through the by-pass condenser which is connected between the tube's plate and ground. The inductance value of the r-f choke is sufficiently low (around 2 to 50 millihenries) so as to permit the low-frequency audio signals to pass through it with ease.

Sometimes, an additional condenser is placed between the output end of the r-f choke and ground to by-pass any r-f energy that may find its way through the choke. This condenser is shown by dotted lines at (B) of Fig. 12. The opposing effect of the plate load resistor or transformer winding, whichever is used in the coupling circuit, forces the remaining r-f to react through this second condenser.

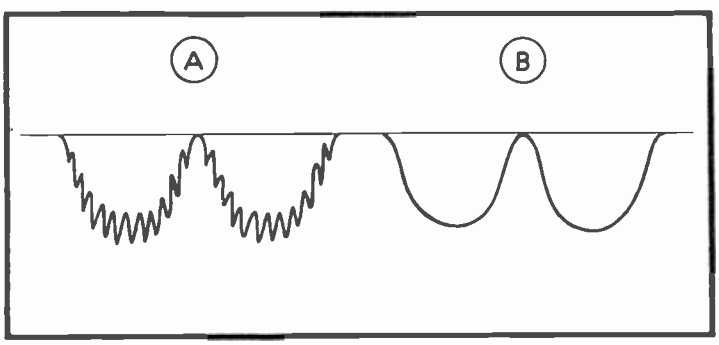


FIG. 13
HOW THE FILTER REJECTS R-F

In the circuit shown at (C) of Fig. 12, a resistor is connected in series with the B-plus lead, serving the same purpose as a choke. Filtering takes place as follows:

The .0005 mfd. condenser by-passes to ground the r-f signal. The r-f energy, having in a great measure been eliminated --- and the a-f energy having been utilized by the a-f transformer --- the plate circuit resistor forces to ground through the .1 mfd by-pass condenser those a-f current variations that have already been utilized by the transformer, as well as any remaining r-f energy that may still be present at this point in the circuit. This prevents either r-f or a-f energy from entering the long B-plus lead and thereby finding its way into other parts of the circuit where it is not wanted. Sometimes, such resistors and associated by-pass condensers are connected in the screen grid and plate leads of r-f and a-f amplifiers for a similar purpose. You may also find a choke coil used in place of the resistor.

DETECTOR SHIELDING AND PLACEMENT OF PARTS

As is true of r-f amplifier tubes and circuits, shielding of the detector stage is also quite important --- in fact, even moreso than in the r-f amplifier. The reason for this is that any r-f feedback between the output and input circuit of the detector will cause violent oscillation, while audio feedback at this same point may cause annoying "howls" and distortion of the signal. Correct placement of the parts and wiring, and proper shielding, prevents such occurrences.

THE AUDIO SECTION

Audio-frequency amplifying stages are either resistance coupled or transformer coupled. Both methods are employed extensively, and each has advantages and disadvantages; however, the requirement of both is to amplify the audio-frequency signal voltage available at the output of the detector. In order for the receiver as a whole to reproduce faithfully the music or speech originating in the studio of the transmitting station, it is necessary that the audio amplifier amplify the signal voltages without distortion.

Speech and the musical sounds transmitted during broadcast programs correspond to a frequency range of about 40 to 10,000 cycles per second. Therefore, if a receiver is to reproduce these frequencies faithfully, it must be designed properly.

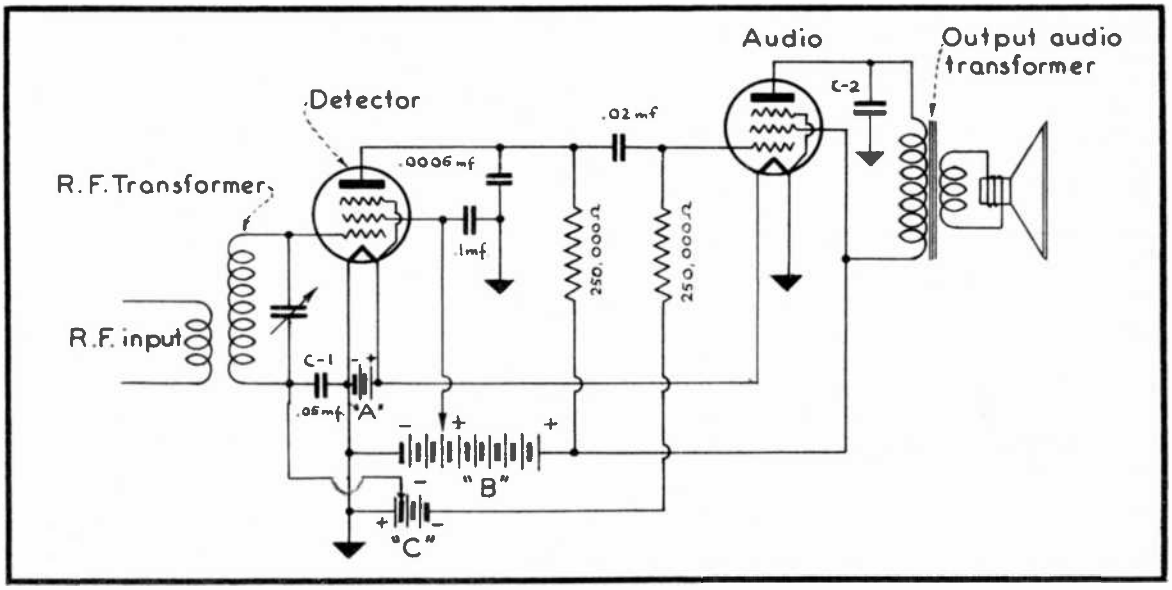


FIG. 14
RESISTANCE-CAPACITY COUPLED AUDIO AMPLIFIER

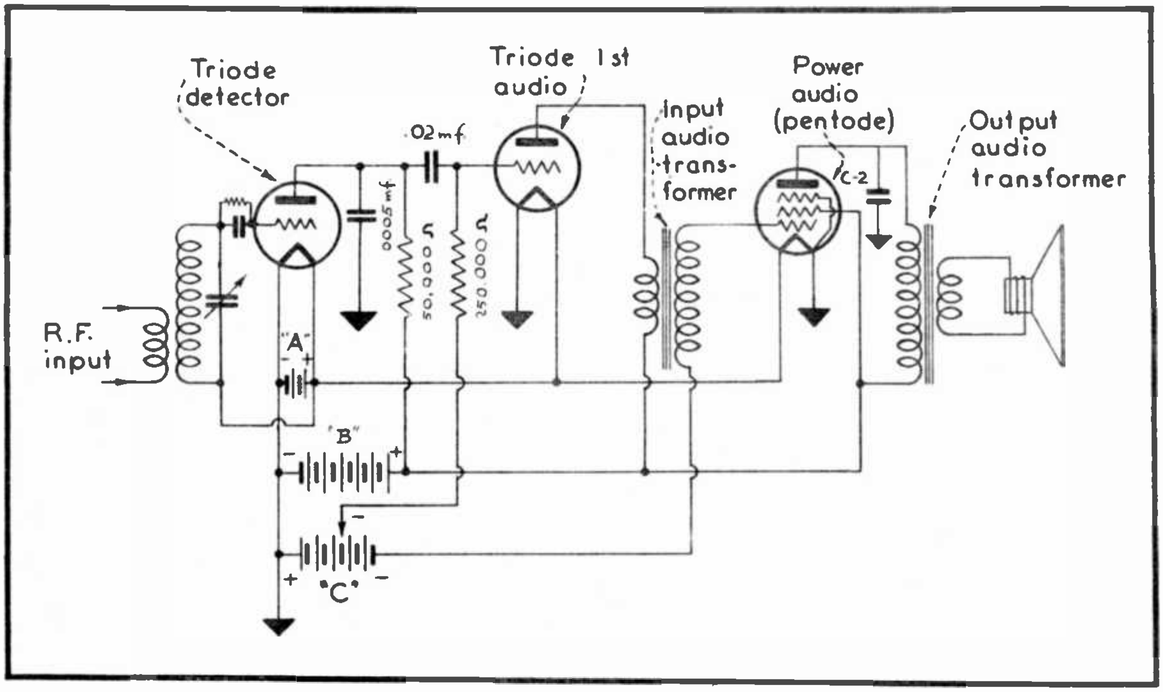


Fig. 15
Application of an Intermediate Audio Stage

RESISTANCE-COUPLED AMPLIFIERS

Resistance coupling is most used in audio-frequency amplifiers. A simple a-f amplifier circuit, typical of a compact battery-operated receiver, is shown in Fig. 14.

Here, a pentode is used in a grid-bias detector circuit. The plate of this tube is coupled to the control grid of an audio power amplifier pentode through the .02 mfd coupling condenser and the two 250,000 ohm plate and grid resistors. A "C" battery is used to furnish the negative grid bias voltage necessary for both the detector and audio tube, bias for the audio tube being greater than for the detector.

This circuit is typical of that used in thousands of present-day radios. Due to its high gain, a pentode is used in both the detector and audio stages, thus permitting a relatively high audio output to be obtained from a minimum number of tubes.

A ground connection to the chassis completes the negative side of the "A" (filament) circuit.

Condenser C-1 is being used to complete the connection between the tuning circuit and the tube's filament so that radio frequency currents can flow freely between these two points without having to pass through the high resistance offered by that portion of the "C" battery which is inserted between these same two points. Any high resistance to radio frequency current in this part of the circuit would reduce the efficiency of the system.

Condenser C-2 is of such capacity as to provide a low reactance path to ground for the very high audio frequencies so that they will be ineffective in the primary winding of the output transformer. By thus preventing the reproduction of the very high audio frequencies, the sound emitted by the speaker will be lower in pitch than would be the case if this condenser were omitted. To put it another way, if condenser C-2 were not used, the general tone reproduction would be somewhat high pitched or "screechy"; whereas including this condenser in the circuit lowers the average pitch enough to make the reproduced sound more mellow in character. A common value for C-2 is .002 mfd.

This diagram shows also how the voice coil of a dynamic speaker is coupled to the amplifier by means of an output transformer.

Another interesting point to observe in Fig. 14 is that the screen grid of audio power amplifier tubes is generally connected to the same high-voltage B-plus lead as is the plate. Whether or not this is true in all cases, depends upon the manufacturer's specifications for the particular tube in question, and the design of the circuit in general.

APPLICATION OF AN INTERMEDIATE AUDIO STAGE

When a triode is used in a grid-leak detector circuit, an intermediate audio stage is often employed between the detector and the power output stage. In such a case, transformer coupling may be used between the two audio tubes; and resistance coupling between the detector and first audio stage, as shown in Fig. 15. Here, a triode is being used in the first or intermediate stage, although a pentode may be employed at this point, feeding into the power amplifier tube through resistance coupling.

Observe that the arrangement in Fig. 15 is such as to amplify the low output voltage of the triode detector sufficiently in the intermediate stage before feeding it into the power amplifier tube. Transferring the signal through the audio transformer also provides an increase in volume.

In this set-up, the metal structure of the chassis is used to complete the negative side of the filament circuit.

AUDIO STAGES EMPLOYING CATHODE-TYPE TUBES

Many audio systems, along with their respective r-f and detector circuits, employ cathode-type tubes. In such cases, the usual "C" battery

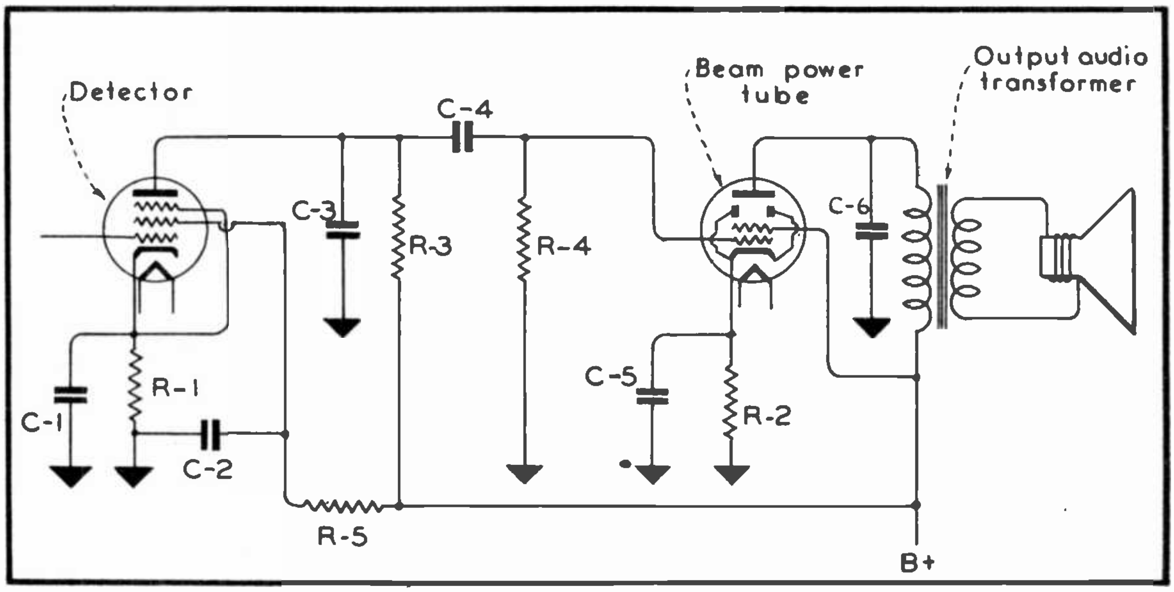


FIG. 16
AUDIO AMPLIFIER CIRCUIT USING CATHODE-TYPE BEAM POWER TUBE

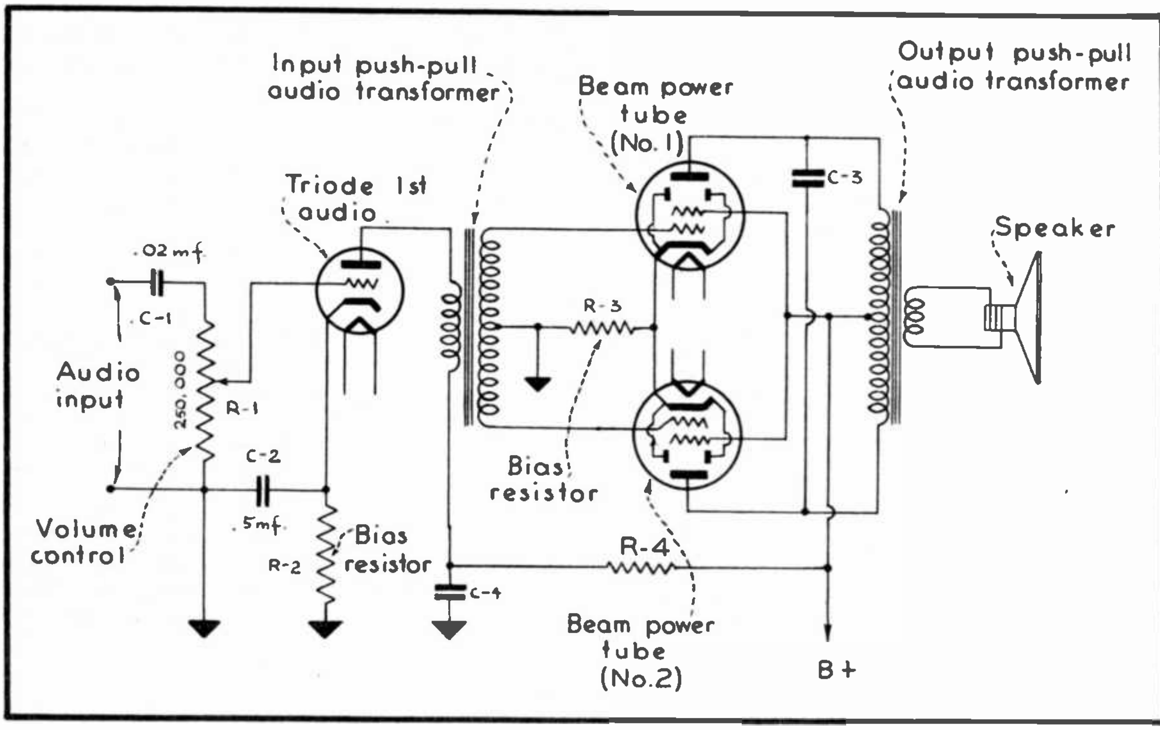


Fig. 17
Application of Cathode-Type Tubes in Push-Pull Audio Stage

may be dispensed with, and a resistor installed in series with the cathode of each tube and B-minus to furnish the bias. Such a circuit is shown in Fig. 16, where we have a pentode detector, resistance coupled to a beam power amplifier tube.

Notice, especially, how the use of resistor R-1 supplies the amount of bias required by this particular tube in order for it to operate as a grid-bias detector; while the use of a separate resistor R-2 provides the amount of bias required by the power amplifier tube.

The bias is applied to the power amplifier tube through grid resistor R-4. It is important to remember, however, that no bias voltage is lost in R-4 for the reason that no direct current flows through this resistor.

Since the current which flows through resistor R-2 has an a-f component in it, condenser C-5 must have considerably greater capacity than would a condenser that is connected across a cathode resistor in an r-f amplifier. This is necessary to by-pass the low audio frequencies around R-2 so that only the d-c voltage required for biasing will be effective across it.

AMPLIFIER WITH PUSH-PULL AUDIO POWER STAGE

In Fig. 17, we have an audio amplifier in which a single triode feeds into a pair of push-pull connected beam power amplifier tubes. Resistor R-2 furnishes the bias voltage for the triode, which voltage is applied to the grid through that portion of potentiometer R-1's resistance that happens to be included between the arm and ground.

Since R-3 is placed between ground and the two power amplifier cathodes that are connected together, it will furnish the bias voltage for both of these tubes. Tube No. 1 receives its bias through the upper-half of the input transformer's secondary winding, while the lower-half of this same winding completes the circuit for applying the bias to the control grid of tube No. 2.

Volume is controlled in this amplifier by means of potentiometer R-1. As the arm is moved upward, more resistance will be included between the grid of the triode and ground, so producing a greater audio voltage between these two points and thereby increasing the volume. As the arm is moved downward, the reverse action takes place, and the volume decreases.

Condenser C-3 serves the same purpose as does the plate by-pass condenser in the power amplifier stage of the other audio amplifiers shown you. Note that it is connected across the complete primary winding of the output transformer so as to be effective for both tubes.

Resistor R-4 is connected in series with the plate circuit of the triode for the purpose of reducing the voltage effective on the plate of this tube to a value less than that applied to the plates of the power amplifier tubes. Of course, such a resistor would only be used in cases where the tube manufacturer's specifications call for the triode's plate voltage being less than that impressed on the plates of the power amplifier tubes.

Voltage-dropping resistors, when used in a manner similar to that of R-4 in Fig. 17, should always be by-passed by a condenser. C-4 is used for this purpose. And, since an a-f component exists in the plate current that flows through R-4, the capacity of condenser C-4 must be large enough so that the reactance of this condenser at the lowest frequency being handled is appreciably less than the ohmic value of R-4.

COMPLETE RECEIVERS

Now that we have studied the circuits of the different receiver sections in detail, let us combine them into complete receivers and analyze the receivers as a whole.

Battery-Operated T-R-F Receiver

A complete circuit diagram of a battery-operated receiver is presented in Fig. 18. This particular receiver consists of one r-f amplifier stage, a grid-leak detector and an audio power amplifier stage. Receivers that have one or more conventional tuned stages of r-f amplification (such as you have studied about thus far) preceding the detector are classed as "tuned radio-frequency receivers" --- more commonly abbreviated to "t-r-f receivers." This classification is used to distinguish this type of receiver from another type --- the "superheterodyne" -- about which you will learn in later lessons.

Impedance coupling is used between the detector and power amplifier (audio) tube; the grid leak resistor being in the form of a potentiometer, used as a volume control.

An interesting feature of this receiver is that no "C" battery is required for biasing purposes, even though the radio is battery-operated. This is made possible by connecting the sensitivity control and resistor R-2 in the B battery circuit, in the manner shown.

You will observe that the upper end of the sensitivity control is connected to the negative side of the filament circuit; and its lower end to B-minus. Electron flow through this resistor, as caused by the B-battery, is therefore from its lower end toward its upper end --- thus making the arm-terminal of the potentiometer negative with respect to the filament-end of its resistance element. Then, since the arm-terminal of the sensitivity control is connected to the control grid of the r-f tube, a bias voltage is applied to this grid. By varying the position of the arm on the sensitivity control, the bias voltage is altered --- so changing the amplification factor of the r-f tube, and the gain of this stage.

In other words, by reducing the gain of the r-f stage through use of the sensitivity control, we avoid overloading the detector to the extent of distortion during the reception of strong local signals. Whereas, by increasing the gain of this stage, we can take advantage of the r-f tube's full amplifying ability while listening to weak station signals.

Resistor R-2 is connected in parallel with the sensitivity control, so part of the total B current flows through it. The direction of electron flow through R-2 is such as to make its lower end (grid end) negative, and its upper end (filament end) positive, thus, a negative voltage (bias) is applied to the control grid of the power amplifier tube.

Resistor R-1, in conjunction with condenser C-1, serves as a filter so that any r-f or a-f voltage that may be developed between the arm and grounded end of the sensitivity control, due to the flow of fluctuating current through this portion of the resistance, will not reach the control grid of the r-f tube. In other words, only the d-c voltage required for biasing is effective between the control grid and filament of this tube.

The plates of all tubes, and the screen grid of the r-f and a-f tube, are supplied with an emf. of 90 volts, while the screen grid of the detector is connected to the 67-1/2 volt terminal of the B battery.

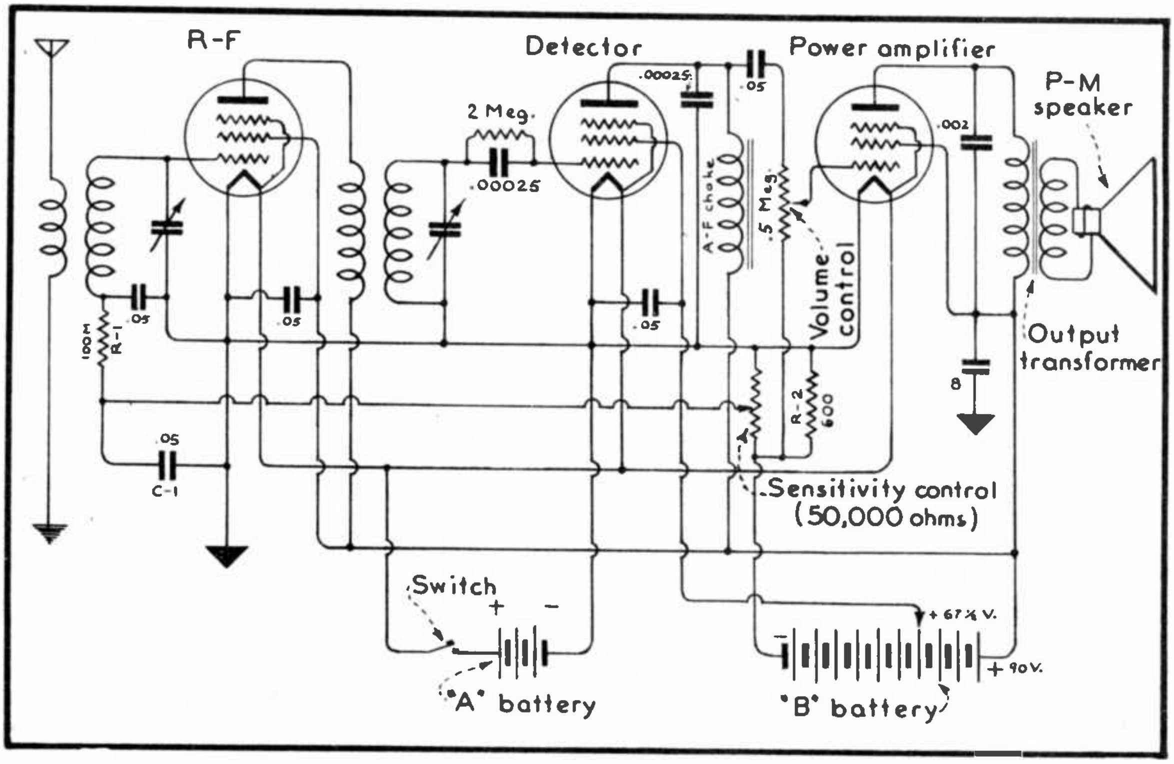


FIG. 18
BATTERY-OPERATED T-R-F RECEIVER

Detector tubes usually function more satisfactorily when the screen grid is operated at a lower voltage than that used for amplifier tubes.

The switch for turning the receiver "on" and "off" is included in the "A" battery circuit. The B battery circuit is interrupted automatically due to absence of an electron flow through the various tubes at the time their filaments become inoperative when the switch in the "A" battery circuit is opened.

The 8 mfd condenser which is connected between ground and the +90 volt "B" lead serves to by-pass to ground any a-f or r-f variations existing in this main lead. Signal energy of these frequencies has already been utilized by the various tubes and coupling devices before the electron flow reaches this main B plus lead. And, through by-passing these current variations to ground, they are effectively short circuited around the B battery in the same way as a by-pass condenser shunts r-f and a-f signal energy around a voltage divider resistor in the power supply of an a-c receiver. In this way, the B battery voltage is not affected by voltages of audio and radio frequency, as would be the case if these currents were permitted to flow through the resistance offered by the "B" battery. (Note: A voltage drop always occurs across a resistance through which current flows, regardless of whether that resistance be in the form of a wire, carbon element, or the internal resistance of a battery.) If variation of the B voltage were not prevented by this means, the plate and screen voltage of all tubes in the receiver would vary at a rate corresponding to all of the different frequenceis being handled by the receiver. The reproduced signals would therefore be distorted.

The condenser and resistor values given in Fig. 18 are typical for circuits of this type, but are intended solely to give you a general idea of what to expect in this respect. The arrangements of receiver circuits vary somewhat, although based on a definite pattern --- and the values of the different parts will therefore be affected accordingly. All this will become more clear as you progress with the course.

All of the condenser values specified in Fig. 18 are expressed in terms of microfarads (mfd). It is to be noted further that the letter "M" is often used to designate "thousand." Thus, 100M means 100,000 (or one-hundred thousand); 20M means 20,000 (or twenty thousand), etc. The value of the volume control is given in our diagram as .5 megohms, which is the same thing as 500,000 ohms, because 1 megohm equals one million (1,000,000) ohms.

All other features of the circuit appearing in Fig. 18 have been explained before, and therefore need not be discussed at this time.

Five-Tube AC T-R-F Receiver

The wiring diagram for this receiver appears in Fig. 19. This radio comprises a two-stage r-f amplifier, a grid-bias detector, an audio power output stage, and a power supply for making operation possible from the a-c lighting circuit.

Cathode-type pentodes are employed in all stages except in the audio output stage --- here, a beam power tube is used. The detector and audio tubes have their individual cathode resistors for biasing purposes.

The volume of this receiver is controlled by varying the negative bias applied to the two r-f tubes. As a further aid to the effectiveness of control, one end of the volume control resistor is connected to the antenna-end of the primary winding on the antenna-stage r-f trans-

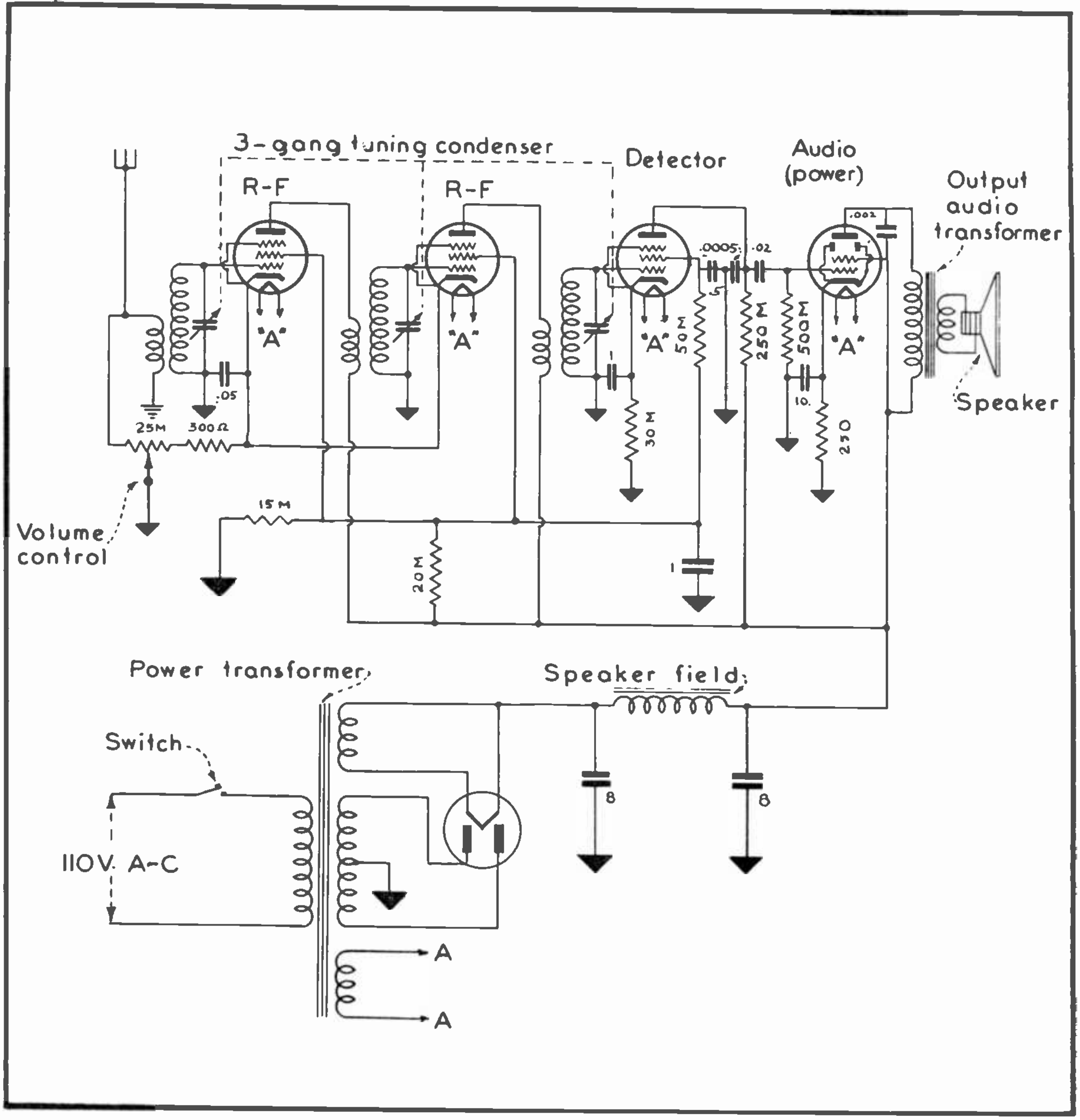


Fig. 19
AC T-R-F Receiver

former. Thus, when the control arm is placed at its extreme left position, this coil will be shorted to ground. At the same time, the total resistance of the volume control and the 300-ohm fixed resistor will be in series with the cathodes of the two r-f tubes and ground. By thus having the maximum amount of resistance included in the cathode circuit, the bias voltage for these two tubes will be so high as to make them inoperative. This, then, is the position for minimum value.

Moving the volume control arm toward the right reduces the shorting effect upon the transformer's primary winding, and at the same time reduces the resistance of the cathode circuit. The latter action causes the bias voltage for the r-f tubes to decrease, and thereby increases the volume.

The reason for the additional 300-ohm fixed resistor in series with the 25,000-ohm volume control, is to assure a certain minimum bias for these tubes when operating the receiver at full volume. This prevents the circuit from oscillating when the volume control is advanced all the way, and is therefore in line with good engineering practice. This fixed resistance may be an integral part of the volume control, or a separate resistor connected in series externally.

Notice also in Fig. 19 that a .05 mfd condenser is connected between the cathode of the first r-f tube and ground. Since the cathodes of the two r-f tubes are connected together, this condenser serves to by-pass the cathode resistor that is common to both these tubes.

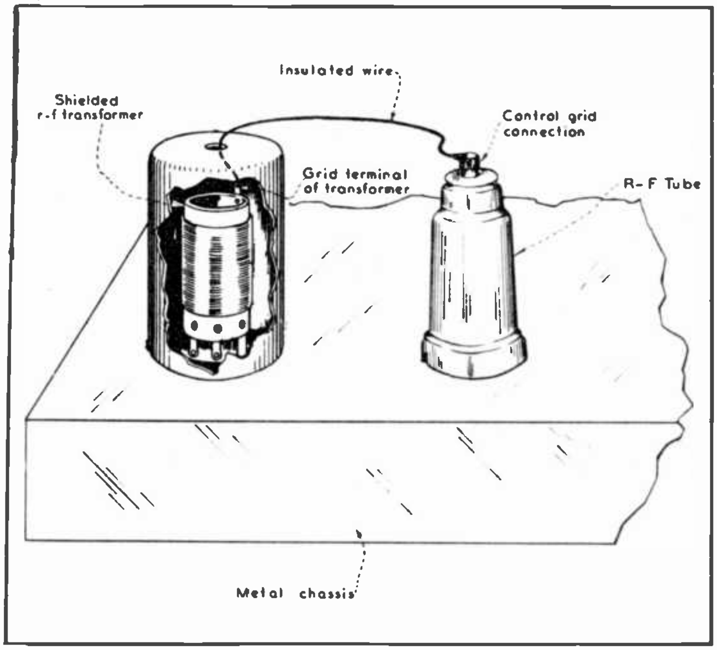


FIG. 20
CONTROL GRID CONNECTION AT CAP OF TUBE

A 20M resistor is used to drop the B voltage from the plate circuit value to a lower value that is suitable for the screen grids of the two r-f tubes. A screen grid voltage of 100, in conjunction with a plate voltage of 250, is typical of such circuits. A 15M bleeder resistor is used.

A 50M resistor reduces the voltage supplied to the screen grid of the detector tube to a still lower value than is desirable for the screen grids of the r-f tubes. A .1 mfd condenser is used to by-pass the screen grids of the r-f tubes to ground, while a .5 mfd condenser serves the same purpose for the screen grid of the detector tube.

A 1 mfd condenser is used to by-pass the cathode resistor of the detector tube, and a 10 mfd condenser for the cathode resistor of the audio output tube. A .0005 mfd condenser is used for the r-f filter in the plate circuit of the detector tube.

Observe how the voice coil of the electrodynamic speaker is connected to the receiver through the audio output transformer, while the field coil of the speaker is being employed as a filter choke in the power supply system.

The various tube filaments marked "A" are understood to be connected to the secondary winding of the power transformer which is also marked "A". This method of indicating circuit connections is often employed in diagrams of commercial receivers to reduce the number of lines that would otherwise have to be drawn on the diagram to illustrate the filament circuits. In this way, the diagram becomes more simple to read.

The switch for turning this receiver "on" and "off" is connected in series with the a-c lighting circuit and the primary winding of the power transformer. By opening this switch, no current can flow through the primary winding; consequently, no voltages will appear in the various secondary windings of the power transformer. The receiver will then be inoperative. Closing the switch completes the primary circuit, and makes the receiver operative.

In conclusion, it should be noted that the control grid connection is sometimes made at a small metal cap on top of the tetrode or pentode tube by means of a metal, cup-shaped clip designed for the purpose --- as illustrated in Fig. 20. If the tube in question does not have such a cap, the control grid connection is made at the proper base prong through the socket. The method of making this connection depends, naturally, upon the design of the particular tube in question --- and will be apparent upon inspecting the tube.

EXAMINATION QUESTIONS

LESSON NO. 17

1. - Why is a fixed resistor sometimes connected in series with the potentiometer that controls the volume of a receiver adjustment of the grid bias voltage of the r-f tubes?

2. - A bias resistor is so placed in a circuit as to carry the cathode current of two tubes for which it is to furnish a bias voltage. If each of these tubes "draws" 10 ma. of cathode current, what value of resistor is required to furnish a bias of 2 volts?

3. - Explain briefly how the automatic method differs from the fixed method of biasing cathode-type tubes.

4. - Draw a circuit diagram of a 5 tube, a-c, t-r-f receiver comprising two r-f stages, a grid bias detector, a power amplifier stage and a power supply system.

5. - Why are pentodes preferred to triodes in r-f amplifiers?

6. - Why is a by-pass condenser frequently connected between ground and the plate of a power amplifier tube?

7. - How may the self-bias principle be applied to the filament-type tubes?

8. - In Fig. 19 of this lesson, why does the volume increase when the arm of the volume control potentiometer is moved toward the right?

9. - Why is a by-pass condenser connected between ground and the plate of a detector tube?

10. - Why is a by-pass condenser connected between ground and the screen grid of a tetrode or pentode r-f amplifier tube?

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LESSON NO. 18

SUPERHETERODYNE RECEIVERS

The superheterodyne receiver has gained tremendous popularity during the past few years, and is considered as an outstanding achievement in modern radio design. The "heterodyne principle" was actually used a number of years ago, but it was only within comparatively recent years that commercial-built receivers of this type were placed on the market. Today, the majority of receivers are of the superheterodyne type.

In the study of superheterodynes, you are going to be introduced to several new principles, but everything which you have already learned relative to radio receivers in general will still apply to this type of circuit. This is one of the reasons why you are going to find the study of superheterodynes easier than you might at first have supposed.

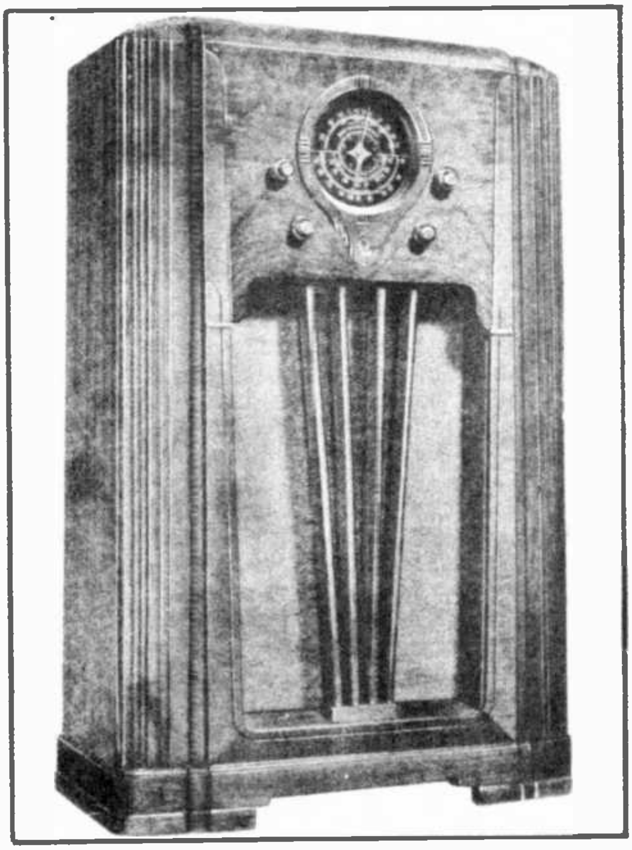

Fig. 1
CONSOLE-TYPE SUPERHETERODYNE RECEIVER

GENERAL LAY-OUT OF A SUPERHETERODYNE

The "block-diagram" in Fig.2 shows the arrangement of the various sections or units of the superheterodyne receiver. Observe in this illustration that this receiver is composed of several sections consisting of the first detector, oscillator, intermediate-frequency amplifier, second detector, audio amplifier, and speaker. That portion comprising the second detector, audio amplifier and speaker is exactly the same as in a conventional t-r-f receiver. Such being the case, you will quickly realize that the only difference between the superheterodyne and a regular t-r-f receiver exists in that portion of the circuit which precedes the second detector.

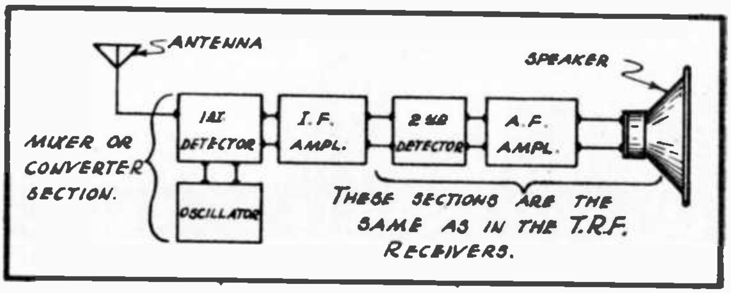

FIG. 2
SECTIONS OF THE SUPERHETERODYNE

The first section of the superheterodyne, shown in Fig. 2, is called the "frequency changer," "mixer," or "converter," and consists of two parts, known as the first detector and the oscillator.

The oscillator portion of the mixer stage is a small generator of radio-frequency energy. It consists merely of a vacuum tube in an oscillating circuit, and a tuning control whereby the operator of the receiver can adjust the oscillator to generate radio-frequency oscillations of any desired frequency.

As you will note in Fig. 2, the mixer section is connected to the intermediate-frequency amplifier. The latter is generally spoken of as the i-f amplifier.

During the operation of this receiver, the signal-energy radiated by the broadcast station will enter the first detector division of the mixer section. At the same time, the oscillator located within the receiver, will also feed radio-frequency energy into the first detector, but the frequency of the latter will be different from that of the incoming broadcast signal.

These two differing frequencies, being impressed upon the first detector simultaneously, are literally "mixed." This action causes a new frequency to be produced, which we call the INTERMEDIATE FREQUENCY, and this new or resulting frequency is fed into the intermediate-frequency amplifier where it is amplified. The intermediate-frequency is still of a radio-frequency character and is therefore inaudible; however, by passing it into the second detector, customary detection takes place and the audio component is at this point separated from the intermediate-frequency. Audio amplification then takes place in the conventional manner.

This brief explanation is intended to give you a general idea of the occurrences in the various sections of the superheterodyne receiver. No doubt, you are now wondering just how this process is actually accomplished, and why these complicated additions are made. This, however, will all be made clearer as you continue reading the following paragraphs.

REQUIREMENTS FROM A RECEIVER

1. - <u>Selectivity</u> is that property of a receiver which enables it to differentiate between one broadcast frequency and another. That is, a "selective receiver" tunes rather sharp and thereby prevents

interference between the various broadcast stations that are "on the air" at the same time.

2. - Sensitivity is that property of a receiver which enables it to "pick up" distant stations with ease, and with very little signal energy supplied to its antenna.

3. - Fidelity refers to the tone quality produced by the receiver. A receiver possessing good fidelity provides a rich and true reproduction of sound.

The principles used in the superheterodyne aid in obtaining all three of these desired qualities from the receiver.

THE HETERODYNE PRINCIPLE

Our next step is to investigate the "heterodyne principle" more thoroughly. Fig. 3 will serve to make this explanation clear.

In the upper portion of this illustration, you are shown a wave form that represents a frequency of 800 kc, whereas a 600 kc wave-form is shown at the center. Combining the 800 kc and the 600 kc frequencies will produce an entirely new frequency which is known as the beat frequency. This beat-frequency will no longer correspond to the 600 kc wave-form nor to the 800 kc wave-form; instead, its frequency will be equal to the arithmetical difference between the original two frequencies. That is, the beat-frequency in this particular case will be 800 kc minus 600 kc, or 200 kc. We then say that the 800 kc and 600 kc frequencies beat, combine, or "heterodyne" to produce a beat-frequency of 200 kc.

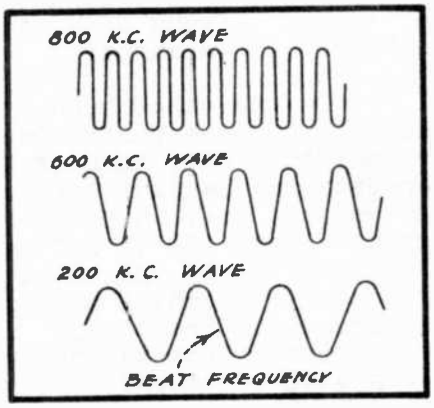

FIG. 3
THE PRINCIPLE OF BEATS

Beside this 200 kc beat-frequency, still another beat-frequency will be produced by the heterodyning of the 800 kc and 600 kc frequencies. This second beat-frequency will be equal to the sum of the original frequencies. In other words, in the particular example given, this second beat-frequency would be equal to 800 kc plus 600 kc, or 1400 kc. This latter frequency, you will note, is higher than either of the two original frequencies; however, in superheterodyne receivers we do not intentionally use this high beat-frequency. The lower one is preferable, for reasons to be explained later.

A brief consideration of the phenomena of beats as found in audio frequencies will no doubt make this important principle even more clear to you. Let us suppose, for example, that two different strings on a violin are plucked at the same time, and that the musical note produced by one of these strings has a frequency of 1000 cycles, while the note produced by the other string has a frequency of 1800 cycles.

As these two musical notes are produced simultaneously, your ear will respond not only to the 1000 cycle and 1800 cycle notes individually, but it will also detect one new note whose frequency is 1800 cycles minus 1000 cycles, or 800 cycles, and likewise another new note whose frequency is 1800 cycles plus 1000 cycles, or 2800 cycles -- the 800 and 2800-cycle frequencies are the beat-frequencies. Altogether then, an 1800, 1000, 800, and 2800 cycle tone will be impressed upon your ear at the same time.

With this principle in mind, it is obvious that if we wanted to change the frequency of a 650 kc broadcast station to a new frequency of 100 kc, all that we would have to do is to "mix" this 650 kc frequency with a frequency of 550 kc or 750 kc which is generated in the receiver. Either of the two latter frequencies will heterodyne with a 650 kc frequency to produce a 100 kc beat-frequency. This is the fundamental principle of all superheterodyne receivers.

SHORTCOMINGS OF STRAIGHT T-R-F RECEIVERS

Before investigating further the application of these principles to the superheterodyne,let us first consider briefly some of the major faults of t-r-f receivers which are overcome through the use of a superheterodyne circuit.

To begin with, the ordinary type of straight t-r-f circuit is expected to "tune in" and amplify all of the different frequencies within the broadcast band. It is physically impossible to design circuits of this type which will operate at each and everyone of these many frequencies at the same efficiency. The result is that at the higher broadcast frequencies, all straight t-r-f receivers have a natural tendency to become less selective than at the lower frequencies, and at the lower frequencies many of them are over-selective to such a degree that they eliminate some of the higher audio frequencies. Both of these extreme conditions affect the performance of the receiver in an undesirable manner.

On the other hand, if these same r-f stages are only expected to amplify but one particular frequency at all times,and no other frequency but this one, then it is a simple matter to design the amplifier to operate at maximum efficiency at this one particular frequency. This is exactly what is done in a superheterodyne receiver, for here the greater part of all r-f amplification is done at only one frequency, regardless of the received station's signal-frequency. We call this frequency, at which practically all r-f amplification takes place, the intermediate-frequency. In other words, the intermediate-fnequency amplifier of the superheterodyne is permanently tuned to a chosen intermediate-frequency, so that this will be the only frequency amplified by it.

APPLICATION OF THE BEAT PRINCIPLE TO THE SUPERHETERODYNE

Now let us suppose that the intermediate-frequency amplifier of a certain superheterodyne receiver is permanently tuned to an intermediate-frequency of 100 kc. The actions taking place within this receiver are all illustrated in Fig. 4, where we assume that a 750 kc station is being received.

Since the intermediate-frequency amplifier will not amplify any frequency other than 100 kc, it will be necessary to change the 750 kc signal-frequency to 100 kc. We do this by tuning the receiver's oscillator to generate either a 650 kc or an 850 kc frequency. Let us suppose that the receiver's oscillator is tuned to produce a frequency of 850 kc. This frequency will heterodyne with the 750 kc signal-frequency to produce a 100 kc beat-frequency. This 100 kc beat-frequency will then be amplified by the intermediate-frequency amplifier, after which it acts upon the second detector,where customary detection takes place. The audio frequencies are then amplified and sent through the speaker windings in the usual way.

The 1600 kc beat-frequency, also produced by heterodyning the 750 kc signal-frequency and the 850 kc oscillator frequency, is useless because the intermediate-frequency amplifier is not tuned to amplify this higher frequency.

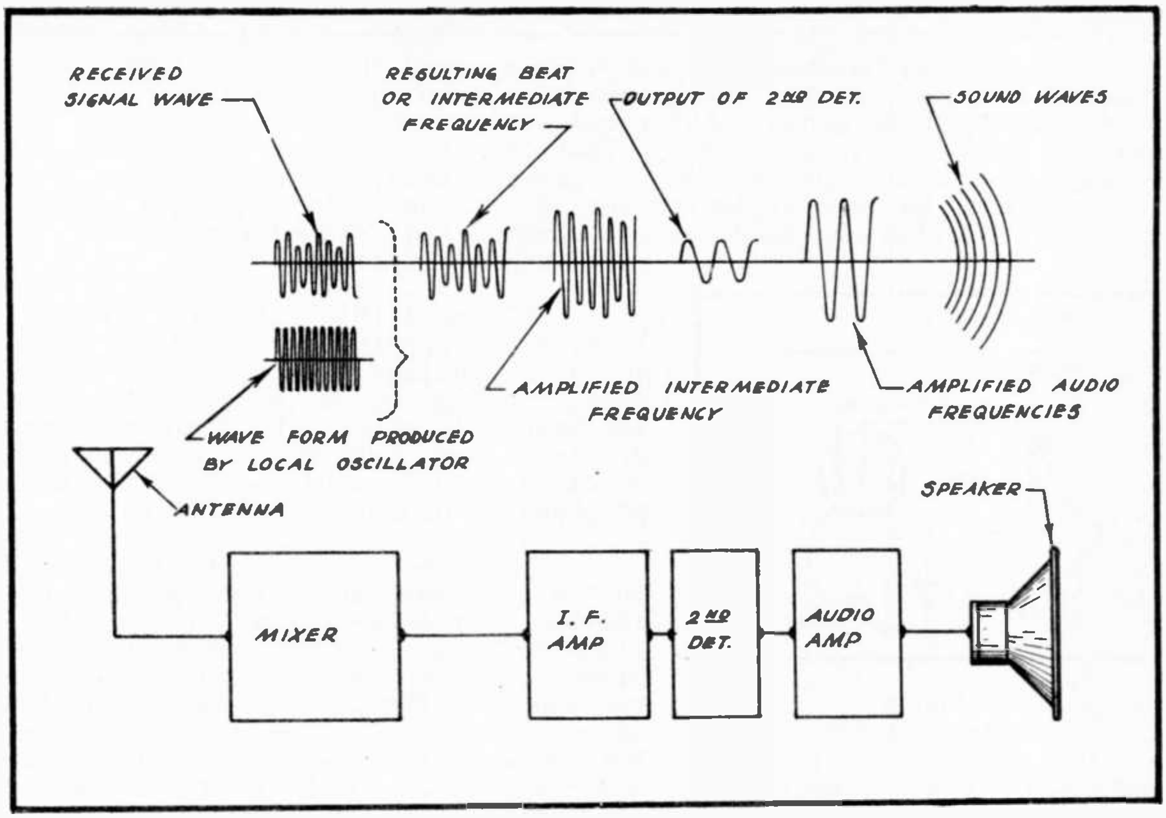

FIG. 4
FREQUENCIES HANDLED BY THE SUPERHETERODYNE

Should it be desired to tune-in a broadcast station operating at a frequency of 1250 kc, when the intermediate-frequency of the superheterodyne is adjusted for 100 kc, then the oscillator would have to be tuned to generate a frequency of either 1150 kc or 1350 kc. Either of these two oscillator frequencies will produce a beat-frequency of 100 kc when heterodyned with the 1250 kc signal-frequency.

The important fact to bear in mind at this time is that to tune in any broadcast station, we simply adjust the oscillator so that the arithmetical difference between the station and oscillator frequencies will produce a beat-frequency for which the intermediate-frequency amplifier is tuned.

Now that you are familiar with the production of beat-frequencies and how they are used in the superheterodyne, let us next investigate the circuits involved and note how these conditions are brought about within the receiver. As our first step we will study briefly a fundamental oscillator circuit, such as used in a superheterodyne receiver.

THE OSCILLATOR CIRCUIT

In Fig. 5 is shown a simple oscillator circuit for an a-c operated superheterodyne. Here you will see that one winding is connected in the plate circuit of the oscillator tube; this plate winding is placed in an inductive relationship with the tuned grid winding. This placement of the winding enables the energy in the tube's plate circuit to act upon the grid circuit in exactly the same way as in regenerative circuits described earlier in the course.

In Fig. 5, however, the coupling between the plate and grid windings is so close,and the energy-transfer from the plate winding to the grid winding is so great, that regeneration becomes excessive and the circuit commences to oscillate. That is, it commences to generate r-f energy, and continues to do so indefinitely, as long as the set is "turned on." By regulating the tuning condenser in the grid circuit of this oscillator tube, we can control the frequency at which this circuit oscillates.

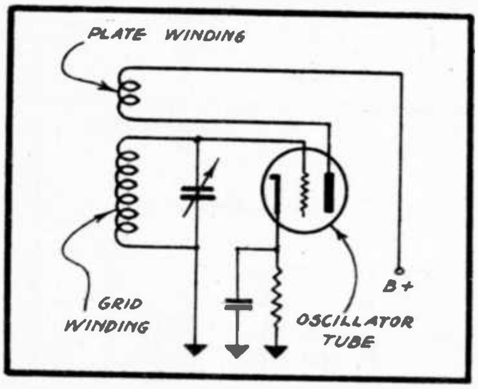

Fig. 5
Oscillator Circuit

To enable this circuit to oscillate,it is imperative to wind the plate and grid windings in the correct direction. In Fig. 6, for example, is shown the manner in which the plate and grid windings are both wound on the same bakelite tube or winding form; the ends of these windings are clearly marked.

A simple rule which will enable you to remember the proper winding direction for these coils follows: Consider both windings as a continuous or single winding which is cut in half at the center. The grid is then connected to one end and the plate to the other. Furthermore, it makes no difference which end you connect to the plate and which to the grid, so long as the windings run in the correct direction.

As a rule you will find the grid and plate windings of the oscillator wound together on the same piece of tubing, the grid winding having a sufficient number of turns to cover the required frequency band when tuned with its variable condenser. The plate winding generally consists of about 25 turns,and is wound near or directly over the top of the grid-return end of the grid winding, with adequate insulation between the two windings.

Now that we have an oscillator circuit, the next step is to provide a means whereby we can transfer the oscillator's r-f energy into the first detector tube. In Fig. 7, you will observe that we have a total of three coils or windings placed in an inductive relationship. Two of them comprise the plate and grid windings of the oscillator, whereas the third is the "pick-up" coil. The latter serves as the connecting link between the oscillator and the first detector.

When using this system, the most common practice is to wind all three of these coils on the same form, with the grid and plate windings wound as already stated; the pick-up coil is usually spaced about 1/8" from the plate winding. As far as operation is concerned, the pick-up coil could be wound either adjacent to the grid winding or adjacent to the plate winding, but a greater energy-transfer is obtained between the plate winding and pick-up coil; it is for this reason that the pick-up coil is generally

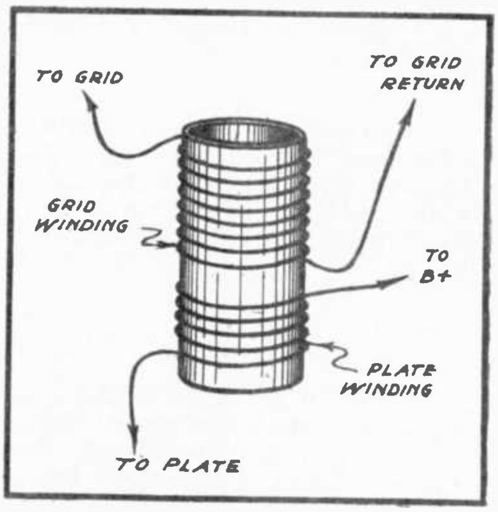

Fig. 6
Connections for Oscillator Windings

wound next to the plate winding rather than next to the grid winding. The physical relation between these three windings is illustrated in Fig. 8.

Pick-up coils generally consist of but six to ten turns of wire, and as you will note from the explanation thus far given, the coupling between the pick-up coil and plate winding of the oscillator is somewhat loose.

There is a natural tendency for a tube to draw more plate current while the circuit is oscillating than when the same tube is installed in a circuit that is not oscillating. For this reason it is advisable to use LESS plate voltage for the tube when used as an oscillator than that specified for its operation as an amplifier. In other words, if the specifications state that a certain tube, when used as an amplifier, should be operated at 135 volts plate voltage and 9 volts grid bias, this same tube when used as an oscillator, should have only about 90 volts on the plate and the bias voltage should be maintained at the same value as recommended for the higher plate voltage, that is, 9 volts. Quite often, the oscillator tube is used with no bias voltage at all. Later instruction will furnish you with more detailed information concerning this matter of voltages.

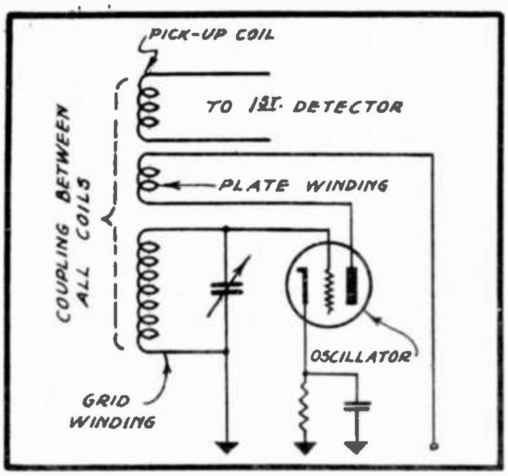

FIG. 7
RELATION BETWEEN PICK-UP AND OSCILLATOR COILS

CHANGING THE SIGNAL FREQUENCY

Leaving the subject of oscillators for the present, let us next see how we are able to "mix" the oscillator-frequency with the incoming signal-frequency.

Fig. 9 shows in diagram form a typical method of coupling the oscillator to the first detector tube. Notice that the pick-up coil is connected in the cathode circuit of the first detector, and is also inductively coupled to the oscillator coils. Such being the case, the high-frequency voltage changes in the oscillator coils will induce voltage changes of like frequency in the pick-up coil. Then, since the pick-up coil is also in effect in series with the first detector tube's grid and cathode elements, it is therefore also a part of the first detector's grid circuit. The r-f voltage changes of oscillator-frequency, induced therein, will therefore act upon the grid circuit of the first detector.

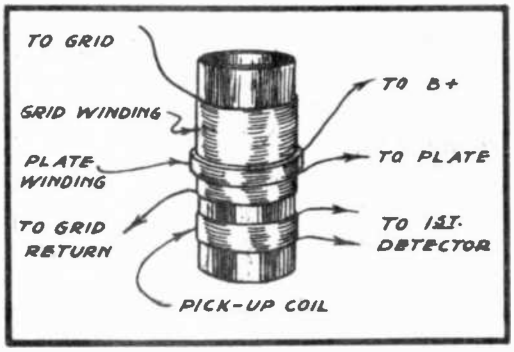

FIG. 8
OSCILLATOR AND PICK-UP COILS

Upon studying the circuit in Fig. 9 more closely, you will further note that the grid circuit of the first detector is also coupled to the antenna through an r-f transformer. Therefore, the signal-frequency and oscillator-frequency will be impressed upon the grid of the first detector simultaneously. This results in a

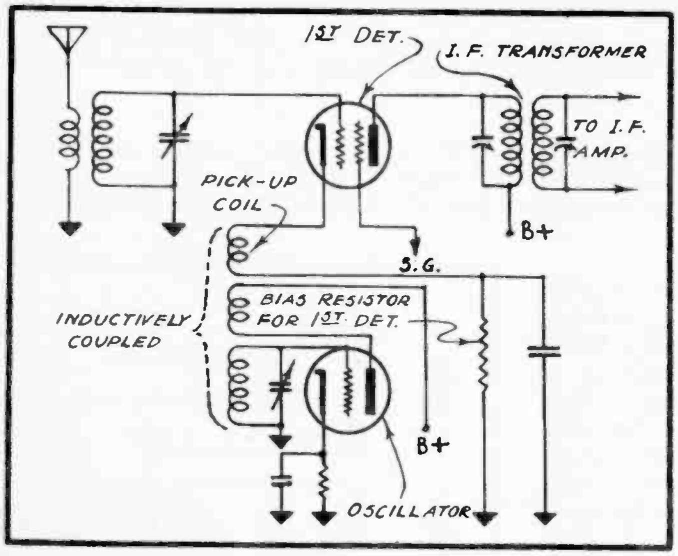

Fig. 9
Coupling the Oscillator to the First Detector

beat-frequency which is equal to the arithmetical difference between the station signal and oscillator-frequency. This beat-frequency controls the plate current variation in the first detector tube, and also the current variation in the primary winding of the i-f transformer which is connected in the output of the first detector tube. In other words, the current flow through the primary winding of the i-f transformer varies in accordance with the beat-frequency.

In Fig. 10 is shown a schematic diagram of the circuit appearing in Fig.9. This will assist you in acquiring a clearer conception of the relation between the various parts, and you will no doubt now agree that this process of changing the signal-frequency to any desired intermediate-frequency is not so complicated after all.

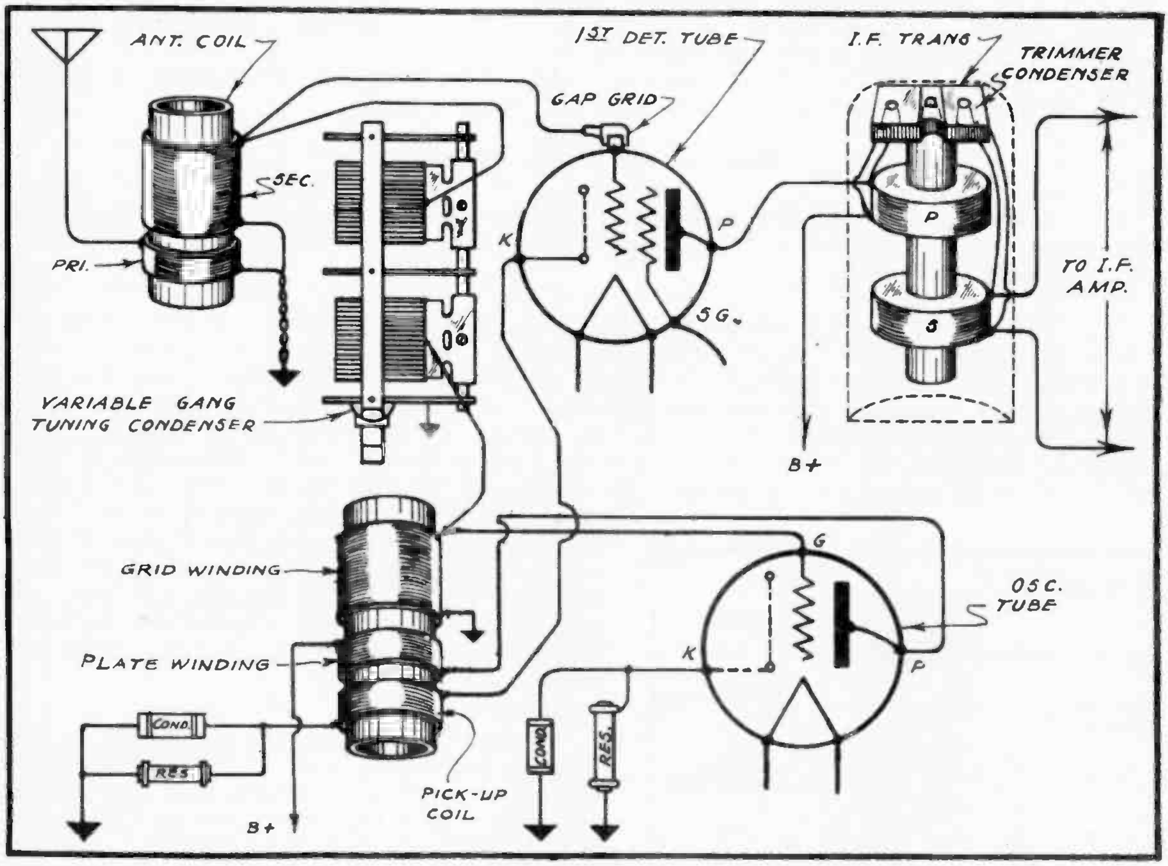

Fig. 10
Schematic Drawing of Typical Mixer Circuit

Now that we have produced our beat or intermediate-frequency, as well as having transferred it to the plate circuit of our first detector, let us next study the intermediate-frequency amplifier in greater detail.

THE INTERMEDIATE-FREQUENCY AMPLIFIER

The circuit arrangement of a typical intermediate-frequency amplifier is shown in Fig. 11. This section of the circuit is sometimes simply called the i-f amplifier, and as you will note, it consists of a chain of tuned transformers and amplifying tubes. We call these particular transformers i-f transformers; the tubes are generally referred to as i-f amplifier tubes.

The primary and secondary windings of each of the i-f transformers in this particular illustration have a small semi-variable trimmer condenser connected across their ends. Thus it is evident that these are all tuned circuits. However, the trimmer condensers in this case have no tuning control which is accessible to the radio-listener; instead, they are set only as a service adjustment by the radio service technician. All of these i-f stages are tuned to the same beat or intermediate-frequency.

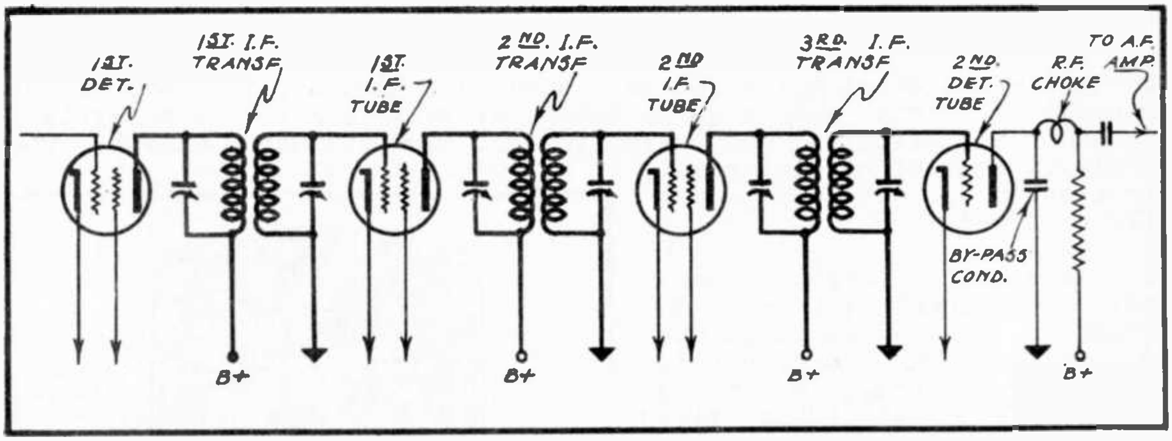

FIG. 11
CIRCUITS OF INTERMEDIATE-FREQUENCY AMPLIFIER

By again referring to Fig. 11, you will observe that while this particular i-f amplifier unit consists of three i-f transformers, it is nevertheless commonly referred to as a two-stage amplifier, irrespective of the fact that three i-f transformers are used.

Only one stage is employed in some i-f amplifiers -- more than three stages are very seldom used. The probability of r-f feed-back and undesirable oscillations limits the number of i-f stages advisable; in contrast to this, the gain and selectivity will be increased proportionately to the number of i-f stages. This subject will be more fully covered in future lessons.

The beat-frequency will be amplified by the following stages of intermediate-frequency amplification, until it is finally delivered to the second detector. Here it acts upon the grid circuit of the second detector, and this tube separates the audio frequencies from the intermediate-frequency in the same manner as the detector in a t-r-f receiver "separates"the audio frequencies from the station's broadcast frequency. The audio frequencies are then passed along through the audio section of the receiver, while the intermediate-frequency is bypassed

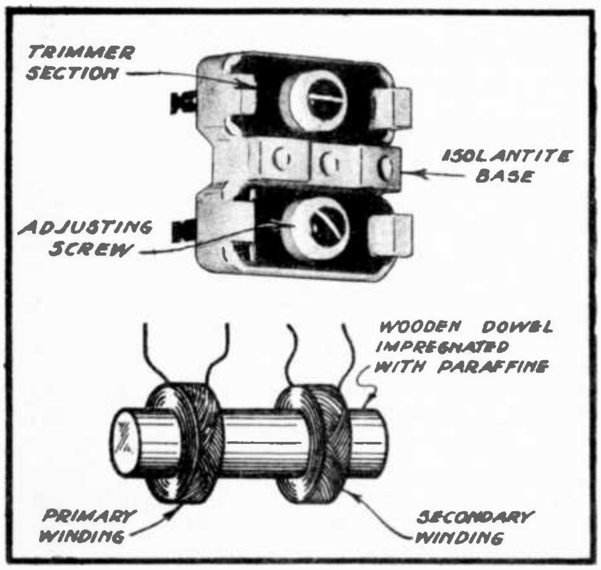

FIG. 12
COILS AND TUNING CONDENSERS OF AN I-F TRANSFORMER

to ground through the bypass condenser which is connected in the plate circuit of this tube.

In Fig. 12 are shown the essential parts of a typical intermediate-frequency transformer. The condenser section in this case consists of two semi-variable trimmer condensers mounted on a porcelain or isolantite base; one of these is used to tune the primary of the i-f transformer, the other for the secondary. The complete coil is then mounted below the condenser unit, and the assembly is housed within a metal shield can, as shown in Fig. 13.

THE QUESTION OF A LOW OR HIGH INTERMEDIATE-FREQUENCY VALUE

In early superheterodynes, the intermediate-frequency was set at a rather low value -- in some cases as low as 25 or 100 kc. Nowadays, however, we have at our disposal efficient screen grid tubes, as well as a better understanding of radio circuits and the actions of high-frequency energy. The result is that higher intermediate-frequencies are now generally employed.

A somewhat higher intermediate—frequency is really an advantage, as long as it is not too high. In fact, a higher intermediate-frequency helps us to obtain "one spot" tuning with the superheterodyne --- this means that any one station will "come in" only on one dial setting. Many of the most modern superheterodynes are, for the reasons already explained, using an intermediate-frequency of 455 kc; in fact, this particular i-f has been adopted as standard in the United States, as well as in the majority of the foreign countries.

You were told previously that to produce a given intermediate-frequency when tuning-in a certain station, the oscillator should be set to generate a frequency equal to either the intermediate-frequency plus the signal-frequency, or else the signal-frequency minus the intermediate-frequency. That is, if the intermediate-frequency is 450 kc and we want

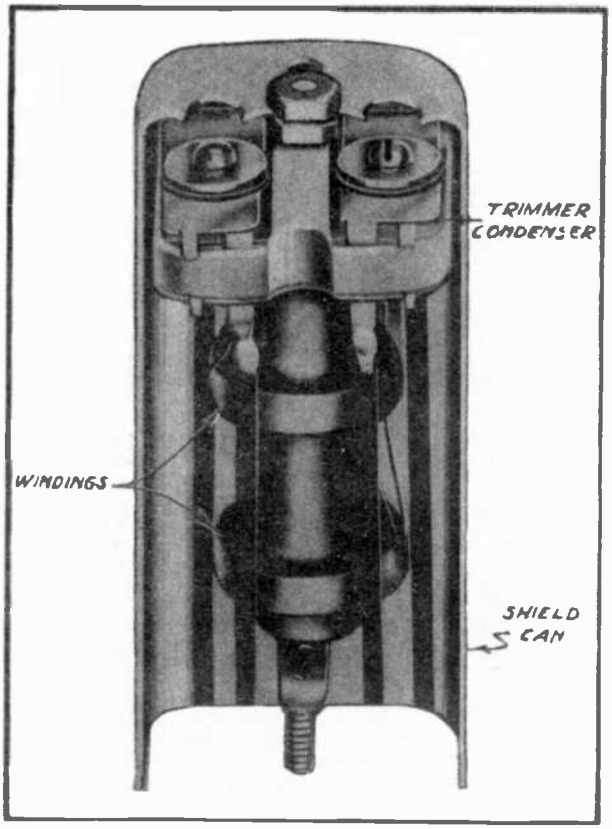

FIG. 13
COMPLETE I-F TRANSFORMER

to tune in a station whose broadcast frequency is 850 kc, then an oscillator-setting of either 1300 kc (450 + 850), or 400 kc, (850 - 450) can be used. In other words, there are two possible dial settings for any one station, but in modern broadcast practice only the higher oscillator frequencies are used.

Carrying this analysis a little farther, we find that if we have an intermediate-frequency of 500 kc, and wish to cover the broadcast band from 550 to 1500 kc with only the high setting of our oscillator, then this will require our lowest oscillator-frequency to be 1050 kc and its highest frequency 2000 kc. Therefore, all that we have to do is to build our oscillator so that it will not tune to any frequency lower than 1050 kc. In this way, together with our high intermediate-frequency, we can obtain one-spot tuning. This may also be stated in another way -- the oscillator will not now tune down to a frequency low enough to heterodyne with any broadcast station at more than one dial setting, and the intermediate-frequency can only be obtained by subtracting the signal-frequency from the oscillator-frequency. Whenever the same station is received at several dial-settings, these various positions of the dial are called repeat points.

There are different ways of looking at these various problems and an equal number of ways of arriving at a solution. For example, a high intermediate-frequency makes it easy to get one-spot tuning, but a lower intermediate-frequency makes the i-f amplifier more stable in its action, and more selective. Consequently, the logical thing to do is to compromise between these two extremes.

At the present time, an intermediate-frequency of 455 kc is most extensively used in commercial types of superheterodynes, as we have previously mentioned.

USING A T-R-F PRE-SELECTOR STAGE

To prevent more than one station at a time from heterodyning with the oscillator frequency, one or two stages of regular t-r-f circuits can be placed in front of the first detector. This is shown in Fig. 14. Let us pause for an instant and see just what effect that this arrangement produces.

The t-r-f stage, or stages, permits only one broadcast-frequency to affect the first detector, and therefore only one broadcast-frequency will be present in the grid circuit of the first detector with which the oscillator frequency can heterodyne. Actual figures will no doubt make this point more clear to you.

For example, consider two stations to be broadcasting at the same

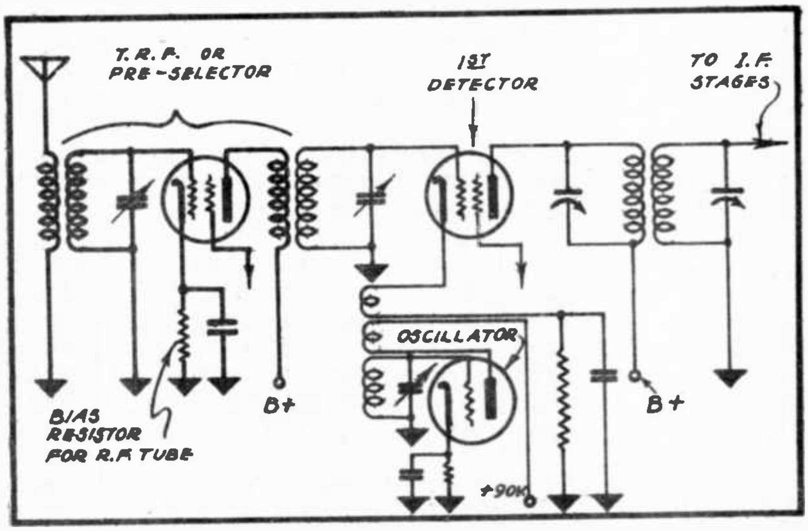

Fig. 14
Application of Pre-selector Stage

time, one of them having a frequency of 650 kc and the other a frequency of 1000 kc. Assuming the i-f to be 175 kc, we would use an oscillator frequency of 825 kc to bring in the 650 kc station.

This same oscillator-frequency would likewise heterodyne with the 1000 kc station to produce a 175 kc beat-frequency, the result being that the intermediate-frequency amplifier would amplify the signals from both these stations at the same time. This, of course, is not a desirable condition.

As will be noted from the example just given, the undesired frequency is separated from the desired frequency by the amount of twice the intermediate-frequency (2 x 175 kc = 350 kc). The undesired frequency in this case is generally referred to as the IMAGE FREQUENCY. In other words, an image frequency is the frequency of an unwanted signal that is separated from the wanted signal by an amount equal to twice the i-f frequency.

By placing a tuned r-f stage ahead of the first detector, we can "tune out" either of these two stations before their signal reaches the first detector and thus prevent their simultaneous amplification. However, it is not advisable to use too many tuned r-f stages ahead of the first detector.

SINGLE TUNING-CONTROL SUPERHETERODYNE

Many of the old style superheterodynes had all kinds of controls and gadgets mounted on their panels, and for this reason considerable patience was required on the part of the operator until he finally juggled these controls around sufficiently to obtain the desired response from the receiver. In straight t-r-f circuits, it is comparatively easy to arrange things so that all of the tuning condensers can be controlled from a common shaft and still tune all of these circuits alike.

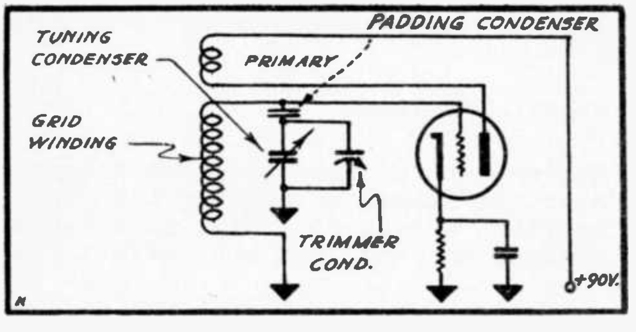

FIG. 15
OSCILLATOR CIRCUIT DESIGNED FOR SINGLE TUNING-CONTROL

In the superheterodyne, however, things are not quite so simple in this respect, because here we must consider that the first detector stage must be tuned through the broadcast frequency-band and the local oscillator through a different band of frequencies, and the relation between these two tuners must always be such as to heterodyne to a given intermediate-frequency.

To solve this problem, the most common practice is to use additional condensers in the tuned oscillator circuit,as shown in Fig. 15. Here the regular oscillator tuning condenser is connected across the grid winding of the oscillator tube, with a small fixed condenser in series. The fixed condenser is referred to as a "padding condenser." A trimmer is shunted across the oscillator section of the variable condenser, and sometimes also across the padding condenser.

These trimmer condensers are set as a service adjustment, and by properly balancing this system of condensers, the oscillator's tuning characteristics can be adjusted to such a point where its rotor plates can be rotated together with those of the first detector and pre-selector stage tuning condensers. During this simultaneous movement of the first detector and oscillator tuning condensers, they will always stay in the proper relation to each other to produce the required intermediate-frequency and for this reason they can both be controlled by a common shaft.

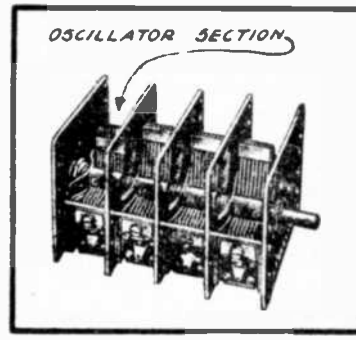

FIG. 16
SUPERHETERODYNE TUNING CONDENSER

The design and construction of single-control tuning condensers has been simplified somewhat through the use of special types of ganged tuning condensers. One of these new condenser gangs is shown in Fig. 16, where you will observe that the oscillator section consists of specially shaped plates of smaller size, so that the capacitive relation between this and the other sections of the condenser group is such that when used with a given combination of coils,the condenser sections will maintain the proper relation to supply the correct beat-frequency without the use of a special padding circuit.

A COMPLETE 7-TUBE SUPERHETERODYNE RECEIVER

Now that we have investigated the different sections of the superheterodyne receiver, let us next look at a complete receiver of this type. A typical superheterodyne circuit is shown in Fig. 17, and in Fig. 18 a typical arrangement of the parts on the chassis of this same receiver is shown.

Upon analyzing this circuit, you will observe that this particular receiver consists first of an r-f or pre-selector stage employing

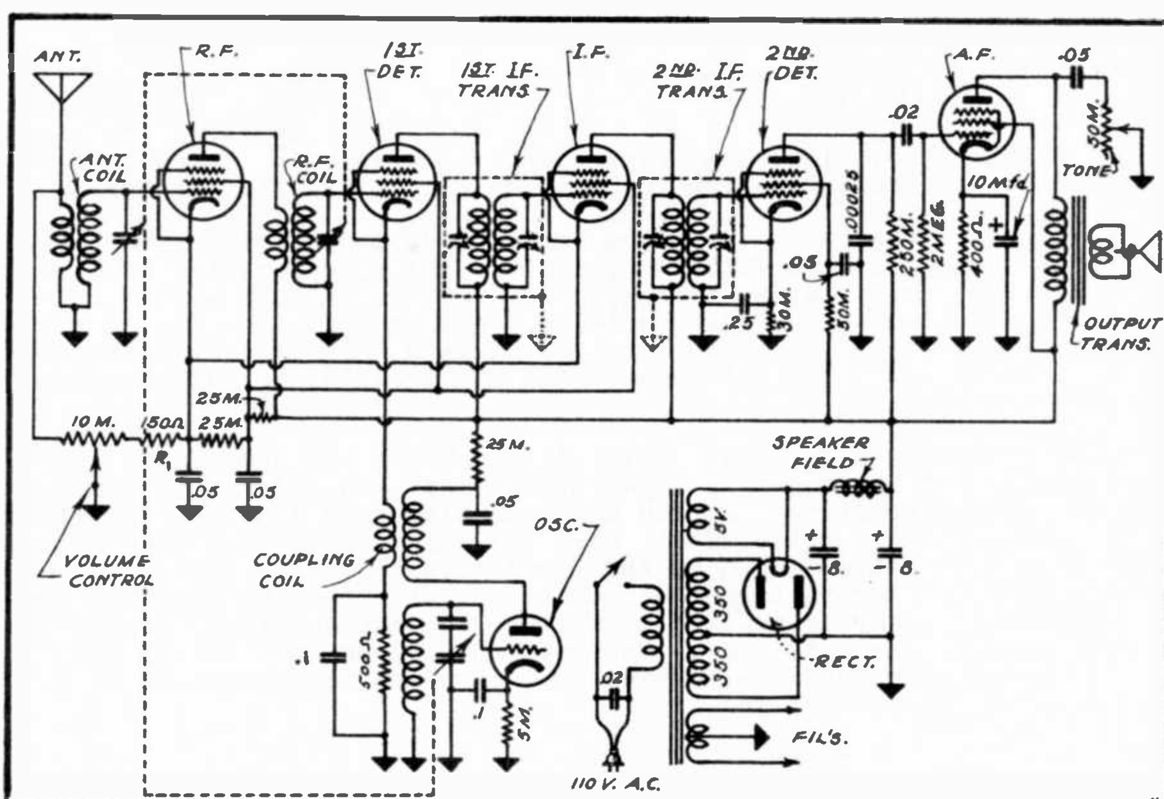

FIG. 17
CIRCUIT DIAGRAM OF SEVEN-TUBE SUPERHETERODYNE RECEIVER

a pentode-type r-f tube. This is followed by the first detector which is inductively-coupled to the oscillator and also "feeds" into the first i-f transformer. The pentode-type i-f tube passes the signal on to the second detector stage, in which an r-f pentode functions as a power detector. This stage in turn works into an audio power stage to which the speaker is coupled. The power supply is conventional.

Upon close inspection,you will no doubt now agree that the superheterodyne circuit in its entirety is really quite simple. Notice particularly that a three-gang tuning condenser is used. Resistor R_1 is connected in the cathode circuit of both the pre-selector stage and the i-f tube, so that both of these tubes will be subjected to the same bias voltage. The volume control connection is such that it will control the volume by simultaneously regulating the bias voltage for the pre-selector and i-f tube, as well as the amount of signal energy passing through the primary input of the antenna transformer.

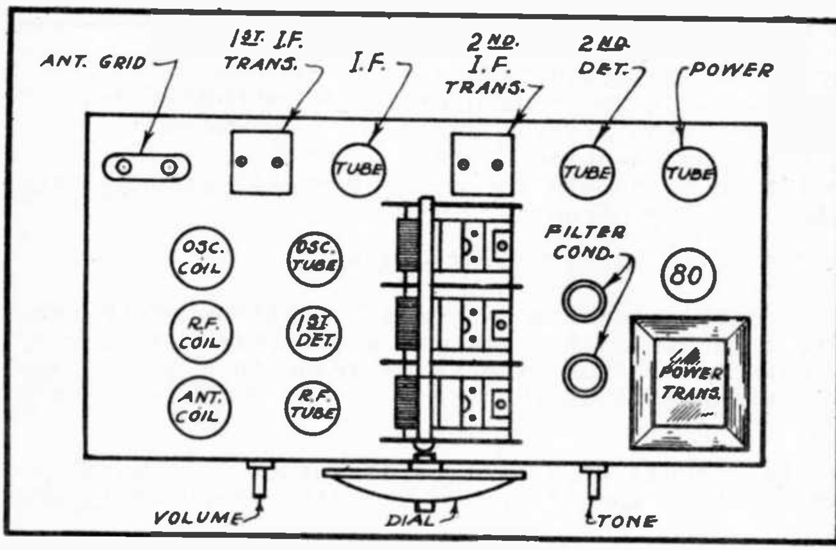

Fig. 18
Typical Chassis Arrangement of Seven-tube Superheterodyne Receiver

The parts values as given in this diagram are typical of circuits of this type, size, and arrangement. However, in later lessons you will receive more detailed information concerning this matter.

In this lesson we confined our discussions strictly to those superheterodyne circuits wherein separate first detector and oscillator tubes were used. By so doing,you were better enabled to acquire a clearer conception of the fundamental principles involved. In the next lesson, however, you will learn how the duties of the first detector and oscillator are cared for by a single tube, employing the electron-coupling principle.

We sincerely hope that this lesson has given you a good basic understanding of the constructional principles and operation of the superheterodyne receiver. As you continue with your studies, you will of course receive a great deal more valuable information concerning this type of receiver, such as the application of the newest tubes, various types of superheterodyne receivers with special features incorporated in their circuits, servicing superheterodynes, designing superheterodyne circuits, etc. In fact, the lesson immediately following is devoted exclusively to many of the modern features used in the latest model superheterodynes.

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EXAMINATION QUESTIONS

LESSON NO. 18

1. - What is the advantage of using a fairly high intermediate frequency in a superheterodyne receiver rather than a low frequency?

2. - What is meant by the expression "repeat point",as related to the tuning characteristic of a superheterodyne receiver?

3. - What advantages does a superheterodyne receiver offer over a straight t-r-f receiver?

4. - What is meant by an "image frequency" relative to a superheterodyne receiver?

5. - If the i-f amplifier of a certain superheterodyne receiver is adjusted or "peaked" to resonate at a frequency of 455 kc and you are listening to a broadcast station operating at a frequency of 800 kc, then to what frequency will the receiver's oscillator circuit be tuned during the reception of this program?

6. - Explain the heterodyne principle, as applied to superheterodyne receivers.

7. - Draw a circuit diagram showing how a pre-selector stage, first detector, and oscillator may all be inter-connected so as to produce a beat or intermediate-frequency.

8. - Explain how it is possible to maintain a constant frequency difference between the oscillator, and other tuned circuits which are all tuned by the same gang tuning condenser.

9. - Why is it advisable to use a pre-selector stage in conjunction with a superheterodyne circuit?

10. - Describe a typical i-f amplifier.

- Self Reliance -

Work is a mighty hard thing to keep track of. A man will go to an employer saying he has been looking for work every where, but cannot find it. The employer gets busy, finds work and gives it to him. Then the employer expects work from the employee, and when he does not get it, pays him off and starts him out looking for work again and the chances are he never finds it.

The less you require looking after, the more able you are to stand alone and complete your tasks, the greater your reward. Then if you cannot only do your work, but also intelligently and effectively direct the efforts of others, your reward is in exact ratio; and the more people you direct, and the higher the intelligence you can rightly lend, the more valuable is your life.

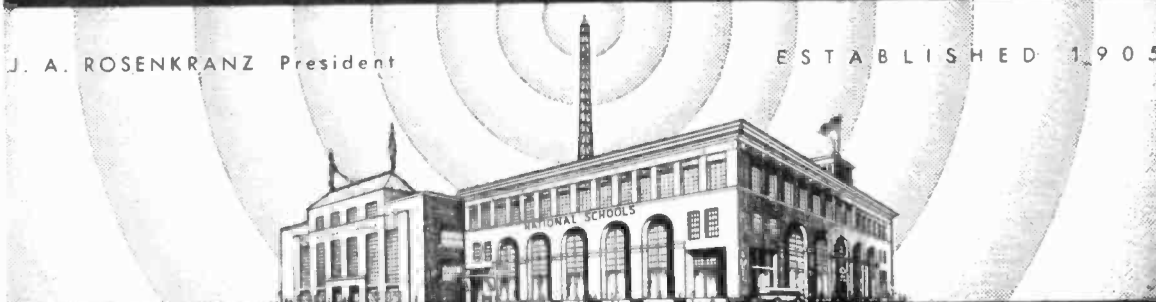
Practical Technical Training In

RADIO·TELEVISION

AND ALLIED ELECTRONICS

J. A. ROSENKRANZ President

ESTABLISHED 1905



NATIONAL SCHOOLS ★ LOS ANGELES 37, CALIF.

LESSON NO. 19

MODERN SUPERHETERODYNE RECEIVERS

You are by this time familiar with the fundamental principles of superheterodyne receivers. A number of important features applicable to this type of circuit which have not yet been discussed will be brought to your attention in this lesson.

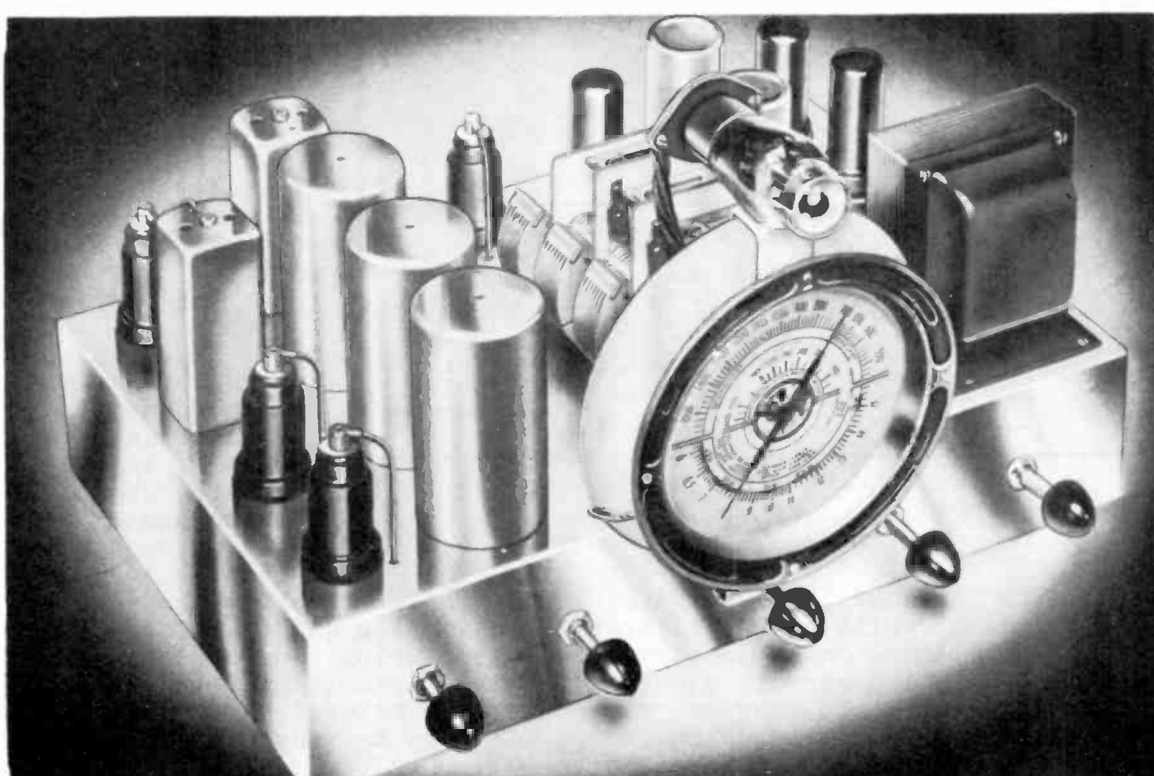


FIG. 1
MODERN SUPERHETERODYNE RECEIVER

THE AUTODYNE SYSTEM

In all of the superheterodyne receivers which you have studied thus far, two separate tubes were employed in the mixer circuit. One of these tubes functioned as the first detector and the other as the oscillator. Soon after the superheterodyne principle became popular in commercial receivers, engineers commenced devising means whereby the separate oscillator tube could be eliminated, and the process of "mixing" accomplished by a single tube.

The AUTODYNE SYSTEM provided the first successful means of accomplishing this. The autodyne system was quite popular some time ago in superheterodyne receivers of compact design, in that by eliminating the additional oscillator tube, considerable space was saved. It is of course true that the more efficient pentagrid converter tube has replaced the autodyne method of frequency conversion in superheterodynes of later design; however, we can not overlook the fact that superheterodynes employing the autodyne principle are still in use, and it is therefore advisable for you to become acquainted with them.

THE AUTODYNE CIRCUIT ARRANGEMENT

In Fig. 2 you are shown a circuit diagram of the mixer section of a superheterodyne receiver wherein the "autodyne" principle is employed. Here you will note that an ordinary r-f pentode-type tube is being used as the combination first detector and oscillator.

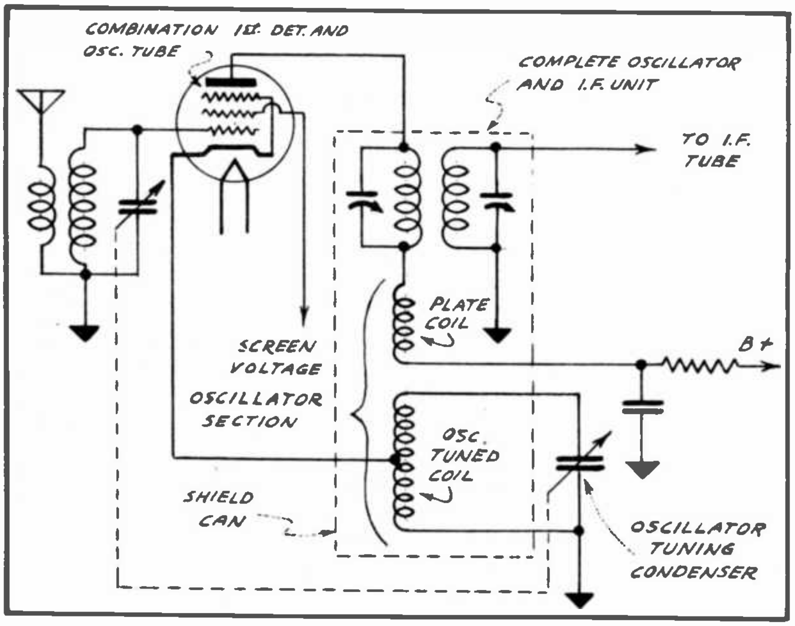


FIG. 2
AUTODYNE METHOD OF FREQUENCY CONVERSION

A common method of arranging the oscillator coil in receivers of this type was to enclose the oscillator coil assembly in the same shield can with the first i-f transformer; this is indicated in Fig. 2 by the dotted lines which form the enclosure for this coil assembly. Complete coil assemblies as this are known as "Composite oscillator--i-f units." In Fig. 3 you are shown the constructional details of such a unit.

The coils of the i-f transformer are in this case mounted on a wooden dowel, while the oscillator tuned-winding and the plate circuit winding are wound on a piece of insulative tubing surrounding the i-f coils. The plate circuit winding is wound directly over the tuned oscillator winding to provide close coupling between them. Insulating material is placed between these two windings to prevent "shorting."

The i-f trimmer condensers are mounted in the upper part of the shield can, holes being provided in the top of the can through which they can be adjusted. All winding leads are brought out through the bottom of the can.

Since part of the oscillator-tuned winding is in series with the cathode circuit of the combination first detector-oscillator tube (see Fig. 2), the oscillator coil will in effect be connected in the control grid circuit of this tube, while at the same time being inductively-coupled to the windings of the first i-f transformer. The oscillator-frequency will therefore react with the incoming signal-frequency to produce the desired beat-frequency that is to be amplified by the i-f amplifier.

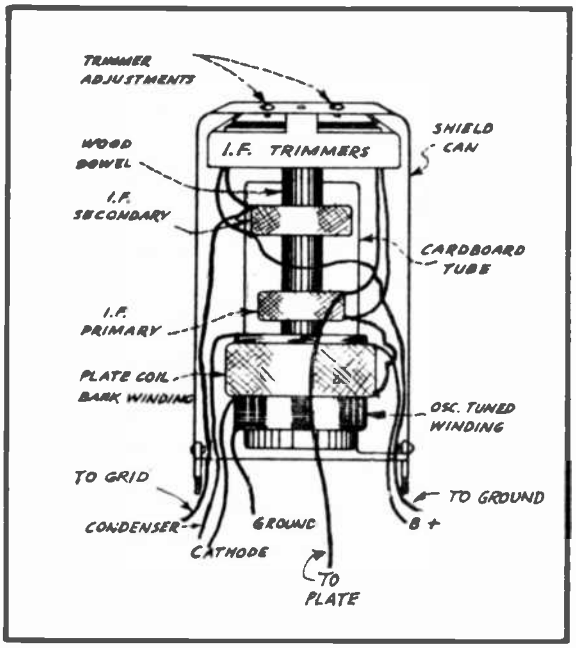


FIG. 3
COMPOSITE OSCILLATOR -- I-F UNIT

PENTAGRID CONVERTER TUBES

In superheterodyne receivers of more recent design, a special tube is used to serve as the combination first detector and oscillator. This tube is known as a PENTAGRID CONVERTER, and it is designed in such manner that the first detector and oscillator sections of the circuit are each connected to individual grids within the tube. The electron stream within the tube thus serves as the coupling medium between the first detector and oscillator sections. We call this method of uniting the first detector and oscillator sections ELECTRON COUPLING.

At this time, we will describe briefly the construction and operation of pentagrid converter tubes as applied to superheterodyne receivers. However, in later lessons other uses for this valuable tube will be brought to your attention. Later lessons will also familiarize you with other applications for electron coupling wherein the pentagrid converter tube is not used.

In Fig. 4 is shown the symbol of a pentagrid converter tube. The constructional features and operating principle of this tube can be analyzed readily by considering it as two individual tube sections, enclosed in a single glass envelope.

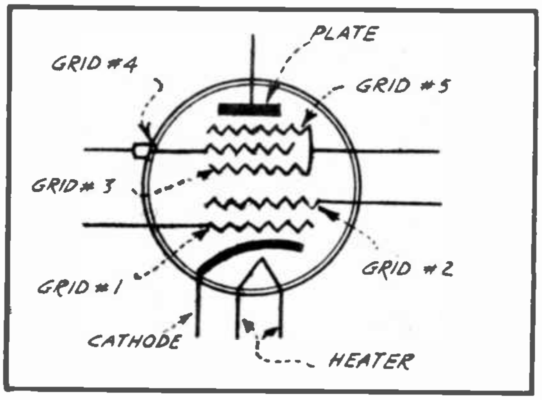


FIG. 4
SYMBOL OF PENTAGRID CONVERTER TUBE

Grid #2, in Fig. 4, instead of being constructed in the form of a conventional grid, is built in the shape of two vertical metal rods which are connected together. This grid in effect acts as a plate of the tube's triode section, and for this reason is called the ANODE GRID.

That section of the tube consisting of the heater, cathode, grid #1 and grid #2 acts as a conventional triode oscillator tube, and is connected to the circuit as shown in Fig. 5. It is well that you familiarize yourself with the circuit connections before commencing with the analysis of its operation.

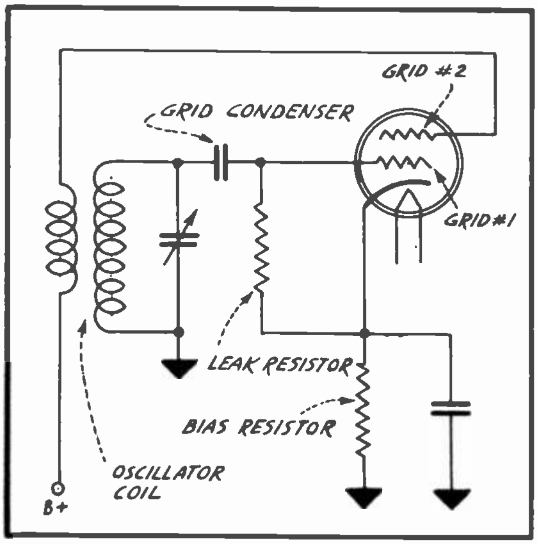


FIG. 5
THE OSCILLATOR SECTION

By studying Fig. 5 closely,you will observe that the oscillator tuning circuit is connected to grid #1 of the tube through the grid condenser, and that the plate winding of a conventional superheterodyne-type oscillator coil is connected between B+ and grid #2. With the connections thus made, the anode grid is in effect being used as the plate of a triode oscillator tube; this section of the tube therefore produces oscillations at controlled frequencies, the same as the oscillator in the older superheterodynes.

Having considered the oscillator section of the tube, let us now investigate the other element connections and analyze the operation of the system as a whole. In Fig.6 is shown the complete circuit of the pentagrid converter.

Observe in Fig. 6, that the oscillator circuit remains exactly the same as illustrated in Fig. 5. Closer inspection of Fig. 6 will reveal that grid #4 serves as the control grid,and to which the tuning circuit of a conventional first-detector is connected. The plate of this tube is connected through the primary winding of an i-f transformer to a B+ potential. Grids #3 and #5 are connected together within the tube, and serve as a shield between the control grid #4 and the plate, as well as between grid #4 and the anode grid #2. In other words, grids #3 and #5 together act as a screen-grid which is connected to a B+ potential of lower value than the plate voltage, and bypassed with a fixed condenser.

This second section of the tube may be considered together with the cathode and heater (which is common to both sections of the tube) as a screen-grid tube.

The transformer (r-f) in the first-detector circuit of Fig. 6 is exactly the same as that used in other superheterodyne circuits which you have already studied, as is also the oscillator coil. However, in the circuit design of Fig. 6, the r-f transformer of the first-detector circuit and the oscillator coils are each wound on separate forms,

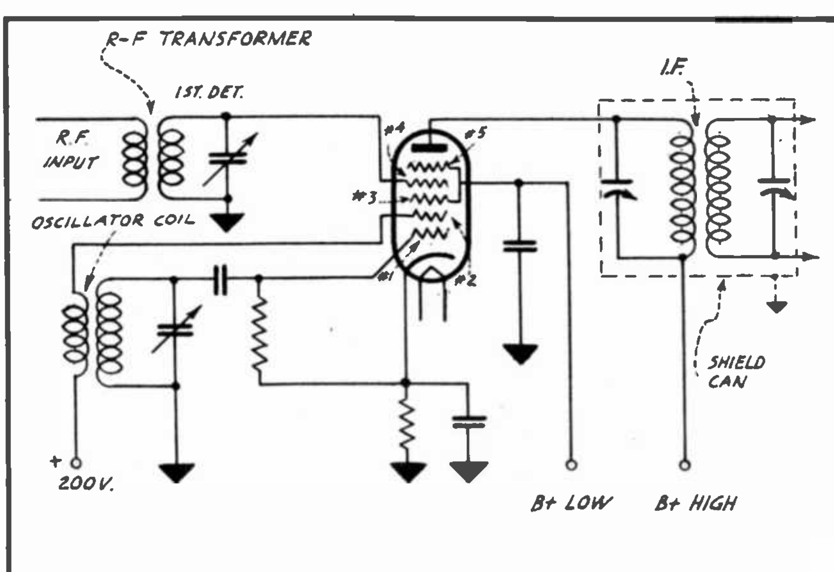


FIG. 6
MIXER CIRCUIT WITH PENTAGRID CONVERTER

so placed on the receiver chassis that there is no inductive coupling between them.

CIRCUIT OPERATION USING A PENTAGRID CONVERTER

With this circuit in mind, let us now see how the complete system operates to produce the desired intermediate-frequency.

To begin with, the heated cathode emits electrons which are attracted toward the positively-charged anode grid #2, and since grid #1 is placed between the cathode and grid #2, these electrons will be controlled in their flow by grid #1 whose potential varies at a rate determined by the frequency to which the oscillator circuit is tuned. Conditions being such, this same electron stream will be modulated (varied in intensity) at the oscillator frequency.

The anode grid is not capable of completely obstructing the flow of electrons toward the plate because it offers but little exposed surface. For this reason, the greater portion of the electron stream continues its movement toward the plate which is charged to a still higher positive potential; however,before reaching the plate, the electron stream first comes under the influence of grid #3 which is also being operated at a positive potential with respect to the cathode. Grid #3 also offers little obstruction toward the electron flow due to its construction; and being charged at a fairly high positive potential, it further accelerates the flow of electrons toward the plate. Remember, however,that the electron stream in this region of the tube is already in a modulated form, conforming to the oscillator-frequency.

The incoming signal-frequency, appearing in the tuning circuit of the first detector section, is applied to grid #4 and therefore further modulates the electron stream which has already been modulated at the oscillator frequency. This two-fold modulation creates a heterodyne effect that produces components of plate current, the frequencies of which are the various combinations of the oscillator and signal frequencies. Then, since the primary circuit of the first i-f stage is designed to resonate at the intermediate-frequency, only the desired intermediate-frequency will be present in the secondary circuit of the i-f transformer for further amplification.

The chief advantages obtained through this system of mixing or frequency conversion are the following:

(1) It simplifies the design of the oscillator circuit and at the same time eliminates one tube from the circuit.
(2) It eliminates undesired intercoupling effects between the signal, oscillator, and mixer circuits, and also its resulting detuning characteristic.
(3) It reduces local frequency radiation and is more stable in operation.

The socket connections, operating characteristics, and other specifications of individual types of pentagrid converters are given in your Job Sheets and other tube reference sources which we furnish you.

A MODERN NINE-TUBE A-C SUPERHETERODYNE

A modern superheterodyne circuit,in complete form,is illustrated in Fig.7. In this case,eight metal tubes and a glass tube are employed.

Here you will see that a tuned-radio-frequency stage precedes the first detector; this feature prevents more than one station acting upon the first-detector at the same time. The three sections of the

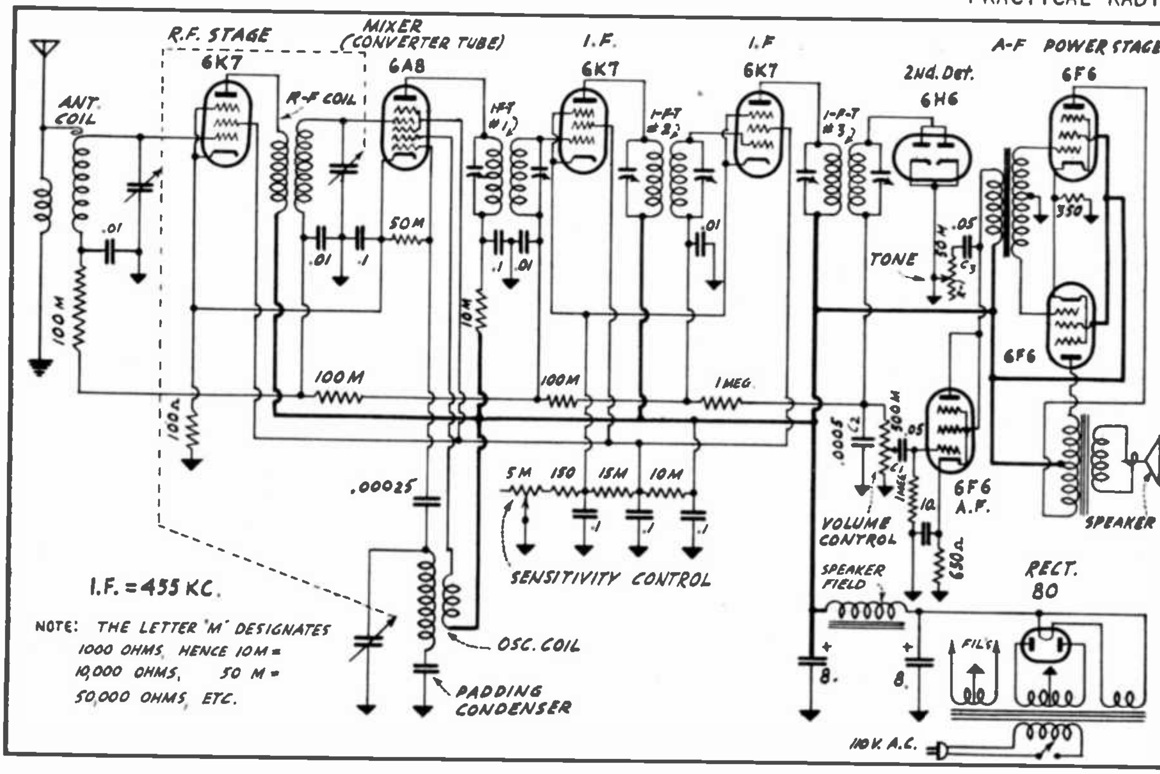


FIG. 7
NINE-TUBE A-C SUPERHETERODYNE RECEIVER

main variable tuning condenser, which are connected in these circuits as well as in the oscillator circuit, are controlled by a common shaft indicated by the dotted-line connection between them.

Two windings are included on the oscillator coil; one is connected in the anode grid circuit of the oscillator tube, and the other in the circuit of the same tube's grid #1. There is no inductive coupling between this coil and the first detector r-f coil; coupling in this new circuit is furnished by the coupling-effect provided between the different elements within the converter tube, as already explained in this lesson.

The tuning controls in Fig. 7 are so arranged that the oscillator-frequency will always differ from any signal-frequency by 455 kc, which is the intermediate-frequency used in this particular receiver. The i-f output from the converter tube (mixer) acts upon the grid circuit of the first i-f tube through the first i-f transformer which is permanently adjusted to tune this circuit to 455 kc.

The first i-f tube is coupled to the second i-f tube by means of transformer coupling. The primary and secondary windings of this transformer are both permanently tuned to the intermediate-frequency by means of trimmer condensers.

The second detector is a half-wave diode detector, which also supplied the automatic volume control action in this receiver. In later paragraphs of this lesson, you will be given an explanation of this principle.

The second detector is connected to the first a-f tube by means of resistance-capacity coupling. Audio frequencies react through this coupling condenser C-1, because the i-f currents are all bypassed to ground through condenser C-2.

The first a-f tube is in turn coupled to two power tubes connected in a push-pull arrangement. A TONE CONTROL, consisting of a condenser and variable resistor in series,is connected across the primary winding of this transformer. These parts are indicated in the circuit diagram as C-3 and R-1. The impedance of this tone control circuit may be varied by regulating the position of the adjustable resistor arm. The greater the resistance-setting, the less will be the percentage of high frequencies bypassed to ground. In this way, the operator of the receiver increases or decreases the effective range of the audio frequencies and thereby regulates the pitch of the sound produced by the speaker. This control is operated from the control panel -- you will hear more about it in later lessons.

Notice in Fig. 7 that pentode-type tubes are used in the preselector, intermediate-frequency, and audio-frequency stages, but the first a-f stage is triode-connected; the mixer section employs the converter-type tube.

WHY AUTOMATIC VOLUME CONTROL IS USED

As previously mentioned, the receiver diagrammed in Fig. 7 has automatic volume control features incorporated in its circuit. No attempt will be made at this time to explain and describe completely all of the many principles of automatic volume control, as this subject is treated thoroughly in future lessons. However, so that you will understand how automatic volume control is applied to the circuits here shown, a brief but comprehensive explanation of this system will be given at this time.

If you have listened to radio receivers in which an automatic volume control system was not employed, you have no doubt noticed that it is a common occurrence while listening to a program, or when tuning from one station to another, for the volume to suddenly increase to a blare or else decrease to such an extent that the speaker sounds are hardly audible. This condition is especially pronounced while tuning-in stations of different power and located at various distances from the receiver.

This condition is really annoying, as it makes it necessary for the operator to turn the volume control either "up" or "down", to keep the volume at a pleasing level. After all, the receiver is simply amplifying whatever signal energy reaches it and consequently, it is no more than natural that the speaker volume should increase when more signal energy is available for amplification.

Since it is impossible to control the amount of signal energy reaching the millions of listeners at all different points of the globe, the logical step for eliminating the annoyance of sudden increases or decreases in volume is to devise some means whereby the receiver automatically provides a volume of constant level when a station has been tuned-in. In the latest types of receivers, this is accomplished by means of AUTOMATIC VOLUME CONTROL -- quite often spoken of simply as "a-v-c."

Briefly, automatic volume control makes the receiver more sensitive to weak signals and less sensitive to strong signals. In this way, it serves to "fill-in" the gaps during the variation of signal strength. This is accomplished electrically by automatically controlling the grid bias voltage applied to the r-f tubes. In some of the more elaborate a-v-c systems the grid bias voltage is controlled by a separate tube; however, in the circuit of Fig. 7, the control action is furnished by the dual-purpose second detector tube. With this fundamental idea in mind, let us continue now and see just how this is all brought about.

HOW AUTOMATIC VOLUME CONTROL IS ACCOMPLISHED

In Fig. 8 you are shown the essential parts of the a-v-c circuit. This particular circuit is similar to the a-v-c portion of the superheterodyne receiver illustrated in Fig. 7. The system operates as follows:

Up to the second i-f transformer, the signal is passed through the circuit in the customary manner, but in the secondary circuit of the second i-f transformer, the signal is impressed upon the two diode plates of the combination diode detector and a-v-c tube. Both of these diode plates are connected to one side of the secondary circuit.

Since the cathodes of this tube are emitting an electron stream, while the two diode plates change their potential from positive to negative, in accordance with the signal-voltage changes, it is clear that the cathodes and the two diode plates together constitute a rectifier or detector. Both diode plates being connected together, this portion of the tube operates as a "diode" or half-wave rectifier.

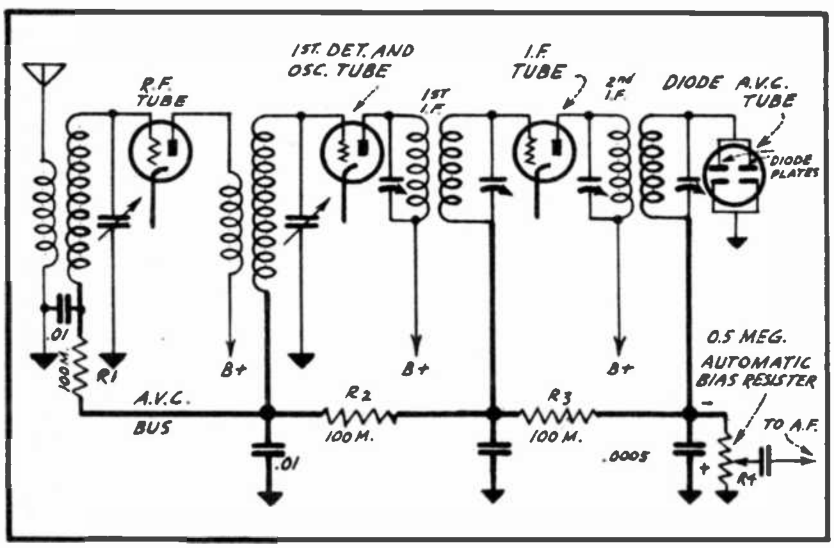


FIG. 8
DETAILS OF A-V-C CIRCUIT

The current flow, which occurs during this process of rectification, passes through the 0.5 megohm resistor, R_4 in Fig. 8, causing a corresponding voltage variation across this resistor and the .0005 mf condenser by which it is shunted.

This rectified current will also produce a corresponding audio voltage across the automatic bias resistor R_4, which is equipped with a variable control arm through which these audio variations are fed to the a-f section of the receiver.

The r-f signal current (electron flow), as it is rectified by the diode tube, will flow from this tube's cathode toward its interconnected diode plates; all of this rectified current flows through the automatic bias resistor R_4 in such a direction as to make the lower end of this resistor positive and its upper end negative.

You will observe that the grid-returns of the r-f, mixer, and i-f tubes are all connected to the a-v-c bus through their respective filters, consisting of the 0.1 megohm resistors and the 0.01 mf condensers. This combined a-v-c bus is in turn connected to the negative end of the automatic bias resistor R_4. Therefore, if the r-f signal voltage as applied to the diode plates is increased, the flow of rectified current through the automatic bias resistor will increase correspondingly; this will bring about a greater voltage drop across this resistor. In this way, the negative bias voltage on the r-f and i-f tubes is increased and the volume will therefore decrease.

In like manner, if the signal voltage acting upon the diode plates is decreased, the flow of rectified current through the automatic bias resistor will decrease, so that less bias voltage is applied to the r-f and i-f tubes;the volume therefore automatically increases. Thus we find that greater signal strengths reduce the volume and lesser signal strengths increase the volume; hence, for any one volume control setting, the volume remains practically constant.

I-F EXPANSION

All of the i-f transformers described thus far, had a fixed coupling relationship between the primary and secondary windings. Such a transformer will pass an r-f signal of a definite band-width; that is, its sharpness of tuning cannot be varied by the set-operator.

The "closer" or "tighter" the coupling, the broader will be the tuning characteristic of the transformer -- the looser the coupling, the sharper will be the tuning characteristic.

The average superheterodyne receiver, equipped with conventional i-f transformers of fixed coupling, is satisfactory under normal conditions of operation. However, there are instances where the receiver will be operated in congested areas, and where it must tune much sharper than normally in order to eliminate interference between stations. While there are many methods for increasing selectivity, the usual practice in such cases is to provide means whereby the coupling between the coils of the i-f transformer can be varied. Such practice is referred to as i-f expansion -- meaning that the broadness of tuning, and the band-width passed, can be increased or expanded, as well as being decreased.

In Fig. 9 you are shown the circuits of a typical i-f amplifier stage, employing i-f expansion. You will observe that the secondary winding of the i-f transformer is tapped at three points, which will allow three different degrees of selectivity to be employed. This arrangement varies the coupling electrically, but not physically. However, in some receivers the position of the two coils is actually changed, but this method calls for a much more costly assembly. The usual practice, therefore, is to change the coupling relation electrically.

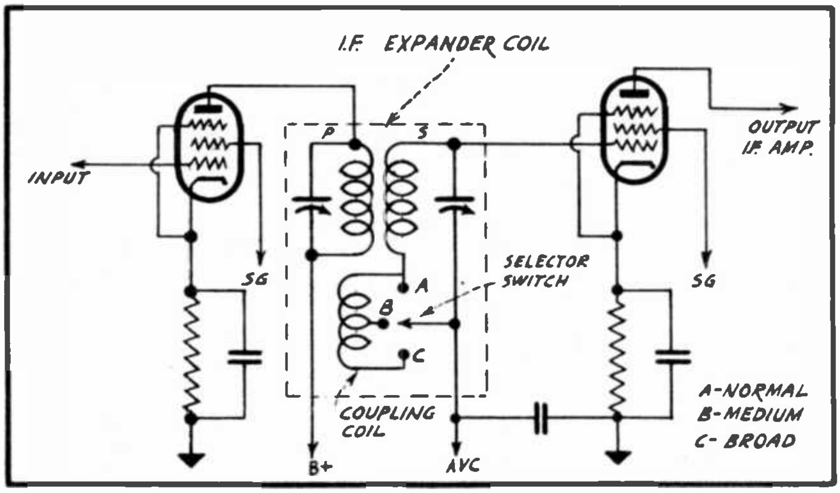


FIG. 9
I-F EXPANDER STAGE

OPERATION OF THE I-F EXPANSION CIRCUIT

In earlier lessons you learned that when two coils of like frequency characteristics are placed in an inductive relationship with each other,maximum energy-transfer between them will take place when the circuit is operated at the particular frequency to which they are tuned. Also the more exact the condition of resonance, the greater will be the amount of signal-energy transferred. You also learned that the coupling or distance between the coils affects the selectivity or band-width of the signal handled by them.

Again referring to Fig. 9, you will observe that when the selector switch is placed in position A, the secondary of the i-f transformer is tuned to exact resonance with the primary; when the switch is placed in position B, a portion of the coupling coil is connected in the circuit. Due to its close inductive relationship to the primary coil, this coil, when connected in the secondary circuit, will provide closer coupling between the primary and secondary circuits, and consequently the transformer-tuning will be more broad. The detuning effect, by adding more turns to the secondary circuit, also broadens the tuning.

Closing the switch at position C will add still more inductance to the secondary winding and at the same time will increase the coupling, so that the tuning of the transformer is even more broad.

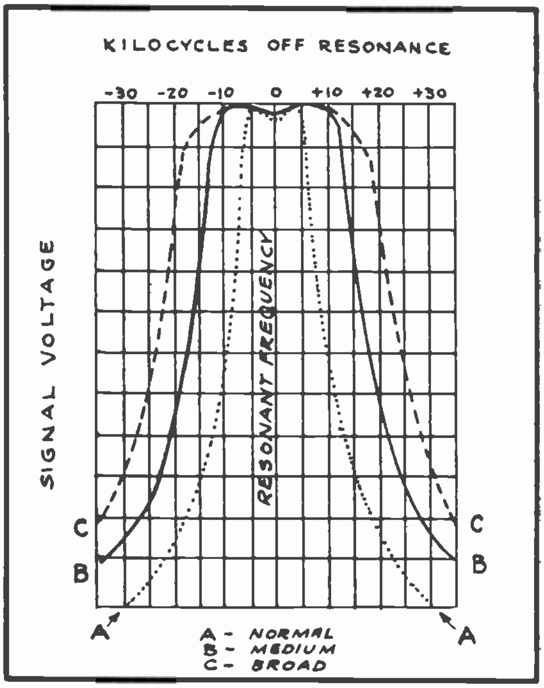


FIG. 10
HOW I-F EXPANSION VARIES THE RESONANCE CURVE

By referring to the resonance curves shown in Fig. 10, you will observe how the actual band-width will vary as the coupling is correspondingly increased or decreased from normal, to medium, to broad. The broader the tuning, the wider is the curve in Fig. 10. You will learn more about these curves in advanced lessons.

PERMEABILITY-TUNED I-F TRANSFORMERS

In the previous lesson, you were shown the constructional details of an i-f transformer that employed small compression-type trimmer condensers, shunted across the primary and secondary windings. You were also told how these trimmer condensers made it possible to properly align the transformer to the particular i-f being used.

While this method of alignment is entirely practical and widely employed in the construction of i-f transformers, there is nevertheless in existence still another very satisfactory method for trimming these windings, and which at the same time materially increased the gain and selectivity of the transformer. The latter method consists of inserting a magnetic material inside of the form on which the coils are wound, and varying the position of this core to change the tuning. An i-f transformer of this type is shown in Fig. 11, where you will observe that no variable trimmer condensers are employed.

SOME FACTS ABOUT IRON-CORE MATERIAL

The core substance now used in iron-core transformers is a magnetic material known as POLYIRON. The chief advantage offered by it is that it produces an increase in the effective inductance of a coil without increasing its effective resistance. At high frequencies, the losses introduced by ordinary iron and other previously known core materials are so high that the reverse is true; that is, the resistance increase is much greater than the inductance increase.

The outstanding properties of this new core material have permitted such remarkable improvements in the design of high-frequency inductors that a new era in radio receiver performance has been initiated. The evidence of this improvement is higher gain and greater selectivity.

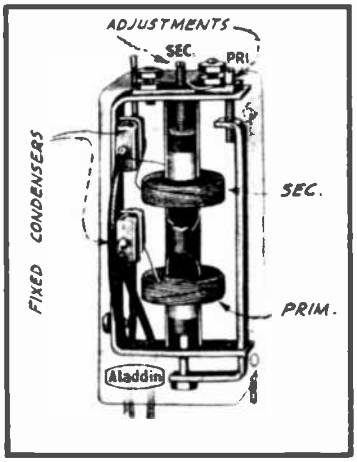


FIG. 11
IRON-CORE I-F TRANSFORMER

The inductance of any air-core coil may be increased without increasing the number of turns on the coil by merely inserting in the field of the coil a small amount of this new core material. This phenomenon can be observed readily when the end of such an iron core is inserted in a coil.

As just mentioned, when a coil is wound on an iron core made of this new material, fewer turns are necessary to secure a given inductance than if the coil did not have such a core. Since there are fewer turns, less wire is required, and the resistance of the winding is therefore reduced. Consequently, when employed in a resonant circuit, the inductor having such a core provides sharper tuning. Furthermore, these units offer remarkable freedom from frequency-drift, and eliminate difficulties previously encountered with mica trimmer condensers.

VARYING THE INDUCTANCE

From this description of the properties of iron-core or permeability-tuned i-f transformers, you can readily see that if this core substance is varied, then the inductance will be changed accordingly. Again refer to Fig. 11, and observe how the magnetic material is moved in and out of the coil-form by means of a screw adjustment. Thus, the i-f transformer can be tuned to the desired frequency.

Upon referring to Fig.12 you will note that two small fixed mica condensers are shunted across each of the windings. These fixed condensers are also shown in Fig. 11. The purpose of these condensers is to increase the tuning ratio of the coils; that is, the inductance-capacity relation is then such that the selectivity is improved to a further degree than is possible with the iron-core alone.

In some iron-core i-f transformers, the iron-core material remains in a fixed position, and the necessary tuning compensation is accomplished by means of small condensers that are connected across the coil windings. In this case these condensers are of the semi-variable type, and the tuning adjustment is then made as on i-f transformer units using compression-type trimmer condensers. Modern i-f transformers are manufactured in both the iron-core and air-core types.

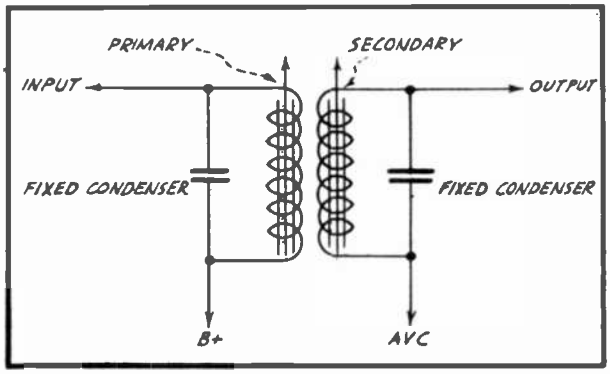


FIG. 12
I-F TRANSFORMER WITH IRON-CORE TUNING

PERMEABILITY-TUNED SUPERHETERODYNE RECEIVERS

Due to the success of iron-core i-f transformers in superheterodyne receivers, considerable effort has been expended by receiver engineers to adapt these coils to r-f circuits, whereby the tuning can be varied from one end of the broadcast band to the other, the same as is accomplished by the variable condenser. The idea in this case is to eliminate the variable tuning condenser from the circuit entirely, and to use in its place a ganged group of continuously variable iron-core tuning coils whose tuning range extends through the broadcast band. This is known as continuous permeability tuning. A modern superheterodyne tuning circuit, illustrating this feature, is presented in Fig. 13.

Upon inspection of the circuit diagram in Fig. 13, you will observe that two such coils are used, one for the antenna-detector circuit and one for the oscillator circuit. You will further notice that no main variable tuning condenser gang is employed; however, a small trimmer condenser is connected across each coil to properly align it. Fixed condensers are also shunted across each of these coils to increase the tuning ratio, as already explained relative to iron-core i-f transformers.

Continuous variable tuning throughout the standard broadcast band is accomplished by moving the iron-core material in or out of the coil forms, as illustrated in Fig. 14, where a bird's-eye-view of the tuning assembly is shown. Moving the iron core farther into the coil increases the coil's inductance and tunes the circuit to a lower frequency.

While the particular tuning assembly shown in Fig. 14 features a drum-type dial scale, the assembly could be adapted easily to the popular "slide rule" type dial scale, by merely mounting a pulley on

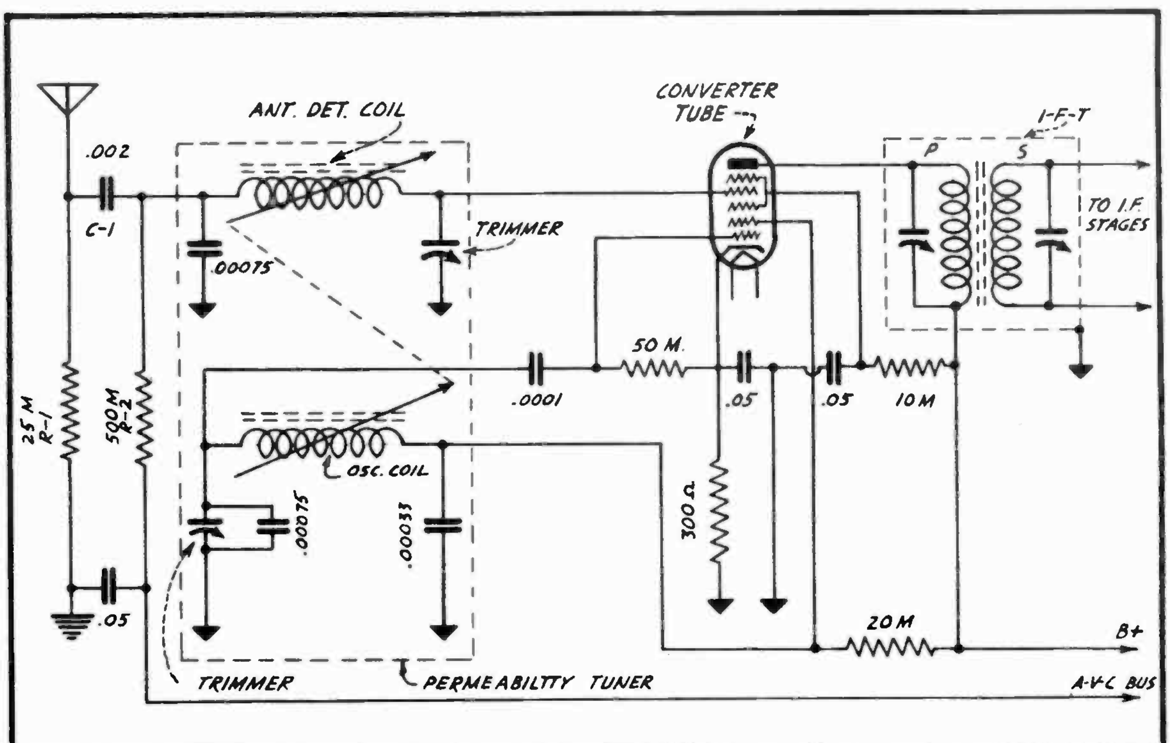


FIG. 13
PERMEABILITY-TUNED SUPERHETERODYNE TUNER CIRCUIT

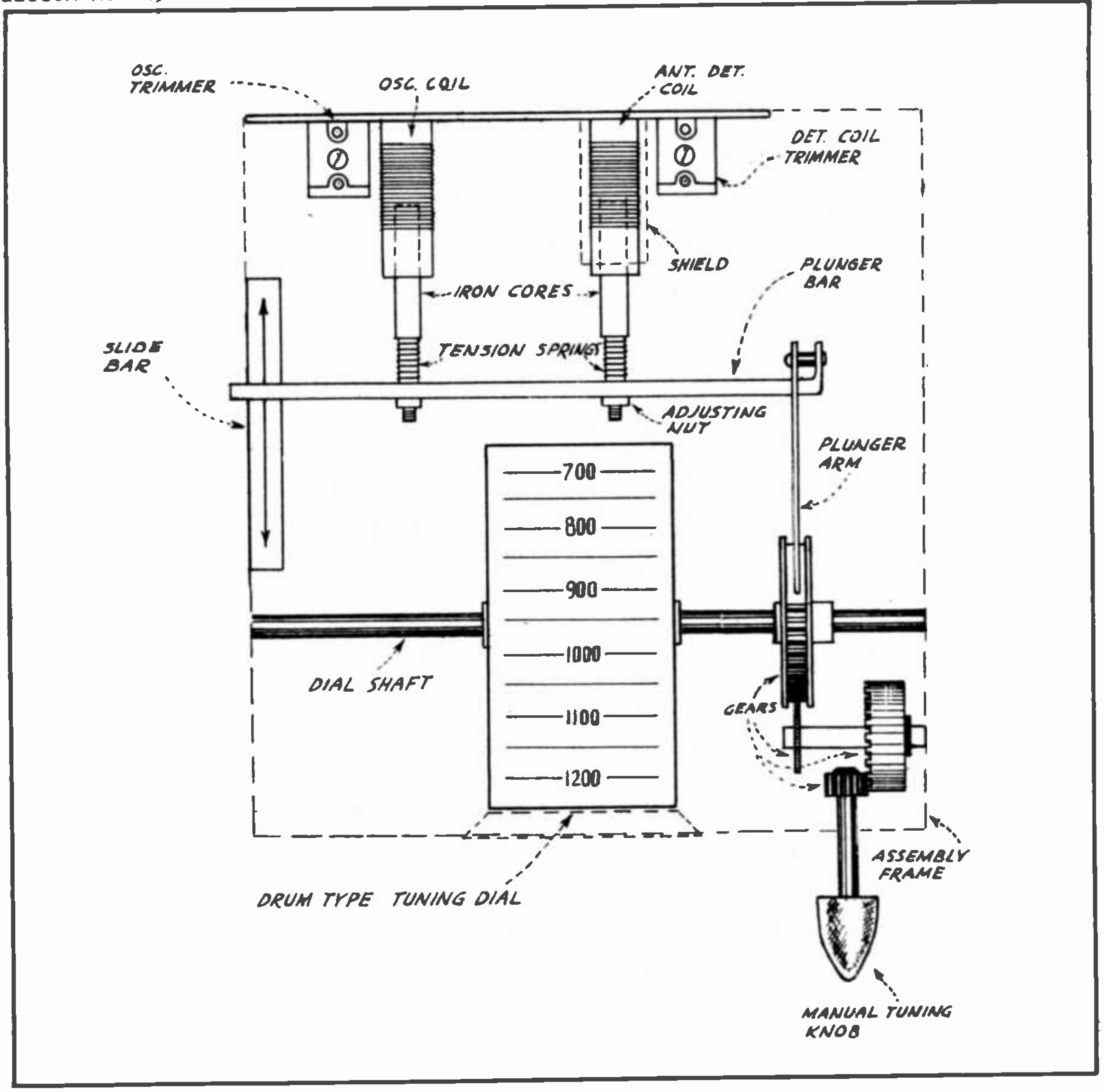


FIG. 14
PERMEABILITY TUNING ASSEMBLY

the dial shaft. A dial cable may then be used as the drive-coupling to operate a slide-rule pointer across the calibrated scale.

Upon studying Fig. 14 more closely, you will observe that rotating the manual tuning knob causes the train of gears and levers to be operated in such a manner as to move the iron-core material either in or out of the two cylindrical coil forms simultaneously. In other words, the tuning adjustments for these two coils are ganged together the same as are the various sections of a ganged variable tuning condenser. This "ganging" of the tuning controls is indicated by a dotted line in Fig. 13.

OPERATION OF THE CIRCUIT

The electrical principle of the permeability tuner shown in Fig. 13 is basically the same as the mixer circuit shown in Fig. 6 of this lesson, where a conventional type variable tuning condenser is used to tune the detector and oscillator coils.

In the circuit diagrammed in Fig. 13, all signal frequencies are received equally well by the antenna circuit, due to the aperiodic characteristic of the 25,000-ohm resistor, R_1. That is, this resistor, being non-inductive, does not possess any tuning characteristic and will therefore not resonate at any particular frequency. Instead, it will be equally receptive to currents of all frequencies that might be flowing through it.

The voltage drops developed across this resistor by the r-f signal currents flowing through it cause the signals to react through the .002 mfd coupling condenser C_1. The antenna-detector coil, being tuned, is resonated to only one frequency at any one setting and thus serves to some extent in selecting the desired signal from the unwanted ones. The desired signal is then applied to the control grid of the converter tube, at which point the incoming r-f signal will heterodyne with the steady oscillations emanating from the oscillator circuit. The resulting beat frequency will produce in the converter tube's plate circuit r-f current variations, the frequency of which will be equal to the resonant frequency of the i-f transformer. This i-f frequency, which appears in the windings of the i-f transformer, is then transferred through a conventional i-f amplifier, second detector, and audio section.

Also observe in Fig.13 that an iron-core i-f transformer is used in the output of the converter circuit so as to insure the highest possible gain from this transformer. Both the primary and secondary windings of this transformer are tuned by small trimmer condensers, and the entire assembly is housed in a shielded container to assure maximum gain and operating stability.

PADDING THE OSCILLATOR OF PERMEABILITY-TUNED CIRCUITS

From a close inspection of the oscillator circuit, you will observe that no padding condenser is employed. Instead, an ingenious method has been employed to compensate for any discrepancies that naturally arise between these two ganged circuits when varying the inductance values throughout the tuning range of the coils.

Correction for tracking is accomplished by constructing the oscillator coil's core of a slightly different grade and density of magnetic material and also by tapering the movement of the core as it is moved in or out of the coil form. This slight change in the permeability of the iron core, together with the relation of movement between the two cores, allows the oscillator to track perfectly with the detector coil.

Every modern superheterodyne receiver of good quality employs an a-v-c system, and the superheterodyne using the permeability tuner shown in Fig. 13 is no exception. In this circuit, a-v-c voltage furnished by the a-v-c system (not shown in Fig. 13) is applied to the control-grid of the pentagrid converter tube. Resistor R_2 and the antenna-detector coil serve to complete this circuit.

A BATTERY-OPERATED SUPERHETERODYNE RECEIVER

In Fig.7 of this lesson you were shown a complete circuit diagram of a modern nine-tube a-c operated superheterodyne. So that you will become intimately acquainted with battery-operated receivers of this type, we are showing you in Fig. 15 the circuit diagram of a similar receiver designed for the use of 2-volt tubes. While the battery-type receiver to be described employs only seven tubes, its performance is equivalent to the nine-tube a-c receiver referred to, because no rectifier is necessary. Upon comparing these two circuit diagrams closely, you will observe that separate push-pull audio output tubes are employed in the a-c set, while a combination type push-pull tube is used in the battery-operated receiver. This combination tube consists of two triode sections contained within a single envelope. The two grids of the tube connect to the secondary winding of the input push-pull transformer and the two plates connect to the primary winding of the output transformer. Thus this single dual-purpose tube satisfactorily serves two functions that would ordinarily have to be taken care of by two separate tubes. The operation of this dual-purpose tube is the same as if two separate tubes were connected in a push-pull arrangement.

C-BATTERY CIRCUIT DETAILS

You will also observe in Fig. 15 that the battery-type tubes in this circuit are not equipped with cathodes. Therefore, the bias voltages cannot be obtained by including bias resistors in the cathode circuits of the different tubes, as is the case in the a-c receiver.

In the battery circuit appearing in Fig. 15 the grid bias voltage is obtained by applying a negative potential directly to the grid of each tube. This bias voltage is supplied by a 9-volt "C" battery, connected across a voltage divider network consisting of the four resistors, R_1, R_2, R_3, and R_4. The voltage drops, developed across these resistors by the flow of C-battery current through them, furnish the correct bias potential required for the different tubes. An "on-off" switch is included in this C-battery circuit to break the flow of current that otherwise would be continuous whether the receiver was in operation or not. This C-battery switch is ganged with the main "on-off" switch so that these two switches can be operated simultaneously.

Since no diode-type tubes are available in the two-volt tube series, the circuit in Fig. 15 employs a type 30 triode connected as a diode. This is accomplished by connecting together the plate and grid elements of the triode --- the tube's operation is then equivalent to the 6H6 diode type tube employed in Fig. 7.

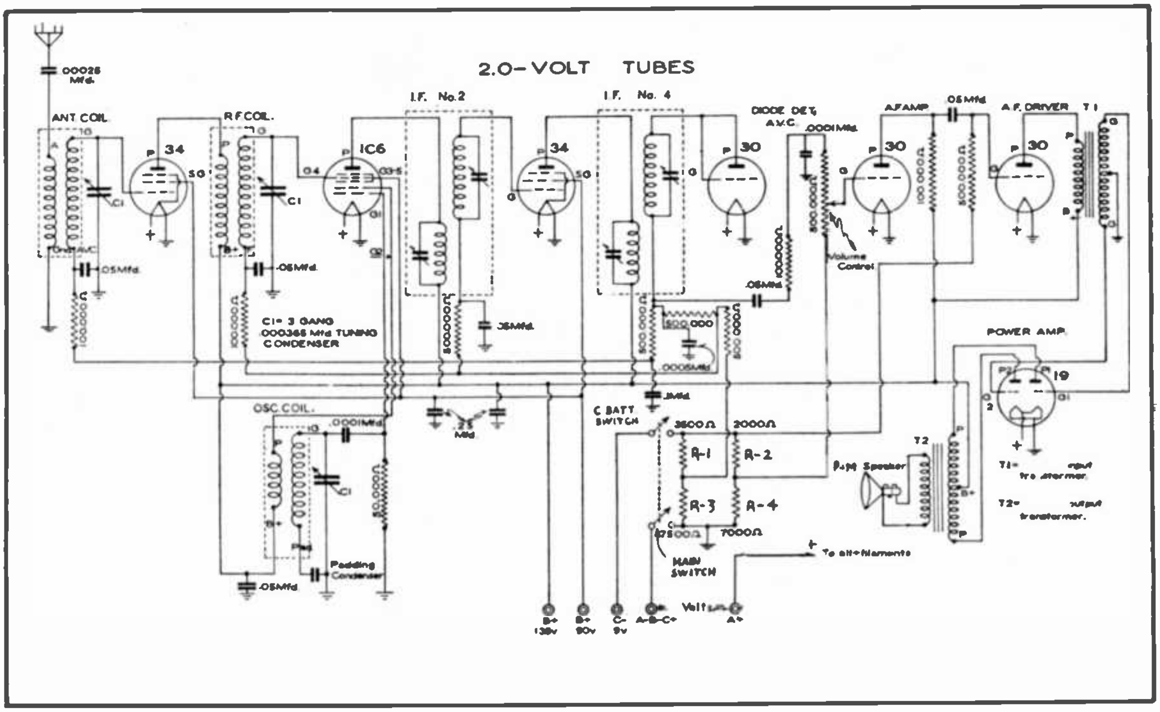


FIG. 15
SEVEN-TUBE BATTERY-OPERATED SUPERHETERODYNE RECEIVER

An electro-dynamic speaker was used in Fig. 7, its field coils serving also as the filter choke. Such a speaker would not be satisfactory in the battery-operated set diagrammed in Fig. 15, as considerable power would be consumed to excite the field. Therefore, a permanent-magnet type dynamic speaker is employed in the battery circuit. The performance of this type of dynamic speaker compares favorably with the field coil type used in a-c sets, and is widely used in many modern battery-operated receivers.

The operating principle of the a-v-c system employed in this receiver is identical to that used in Fig. 7. Therefore, no further explanation of its circuit action need be given at this time. However, in later lessons you will receive full and complete instruction in all phases of automatic volume control systems.

New radio developments are continually being worked out, and in order for a man to rise to the top of the radio profession, he must at all times be alert and ready to learn about these new features as soon as they make their appearance in the industry.

EXAMINATION QUESTIONS

LESSON NO. 19

1. - What are the chief advantages offered by iron-core i-f transformers as compared to the conventional type air-core i-f transformers?

2. - What is meant by i-f expansion?

3. - What are the chief advantages obtained through the use of an electron-coupled oscillator as explained in this lesson regarding the application of pentagrid converter tubes to superheterodyne receivers?

4. - Why is "a-v-c" used in modern superheterodyne receivers?

5. - Describe briefly the basic principle of the autodyne system as employed in some superheterodyne receivers.

6. - Explain briefly the operating principle of the continuous permeability-tuning system.

7. - Draw a circuit diagram of only that section of a superheterodyne receiver wherein a pentagrid converter tube is used.

8. - Explain briefly how the pentagrid converter tube operates in the circuit which you have drawn in answer to Question #7.

9. - What is the basic principle whereby a-v-c action is obtained in a receiver?

10. - Describe briefly the important constructional details of a permeability-tuned i-f transformer.

Practical Technical Training In
RADIO·TELEVISION
AND ALLIED ELECTRONICS

J. A. ROSENKRANZ President ESTABLISHED 1905

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LESSON NO. 20

SERVICE EQUIPMENT

In order to make reception of programs possible, a radio receiver makes use of mechanical motion, electricity, light, heat and sound. All of these elements can cause definite wear on the parts of the receiver so that, eventually, some of them must be repaired or replaced.

The problems of locating, repairing, and replacing these worn parts have resulted in the development of a number of special tools and various types of testing equipment. For instance, in Fig. 1 a technician is shown making measurements on a television chassis. As can be seen from this picture, the amount of equipment necessary for this work is not extensive, nor is it extremely complicated.

While studying this lesson, we want you to realize that it is not necessary for you, as a student, to avail yourself of all the tools and testing instruments described herein before you are ready to go to work. This equipment is suggested for the established radio technician, and can be acquired gradually over a considerable period of time.

FIG. 1
CHECKING A TELEVISION RECEIVER WITH MODERN TESTING EQUIPMENT

HAND TOOLS

Before discussing various testing instruments employed by radio servicemen, you should first know something about the more common hand tools that are an absolute necessity to every radio technician. In

Figs. 2 to 7 inclusive are shown the most important tools to be incorporated in a complete tool set.

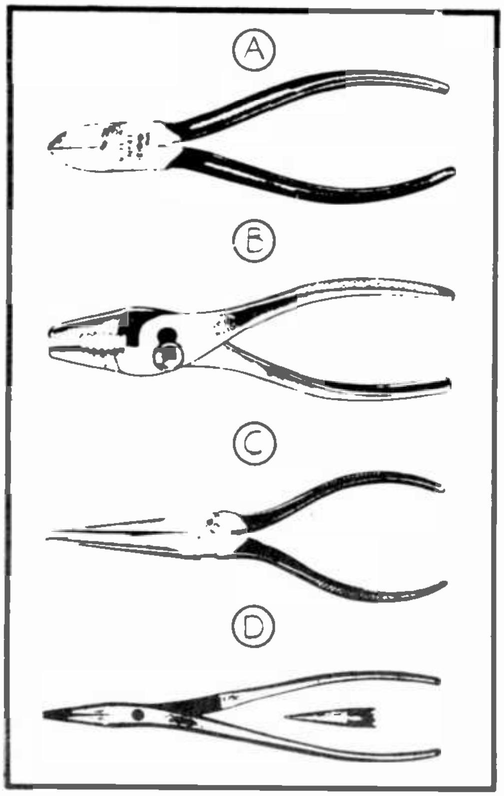

FIG. 2
PLIERS FOR THE SERVICEMAN'S TOOL KIT

DIAGONAL CUTTING PLIERS: Diagonal cutters, shown at (A) of Fig. 2, are one of the most important tools to the serviceman. They are used to cut wires to the proper lengths; to clip off the surplus ends of wires after they have been soldered; and to clean insulation from connecting wires preparatory to soldering them to some part.

SLIP-JOINT PLIERS: Of somewhat less importance, but nevertheless a needed part of every serviceman's tool kit, is the slip-joint plier shown at (B) of Fig. 2. Such pliers are often called combination pliers. They are used to hold heavy parts, to bend parts into shape, to hold large nuts while a screw is being tightened, to loosen or tighten large nuts such as employed for holding volume controls and switches in place, etc.

LONG-NOSE PLIERS: A side-cutting long nose, or chain-nose plier, is shown at (C) of Fig. 2. Such pliers can be used to cut wires, to hold wires, to bend wires, hold screws, turn nuts, etc. In general, long-nose pliers can be made to serve as a pair of steel fingers for the serviceman. Without them, he would be almost as helpless in repairing or building a radio as he would be without his fingers.

At (D) of Fig. 2 is shown a plier similar to the long-nose type, but it differs as to size and length of nose. The latter is called a "wiring long-nose plier." As can be seen, the handles are much longer than those of the standard long-nose plier, and the jaws are much shorter. These features provide this plier with greater holding strength, which is desirable for pushing wires into socket terminals and for holding them in position while the soldering iron is being applied.

SOLDERING IRONS: Next to his pliers, the serviceman will find his electric soldering iron to be most important. A typical soldering iron is shown in Fig. 3; an iron of this type can be obtained in several wattage sizes.

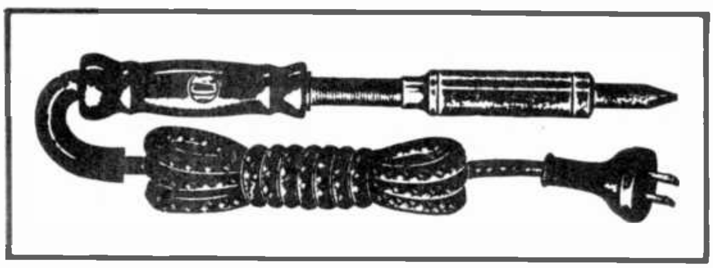

FIG. 3
SERVICEMAN'S SOLDERING IRON

Ordinarily, a radio man possesses only one iron -- usually, of light design and small wattage (around 75 or 80 watts). An iron of this size is satisfactory for soldering connections to terminals and various radio parts, but is practically useless for soldering connections to the chassis. To make good soldered connections to the chassis, it is necessary to use an iron rated at 100 watts or more.

It is a good policy to have two soldering irons -- a light one for use during service calls in the customer's home, and a heavy one for shop use.

Where service calls are to be made in communities that do not have power lines or lighting service, two alternative methods can be employed for soldering connections. One is to use a small alcohol or gasoline blow torch for heating an ordinary non-electric soldering iron; the other is to connect a small 6-volt electric iron to a storage battery. An iron, heated by the small blow torch, is perhaps the most desirable; however, when using a blow torch in the customer's home, care must be exercised to see that the furniture, rugs, or curtains are not damaged by the flame. A blow torch suitable for this purpose is shown in Fig. 4.

FIG. 4
BLOW TORCH

SCREW DRIVERS: Various types of screw drivers, necessary as part of the tool equipment of every serviceman, are shown in Fig. 5. The type ppresented at (A) is made in many different sizes and lengths. The average radioman requires screw drivers in at least three different sizes; a large one for use on heavy screws and parts; one of medium size for lighter screws; and a small one which will allow the small set screws of control knobs to be turned.

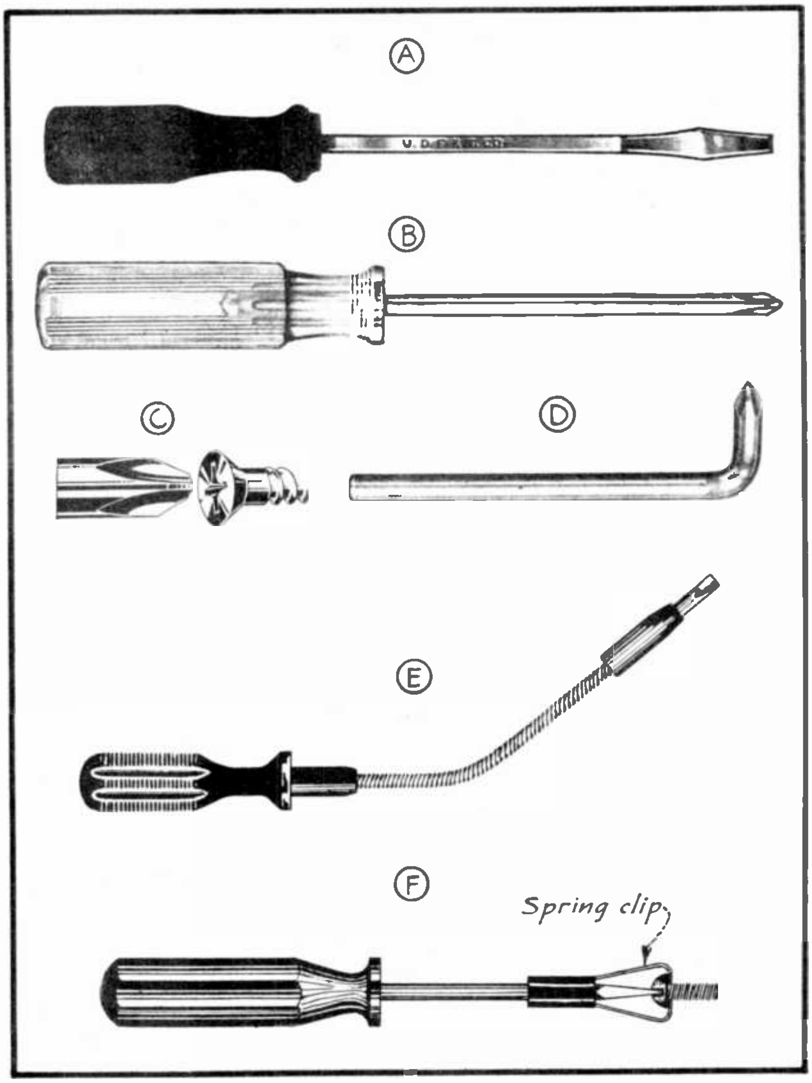

FIG. 5
SELECTION OF SCREW DRIVERS

Details of the Phillips screw driver, and the manner in which it is applied to Phillips-head screws, are shown at (B) and (C) of Fig. 5. As can be seen from illustration (C), this type of screw-head has two slots that cross each other at right angles, and taper in depth toward the center. The slots do not extend across the entire head. The peculiar shape of the driver point allows tremendous pressure to be applied without burring the recess or damaging the driver.

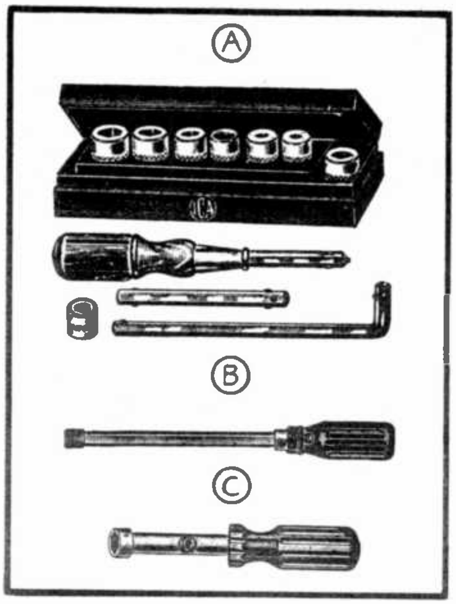

Fig. 6
Socket Set and Wrenches

Since a great many receivers employ self-tapping screws with Phillips-type heads, it has become almost a necessity to have on hand at least two sizes of the screw driver illustrated at (B). The bent shank type, illustrated at (D), is useful for certain applications where a straight shank screw driver cannot be used.

The screw driver shown at (E) of Fig. 5 consists of a shank made of a tightly wound coil of heavy steel wire; a screw driver blade is attached to its free end. The shank can be bent around interfering objects so that the blade will fit into the head of a screw which would ordinarily be inaccessible when using a conventional screw driver.

Screw-holding drivers, as shown at (F) of Fig. 5, are also used extensively. In this case, the screw-head is held to the blade of the driver by small spring clips while starting the screw in a hole which cannot be reached with the fingers.

SOCKET SETS: In addition to the tools mentioned thus far, the serviceman's kit should also include a socket set similar to that illustrated at (A) of Fig. 6. The 1/4", 5/16" and 3/8" socket sizes are most frequently used, although sockets of other sizes are available.

Instead of buying a complete socket set, it may be more economical, and better from a standpoint of time saved on the job, to acquire socket wrenches of the type shown at (B) of Fig. 6 -- in three or four standard sizes. Here the socket is attached permanently to the shank which feature makes it unnecessary to first select the socket of proper size and then apply it to the handle, before the tool is ready for use.

The socket wrench shown at (C) is a special type, designed to fit the large nuts which hold volume controls and switches to the chassis. Its long, hollow shank slips over the shaft of such controls so as to permit the socket to engage the nut.

ALIGNING KITS: The aligning kit shown in Fig. 7 can be folded and carried in the pocket. This set of aligning tools is perhaps more complete than would ordinarily be necessary, but since each different tool is designed to fit the trimmer adjustments of a particular

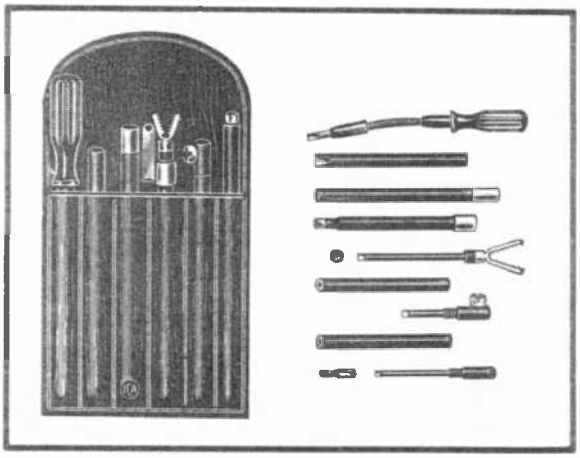

Fig. 7
Alignment Tool Kit

commercial receiver, it is often advantageous to have it on hand. The handles and shanks of these tools are all made of insulating material to reduce the danger of electric shock, and also to reduce as much as possible the body capacity effect upon the circuit being adjusted.

MISCELLANEOUS EQUIPMENT

Besides those tools already described, there are also other items which should be included in the tool kit. Some of these are necessary and some are not so important. The most important items are listed below under the heading "Miscellaneous Necessary Items." Those of lesser importance are listed under the heading, "Miscellaneous Items, Desirable but not Necessary."

MISCELLANEOUS NECESSARY ITEMS:

Small flat file.
Rosin-core solder (small roll).
Roll of friction tape (also roll of live rubber tape).
Penknife or jackknife.
Paint brush with long bristles (medium size).
Hand drill and assortment of twist drills of various sizes (1/16", 3/32", 1/8", 5/32", 3/16", and 1/4" sizes are most used).
Hacksaw.
25 feet of rubber-covered a-c cord.
Hook-up wire.

MISCELLANEOUS ITEMS, DESIRABLE BUT NOT NECESSARY:

Assortment of machine screws and nuts.
Fine sandpaper.
Flashlight.
Bicycle pump.
Battery volt-ammeter.
Dentist mirror.
Large, soft piece of cloth.

The purpose of this extra equipment is self-evident; therefore, it will not be necessary to enter into a lengthy description of it. The following paragraph explains the use of those items about which you may be in doubt.

The main purpose of the file is to clean the soldering iron of scale and carbon, and to trim small parts so that they will fit properly. The paint brush is used to clean accumulated dust from between the plates of the tuning condenser, or from between parts on the chassis. Volume control shafts can be cut to the proper length with the hacksaw. The sandpaper is used to remove enamel insulation from the ends of wires which are to be soldered. Dark corners in a cabinet can be illuminated with the flashlight. The dentist's mirror aids in observing parts that are located in an obscure place under the receiver chassis. The bicycle pump can be used for blowing dust from the chassis and parts mounted on top of the chassis.

THE TOOL BOX

A container or box, in which to carry the various tools described, is necessary. In Fig. 8 is shown a steel box with handle, and a removable compartment tray. Various small replacement parts and miscellaneous items as screws, nuts, soldering lugs, etc., can be carried in the compartments of the tray; the tools are placed in the bottom or main section of the kit. Always arrange your tools in the box so that you can find what you want without wasting time.

SUGGESTIONS FOR THE SELECTION OF TOOLS

It is frequently the tendency to buy tools which are lowest in price ("dime store" tools). These are definitely the wrong type of tools for one who intends to earn his living by their use.

FIG. 8
THE TOOL BOX

You are going to use them constantly, day after day. Cheap tools cannot stand up under such conditions. The joints of cheap tools become loose in a short time, cutting edges will become dull quickly, the jaws of pliers will bend and break easily; inferior screw drivers will bend out of shape with the slightest amount of extra pressure; and cheap boxes will not stay closed. Therefore, it is much cheaper in the long run to purchase tools of good quality.

The list of tools and equipment given in this lesson is not necessarily complete, because the serviceman often finds that he needs additional tools to handle special types of jobs. However, the equipment listed will meet most requirements. Of course, you understand that it is not necessary to buy all of the equipment at one time. Usually, a beginner in the radio service field starts out with a jackknife, a pair of diagonals, a pair of long-nose pliers, a pair of slip-joint pliers, a soldering iron, and one or two screw drivers. He then gradually adds the rest of the tools to his kit as his business prospers.

TESTING EQUIPMENT

Tools alone do not enable the serviceman to service or repair a radio receiver. It is true that some faults in a receiver can be located by shorting the screw driver across various socket terminals and points of high voltage, but this method of servicing is only a matter of guess work because it very rarely gives any definite indication as to the real cause of the trouble -- besides, certain parts of a receiver may be burned out by willfully shorting circuits in this way.

Additional equipment in the form of miscellaneous meters, a tube checker, and an oscillator is necessary. It is not practical to carry around several individual meters, because they will nearly always get out of adjustment, and their glass crystals are easily broken. Since there are many instruments on the market which combine the operations and measurements of several meters into one, this is the logical type of apparatus for the serviceman. Such instruments are generally housed in a convenient carrying case to protect them against damage.

Radio service work is based primarily on the proper use of meters and the deductions that can be made from the voltage, current, and resistance measurements indicated by these meters. Before discussing the several commercial analyzers, tube checkers, oscillators, and special instruments that are available, let us first investigate the manner in which a single meter is used to indicate current, voltage and resistance values.

MULTI-RANGE D-C MILLIAMMETERS

In Fig. 9 is shown a d-c milliammeter being used with a switch arrangement that will allow several different ranges of current to be measured. The manner in which this is done is very simple.

As you will observe in Fig. 9, the scale of the meter is divided into ten main divisions. We will assume that the milliammeter is designed to measure a maximum current of 1 milliampere when no shunt resistance is connected across its terminals. This, then, would be the maximum current indicated on the meter scale under such a condition. Any current greater than 1 milliampere would deflect the needle completely off the scale and would probably damage the meter.

In order to measure a current higher than 1 milliampere, the total current must be divided between two paths -- part of it flowing through the meter, and the rest of it shunted (bypassed) around the meter. If a good electrical conductor were connected directly across the meter terminals, no current would flow through the meter; all of it would flow through the conductor (shunt). Therefore, in order to cause a definite portion of the current to flow through the meter, the shunt must have a certain value of resistance.

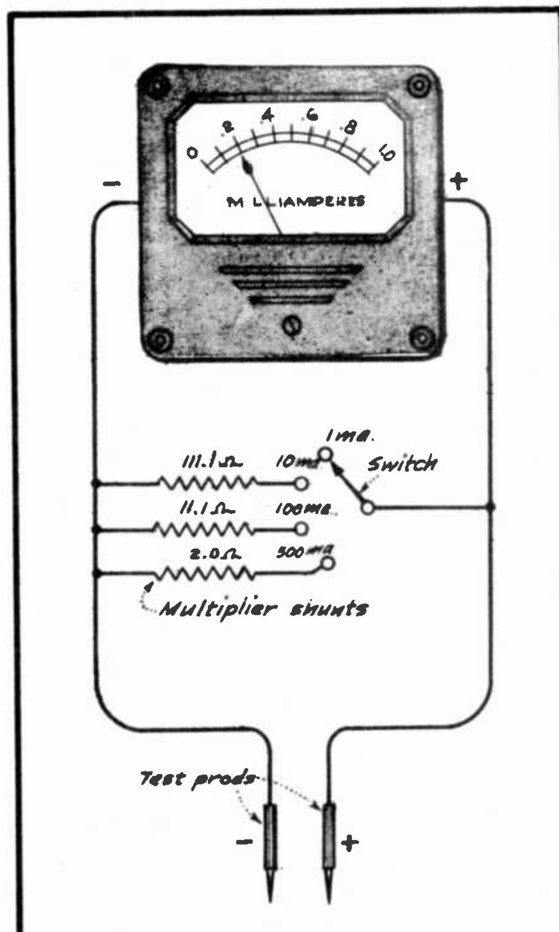

Fig. 9
MILLIAMMETER WITH FOUR RANGES

Formulas and computations of meter shunts will be given in a later lesson. For the present, it will be sufficient to say that the values of the shunt resistors required for the particular meter used in Fig. 9 are as indicated in this illustration. (These resistor values vary in accordance with the design of the meter and the extended range.) As the switch is rotated, each of the three different shunt resistances is connected across the terminals of the meter in turn. Thus, the desired range can be selected by simply setting the switch at the desired position.

You will note that as the current range increases in value, the value of the shunt resistance decreases so that a greater portion of the total current will be bypassed around the meter. For instance, when the switch is turned to the 1 ma. position, the test prods are connected directly across the meter terminals with no resistance in shunt. For the 10 ma. range, the switch connects a 111.1 ohm resistor in shunt with the meter terminals; for the 100 ma. range, the value of shunt resistance is 11.1 ohms, and for the 500 ma. range, it is 2.0 ohms.

To determine the value of current indicated by the meter needle for any range greater than 1 ma., it is necessary to multiply the actual reading on the meter scale by the maximum value of the range. For example, if the switch is adjusted for a current measurement in the 10-milliampere range, and the meter needle swings to the .6 division, then the actual or true value of current is ten times .6, or 6 milliamperes. Similarly, the true current value in the 100 ma. range will be the value indicated on the scale, multiplied by 100. When using the 500-milliampere range, the reading must be multiplied by 500 to ascertain the true value of the current being measured.

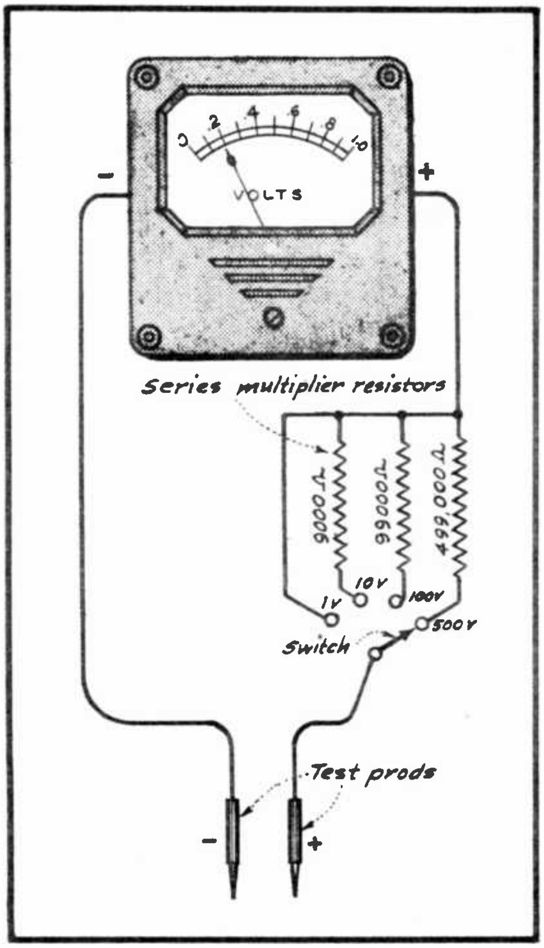

FIG. 10
D-C VOLTMETER WITH FOUR RANGES

MULTI-RANGE D-C VOLTMETERS

The method of extending the range of a d-c voltmeter is somewhat different than for a milliammeter. The range-extending circuit of a typical voltmeter is shown in Fig. 10. Here we are concerned with keeping the voltage-drop across the meter terminals to the value which will give a full-scale deflection when indicating the maximum voltage in any range that may be selected.

We will assume that this meter is designed to measure a voltage of 1 volt, without the use of any series multiplier resistance. Also, we will assume that a current flow of 1 milliampere through the meter is required to produce full-scale deflection. According to Ohm's Law, the internal resistance of the meter is E ÷ I, or 1 ÷ .001, which is equal to 1000 ohms. This value of 1000 ohms is called the "ohms-per-volt resistance" of the meter.

It is evident that if a voltage higher than one volt is applied across the meter, a current larger than one milliampere will flow through it. Therefore, to measure voltages higher than one volt, resistance must be connected in series with the meter terminals and the voltage source so as to limit the voltage across the meter terminals to one volt.

Since series multiplier resistors for voltmeters will be discussed in detail in a later lesson, the values of the resistors required for the various ranges shown in Fig. 10 will not be worked out here. Notice, however, that as the voltage range increases in value, the series multiplier resistance also increases. This is opposite to the conditions required for the milliammeter. With the switch in Fig. 10 closed in the 1-volt position, the test prods are connected directly to the voltmeter terminals. When the switch is closed in the 10-volt position, a 9000-ohm resistor is connected in series with the test prods. A series resistor of 99,000 ohms is required for measurement of 100 volts, and 499,000 ohms for a maximum measurement of 500 volts.

Meter indications on the multi-range voltmeter are read in the same manner as for extended ranges on the milliammeter scale. That is, if the switch is turned to the 1-volt position, the meter is read direct. If the switch is turned to the 10-volt position, any indication on the scale must be multiplied by 10. Meter readings in the 100-volt range must be multiplied by 100; and in the 500-volt range, by 500. In other words, an indication of .4 volts, when using the 10-volt range, actually represents .4 x 10, or 4 volts; a reading of .8, when using the 100-volt range, represents .8 x 100, or 80 volts, etc.

SINGLE-METER MEASUREMENT OF CURRENT AND VOLTAGE

The two circuits of Figs. 9 and 10 can be combined so that a single meter will indicate either voltage or current in several different ranges. In Fig. 11, this is accomplished by the use of a simple switch (Sw-3), which connects the meter and test prods either to the shunt resistors or to the series resistors. An arrangement similar to this is employed in all analyzers which are designed to measure several ranges of current and voltage.

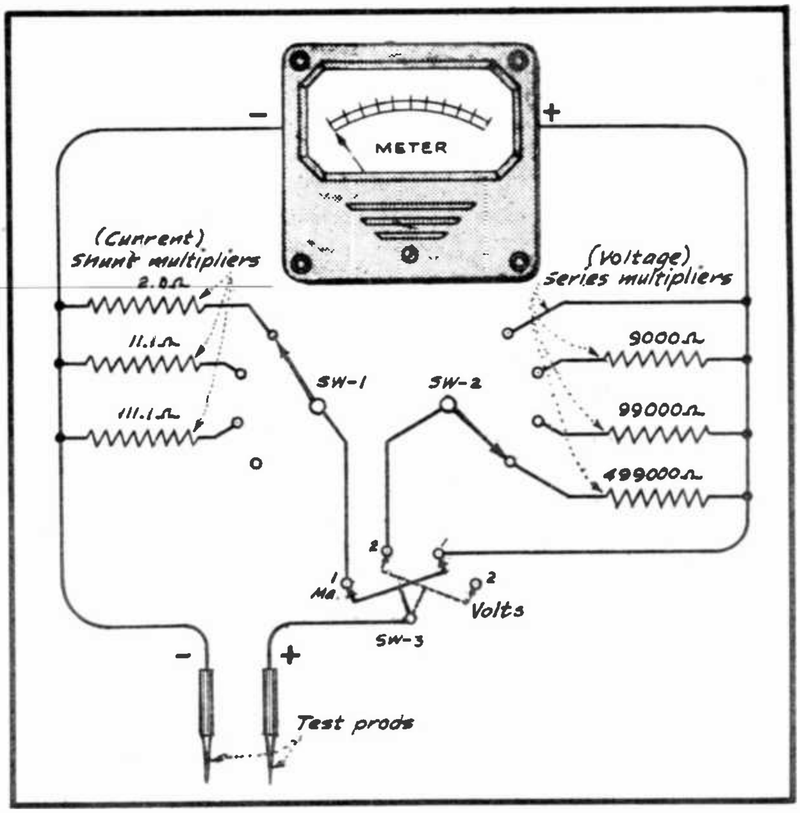

FIG. 11
COMBINATION D-C VOLTMETER AND MILLIAMMETER

In the case of Fig. 11, turning switch Sw-3 to the left (position 1, or the milliampere setting) causes the contact arm of switch Sw-1 to be connected directly to the positive terminal of the meter and also to the positive test prod. Then, by adjusting switch Sw-1, the desired current measuring ranges may be selected; in other words, Sw-1 now connects the desired shunt resistor across the terminals of the meter so that different ranges of current may be measured.

When switch Sw-3 is turned to the right, or to the "volts position," the voltage multiplier resistors are connected in series with the positive terminal of the meter and the positive test prod. Now, by proper adjustment of switch Sw-2, the desired voltage range may be selected.

COMMERCIAL TESTERS

The rest of this lesson is devoted to a brief description of commercial testing equipment which is available to the radio technician. No attempt is being made to describe the operation and application of each of these testers in detail, as it would be impossible to do so because each make and model (of which there are hundreds) differs from all others in this respect. Furthermore, the manufacturer furnishes complete instructions with each instrument.

The sole purpose of our discussion on this subject is to bring to your attention the basic types of testing equipment, so that you will become acquainted with them by name and so that you will know what kinds of tests can be made with them.

The instruments described and illustrated in this lesson are representative only of such equipment. There are many variations of each type, and prices of each range from only a few dollars to hundreds of dollars.

OHMMETERS

Ohmmeters employ a d-c milliammeter so connected in a circuit as to make use of a source of voltage, which, when connected in series with an unknown resistance and the milliammeter, will cause the meter needle to indicate the value of the unknown resistance on a calibrated scale. Actually, the meter indicates current, because it is the current flow through the unknown resistance which causes the needle to be deflected -- but, the scale is calibrated to indicate in ohms the resistance which permits this current to flow when a voltage of a definite known value is applied across it. (This is explained thoroughly in a more advanced lesson.) Either shunt multiplier resistors or series multiplier resistors can be employed with the meter to provide extended ranges. A typical ohmmeter is shown in Fig. 12. Frequently, the ohmmeter features are incorporated in such a manner that a single meter with several scales can be used to indicate current, voltage and resistance values. Instruments shown later in this lesson illustrate this.

FIG. 12
AN OHMMETER

A-C METERS

In radio work, it is the standard practice to read d-c and a-c currents and voltages on a single meter. A small rectifier is incorporated into the circuit to convert the a-c into d-c so as to make this possible..

When converting a-c voltage into d-c voltage, the a-c calibration on the meter face does not correspond with the d-c calibration. Consequently, such meters usually have two sets of current and voltage scales -- one for d-c measurement, and another for a-c measurement. You will observe this in the illustrations of the analyzers described in the following paragraphs.

ANALYZERS

Several names are applied to single meter arrangements which can be used to make the types of measurements that we have been discussing. Typical among these, are the terms "multi-tester", "multimeter", "multi-checker", "rota-meter", "analyzer", etc. The term "analyzer" is the most used, and is the term which most accurately describes the purpose of this type of instrument; therefore, in the following portion of this lesson, we will refer to it by this name.

The analyzer shown in Fig. 13 is a very fine type of instrument. It combines all of the functions of a single-meter voltage, current, and resistance measuring instrument. In addition, it has several other valuable features.

The meter employed in this analyzer has an internal resistance of 20,000 ohms-per-volt. This high internal resistance means that very little current is required to operate its mechanism; therefore, its readings are exceedingly accurate. Meters of a lesser ohms-per-volt sensitivity do not provide such accuracy. In fact, the readings on a 1000 ohms-per-volt meter will often be as much as 50 per cent in error on certain voltage measurements.

The d-c voltage scales on this particular meter are 2.5 volts, 10 volts, 50 volts, 250 volts, and 1000 volts. The a-c voltage ranges are the same as the d-c ranges; however, a separate scale is employed for the a-c readings. The latter is colored red and is located under the d-c scale.

Both d-c voltage and d-c current measurements are indicated directly on the one d-c scale. Similarly, both a-c voltage and a-c current are indicated on the one a-c scale.

The top scale is calibrated in ohms. For resistance measurements ranging from 0 to 1000 ohms, the scale is read direct; for measurements ranging from 0 to 10,000 ohms, the scale readings are multiplied by 10; in the 0 to 500,000 ohm range, the readings are multiplied by 1000; for the 0 to 20 megohm range, the scale readings are multiplied by 10,000.

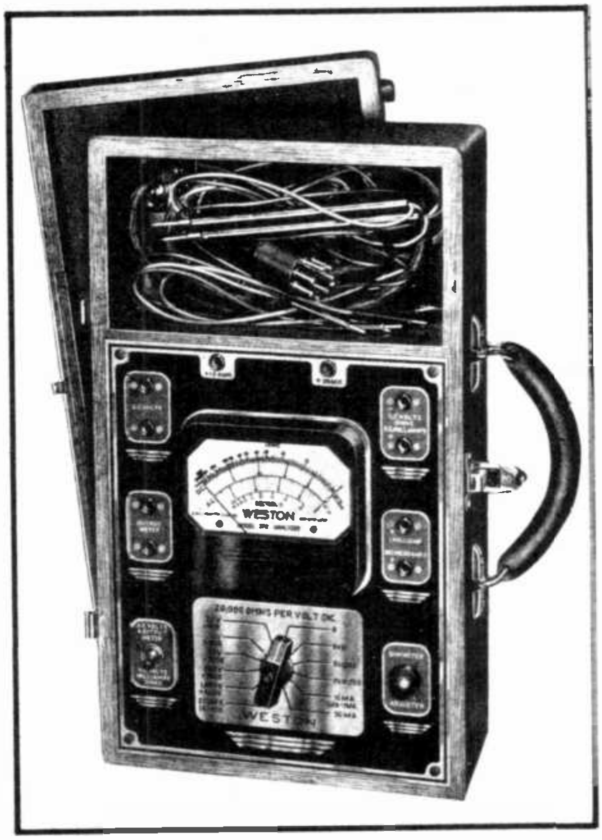

FIG. 13
A 20,000 OHMS-PER-VOLT ANALYZER

Four sets of jacks are provided on the panel to allow for the different types of measurements. All d-c volts, ohms, and current measurements above one milliampere are made with the test leads inserted in the jacks at the upper right. A-C volts and current are read with the test leads inserted in the jacks at the upper left. Very small currents, from one microampere up to one milliampere, are measured by inserting the (+) test lead in the jacks at the right center, and by turning the switch to the proper position. The (-) test lead is inserted in the extreme upper right jack.

The jacks at the left center provide connections for use of the meter as an output indicator for aligning receivers, etc. The toggle switch in the lower left-hand corner is for switching from a-c to d-c or to resistance measurements. All ranges are selected by the central switch and pointer. The little knob in the lower right-hand corner is for zero adjustment of the pointer on the ohmmeter scale.

Db measurements are provided by a separate scale. This is a measurement of sound intensity about which you will learn in later lessons.

Several instrument manufacturers make precision analyzers similar to the one illustrated in Fig. 13, all of which are priced fairly high. However, many of them also make less expensive analyzers with high-sensitivity meters, but these are not constructed as sturdily nor do they contain the same high-quality materials as do the more expensive testers.

Most of the multiple-range meters or analyzers of the less expensive type are of the small pocket-size variety, and have a meter sensitivity of around 1000 ohms-per-volt.

TUBE CHECKERS

Next to an analyzer or multi-purpose tester, the tube checker is second in importance. In selecting a tube checker, accuracy, dependability, size, weight, and price are important factors to be considered. Of these, accuracy is perhaps the most important; however, accuracy and dependability usually depend on the price of the instrument.

Accuracy is especially desirable in a tube checker, because many customers have the habit of taking their tubes to one or more radio stores for a test, before they call on you to look the receiver over. Usually, low-priced tube checkers tend to indicate doubtful tubes as being completely "BAD". Therefore, if your checker shows one or more tubes to be bad, whereas some radio store may have given them a doubtful O.K., the customer is likely to brand you as a cheat. As a result, you are never called upon again to service his receiver, and your reputation may suffer considerably in his neighborhood.

The size and weight of a tube checker is not necessarily reflected in the price of the instrument. However, size and weight are two factors to consider if you intend to carry the tube checker with you to the customer's home. For such use, a small tube checker of light weight is preferable. For use in a radio shop or store, the larger counter-type is desirable because of the impression it makes on the customer while he watches his tubes being checked.

FIG. 14
VERSATILE TUBE CHECKER

A fine type of tube checker is shown in Fig. 14. Briefly, the tube checker in Fig.14 is operated in the following manner: The cylindrical chart at the bottom of the panel is rotated by means of the wheel in the lower right corner, until the number of the tube to be checked shows under the indicating hair-line. This same chart will then indicate the position to which each of the pointer knobs on the panel should be turned to check that particular tube. After plugging the checker into an a-c outlet, the tube is inserted in the proper socket. In a few seconds (depending on the amount of time required for the tube filament to heat) the meter needle will swing across the dial and indicate the condition of the tube.

As can be seen in the illustration, only six tube sockets are needed to test the many different types of tubes now being used.

Improper tube operation, due to insufficient electron emission, will be indicated directly on the dial. However, the meter will often show a tube to be in good condition, whereas, in reality, one of the internal elements may be shorted to another. Provisions for checking the internal elements of the tubes for possible shorts are therefore made on the tube checker appearing in Fig. 14. This consists of a small neon bulb and a special switching arrangement which connects an a-c voltage in series with the neon bulb and the various elements of the tube so that they may be checked for possible shorts. The neon tube will glow when one of the elements is shorted to another within the tube structure.

Several manufacturers of testing equipment make their analyzers and tube checkers of such size and shape so that two or more units can be combined into a single carrying case. Such a combination is illustrated in Fig. 15, where the analyzer described previously is combined with a tube checker.

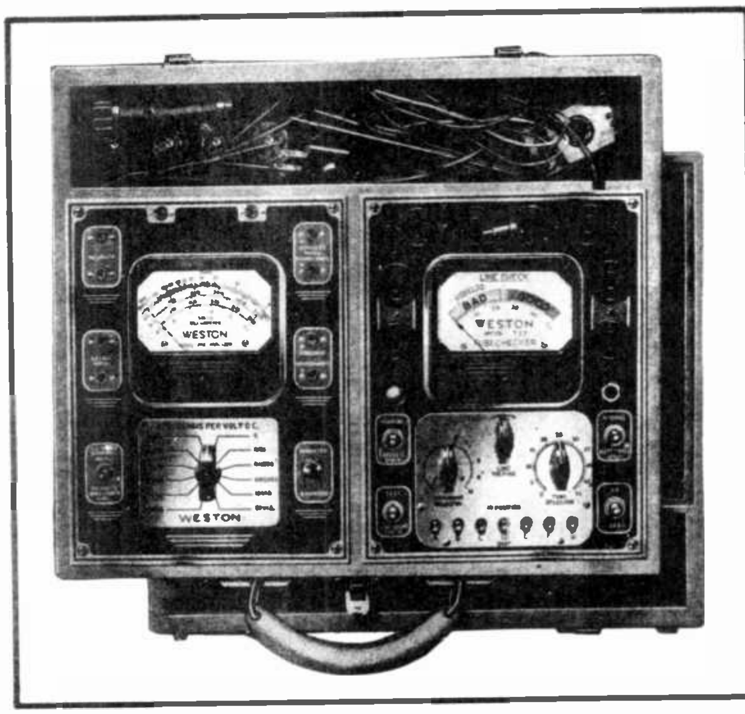

FIG. 15
ANALYZER AND TUBE CHECKER COMBINED IN ONE CASE

So combining two instruments in one case facilitates transporting the equipment to and from service calls. Furthermore, the analyzer and tube checker are always at hand, when testing the receiver in the customer's home, or when checking the tubes, and it is therefore not necessary to scatter equipment all over the room.

A chart is supplied with the tube checker incorporated in the case illustrated in Fig. 15. The various settings of the toggle switches and pointers are obtained from this chart for each tube to be checked.

Very often, other combinations of instruments are similarly incorporated into a single case. The two most popular combinations are the analyzer and tube checker arrangement (just described), and the analyzer-test oscillator combination.

Some manufacturers even go as far as combining three instruments in a single case; however, when this is done, the third instrument is usually an auxiliary or aid to one of the other main instruments. For instance, one such combination combines an analyzer, test oscillator, and point-to-point ohmmeter. The latter section of the combination is used in conjunction with the analyzer to make direct measurements of the resistances in a circuit, without having to remove the receiver chassis from the cabinet.

THE SERVICE OSCILLATOR OR SIGNAL GENERATOR

Service oscillators, or signal generators, are used to feed a radio signal into a receiver instead of using a station signal during tests.

There is very little difference between a signal generator and a service oscillator. These two terms are applied indiscriminately to all types of oscillators which are used by the serviceman. The term "signal generator" is applied more specifically to a laboratory type of oscillator, while the term "service oscillator" better describes the instrument that a serviceman carries with him on service calls. In other words, the latter is a smaller and lighter type of oscillator. The signal generator is a more complicated type of instrument than the service oscillator.

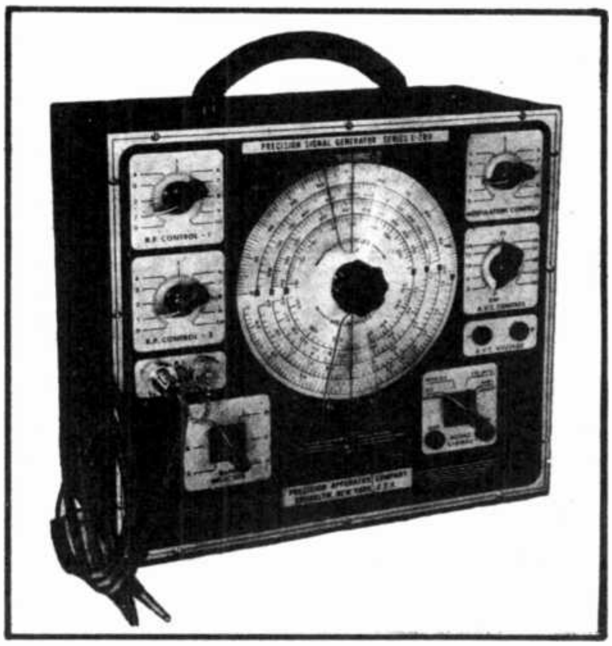

FIG. 16
SIGNAL GENERATOR

The radio-frequency oscillator shown in Fig. 16 is a high-quality instrument. Low-priced oscillators are also obtainable, but, as is true of practically any type of testing apparatus, low-priced oscillators are not of the same quality as the more costly instruments.

The signal generator shown in Fig. 16 has two radio frequency outlet terminals, one for the low range of frequencies and the other for the high range. Two variable attenuators control the amount of r-f output from either of these terminals. When the output from only one terminal is being applied to a receiver, the unused terminal is covered with a small metal screw-on cap so as to prevent any r-f leakage from this terminal. (The cap is shown screwed in position in Fig.16.)

The radio frequencies covered by this signal generator extend from about 100,000 cycles up to 33 megacycles per second (33,000,000 cycles) -- this range being covered in four bands. In addition, audio frequencies are available from 10 to 10,000 cycles per second. The latter can be fed direct to the receiver through a pair of leads plugged into the jack directly under the audio signal control, or can be used to modulate the r-f signal. In the latter case, a special control is provided for obtaining the amount of modulation desired.

As you can see in the illustration, the pointer, second from the top at the right, is labeled "a-v-c control." By inserting test leads in the two small pin jacks directly under this control, and by the proper connections of the test lead clips, a-v-c voltage may be applied to any of the receiver's r-f or i-f circuits which are being aligned with the aid of the signal generator. This permits the receiver to be aligned under actual operating conditions, in the event that it is not producing its own a-v-c voltage because of this circuit being interrupted during the test.

Usually, the acquisition of a good analyzer, tube checker, and signal generator (or service oscillator), completes the average serviceman's equipment. These are the most necessary items.

The rest of this lesson is devoted to a description of various types of apparatus which are not absolutely necessary to a serviceman, but which are desirable in that they can be employed to check parts more accurately, and to make difficult measurements simple. The use of this type of apparatus gives the serviceman that extra professional touch, which lifts him above the ranks of ordinary serviceman into the technician class.

CAPACITY CHECKER

Fig. 17 shows a capacity checker being used to test a condenser in a receiver.

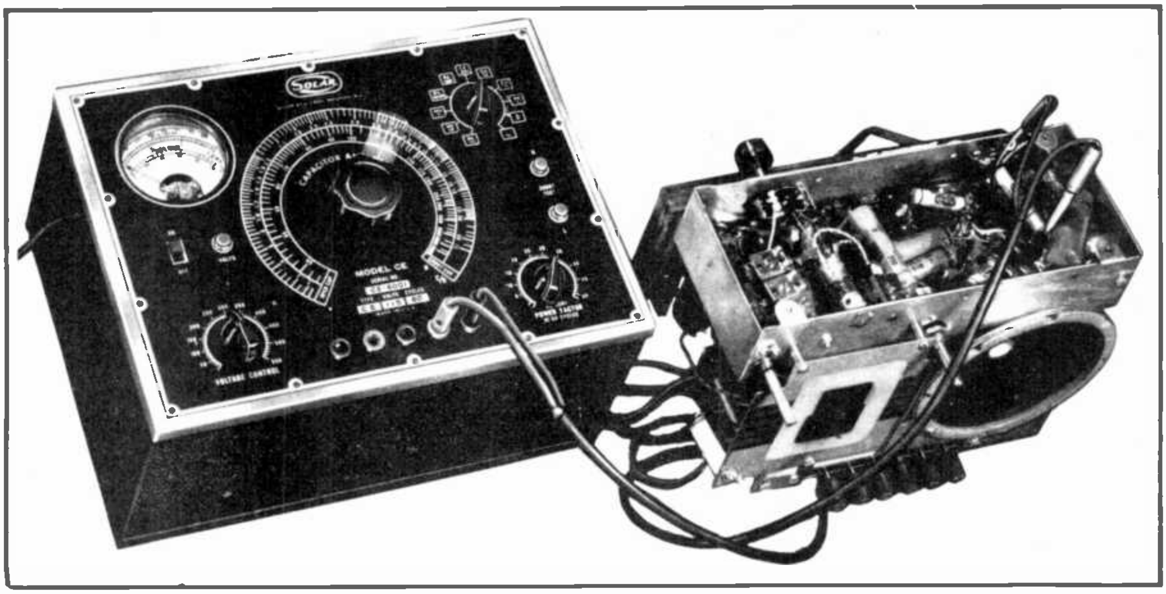

FIG. 17
TESTING CONDENSERS WITH A CAPACITY CHECKER

The outstanding advantage claimed for the particular capacity checker illustrated is that it permits condensers to be checked while they are connected directly in the circuit, under operating conditions. It also provides indications of the capacity value of the condenser and of its condition.

When checking condensers by this means, a d-c potential, equal to the working voltage of the condenser, is applied across its terminals. The leakage current and internal resistance of the condenser are indicated by the meter. Provision is also made for measuring the power factor of electrolytic condensers. Since the power factor of a filter condenser is a measure of its efficiency in the filter circuit, it is of great value in locating obscure troubles in power supply systems.

VACUUM-TUBE VOLTMETERS

Vacuum-tube voltmeters are capable of giving accurate voltage indications at radio frequencies, which an ordinary alternating current meter is not able to do. An important advantage of vacuum-tube voltmeters is that they have such a high input impedance that practically no power is absorbed from the circuit being checked to operate the measuring instrument. Therefore, exceedingly accurate readings can be made of very feeble r-f energy.

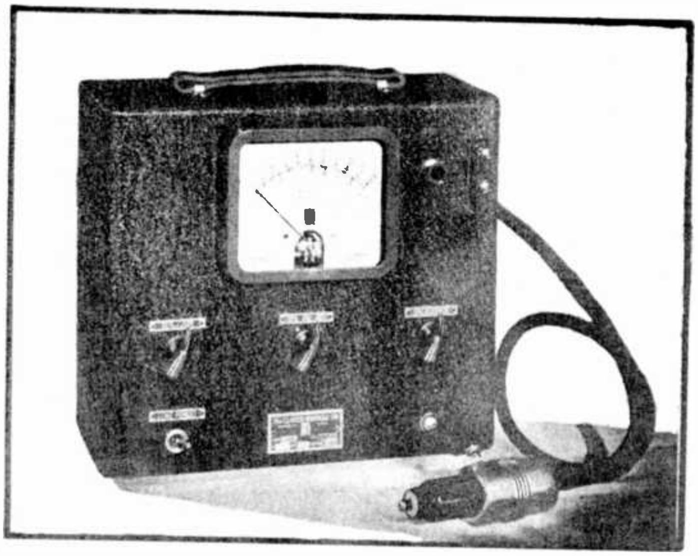

FIG. 18
VACUUM-TUBE VOLTMETER

Since the high input impedance of a vacuum-tube voltmeter is mainly dependent upon a very low capacity in its input circuit, the first tube of this instrument (usually the amplifier tube) is connected to the end of the input leads, as shown in Fig.18.

When measuring r-f voltages with such a vacuum tube voltmeter, the grid of the tube is applied directly to the point or connection at which the voltage value is to be obtained. The other side of the circuit is completed by means of a wire which is extended from the chassis of the receiver (ground terminal) to the ground terminal of the vacuum-tube voltmeter. The elimination of the long lead between the receiver and the grid of the first tube in the vacuum-tube voltmeter eliminates practically all capacity at this point and keeps the input impedance at a maximum.

MEASURING BRIDGES

Resistance and capacity measuring bridges are also handy. In Fig. 19 is shown such an instrument which is direct-reading, and very simple to operate. The "magic eye" tube is used to indicate when the bridge is in a state of electrical balance which condition is the basis of this method of measurement. The principle involved is explained elsewhere in the course.

Resistance values ranging from 0 to 10 megohms and capacity values from .00001 to 150 mf can be measured with it. In addition, d-c leakage tests can be made, and the power factor of electrolytic condensers can be measured quickly and easily. The turns-ratio between the primary and secondary windings of a transformer, and the correct polarity of the windings, can also be easily determined with this instrument.

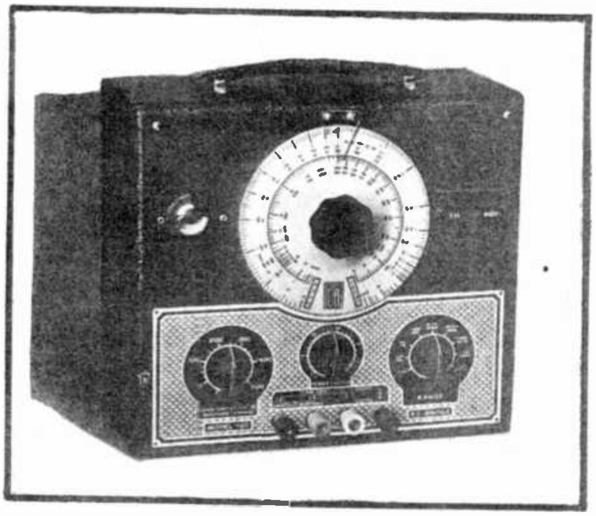

FIG. 19
RESISTANCE-CAPACITY MEASURING BRIDGE

THE DYNAMIC SIGNAL ANALYZER

The trend in modern receiver servicing has been toward a method of analyzing the chassis components under actual operating conditions. This has led to the development of a method of receiver analysis known as "dynamic signal tracing." During this test, the various stages of the receiver are checked in terms of "comparative gain" while a signal, produced by an ordinary signal generator, is being injected into the r-f, i-f, and audio circuits.

The manner in which this is done is very simple. It does not involve disconnecting any of the parts in the receiver -- the gain measurements being indicated by the dynamic signal analyzer without disturbing the operation of the receiver.

The dynamic signal analyzer shown in Fig. 20 makes use of a tuned r-f vacuum-tube voltmeter for checking the gain of the stage or stages under test. The vacuum-tube voltmeter is adjusted to resonance with the signal of the signal generator and to which the receiver circuit being checked is also tuned. The large dial at the center of the dynamic signal analyzer, shown in Fig. 20, is used to tune the meter's input circuit. The tuning range of the input to the vacuum-tube voltmeter extends from 90 kilocycles to 16 megacycles. This range of frequencies is covered by five bands, read directly on the dial scale. Push-buttons are used for range selection.

The r-f gain of the receiver stage being checked can be read directly on the r-f gain meter. Ranges for this meter are from 0 to 10, 0 to 100, 0 to 1000, and 0 to 10,000. Either the gain of each stage of r-f and i-f can be determined separately, or the over-all gain of the r-f sections and i-f sections can be determined. Audio-frequency

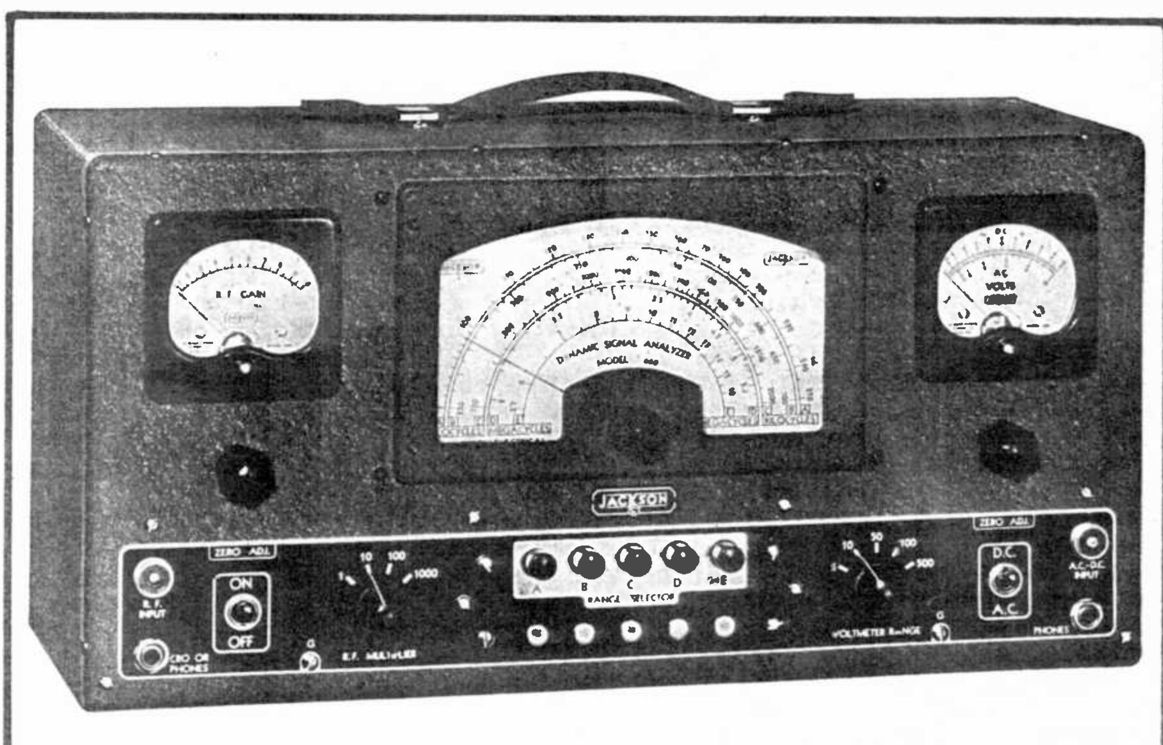

FIG. 20
DYNAMIC SIGNAL TRACER

gain can also be measured accurately. A combination ac-dc voltmeter is also supplied for additional measurements.

By means of the vacuum-tube voltmeter incorporated in this instrument, all r-f voltages in the receiver can be measured directly with the receiver in operation. Aside from all r-f and i-f voltages, the oscillator output voltage in a superheterodyne can be determined at each frequency throughout the tuning range of the oscillator circuit. A-v-c voltages can be measured accurately without disturbing the operation of this part of the receiver circuit, and automatic frequency control voltages and the operation of such systems can be checked.

Some of the other important measurements and checks made possible by this instrument are: The location of any distortion, noise, or hum in the r-f, i-f, or audio-frequency sections of the receiver; bias, cathode, and power supply measurements; efficiency tests on antennas; condenser, resistor, and inductance tests; etc.

THE OSCILLOSCOPE OR OSCILLOGRAPH

An oscilloscope differs from an oscillograph mainly in the fact that the latter has a transparent window over the screen of the cathode-ray tube. This window is divided into small spaces similar to ordinary graph paper. The purpose of this transparent graph over the screen of the cathode-ray tube is to make it possible to carry out comparative measurements with the oscilloscope.

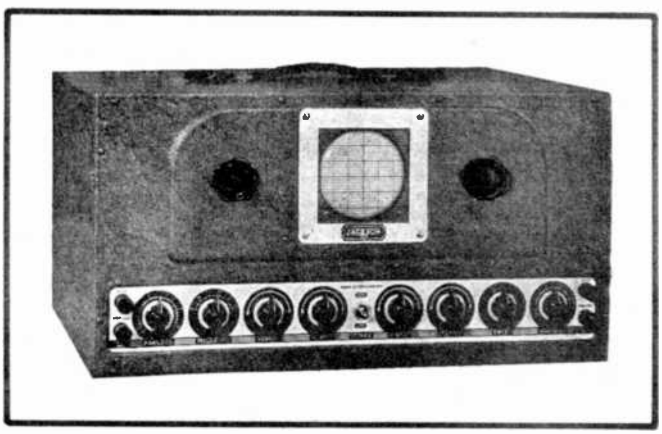

FIG. 21
TYPICAL OSCILLOGRAPH

Fig. 21 shows one type of oscillograph. The cross-ruled window is removed by unscrewing the four small screws in each corner; the instrument then becomes an oscilloscope.

The oscilloscope or oscillograph is an instrument which can convert electrical phenomena into a visible pattern. For example, the actual development of an r-f response curve can be viewed on the screen of a cathode-ray tube as the circuit is brought into resonance; i-f resonance curves, audio-frequency response, distortion, and power supply filter output ripple are some of the many other valuable indications which the oscillograph is capable of producing in visible form on the screen.

Servicemen find their greatest use for the oscillograph in the alignment of receivers -- especially for high-fidelity, broad-band i-f receivers. The alignment of frequency-modulated receivers can be carried out much faster and more accurately by means of the oscillograph than by any other means.

The oscillograph shown in Fig. 21 has a three-inch cathode-ray tube. This is the standard size for oscilloscopes and oscillographs.

As can be seen from the illustration, a number of controls are associated with the operation of the device. Each of these controls has a very definite purpose. For instance, two of the controls take care of vertical and horizontal amplification of the signal input to the cathode-ray tube. Another control varies the timing circuit for different types of curves or measurements. Two more controls take care of the focus and intensity of the spot on the screen. This does not complete the description, but it will serve to show you that each of the controls has a definite task to perform.

An oscillograph is not the type of instrument that can be carried about, due to its size and weight; also, because it is more fragile than other types of apparatus. Therefore, the oscillograph, or oscilloscope, is best suited for use in the shop.

SHOP EQUIPMENT

The shop of a successful radio technician need not consist of a complicated conglomeration of meters, switches, and controls --- although the equipment for the shop may be more extensive than that used for service calls. However, it should be remembered that elaborate equipment is more expensive than the fundamental tools and testing equipment required for ordinary service work. For example, a bench panel similar to that illustrated in Fig. 22 may cost as much as two hundred to three hundred dollars.

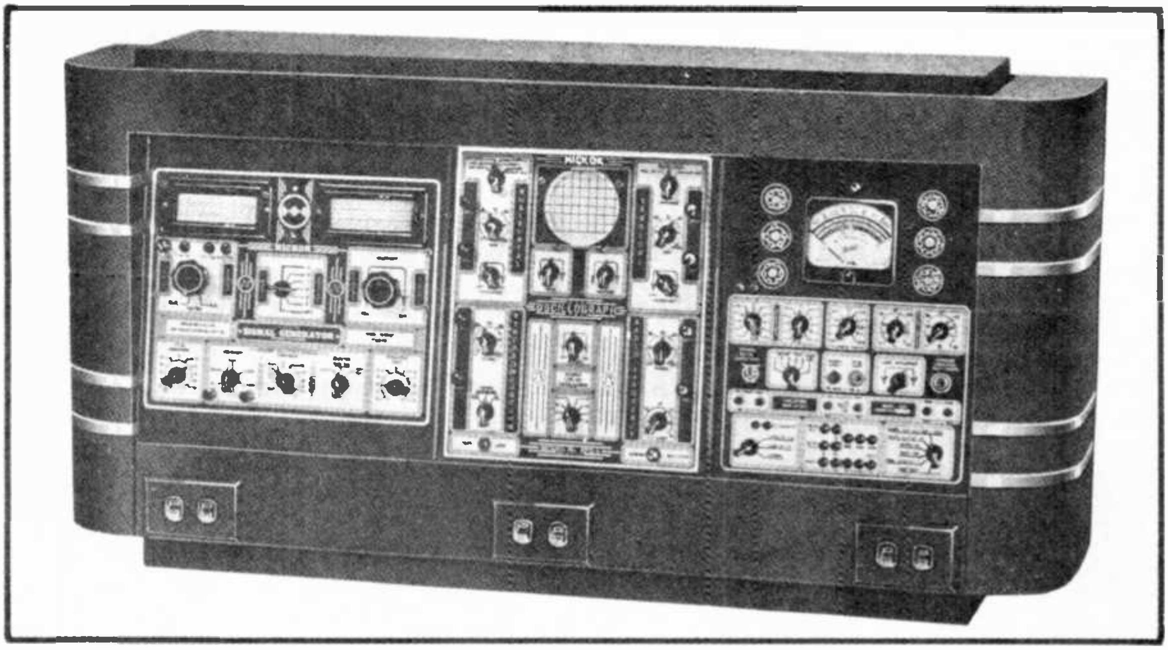

FIG. 22
ELABORATE BENCH PANEL

A shop panel of this type represents the ideal in layout and equipment. This panel of instruments makes it possible for the technician to perform practically every kind of test that may ever be required.

Also, there is a certain amount of psychology connected with a shop having a panel layout similar to that shown in Fig. 22. An instrument panel of this type is usually very impressive if exposed to the view of the general public, or to any customer who might enter the shop. Thus, even though it may not be used very often, it may pay dividends in boosting one's reputation. The customer, upon viewing a panel containing such fine-looking apparatus -- laid out neatly, and well illuminated -- will immediately form a good opinion of your ability.

The enterprising radioman need not necessarily go to such expense just to acquire a group of impressive instruments. A very simple bench and test panel, if well laid out, will often be as impressive as an expensive arrangement.

EXAMINATION QUESTIONS

LESSON NO. 20

1. - What three test instruments are most necessary in order for a serviceman to satisfactorily analyze the operation of and repair radio apparatus?

2. - How can a single meter be made to measure several ranges of voltage?

3. - Explain how a single meter may be used for measuring both current and voltage.

4. - What is a "Dynamic Signal Analyzer," and for what purposes is it used?

5. - Explain the reason for multiplying a voltage or current reading on a multi-range meter by the maximum value of the range.

6. - (a) What is an analyzer?
(b) What functions does it usually perform?

7. - What is a service oscillator?

8. - Name the six most important hand tools used for radio repair and service work.

9. - (a) Does an ohmmeter actually measure resistance?
(b) Explain your answer.

10. - Describe the manner in which shunt resistances are used to increase the current ranges of a milliammeter.

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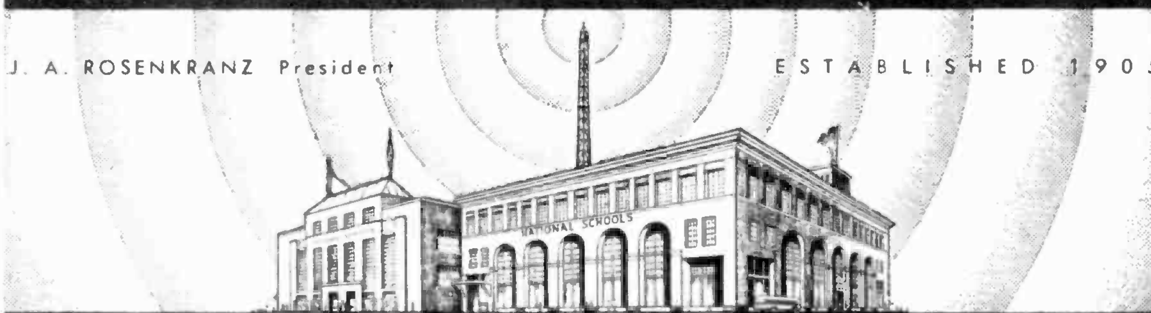

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LESSON NO. 21

ANTENNA INSTALLATIONS

Old types of receivers were built specifically for use with an outdoor antenna. When installing one of these older receivers, the usual practice was to run a few feet of wire under the rug or around the molding of the room. This type of antenna gave satisfactory results on local stations, but its performance was frequently poor during the reception of signals from distant stations. Modern receivers generally have a factory-built antenna system installed in the cabinet, but with provisions for connecting an outdoor antenna when better long-distance reception is desired.

While the actual installation of an antenna is usually a simple matter, there are, nevertheless, several important factors which must be taken into consideration.

The illustration presented in Fig. 1 shows the relation between the various units which go together to make up a complete antenna and grounding system. Study this drawing carefully so that the entire layout will become a clear picture in your mind. This will enable you to visualize the installation as we continue our discussion.

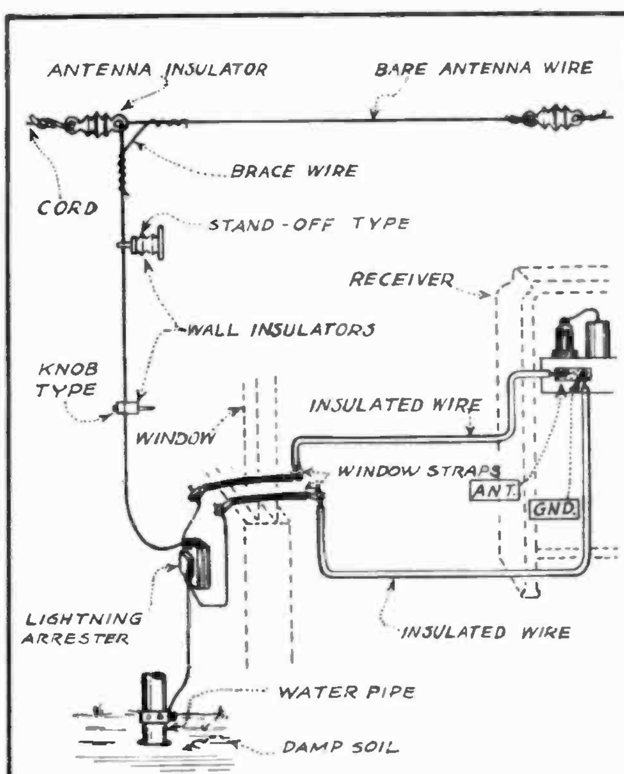

FIG. 1
DETAILS OF A TYPICAL ANTENNA INSTALLATION

LOCATION FOR THE ANTENNA

The first problem confronting us concerns the LOCATION for the antenna, and the type to be used. In Fig. 2 you are shown a typical "inverted L" type antenna, suspended horizontally between a house and garage. This type of antenna is very popular because of its simplicity of construction and good performance. It is also neat in appearance.

The location for any type of outdoor antenna depends greatly upon the general surroundings and possible points from which it can be satisfactorily suspended. Its location should also be such that the lead-in wire can be run to the receiver conveniently.

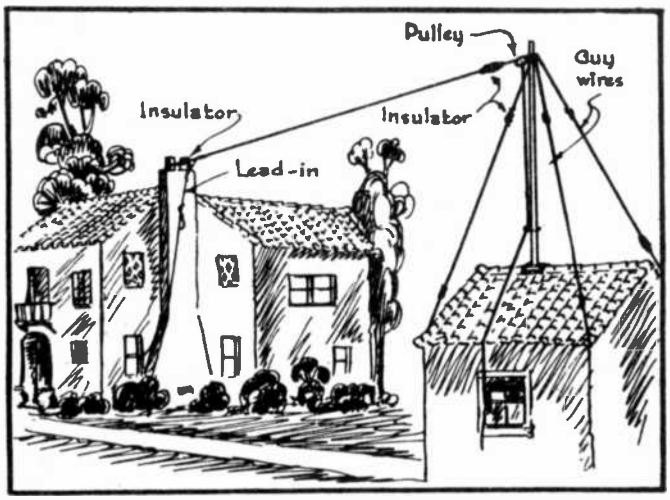

FIG. 2
INVERTED "L" TYPE ANTENNA

Returning to Fig.2, you will observe that this particular form of antenna consists of a horizontal, elevated wire. The lead-in wire, extending downward at one end, gives it the shape of an inverted "L" --- from which it derives its name. It is preferable to extend the elevated wire above ground throughout its entire length -- and as far as possible from trees, buildings and other bodies which make contact with ground.

All grounded objects such as metal roofs, trees, and structures of all kinds, located near the antenna wire, have a tendency to absorb signal energy and thereby reduce the signal "picked up" by the antenna. Therefore, keep as much of the antenna as possible out in the "clear." Fig. 2 is a good example of this.

Also observe in Fig. 2 that an insulator is placed at each end of the elevated wire so that this wire will be thoroughly insulated from its points of suspension. The mast on the garage roof is equipped with a pulley so that the elevated portion of the antenna can be kept fairly taut, and thus be prevented from swaying on windy days. A swinging antenna is undesirable, as it leads to premature wear at the connections; in some instances this has been found to be responsible for "fading" and noisy reception.

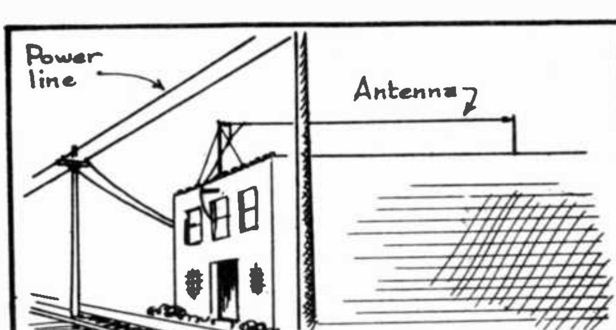

FIG. 3
ERECTING AN ANTENNA NEAR A POWER LINE

Another important point to bear in mind is to keep the antenna as far away as possible from power lines. If conditions make it necessary for the antenna to be located near a power line, then place the elevated horizontal wire at right angles to the line.

Whenever an antenna is erected near and parallel to power lines that carry an alternating current, the magnetic field which continually builds up and collapses around the power line (due to current reversals through it) will react upon the antenna and induce humming and interference noise into it. If the power line carries a direct current, it is quite likely to induce interference noises (man-made static) into the antenna. Such noises may have their origin at some distant point, but are carried and radiated by the power line.

If there is no alternative, and you are compelled to suspend some portion of the antenna near a power line, then follow as closely as possible the method illustrated in Fig. 3. Here you will see that the antenna is quite close to a power line, but all portions of it are at right angles to the line. By applying this method, the inductive effects between the power line and antenna can be kept at a minimum.

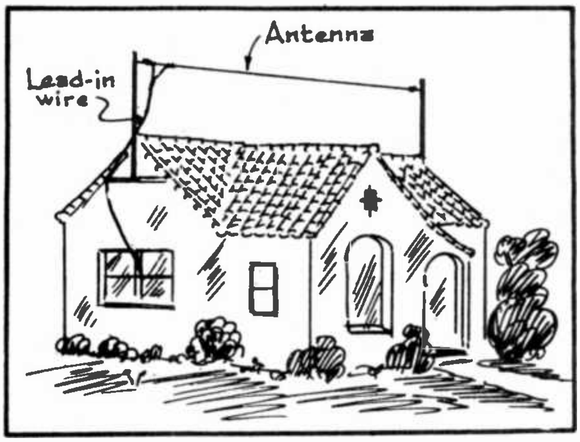

FIG. 4
ANTENNA ERECTED ON GABLE-TYPE ROOF

ERECTING ANTENNAS ON ROOFS

Quite often, a very limited area of ground space is available over which the elevated portion of the antenna can be suspended, as is generally the case in crowded residential districts. Under such circumstances, you can erect an antenna such as illustrated in Fig. 4. Since the roof of this house is of the gable type, the most convenient method for erecting the antenna is to fasten a wooden mast at the peak of each gable. The elevated wire is then suspended from one gable to the other, parallel to the roof.

Whenever masts are used to support an antenna, it is advisable to use wood rather than pipe or steel. Iron and steel have a greater tendency to absorb radio energy and, therefore, reduce the strength of the signal received by the antenna.

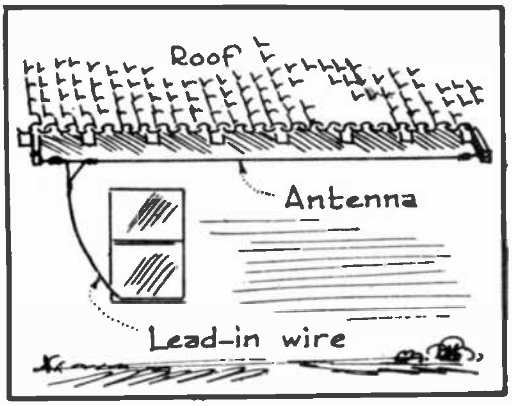

FIG. 5
ANOTHER ROOF ANTENNA

Also observe in Fig. 4 how the lead-in wire is kept clear of the house by means of a wooden stick and insulator. This is important because the closer the lead-in wire is placed to the building, the more nearly will the antenna system be grounded. The latter condition results in a definite loss of signal energy.

The method illustrated in Fig. 5 is also sometimes used when antennas are erected on a roof -- particularly when the home-owner objects to the overhead installation of Fig. 4, because of its appearance. In the case of Fig. 5, two wooden arms are mounted so as to project beyond the eaves of the roof. The antenna wire is then suspended on insulators between them. Thus, the antenna is kept clear of the building; and although it will not be quite as efficient as an antenna of the overhead type, it will, nevertheless, meet certain requirements.

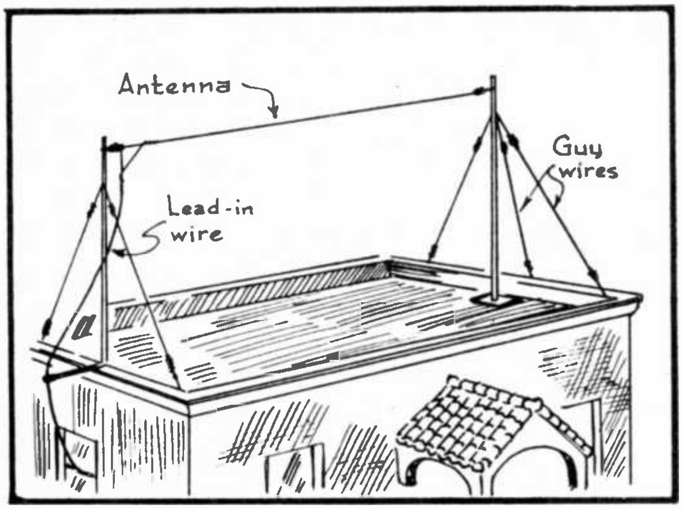

FIG. 6
ANTENNA INSTALLED ON A FLAT ROOF

In Fig. 6 is shown an antenna erected on top of a flat roof. Here, two masts are mounted on the roof and the elevated wire is suspended between them. The masts should be thoroughly braced with adequate guy wires, and at least two insulators should be included in each guy wire so as to isolate it as completely as possible from contact with any grounded object.

Iron wire may be used for the guy wires, but rope is preferable because it will not absorb radio energy so readily.

In Fig. 6 you will also see that precautions have been taken to keep the lead-in wire clear of the building along its entire length from the elevated wire to the point at which it enters the building.

ADDITIONAL ANTENNA SUPPORTS

Sometimes, a tree is located in such a position as to be desirable for supporting one end of the antenna. If you use a tree for this purpose, be sure that none of the branches contact the insulated section of the antenna.

One method of preventing the antenna from contacting the tree is to fasten one end of a rope or wire to the tree, connect an antenna insulator to the other end of this wire, and then attach the antenna wire to the insulator. Thus, the insulated portion of the antenna is kept out in the clear.

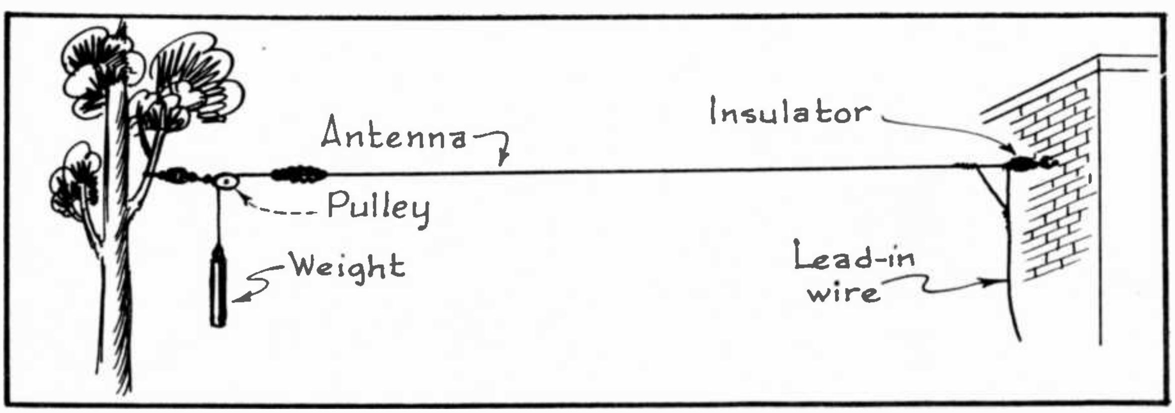

FIG. 7
USING A TREE AND SCREW-HOOK FOR ANTENNA SUPPORT

A tree cannot be considered as a very rigid antenna support, because it is subject to swaying on windy days. Therefore, it is advisable to suspend the other end of the antenna to a rigid support such as a building or mast, and to provide some means whereby the slack in the antenna is always "taken up," so as to compensate for any movement of the tree. One method of doing this is to use a pulley and a weight, as shown in Fig. 7.

Another method for preventing slack and swaying is to insert a coil spring between the antenna and a rigid support, as suggested in Fig. 8. The upper illustration in Fig. 8 shows a close-up view of the coil spring, and the manner in which it is hooked into the ends of two insulators. An alternate method for attaching the coil spring between the antenna insulator and a hook in a wall is shown in the lower illustration.

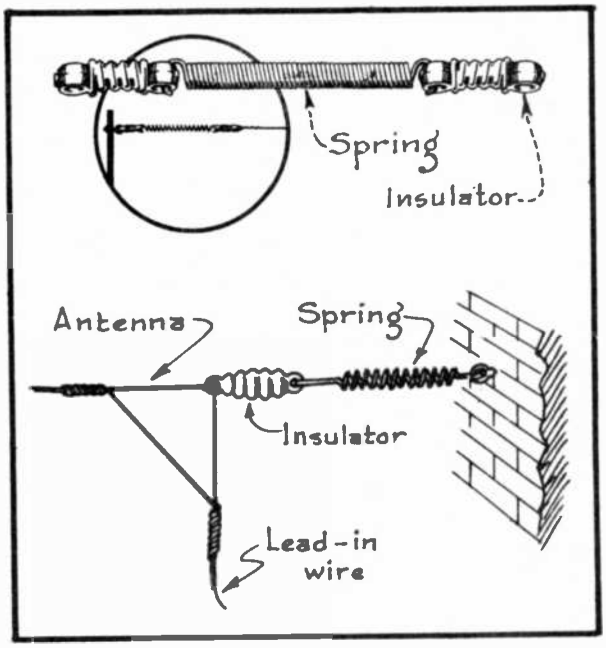

FIG. 8
SPRING SUSPENSION FOR THE ANTENNA

VERTICAL TYPE ANTENNA

This type of antenna is extremely popular in large cities, or in crowded suburban areas. It is easy to install and is highly efficient for local and not too distant reception. Two different types of vertical antennas are shown in Fig. 9 -- and three methods for mounting them.

All three of these antennas are of the telescoping type; that is, they are made of hollow sections which slide inside each other. After being installed, the sections are pulled out to full length, which may be anywhere from eight to fifteen feet.

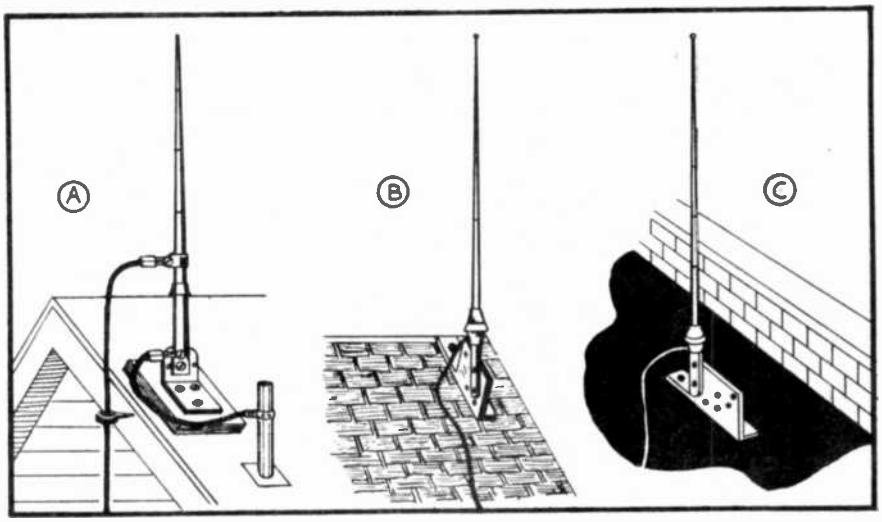

FIG. 9
VERTICAL-ROD ANTENNA INSTALLATION

Notice that the antenna shown at (A) is connected to the lead-in and also grounded to a vent pipe that protrudes through the roof. It is not necessary that the antenna be mounted in such a position that it can always be grounded in this manner; however, the special coupling unit incorporated in the base of this antenna requires grounding. The other type of antenna, illustrated at (B) and (C), is connected directly to the lead-in wire -- no direct ground connection being used.

Brackets are supplied, which allow these antennas to be mounted correctly under various conditions. Usually, they are mounted on the roof of a dwelling, as shown in the illustrations.

METHODS OF INSTALLING WOODEN MASTS

Antenna masts can be mounted on a building in a number of different ways. The type of mounting and method of fastening the mast are dependent upon the position and place at which it is to be erected. Three different suggestions for fastening a wooden mast to a building are offered in Fig. 10.

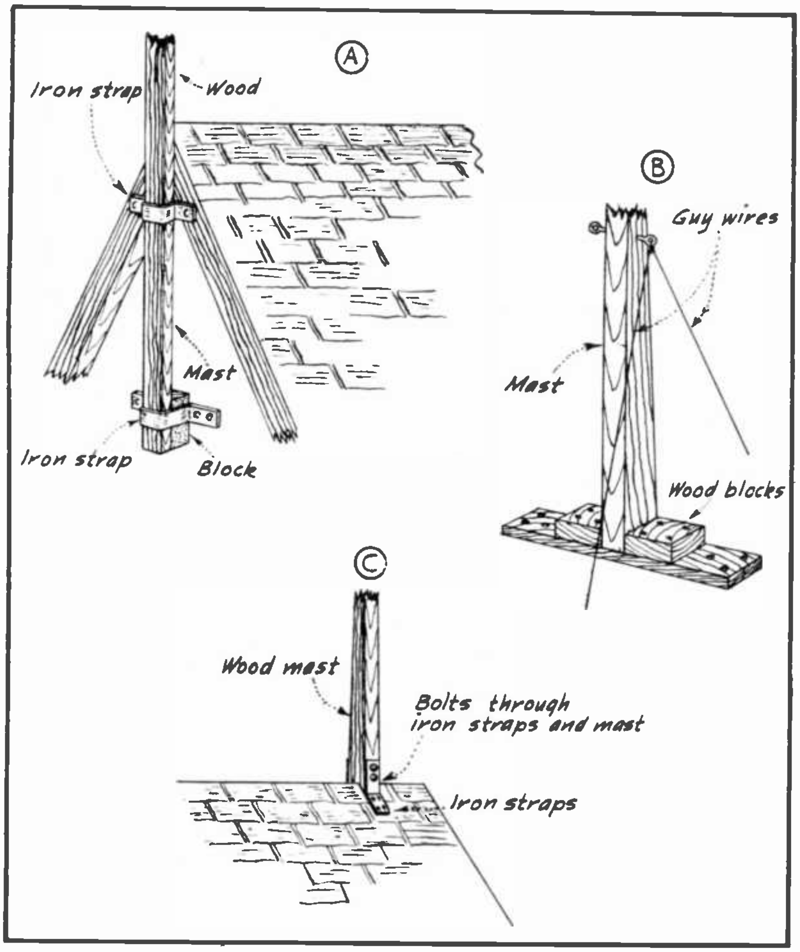

FIG. 10
SUGGESTIONS FOR MOUNTING WOODEN ANTENNA MASTS

The mounting methods shown in Fig.10 are all very simple. At (A) the mast is fastened to the end-gable of the building. The mast does not necessarily have to be installed directly at the peak of the roof, but, since this is the highest point of the building, it is usually the most desirable location.

Notice that a thick block of wood is placed between the lower end of the mast and the outer wall surface of the gable. This block should be thick enough to bring the bottom of the mast out even with the projection of the eaves. Heavy, flat iron straps hold the mast rigidly in position.

Guy wires are not necessary if the antenna is to run parallel with the peak of the house. However, if the antenna wire is to extend away from the house, guy wires should be fastened about half way up on the mast and anchored securely so that their pull is exerted in a direction opposing that of the antenna wire. It is wise to use at least one insulator in each guy wire.

At (B) is shown a means for mounting a mast on a flat surface. In this case, a flat piece of board (about 1" thick) is first nailed to the lower end of the mast. Then, two heavy blocks of wood are pushed up tightly against the sides of the mast and nailed both to the mast and the bottom board. The whole assembly can now be fastened easily to any flat surface. Several guy wires must be used with this type of installation in order to hold the mast rigidly.

Still another type of mast mounting is shown at (C). Here the mast is fastened directly to the peak of the roof. Notice that a "V"-shaped notch is sawed out of the lower end of the mast. This allows the mast to fit down snugly over the peak. Two flat pieces of heavy strap iron are bent to the desired angle, and fastened to the mast with bolts. Several holes, drilled in the extended portion of the iron straps, permit the whole assembly to be fastened securely to the roof surface with lag screws or bolts. At least four guy wires are necessary to hold this mast in position.

HEIGHT OF ANTENNA

It seems to be the popular opinion among laymen that the higher the antenna, the better -- and that an antenna on the roof of a high building is more efficient than one located only 25 feet above the ground. However, things do not actually work out in this way, because the PHYSICAL height and the EFFECTIVE height of the antenna must be considered.

Fig. 11 will help to illustrate what we mean by the terms "physical height," and "effective height." By "physical height", we mean the vertical distance between the ground (earth) and the elevated antenna wire. The "effective height" of an antenna is the distance as measured from the elevated antenna wire to the <u>nearest grounded object</u>.

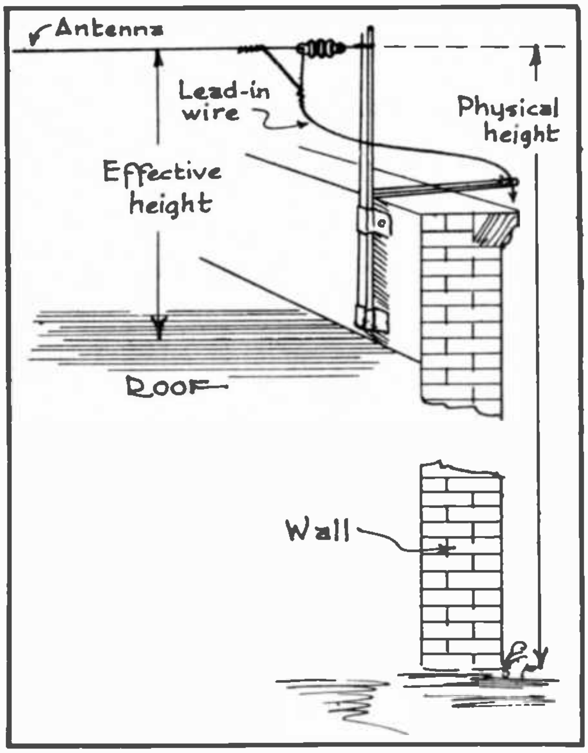

FIG. 11
PHYSICAL AND EFFECTIVE HEIGHT OF ANTENNA

For example, let us assume that the roof of a certain apartment building is 50 feet above ground level, and that the antenna is suspended between two masts 15 feet above a mass of metal work which in some way or other is connected to ground -- such as a drainage system for water. Under these circumstances, the PHYSICAL height of the antenna will be 50 feet plus 15 feet, or 65 feet. The EFFECTIVE height, however, will be only 15 feet. Therefore, the ability of this installation to pick up radio signals will be approximately equivalent to that obtained from an ordinary antenna which is erected only 15 feet above the ground.

Since it is the EFFECTIVE height which is most important, we give this dimension precedence over any other when erecting the antenna. It has been found from long experimentation that for the ordinary receiving type antenna, no particular advantage is gained by erecting it at an effective height exceeding 25 feet.

LENGTH OF ANTENNA

The length of the antenna also affects reception in somewhat the same manner as does height. That is,the longer the antenna, the greater will be the signal pick-up -- but, the static pick-up also increases with an increase in the length of the antenna. Another important fact to be considered is that a long antenna has a tendency to make a receiver less selective.

Since modern receivers are very sensitive, the signal energy picked up by the antenna need not be quite as great as with the older type receivers in order to provide good reception. Therefore, to keep static at a minimum, and at the same time, preserve selectivity, it is preferable not to make the antenna too long. For all ordinary purposes, the length of the antenna, as measured between its suspension insulators, should not be greater than 60 feet.

ANTENNA WIRE

Hard-drawn copper wire of a #14 B & S size, or larger, may be used for the antenna. It may be of the solid or stranded type, bare or enamel-coated.

Copper, as you have already learned, is a good electrical conductor -- but when bare copper wire is exposed to atmospheric conditions, it will in a short time become coated with copper oxide. The copper oxide is produced by a chemical action between the copper and the oxygen contained in the air. It is a very poor electrical conductor, and will, therefore, seriously affect the conducting qualities of the antenna wire.

Radio-frequency currents have a natural tendency to confine themselves quite close to the surface of a conductor through which they flow, rather than passing through the central portion of the wire. This is commonly spoken of as "skin effect." Therefore, since the copper oxide forms on the exposed surface of the wire, it will reduce the efficiency of the most effective part of the conductor.

To prevent the formation of copper oxide, it has become the popular practice to coat copper wire with enamel. This protective coating of enamel prevents the oxygen of the air from coming in direct contact with the copper and thereby prevents the copper from becoming oxidized. For this reason, it is advantageous to use enamel-coated copper wire for outdoor antennas.

Stranded antenna wire consists of about seven lengths of #26 to #22 B & S size wire, twisted together to form a single conductor. This type of wire can be obtained with or without an enamel coating. Stranded wire can be handled with greater ease than solid wire, because it is more flexible.

Another advantage derived from stranded wire is that twisting several individual wires together provides a greater surface area than offered by a solid conductor of equal current-carrying capacity. And, since high-frequency currents confine themselves to the surface of a conductor, stranded wire offers less resistance to their flow than does a solid wire.

ANTENNA INSULATORS

Since very little signal energy is available at the antenna, we must make an effort to get as much of this energy as possible to the receiver. We have already seen to it that the antenna is most favorably located,and that the proper type of wire is used. The next step is to select the correct type of insulator with which to suspend the antenna.

Pyrex glass, porcelain, and various molded compositions are the most common materials used in the construction of antenna insulators. Of these, the glass and porcelain types shown in Fig. 12 are most used. The insulator shown at (A) is made of glass, while those appearing at (B) and (C) are made of porcelain.

As you will observe, the insulators (A) and (B) are provided with a series of ridges at their mid-sections. The purpose of these ridges is to increase the effective distance between the two ends of the insulator without the need for using an insulator of excessive length. The effective length of the antenna insulator to a great measure determines the amount of leakage current which may pass over the insulator surface from one end to the other. This leakage current, and resulting loss of signal energy, can be kept to a minimum by using an insulator of greater effective length. Notice that a hole is provided at each end of insulators (A) and (B) so that wires can be attached to them conveniently.

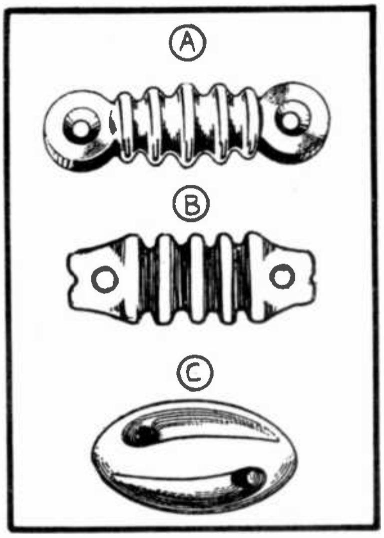

FIG. 12
ANTENNA INSULATORS

The type of insulator shown at (C) is called by various names, such as: egg-insulator, strain insulator, and airplane-type insulator. The reason for the last mentioned name is that this type of insulator offers a low wind resistance, and therefore is used to a great extent on radio installations aboard aircraft. For standard antenna installations, this type of insulator finds its greatest application as a guy wire insulator. The construction of the insulator is such as to give it great strength and resistive qualities to a constant and heavy strain. Thus, its extensive use as a guy wire insulator is quite apparent.

All good insulators have a smooth surface so that water and dust will not accumulate on them readily. Such accumulations will reduce the electrical resistance across the surface of the insulator, and thereby permit a greater leakage current to flow. Porcelain insulators are glazed so as to obtain a smooth surface. Remember -- for best results, use good insulators.

THE LEAD-IN

It is not advisable to splice the lead-in wire to the elevated antenna wire. There are two important reasons for this: first, it is not very convenient to do a good soldering job at such a point out-of-doors, when using the ordinary type of soldering iron; second, this part of the antenna is subject to swaying, and there is a possibility of the connection working loose. The latter condition may at some later time cause crackling noises to be reproduced by the receiver.

A better method of joining the lead-in to the antenna is illustrated at the top of Fig. 13. Here you will see that a separate piece of wire, about 18 inches long, is passed through one hole of the supporting insulator. Both ends of this wire are then twisted firmly around the antenna wire at two points. In this way, the antenna wire will not pass through the insulator at all, and will serve as a part of the lead-in as well.

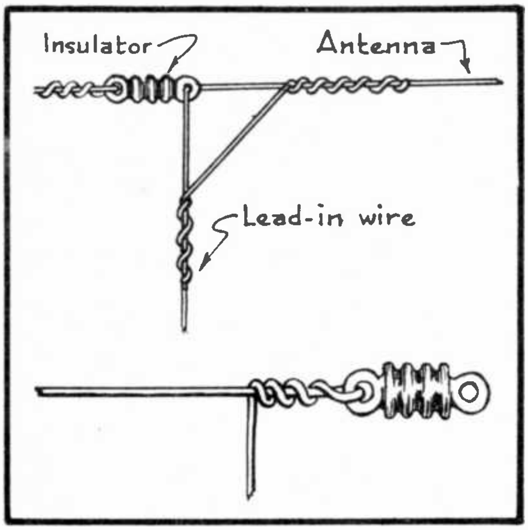

FIG. 13
SUGGESTIONS FOR THE LEAD-IN

Another method for fastening the antenna wire to the insulator is suggested by the bottom illustration of Fig. 13. Here, the antenna wire is inserted through the insulator hole, twisted around itself a couple of times and then run on down to the lead-in circuit.

The lead-in wire to the receiver should be kept as short as possible, and at least 6 inches away from the building. Stand-off insulators, such as shown in Fig. 14, will assist in keeping the lead-in wire clear of the building. Stand-off insulators of the type illustrated at (A) and (D) are generally made of glazed porcelain, and are provided with a flat base having the necessary holes so that the unit can be fastened to any wall surface conveniently.

Some insulators of this type, as shown at (D), are furnished with a screw-and-nut terminal. This terminal can be used as a means for connecting together that portion of the lead-in still consisting of the antenna wire, and the remaining part of the lead-in which may be made with #14 B & S rubber-covered, weatherproof wire.

The knob insulator shown at (B) is used where the heavy rubber-covered lead-in wire is to be run over a considerable distance under the eaves of a house, or under the floor. This results in a somewhat more rigid support of the lead-in wire than that obtained by the use of a stand-off insulator such as the one shown at (A). The insulator illustrated at (A) is preferable when the lead-in wire is to be run for short distances and where it will be exposed to all kinds of weather conditions.

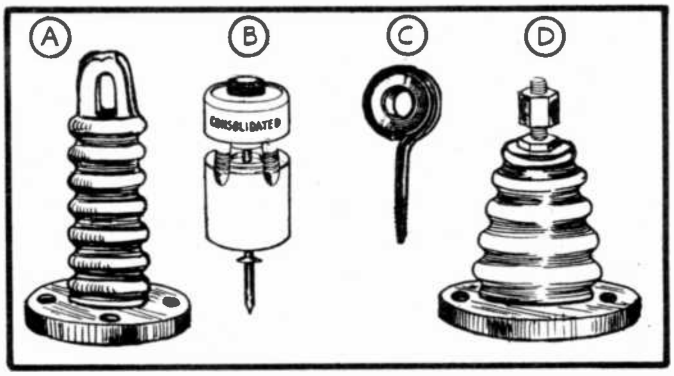

FIG. 14
STAND-OFF INSULATORS

Sometimes, a wooden arm, with an insulator at its far end, will have to be mounted to the building as shown in several illustrations of this lesson, so that the lead-in wire will clear the roof. A stand-off insulator of the type shown at (C) is very handy for this purpose. This insulator can be screwed into the end of the wooden arm.

Another use for this type of insulator is in cases where the lead-in wire must be run over sharp corners or projections of the roof. Various lengths of screw-in shanks can be obtained up to as long as ten inches. Special fixtures that simplify the installation of antenna systems frequently appear on the market. These will be available in all of the larger radio supply stores; it is therefore well to keep in touch with your local store and to familiarize yourself with them.

ENTERING THE BUILDING

The next step is to run the lead in into the building, and thence, to the receiver. At (A) of Fig. 15 is shown a simple method of entering the lead-in under the window frame. Here a special window strip is used to complete the connection between the outdoor and indoor lead-in wires.

Such window strips are made of flat, flexible copper conductors equipped with weatherproof insulation, and having a terminal at each end. By placing it in the position here shown, and bending it to the shape required, it will still be possible to close the window. The wiring between the receiver, and the point at which the lead-in wire enters the building, should preferably be made with a #18 B & S size rubber-covered, single braid fixture wire.

This indoor wire should be concealed as much as possible on its way to the receiver. This can be done by running it along the top of the baseboard, holding it in place with insulated staples or upholstery tacks placed every few feet, as found necessary. This wire may also be concealed in wooden molding or other advantageous woodwork, or it can be hidden under carpets.

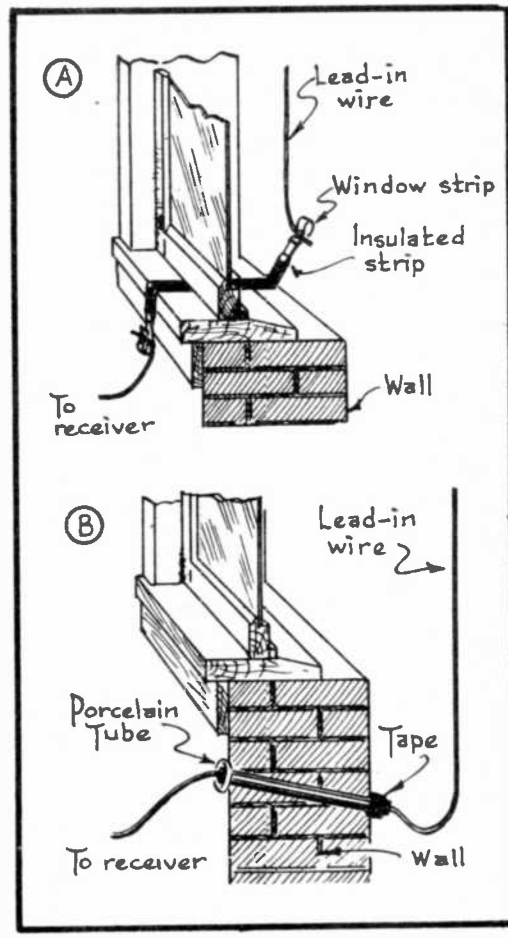

FIG. 15
BRINGING LEAD-IN INTO THE BUILDING

At times, it may be more desirable to bring the lead-in wire up through the floor, directly below the receiver. In this case, the entrance to the building can be made at some point below floor level by running the wire through a vent, using a porcelain tube insulator, or window strip.

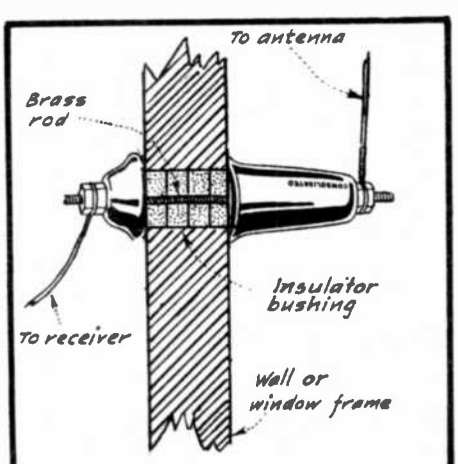

FIG. 16
"FEED-THROUGH" LEAD-IN

If necessary, a hole can be drilled through the wall at the desired point; this hole should be large enough to accommodate a porcelain tube insulator, as shown by (B) of Fig. 15. Notice that the hole is drilled on a slant so that upon inserting the porcelain tube, its outdoor end will be lower than its indoor end; this will prevent water from passing through it into the room. It is also important that the "head" of the tube be placed indoors, and that friction tape be wrapped around the outer end of the tube, close to the wall. The tape prevents the tube from working its way back out of the wall.

The lead-in wire should be bent downward into the form of a loop where it enters the porcelain tube. This is done so that any accumulation of water on the lead-in wire will not run into the building through the tube.

If the lead-in wire enters the building below floor level, it can be supported by insulators fastened to the joists, up to the point where it is desired to bring the wire up through the floor, and to the receiver.

Still another type of lead-in device is shown in Fig. 16. This is called the "feed through" type. This lead-in fixture comprises two separate stand-off insulators, one short and the other fairly long; several sections of uniform, round insulator bushing material; and a long, threaded brass rod. To install it, a hole is first drilled thru the wall or window frame, large enough to allow the sections of insulating bushing to fit snugly. Several sections of the bushing are then pushed into the hole until it is filled, flush with both the outer and inner wall surfaces. Then, the threaded brass rod is inserted through the central hole of the insulator bushing, and the short stand-off insulator pushed on the brass rod from inside the room -- one nut being screwed on to hold it in position. The long stand-off insulator is placed on the rod at the outer wall surface, and a nut is screwed on the rod to hold it in place. The two nuts are tightened so as to hold the stand-off insulators firmly against the surfaces of the wall.

The outer portion of the lead-in wire is attached to the outdoor end of the brass rod and a nut is applied to hold the wire in place. Another wire is similarly attached to the indoor end of the lead-in device and is extended to the receiver as already explained.

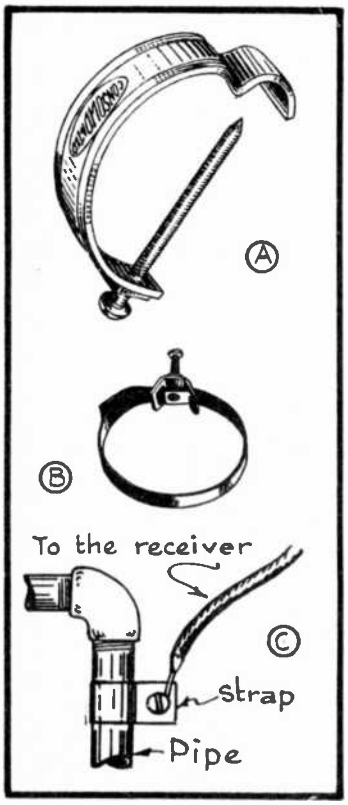

FIG. 17
GROUND CONNECTOR CLAMP

THE GROUND CONNECTION

The wire which connects the receiver to ground should be as short as possible; however, no special precautions need be taken regarding its insulation. A #14 B & S rubber insulated wire with a braid covering can be used for this purpose.

One way of extending the ground wire to the point of grounding is to drill a hole in the floor, directly below the receiver. The ground wire can be run through this hole and fastened to the nearest cold water pipe. This connection can be made with a screw-type clamp as shown at (A) of Fig. 17, or by means of one of the clamps illustrated at (B) or (C). Illustration (C) shows how the clamp is fastened around a cold-water pipe and how the ground wire is fastened to it. Be sure to scrape the pipe clean of all rust, paint, or other coating, before applying the ground clamp. Make this connection as tight as possible.

A copper plate about 2 feet square, and buried in a hole about 10 feet deep in moist earth, will also provide a good ground connection. A bolt can be used to fasten the ground wire to the plate.

To insure good contact between the plate and the earth, dump a generous quantity of charcoal and salt into the hole before placing the plate in position; then put some more charcoal and salt on top of the plate. Add water and fill in the hole with damp earth. Water the ground from time to time so that it will always remain moist.

If desired, the ground wire can be run out through the window or through a porcelain tube, and fastened to a 6-foot length of iron pipe which has been driven into moist earth. This type of ground connection is shown in Fig. 18.

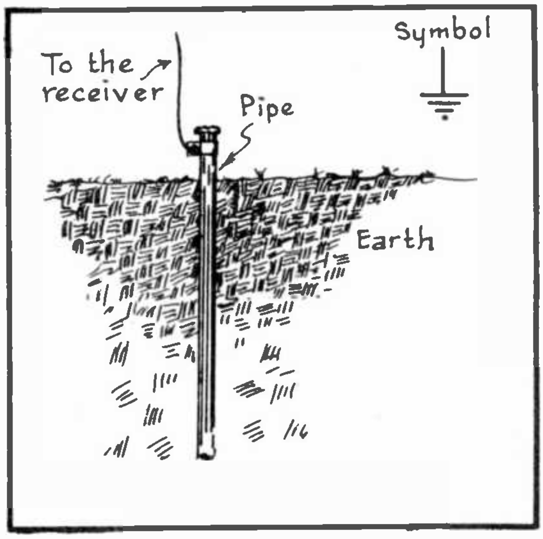

FIG. 18
ANOTHER FORM OF GROUND CONNECTION

When used outdoors, braid-covered wire is soon attacked by the weather. This causes the cloth braid to peel off. Therefore, it is better to use a conductor having weatherproof insulation for this purpose.

APPLICATION OF ANTENNA-GROUND POWER OUTLETS

Modern architects include wiring facilities for combination power, and antenna-ground outlet boxes in new homes. This fixture is similar to a double-receptacle power outlet, with the exception that the slot for the ground connection is placed at an angle to that for the antenna connection. This is illustrated clearly at the left of Fig. 19, where is shown a front-view of the face-plate which fits over the outlet box and receptacle assembly.

A special plug is provided for the antenna-ground receptacle, which will fit it properly. The receiver power plug will also fit its receptacle properly but neither of these plugs will fit the receptacle for which it is not intended. Thus, wrong connections are prevented.

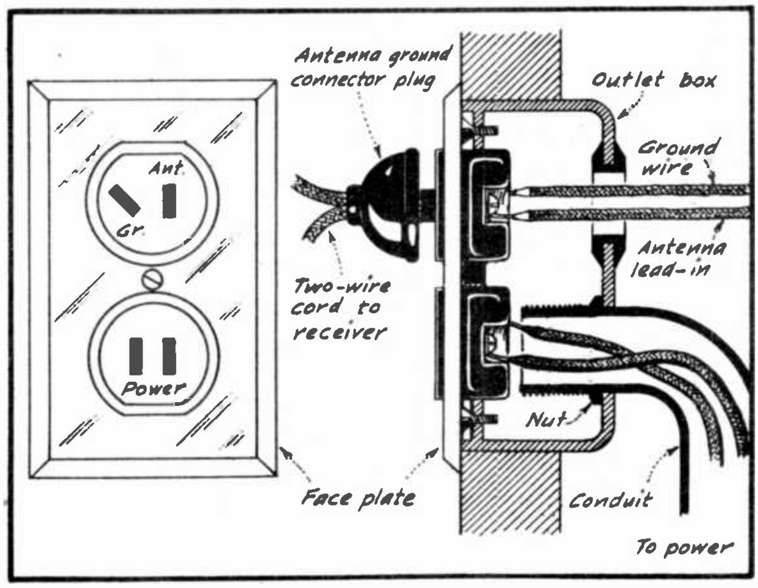

FIG. 19
METHOD OF INSTALLING ANTENNA-GROUND POWER OUTLET

Outlets of this type are installed in the wall, just above the baseboard, and are often placed in at least two corners of each room in which a radio is likely to be installed.

One precaution which must be rigidly observed when installing an antenna-ground outlet box is to use either BX metal cable for the power lines or else to run the power lines through rigid conduit right up to the outlet box.

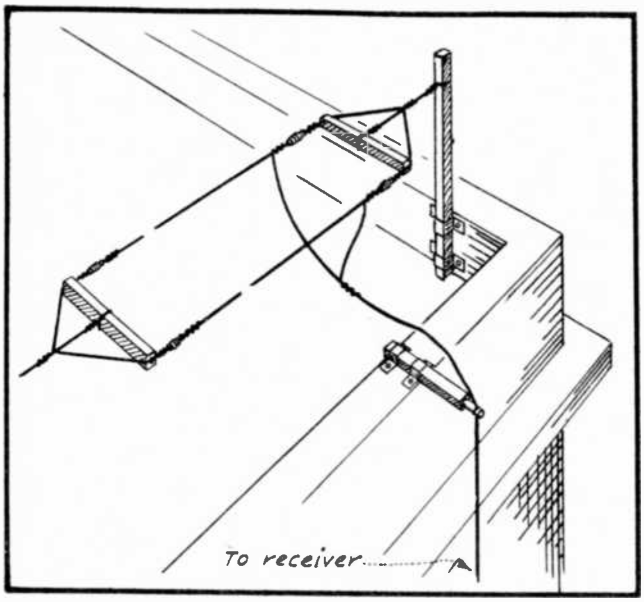

FIG. 20
TWO-WIRE, SHORT ANTENNA

In fact, this metal enclosure should be run into the box, at least one inch, so as to serve as a shield around the wires almost up to the point where they are attached to the screws of the receptacle. The antenna lead-in and the ground wire must be kept as far away as possible from the power supply wires to prevent any hum from being introduced into the receiver. The illustration at the right of Fig. 19 shows how this wiring should be done.

TWO-WIRE ANTENNAS

If space is limited so that only a very short outdoor antenna can be erected, the signal pick-up can be increased somewhat by using an antenna system similar to that shown in Fig. 20. Here two comparatively short lengths of wire are arranged parallel to each other. Each length is completely insulated, and the wires are held apart by a wooden cross-arm at each end. The separation between the two wires may be around three feet. The wires are connected together at one end by the lead-in which is extended to the receiver by one of the methods already described.

INDOOR ANTENNAS

Although indoor antennas are not as efficient as the outdoor types, there are times when you will be called upon to make an indoor installation. This will be necessary in such instances where the receiver has no self-contained antenna, or where the home-owner does not want an outdoor antenna, or when an outdoor antenna is impractical because of installation difficulties.

A simple indoor antenna is illustrated in Fig. 21. Here a wire is concealed as much as possible in the groove of the molding all around the room. A total length of 25 to 30 feet will meet most requirements. #18 B & S fixture wire can be used for this purpose.

Metallic braid, woven into a flat ribbon, and decoratively colored, is also available for this purpose. This is generally called "ribbon aerial" and is sold by most of the larger radio supply concerns in 60-foot rolls.

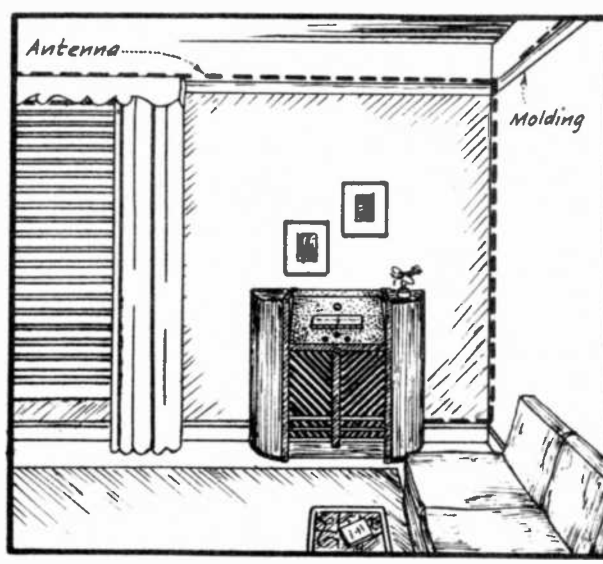

FIG. 21
INDOOR ANTENNA

Another method for installing an indoor antenna (provided that no sheet metal roof is used) is to suspend an antenna wire in the attic, using porcelain knobs or antenna insulators to hold the wire in position. This is shown in Fig. 22. The antenna wire should be kept as far as possible from the lighting circuit wires, and if the wire is to be doubled back to increase the antenna length, each run should be separated from the one next to it by about two feet.

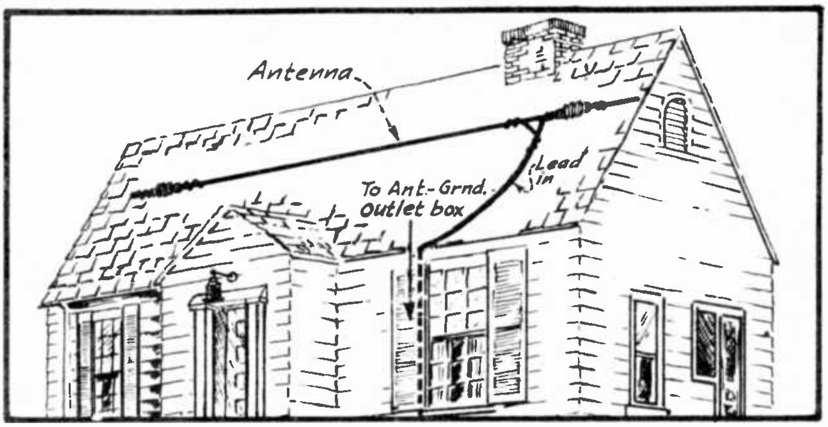

FIG. 22
ANTENNA INSTALLED IN THE ATTIC

APPLICATION OF THE COUNTERPOISE

In such localities where it is impossible to obtain a good ground connection (due to dry, rocky, sandy soil), the conventional grounding system can be replaced with a COUNTERPOISE.

The method of using a counterpoise is illustrated in Fig. 23. As you will observe, this system consists of a conventional type of elevated antenna wire in combination with another wire which is extended parallel to the antenna wire and directly beneath it. The latter replaces the usual ground system.

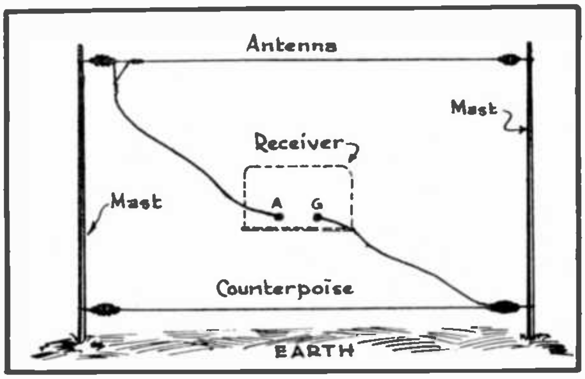

FIG. 23
COUNTERPOISE ANTENNA SYSTEM

The lower wire is called the COUNTERPOISE. It may consist of the same type of wire as used for the antenna, and should be insulated from ground with the same care as employed for the antenna. The antenna lead-in wire is connected to the antenna terminal of the receiver in the usual way; the lead-in wire from the counterpoise is connected to the ground terminal of the receiver.

Ordinarily, the counterpoise is suspended about 1 to 2 feet above the ground; but in some cases, it is more practical to elevate it approximately 8 or 10 feet above ground so as to clear obstructions.

The counterpoise is not so effective as a good ground connection, but it is superior to a poor ground system.

Quite often, several parallel wires, separate from each other by two feet or so, are used together to form the counterpoise. In fact, a sheet metal roof, or other metallic mass of considerable size may often be used as a satisfactory counterpoise.

SUBSTITUTE ANTENNA DEVICES

From time to time the market has been flooded with a number of antenna substitutes or antenna eliminator devices. Several of these are illustrated in Fig. 24. Since then, the "electric socket adapter" type, shown at (A), has been banned by the National Board of Fire Underwriters because of its fire hazard and danger of electric shock.

The "aerial eliminator" type at (B) is of no use whatever. In a later lesson you will find that the amount of signal picked up by an antenna is dependent, not upon a large amount of wire which is compressed into a small space, but upon the capacity existing between the antenna and ground; also upon very definite lengths of straight wire which are suspended above the earth.

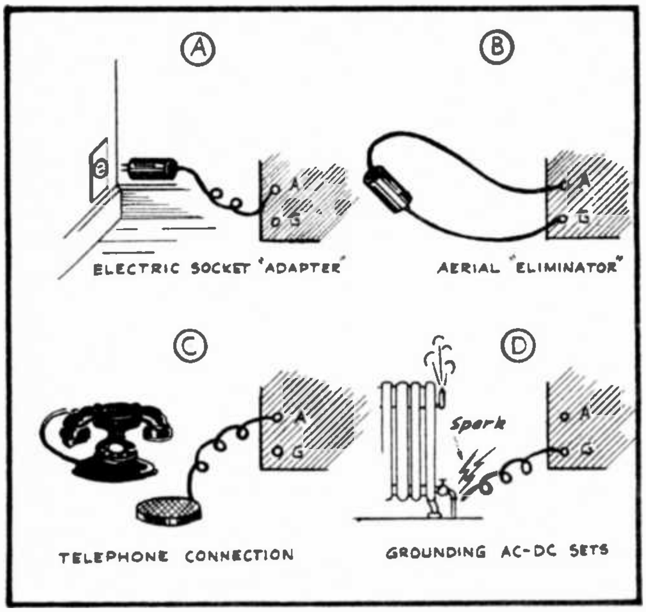

FIG. 24
TYPES OF ANTENNA ELIMINATORS TO BE AVOIDED

Both the electric socket adapter type and the telephone inductor type of antenna eliminators (C) can be responsible for excessive amounts of interference. In some instances, the amount of interference fed into the receiver by these so-called "eliminators" is sufficient to completely over-ride the station signal.

Attempts to use the steam radiator or water system as an antenna (see illustration D of Fig. 24) have resulted in a number of deaths due to electric shock, especially in instances where the receiver was an ac-dc type. Very often, this type of receiver has one side of the power line grounded directly to the receiver chassis. If the receiver's ground terminal (which is normally insulated from the chassis in such receivers) should happen to become shorted to the chassis, it is probable that the full power line voltage will be applied to the ground terminal. Anyone taking hold of the ground terminal and a water pipe, at the same time, might then have a high voltage applied across his body.

LIGHTNING ARRESTERS

Every first-class outdoor antenna installation should include a lightning arrester, especially in those districts where electrical storms are frequent.

The atmosphere is always electrically charged to a greater or lesser degree, and similar charges accumulate on the antenna. Ordinarily, these electrical, or so-called static charges, are present in the antenna in a weak form and discharge themselves harmlessly to ground, by passing through the antenna coil within the receiver. The only indication of their passage is a crackling noise in the loudspeaker.

During electrical storms, the antenna may become electrically charged to quite a high voltage, and if permitted to discharge to ground through the receiver in the usual way, may damage the receiver or start a fire. To prevent such an occurrence, it is advisable to install a lightning arrester in the antenna system.

The internal construction of a typical lightning arrester is illustrated in Fig. 25. By studying this illustration carefully, you will observe that this unit consists of a glass bulb in which the ends of two metallic electrodes are separated from each other by a slight distance. A vacuum exists within this glass enclosure.

A fiber tubing surrounds the glass bulb and an enclosure, made of insulative material, seals the assembled unit. One of the electrodes is connected to a terminal which is to be connected to ground. The other electrode is connected to the arrester terminal which is to be connected to the antenna, as well as to the antenna terminal of the receiver.

A bakelite hood serves as an insulative cap over the unit, and also serves to support the antenna terminal and to protect the arrester from water. The arrester is installed in the antenna system, as illustrated in Fig. 1 of this lesson.

From the explanation so far given, you will notice that even though the lightning arrester is installed out-of-doors, its electrodes are actually connected across the receiver's antenna coil. Under ordinary conditions, the electrical charges accumulated by the antenna will discharge to ground through the antenna coil; but, if the voltage charge on the antenna exceeds 500 volts (which may occur during electrical storms), the voltage will be sufficient for the charge to produce an arc across the gap in the arrester. The reason for this is that the lightning arrester gap has a much lower impedance at this high voltage than does the antenna coil. Thus, the spark-discharge is kept out of the receiver, and the receiver equipment and building are thereby protected.

The lightning arrester will not, however, offer adequate protection in the event that a bolt of lightning strikes the antenna directly; but this is not very likely to happen. The sole purpose of the arrester is to prevent the accumulation of an electrical charge to any excessive amount.

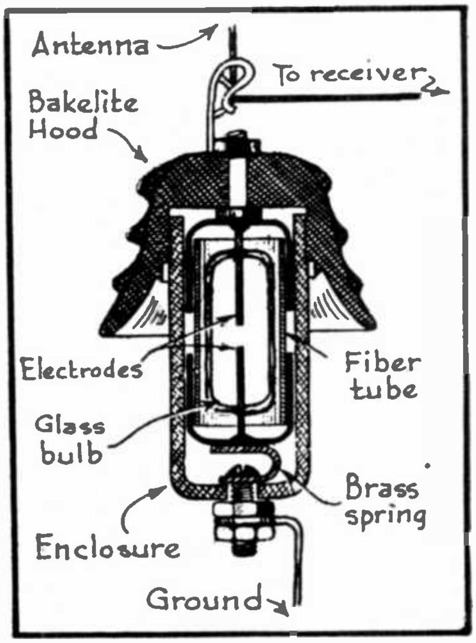

FIG. 25
CONSTRUCTION OF LIGHTNING ARRESTER

LIGHTNING SWITCH

Sometimes a lightning switch is used, as suggested in Fig. 26, instead of the lightning arrester. This switch is an ordinary commercial type single-pole, double-throw switch, mounted on a porcelain base. The switch is installed in the circuit out-of-doors, the same as the arrester. Its center terminal is connected to the antenna, one of its remaining terminals is connected to the antenna terminal of the receiver while the other is connected to ground. The receiver ground lead is also connected to this latter terminal.

When the receiver is in use, the switch is closed in the upper position, thereby connecting the antenna to the receiver. During storms, and when the receiver is not in use, the switch is closed in the lower position; this connects the antenna directly to ground, and thus prevents any accumulation of electrical charges upon it.

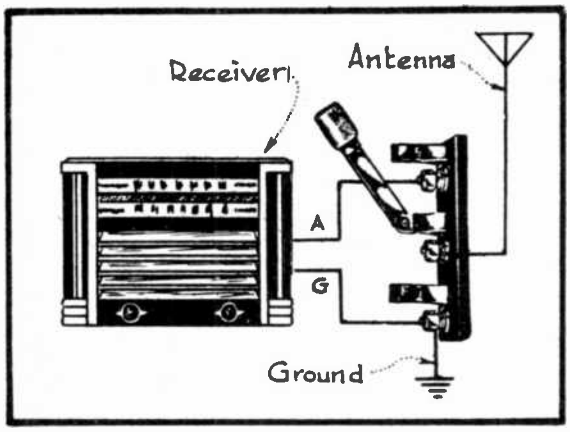

FIG. 26
APPLICATION OF THE LIGHTNING SWITCH

ESTIMATING AN ANTENNA INSTALLATION

When a prospective customer approaches you for information on the cost of installing a receiving antenna, you should proceed to determine the type of receiver he owns, his listening tastes, and the conditions under which the antenna is to be installed.

If the prospective customer owns an expensive, high-quality receiver, he will naturally desire an antenna installation in keeping with the type of receiver. On the other hand, if he is a "shortwave fan", it is a good policy to install a type of antenna which is designed primarily for good shortwave reception. Finally, study the conditions under which the antenna is to be installed and select the proper type of antenna to best fit the particular requirements.

It is possible to obtain materials of several different qualities with which to construct an antenna system, to purchase the complete antenna system in kit form, or to buy it piece by piece as required. In any case, the quality of parts purchased in a "dime store" is on a par with the price.

Other important factors to be considered follow: Enameled antenna wire costs more than plain wire, but the advantages of the enameled type over a period of time will more than make up for the difference in price. Glass insulators have a very high leakage factor, but porcelain insulators are even worse because they absorb moisture. If glass insulators are to be used, the pyrex type is much more desirable because of its greater purity which results in less leakage at the higher frequencies. Several other types of high-quality insulators, made of special low-loss materials such as isolantite, are also available and highly desirable.

Lead-in wire and lead-in insulators are very important, because leakage in this portion of the antenna system is quite extensive due to the framework or masonry of a building being highly conductive. Therefore, only the best type of insulated lead-in wire and insulators should be employed.

The quality of the installation depends much upon the method of entering the building. The feed-through method shown in Fig. 16 will prevent excessive current leakage, but is, of course, somewhat more expensive than the other types.

A noise-reducing shortwave antenna system should be installed for best shortwave reception. Later on in your course, you will study the theory of operation and installation of noise-reducing antennas and shortwave doublet systems. However, many commercial types of shortwave antenna kits are available which contain all instructions necessary for their installation.

Whether or not the installation will require a long antenna or a short antenna depends much upon the particular conditions under which the antenna is to be installed. For instance, if the amount of space available for mounting the antenna is limited to a roof-top, then it might be preferable to install a two-wire antenna of the type shown in Fig. 20, or an attic antenna of the type shown in Fig. 22.

All of the conditions mentioned should be investigated thoroughly before giving an estimate on the cost for installing an antenna. Also, be sure to make a list of the length of antenna wire, lead-in wire, insulators and other parts needed. Once the requirements have been learned, it is an easy matter to figure the cost of the parts. By multiplying the cost of parts by 1.5 and adding your labor charge for the installation, you can give the customer a fair estimate of what it will cost him to have the antenna installed.

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The information contained in this lesson will take care of all conventional forms of antenna installations so that you should now be in a position to convert this instruction into cash immediately. Without a doubt, there is a great need for first-class antennas in your community. We earnestly urge you to impress this fact upon the set-owners and thus avail yourself of the opportunity to do the job as it should be done. You may rest assured that a critical customer will note a marked improvement in the performance of his receiver, and you, in turn, will find this work profitable.

We have covered receiver antennas quite thoroughly in this lesson, but in other sections of the course, you will find additional information regarding special antenna designs such as the static-rejecting type, all-wave antenna systems, etc.

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EXAMINATION QUESTIONS

LESSON NO. 21

1. - Does a tree provide a good support for one end of an antenna wire?

2. - How does corrosion affect the resistance of an antenna wire?

3. - Why are "antenna substitutes" undesirable?

4. - How does the length of an antenna affect its signal pick-up?

5. - Name five important points to be considered when determining the proper location for an antenna.

6. - Describe how a lightning arrester protects a receiver against heavy static discharges?

7. - Explain the difference between EFFECTIVE height and PHYSICAL height.

8. - (a) Name three methods which are employed to enter the lead-in wire through the building to the receiver.
   (b) Describe one method in detail.

9. - Why should the antenna wire be installed in a direction perpendicular to a nearby power line?

10. - What is the PHYSICAL height of an antenna which is mounted 20 feet above the roof of a building, if the building is 40 feet high?

Practical Technical Training In
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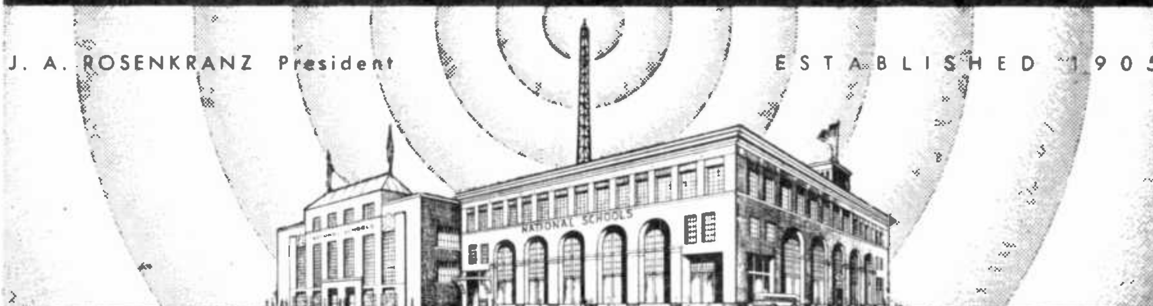

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LESSON NO. 22

DYNAMIC SPEAKER

Speakers are manufactured in many types -- including magnetic, crystal, and dynamic speakers. The dynamic speaker predominates in number and use over all of the other types combined. Modern dynamic speakers still operate on the original principle, but the method of manufacture, assembly, and performance of these speakers have all been greatly improved.

As an example of the changes that have been made in the underlying methods of construction, notice the small size of the speaker presented in Fig. 1. This speaker has a cone which is only three inches in diameter, yet it provides good sound reproduction in comparison with much larger dynamic speakers of a few years back.

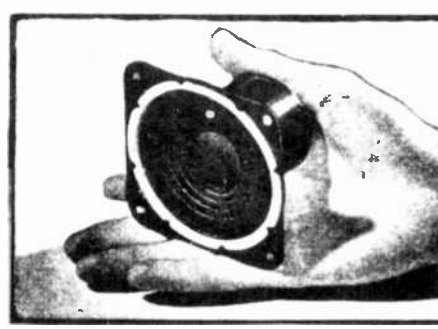

Fig. 1
Small Permanent Magnet Speaker

Although the speaker in Fig. 1 is a dynamic type, it does not have a field coil as do electrodynamic speakers. The main magnetic field, in this case, is furnished by a small but powerful permanent magnet.

The permanent-magnet dynamic speaker has gradually been gaining in popularity, with the result that it is now being employed in commercial receivers almost as much as the electrodynamic type. Some of the advantages which permanent-magnet type speakers offer over the electrodynamic types have already been covered in an earlier lesson.

MODERN ELECTRODYNAMIC SPEAKERS COMPARED TO OLDER TYPES

An electrodynamic speaker is one in which the main magnetic field is obtained by means of a direct current which flows through a field coil. This field coil is wound in a circular form, with a hole at the center, and consists of several hundred turns of enamel-covered copper wire. The construction of speakers of different manufacture varies, but the component parts and operating principles are the same for all. Several speakers of this type are shown in Fig. 2.

As will be observed in Fig. 3, the component parts of all electrodynamic speakers consist of a cone housing (frame) made of stamped sheet steel; a cone (usually made of special paper); a voice coil, attached to the apex of the cone; a field frame, made of heavy iron, usually 3/8" to 1/2" thick; a round central pole piece which protrudes through a hole in the front plate, forming the junction of the cone housing and the field frame; a field coil; and a flexible support (spider) which holds the cone in position.

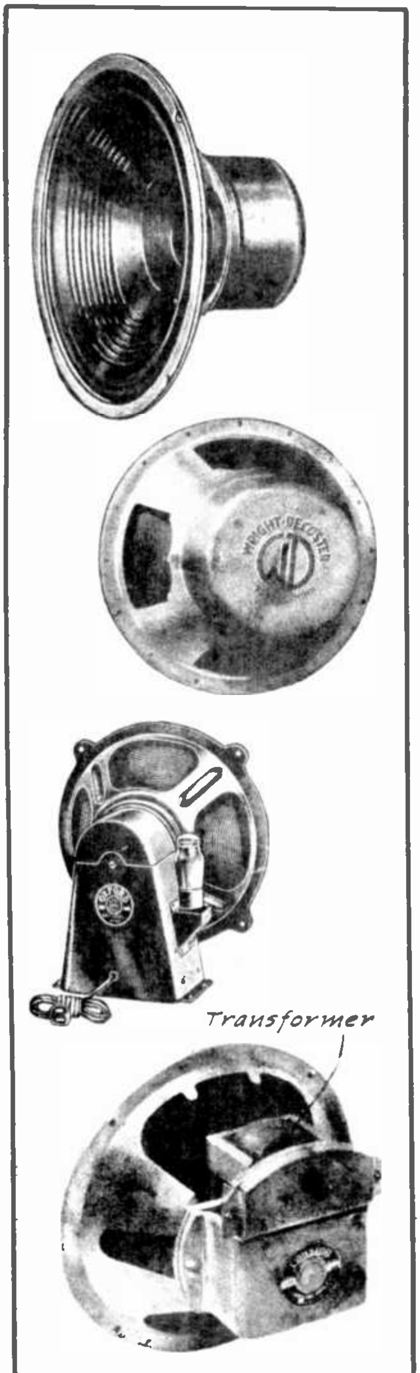

Fig. 2
Different Types of Electrodynamic Speakers

Cones for modern speakers are made of a special, tough flexible paper -- and are formed in one piece instead of being cut and the ends cemented together, as were some of the older types. By forming the cone from one piece of paper, most of the disadvantages of the older type of speaker cones are eliminated, especially breaks occurring in the paper, along the joined edge.

Many new cones are made with ridges or depressed rings formed in the paper. This can be seen very clearly in the speaker shown at the top of Fig. 2. The purpose of these rings or corrugations is to prevent the development of harmonic vibrations at certain points in the sides of the paper wall. These extraneous vibrations often caused a disagreeable "tinny" sound to be prominent in the output of the older speakers.

The spider, or flexible support which holds the voice coil in its proper position in the voice coil well, is made in a variety of shapes -- and various methods of suspension are employed. The spider of modern speakers is made of paper similar to the material used for the cone. This paper is cut in the form of a circle, with a hole in the center through which the voice coil sleeve extends into the speaker well. This paper is also corrugated, or folded in concentric rings so as to give the spider great flexibility, but at the same time serves to hold the voice coil rigidly in position.

The field of an electrodynamic speaker is wound so that it fits fairly snug about the central pole piece of the unit. Some manufacturers design their speakers in such manner that the field coil can be changed very easily. A speaker of this type is illustrated in Fig. 4. To remove the field coil, it is necessary only to remove a single screw from the rear cover.

This loosens the central pole piece and allows it to be drawn out through the front of the speaker assembly. The field coil can then be lifted out of the field frame, as shown.

In other types of speakers, it is not so easy to remove the field coil. The removal of the coil from the latter usually necessitates removing several large screws. These screws are often so located that it becomes necessary to cut small holes in the cone before the screw heads can be reached with a screw driver. These holes in the cone can later be repaired or patched with clear collodion or acetone-base cement, after the field coil has been removed and a new one installed.

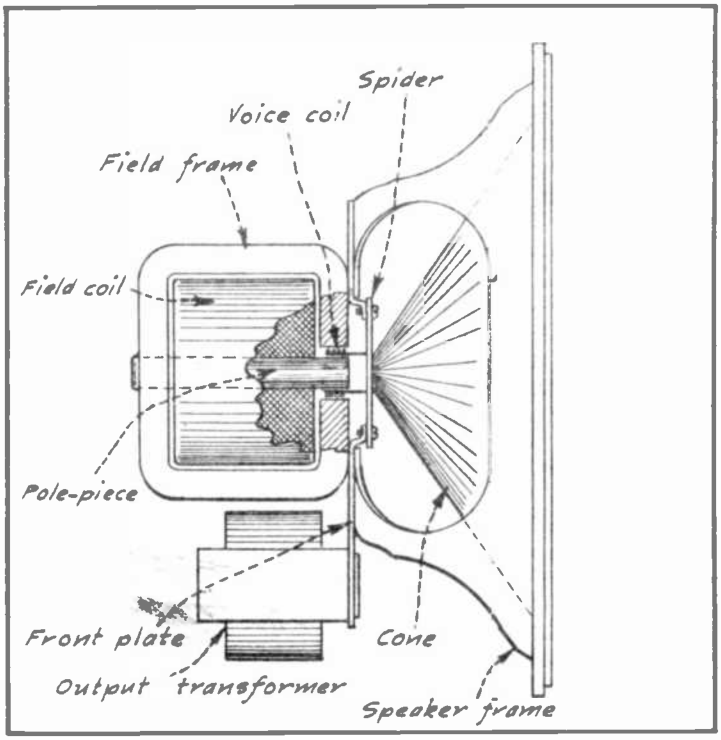

FIG. 3
STRUCTURAL DETAILS OF DYNAMIC SPEAKER

On other types of speakers, where the various parts are riveted together, it is practically impossible to effect a satisfactory repair. The idea of the manufacturer, in this case, has been to prevent any repairs. Since speakers of this type are usually of low price and quality, it is generally advisable to replace the entire speaker with a new one rather than to attempt any repairs.

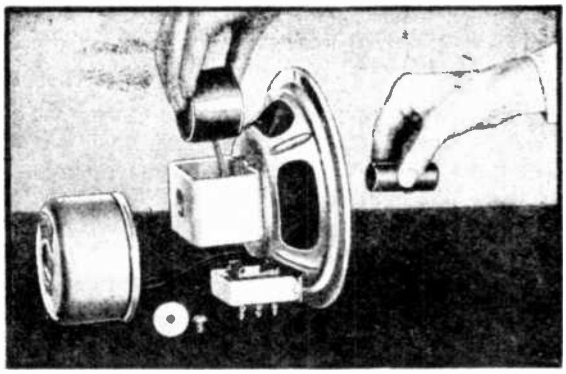

FIG. 4
SPEAKER WITH INTERCHANGEABLE FIELD WINDING

SELECTING A NEW ELECTRODYNAMIC SPEAKER

Several important factors govern the selection of a new speaker for a specific installation or replacement. Therefore, judgment must be exercised when selecting a new speaker.

It must be remembered that there are numerous speakers on the market which are far below the approved standard in quality. Thus, to be assured of getting the best in quality for the price, buy the speaker from a known and trusted radio parts supply house -- or, accept only a speaker manufactured under a well-known trade name.

Before purchasing the new speaker, some very important data must be obtained regarding the manner in which it is to be used. The required field resistance (in ohms), impedance of the voice coil, and maximum audio power to be applied to the voice coil, all must be known.

The maximum audio power to be applied to the voice coil is determined by the output stage of the amplifier or receiver. In the case of a commercial receiver, the amount of audio power will usually be specified by the manufacturer.

For certain amplifiers, or custom-built receivers, the power output will have to be obtained from tube characteristic charts or databooks. This value is dependent upon the types of output tubes employed, and the amount of voltage applied to the plate, or plate and screen grids of these tubes.

Knowing the power which will be applied to the speaker, the next problem is to choose the proper speaker for the particular conditions under which it will have to operate. In most cases, the speaker manufacturer specifies the maximum amount of power that can be applied to each speaker, but in case this information is not available, it is possible to deduce the approximate value by measuring the diameter of the cone.

Although there is no set rule which governs the following approximation, it is nevertheless customary to express the number of watts that can be applied to a certain speaker in terms of the diameter of the cone, in inches. For example, a speaker having a cone diameter of six inches will be able to operate satisfactorily under a full power load of six watts. A 12-inch speaker is capable of converting twelve watts of audio power into sound without undue distortion or trouble.

Some manufacturers try to impress the prospective buyer with the use of speakers that have large cones in relation to the amount of audio power that will be applied. While this may be desirable, it is not at all necessary, because a smaller speaker will operate without distortion as long as the maximum power is not exceeded. Thus, in cases where the manufacturer or retailer attempts to sell larger speakers in preference to a more suitable size, the better policy is to obtain the exact manufacturing data and use your own judgment in selecting the proper speaker.

The impedance of the voice coil is of importance only when the speaker does not come equipped with an output transformer. In such a case, the voice coil impedance must be matched correctly to the secondary impedance of the output transformer. If the output transformer is mounted on the receiver or amplifier chassis, its secondary impedance must be known before the speaker is selected.

However, where the speaker is to be employed with a receiver, it is hardly ever necessary to know the voice coil impedance for the simple reason that the speaker can be obtained with an output transformer already correctly matched, and mounted to the speaker frame. Of more importance in such a case is the primary impedance of the output transformer. That is, the primary impedance of the output transformer must match the plate impedance or plate-to-plate impedance of the output tube or tubes.

In most cases, the speaker manufacturer specifies the types of output tubes which the speaker coupling transformer will match. Thus, it is only necessary to know the type and number of output tubes in order to obtain a speaker with the proper output transformer. For example, if the receiver or amplifier has one 6F6G tube in the output stage, you would select a speaker having a transformer the primary of which will match the plate impedance of the 6F6G tube (no plate impedance values need be given).

But, if the speaker does not come equipped with an output transformer, it is necessary to know the value of the voice coil impedance.

This impedance value is expressed in ohms, and is measured at a frequency of 400 cycles. Voice coil impedance can be pure resistance, or a combination of a very small inductive reactance and comparatively large resistance. If the voice coil is somewhat reactive, the voice coil impedance will also change slightly with the variations of audio frequency applied to it. However, the change in impedance of the voice coil over the complete audio-frequency band is never great enough to have any appreciable effect on the operation of the speaker. Therefore, the value of voice coil impedance as specified by the manufacturer's data can be used for all calculations with practical accuracy.

Sometimes, the secondary impedance of a particular output transformer is unknown, but it is necessary to replace the speaker. The question then is, "What voice coil impedance will be required to match the secondary impedance of the output transformer?" A guess will not be satisfactory, because the secondary impedance may be anything from three ohms up to fifteen ohms. It is evident, then, that we must determine the secondary impedance at least approximately.

A simple measurement can be made to determine the impedance of the output transformer's secondary quite accurately. This is done in the following manner:

First, apply a 400-cycle audio signal to the input of the receiver's audio section or to the input stage of the amplifier. Next, measure the a-c voltage across the terminals of the output transformer secondary winding, while the secondary circuit is open. (Do not operate the output tubes with the secondary winding on open circuit for more than a few seconds because this leaves the plate load for the output tubes wholly reactive. Consequently, large voltages may be built up across the primary winding and may damage either the transformer or the output tubes.)

After determining the secondary voltage on open circuit, connect a rheostat of about 15 ohms across the secondary terminals, but do not alter the audio input signal from the exact value as used for the open circuit measurement. With the rheostat connected across the secondary terminals, adjust the value of resistance until the 400-cycle a-c voltage, as read across the rheostat, is exactly one-half the open circuit voltage. Now, measure the amount of resistance which is connected across the secondary terminals. This will be the proper value for the voice coil impedance of the new speaker.

If a "universal" type of output transformer is to be used with the speaker, the procedure for matching the speaker voice coil impedance to the secondary impedance of the output transformer is very simple. All that need be done is to try the various secondary taps until a connection is found for the voice coil leads which will give the best sound output -- both in quality and in maximum output.

A small amount of mismatch between the secondary and voice coil impedances will not make much difference. However, considerable mismatch will cause serious loss of power and distortion. Therefore, the proper operating conditions should always be provided.

SELECTING A SPEAKER WITH THE PROPER FIELD RESISTANCE

Another important point to be considered when selecting a speaker is to obtain one which will have the proper field resistance for the circuit in which it is to be connected. When replacing a defective or damaged speaker, the new one should have approximately the same characteristics as the old one; otherwise, it will not function at maximum efficiency. Large variations from the required value of field resistance may cause serious disturbances in the operation of the receiver or amplifier. This is especially true when the field winding serves as part of the power supply's filter system, where a variation from the required value of field resistance may result in an excessive increase or decrease in plate voltage. However, it is sometimes permissible to allow about 20% variation from the exact value without seriously affecting the operation of the circuit. For example, if a receiver employs a speaker having a field resistance of 1800 ohms, it would ordinarily be permissible to replace it with one having a field resistance of 1500 or 2000 ohms.

Commercial speakers are generally manufactured with field resistances varying from 1000 to 10,000 ohms. A special field is manufactured for automobile or storage battery operated receivers. The latter usually have a resistance of around 6 ohms. The most usual values of field resistance are: 6; 1000; 1,500; 1,800; 2000 and 3000 ohms. Other values of field resistance can be obtained for practically any special purpose.

When it is required to select the proper speaker for a given installation, from the standpoing of field resistance, it is necessary to first determine the required amount of resistance for the field, the method of connection in the circuit, and the required amount of voltage drop that can be allowed across the speaker field.

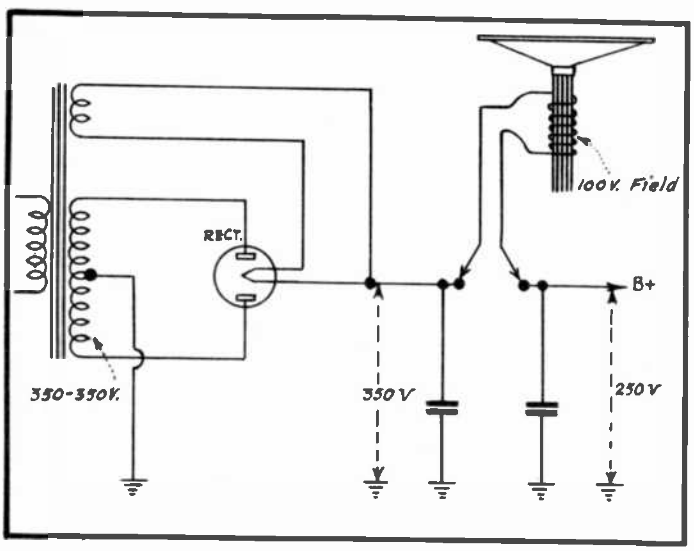

FIG. 5
USING THE SPEAKER FIELD AS A FILTER CHOKE

So that you may better understand this problem, let us examine Fig. 5. Here is shown the common method of connecting a speaker field in the circuit so that it will serve as a filter choke for the "B" power supply. Observe that the speaker field is connected between one side of the rectifier tube's filament and the B+ line. The voltage available at the latter point is equal to the output voltage of the rectifier tube minus the voltage drop across the speaker field resistance.

In the example of Fig. 5, the voltage output from the rectifier tube is 350 volts. The resistance of the speaker field causes a loss of 100 volts; therefore, the "B" voltage output is 350 - 100, or 250 volts.

It is now easy to understand how an incorrect field can cause the "B" voltage output to vary. For instance, if the voltage loss in the field should be greater than 100 volts, the "B" voltage output would be lower than the required 250 volts. On the other hand, if the voltage drop across the field is less than 100 volts, the "B" voltage output would be greater than 250 volts.

The loss in voltage across the speaker field is a direct function of the amount of current which flows through the field winding. Thus, it is very important that the speaker field carry the current intended by the receiver manufacturer. The current flow through the speaker field must not be less than the prescribed value; otherwise, the magnetic field will not be sufficiently intense for proper operation of the speaker.

A greater current than the rated value will cause a greater loss in voltage across the speaker field, and will also cause the field winding to overheat. Sometimes, a large overload current through the speaker field may cause sufficient heat to burn the insulation off the winding. When this happens, the field becomes useless.

Because of the foregoing statements, you may have come to the conclusion that choosing the proper speaker field resistance for a given installation is an extremely difficult task. But, such is not the case, because there are several very simple formulas which make it possible to determine all these requirements quite easily.

However, before these formulas can be used, several factors concerning the operation of the receiver or amplifier must first be accurately determined. We begin by ascertaining the total amount of current taken from the power supply. This will be the total current which will flow through the speaker field. (That is, considering the speaker field to be connected as shown in Fig. 5.)

In a number of typical speakers having various speaker field resistances, the number of watts dissipated by the field may vary considerably, depending upon the current flowing through the field, or more directly, on the number and type of output tubes. The greatest amount of current is taken from the "B" power supply by the power tubes. That is, approximately 30 to 40 per cent of the power delivered by the power supply is dissipated in the plate load and plate resistance of the output tubes. If the constants of this circuit are accurately matched for maximum power transfer from the primary of the output transformer to the secondary and voice coil, only a small percentage of the input power will be dissipated at the plate, or plates, of the output tubes. In other words, about 60 to 70 per cent of the power from the plate supply system is that which is transferred from the plate circuits of the output tubes to the voice coil of the speaker.

Now, the magnetic field of an electrodynamic speaker varies with the amount of current that is flowing through the winding of the speaker field and upon the number of turns of wire contained in the winding. There is no need for producing a magnetic field greater than that which will saturate the magnetic path of the speaker. Any number of lines of magnetic force, or field strength, greater than is necessary to produce saturation is only a waste of power, and usually results in a lower "B" voltage at the output of the power supply.

A general rule which tells approximately how much power must be dissipated in a certain speaker field coil to produce a saturated field states that the amount of this power should not be less than the total or maximum amount of power for which the voice coil is designed. That is, if the voice coil is designed to operate at maximum volume when supplied with an audio power of 10 watts, then the amount of power to be dissipated in the speaker field winding should not be less than 10 watts.

Ordinarily, in the smaller speakers it is desirable to dissipate more power in the speaker winding than that which is applied to the voice coil. For instance, a speaker having a cone diameter of 6 inches would have a power-handling capacity of approximately 6 watts, but more than six watts of power may have to be dissipated in the speaker field winding to produce the maximum volume of which it is capable.

VALUE OF RESISTANCE REQUIRED FOR THE SPEAKER FIELD

The following formula will give the value of field resistance required to dissipate a given amount of power at a certain flow of current:

$$R = \frac{\text{watts} \times 1{,}000{,}000}{(\text{milliamperes})^2}$$

(Required resistance of the speaker field equals the required watts to be dissipated times 1,000,000 divided by the current flow in milliamperes squared.)

As an example, suppose we have a speaker which has a cone diameter of twelve inches: According to the general rule given previously, the field of this speaker should dissipate at least 12 watts. Let us further assume that the total current drain from the power supply has been found to be 80 milliamperes. Substituting these known values in the formula, we have:

$$R = \frac{12 \times 1{,}000{,}000}{(80)^2} \quad \text{or,} \quad R = \frac{12{,}000{,}000}{6400} = 1{,}875 \text{ ohms}$$

In this particular case, then, the speaker should have a field resistance of 1,875 ohms. However, in selecting a speaker, we find that standard field resistance values are available only in round values of one hundred. That is, the commercial resistance value nearest the required value of 1,875 ohms would be 1800 ohms or 2000 ohms. Either of these values would be satisfactory.

Knowing the resistance of the speaker field, and the amount of current flowing through the winding, it is an easy matter to approximate the secondary voltage of the power transformer. This voltage will be the sum of the maximum "B" voltage required by the receiver circuits plus the voltage drop across the field resistance. In the case of the 12-inch speaker with a field resistance of 1,875 ohms, the voltage drop across the field winding will be:

$$V = \frac{1{,}875 \times 80}{1000} = 150 \text{ volts}$$

Adding this voltage to the 250 volts necessary for the plate supply circuit we obtain a total of 400 volts. This, then, is the voltage that will be applied to one plate of the rectifier tube during each half-cycle. Therefore, the total voltage required from the power transformer secondary would be 2 x 400, or 800 volts; or 400 volts each side of the center-tap. The winding of the secondary would have to have a current capacity of 80 milliamperes.

RESISTANCE FOR A FIELD CONNECTED IN SHUNT WITH THE POWER SUPPLY FILTER

In the preceding example, we have considered the case of a speaker in which the field is connected in series with the "B" circuit. The required amount of current flow through the field was known, and consequently, it was an easy matter to apply the required voltage to the plates of the rectifier simply by selecting a power transformer which has the proper secondary voltage.

There are several other methods of connection for the speaker field, where it is not in series with the "B" supply circuit. In one type of alternate connection, the field is connected directly across the "B" voltage output, and acts as a bleeder circuit for the power supply system. This is a common type of connection for direct-current receivers, and also for ac-dc type receivers.

For a connection of this type, the resistance of the field is governed by the voltage output of the filter system and by the required number of watts which must be dissipated in the field winding. The value of this resistance can be calculated very easily by the following formula:

$$R = \frac{(\text{voltage})^2}{\text{watts}}$$

That is, the number of ohms of resistance for the field is equal to the output voltage of the power supply system squared and divided by the watts to be dissipated by the speaker field winding. It must be remembered that this formula is correct only when the field is connected to the power supply in such a manner that its resistance governs the amount of current that flows through it. If the field is connected in such a manner that current for some other parts of the receiver or amplifier circuits must pass through it, then the formula will not hold true, because the total watts dissipated by the field winding will be some value other than that assumed for the formula.

The following example illustrates this: Suppose we need a speaker having a cone diameter of eight inches, and that this speaker is to be connected in a d-c circuit of 110 volts. As has been stated before -- the maximum number of watts generally applied to the voice coil of the speaker is approximately equal to the diameter of the cone expressed in inches. In this case, a maximum of 8 watts will be required for full volume operation of the speaker. Taking the number of watts of operating power supplied to the voice coil as the wattage dissipation of the speaker field, and applying our formula, we have:

$$R = \frac{110^2}{8} \text{ or, } R = \frac{12,100}{8} = 1512 \text{ ohms}$$

Since there is no speaker available which has a field resistance exactly equal to this value, we will have to use one having a field resistance of 1500 ohms. This will be entirely satisfactory.

A-C ELECTRODYNAMIC SPEAKERS

The field of this type of speaker is supplied with rectified current obtained from a self-included power supply -- an example of which is illustrated in Fig. 6. The power supply cannot be seen, because it is mounted inside the metal base.

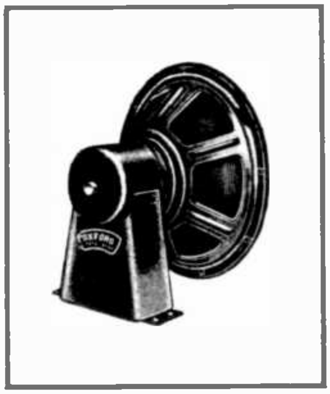

FIG. 6
A-C OPERATED SPEAKER

A speaker of this type is suitable for certain installations where the speaker field is not connected in the circuit of the apparatus which supplies power to the voice coil. Its advantages are most evident when various speakers are to be placed at relatively great distances from the amplifier or source of audio power.

It must be remembered that the new permanent magnet type speakers have the same advantages as a-c speakers, but the permanent magnet type is usually slightly higher in price. However, the permanent magnet speaker offers an additional advantage in that it does not require a connection to the power line with consequent consumption of energy. Also, a permanent magnet type speaker is exempt from the constant care and watchfulness which is necessary when an a-c type speaker is used.

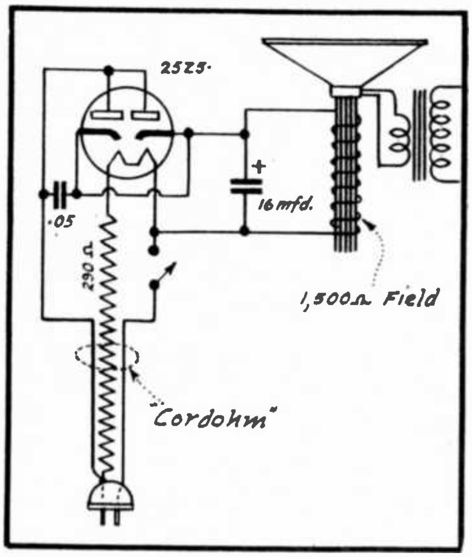

FIG. 7
FIELD ENERGIZED BY A-C OR D-C LINE

In Fig. 7 is shown a diagram of a power supply for an electrodynamic speaker, the design and construction of which could not be more simple. The proper drop from the 110-volt power line voltage to the 25 volts required for the filament is obtained by a 290-ohm resistance element which is incorporated as a part of a line connector cord. The resistance element of this cord is connected to the common side of the power line. This is the same connection that leads to the plates of the 25Z5 tube. The other side of the power line is connected to a switch, which in turn, connects to one side of the filament and one end of the field winding.

The values given in Fig. 7 are for operation from a 110-volt a-c power line. The speaker field must have a resistance in accordance with the number of watts of power that it will be required to dissipate and the voltage output of the 25Z5 rectifier tube. The 25Z5 tube in Fig. 7 will have an output of around 100 volts. Thus, the resistance of the speaker field will be found by means of the formula:

$$R = \frac{V^2}{\text{watts}}$$

This method of furnishing power for the speaker field has the advantage of requiring very few components and also of being very compact. But, on the other hand, its operation is not very economical because considerable power is consumed by the resistance which is connected in series with the filament.

A more efficient arrangement is shown in Fig. 8. Instead of using a series resistance element to drop the line voltage down to a proper value for heating the filament of the rectifier tube, a small transformer is used. If the voltage of the line is equal or approximately equal to the required voltage for the speaker field, the connections as shown in Fig. 8 can be used for this type of power supply.

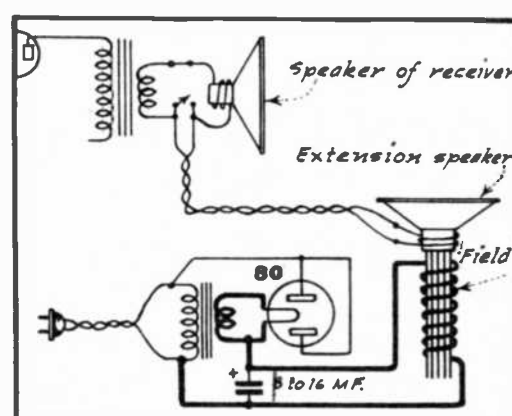

FIG. 8
CONNECTIONS FOR A-C SPEAKER EXTENSION

When the voltage of the line, or the voltage output from a rectifier system, such as illustrated in Figs. 7 and 8, is not sufficient for proper operation of the a-c speaker field, then it becomes necessary to use a power transformer equipped with a winding which will supply voltages for both the filament and the plates of the rectifier tube. The method of connecting a power transformer and rectifier for such a purpose is shown in Fig. 9.

As has already been stated, it is often preferable to use a permanent magnet type speaker when it is necessary to add another speaker to a receiver. However, it is probable that you may have an extra electrodynamic speaker on hand. The latter could be used with one of the circuits described, and then the extra expense of a new speaker would not be necessary.

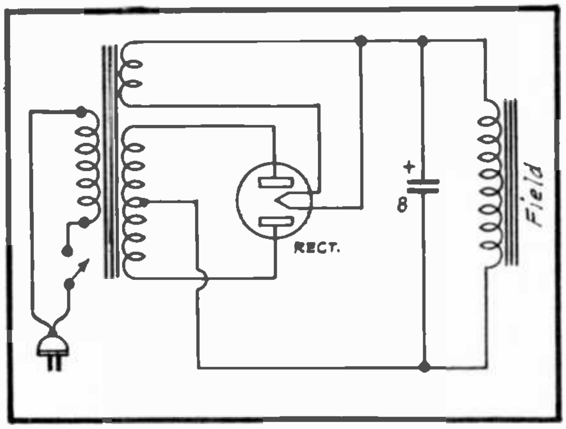

FIG. 9
POWER SUPPLY FOR A-C SPEAKER

Additional speakers are often desired in homes to increase listening pleasure. For instance, an extension speaker can be installed in the dining room, workshop, or other part of the house distant from the room in which the receiver is located.

Connections to the extension speaker are very simple, as is shown in Fig. 8. The voice coil of the extra speaker is connected in series with the secondary of the output transformer and voice coil of the receiver's speaker. In order to be able to cut the additional speaker in or out of the circuit, a switch is connected as indicated on the diagram. When this switch is closed, the voice coil of the extra speaker is short-circuited, and receives no audio power. When this switch is in the open position, the two voice coils are connected in series, and audio power is applied to both.

PERMANENT MAGNET TYPE DYNAMIC SPEAKERS

Speakers of the permanent magnet (p-m) dynamic type were developed many years ago, but not until quite recently did they become popular. The principle defect of early p-m speakers was a gradual loss of power-handling ability, due to a gradual weakening of the magnet or magnets. Also, it was difficult to obtain magnets strong enough for speakers required to handle considerable audio power.

In the newer type of p-m speakers these difficulties have been overcome through the use of a special iron alloy, called Nipermag. This new type of alloy can be magnetized to a very great strength, and will not easily lose its magnetization when exposed to great changes in temperature or vibration. Also, the cost of the new p-m speakers has been reduced considerably.

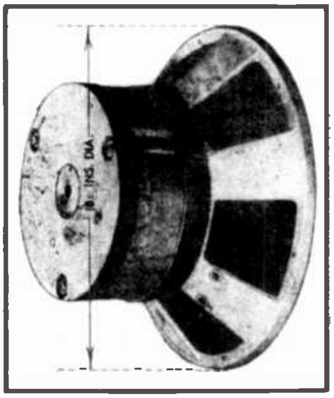

FIG. 10
LARGE P-M SPEAKER

Modern p-m speakers are manufactured in many different sizes, ranging from the very small 3-inch type to 18-inch units. A large 18-inch p-m speaker is illustrated in Fig. 10. The absence of a field winding, accessories required for supplying excitation current, and ease of installation makes the permanent magnet type speaker very desirable, especially for use as an extension speaker.

The construction of most p-m speakers is very simple. They consist of a permanent magnet in the form of a heavy ring; a round, soft iron core; and two round end-covers for the magnet (see Fig. 11). These two iron cover plates serve several purposes. The back cover plate forms the magnetic path from the magnet to the central iron core, and at the same time holds the

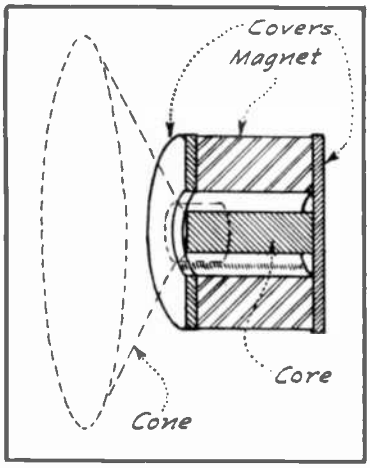

FIG. 11
CONSTRUCTIONAL DETAILS OF P-M SPEAKER

core in proper position with relation to the circular hole in the front cover plate. The front cover plate serves to complete the magnetic path of the magnet, is a foundation for the speaker cone housing, and serves as a support for the voice coil supporting mechanism.

Since the magnet is in the form of a closed ring, there is very little loss of magnetism in the magnetic circuit. All of the lines of force are concentrated in the space between the inner surface of the circular hole in the center of the front cover and the adjacent surface of the centrally located iron core. The voice coil is placed in this concentrated magnetic field in such a manner that it can move freely. This is shown by the dotted lines in the illustration of Fig. 11.

CINAUDAGRAPH P-M SPEAKER: Although the construction of most p-m speakers is similar to that just described, several types of p-m speakers are constructed differently. One of these is made by the Cinaudagraph Corporation. In Fig. 12 is shown one of these speakers of the 8-inch size (cone diameter). The special construction of this speaker is apparent from the illustration.

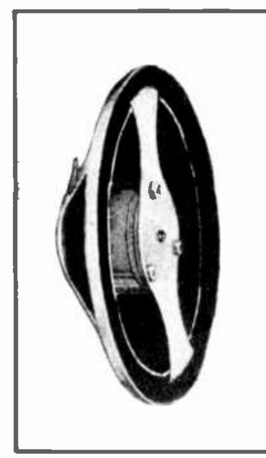

FIG. 12
CINAUDAGRAPH P-M SPEAKER CONSTRUCTION

The principle difference between this type of speaker and the more common type is in the placement of the permanent magnet and the operation of the voice coil. Instead of being mounted on the back part of the cone and serving in part as a housing, the magnet is mounted directly in front and at the center of the speaker cone. The internal construction of the speaker is shown more clearly in Fig. 13, in which the parts are pictured separately in their proper relation to each other.

The supporting frame of the speaker is formed from a piece of stamped sheet steel. A brass rod (2) is riveted to the exact center of the conical shaped housing (5); its purpose is to center the cone and the pole piece. The cone is made from a special paper, its apex being molded into a series of concentric corrugations. The central part of this flexible portion of the cone is fastened to the brass rod. The cone spider, or bellows, is shown at (3) of Fig. 13.

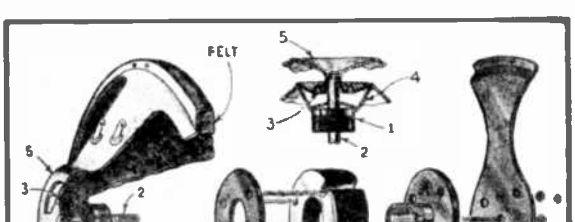

FIG. 13
PARTS OF THE CINAUDAGRAPH P-M SPEAKER

The cylindrical form or support for the voice coil winding is fastened securely to the bellows or spider, as shown by (4). This voice coil form is extremely light, yet very strong and rigid. It must be made so in order to permit the speaker to reproduce sounds with fidelity, and also to keep the voice coil in correct alignment. To prevent distortion of the coil form due to heat and humidity, it is made of quartz. The wall-thickness of this form is only about .002".

Proceeding now to the construction of the field, we observe that the permanent magnet (6) has two soft iron end-covers, which are held together by long screws. The central soft-iron pole piece (8) is securely fastened in the exact center of the front cover. The whole assembly comprising the magnet, covers and pole piece is attached to the front support (10).

The brass rod (2), which extends part way through the center of the pole piece (8), holds the assembled magnet, covers, pole piece, and front support in rigid alignment. A long screw, extending through the center of the assembly from the front support, through and out of the back of the cone housing, holds the whole unit together.

Most of the permanent magnet type dynamic speakers employed U-shaped magnets. As has been mentioned before, these speakers did not prove very satisfactory because the magnets gradually lost their magnetism. Therefore, when one of these old speakers is to be repaired, it is a better policy to replace it with a modern p-m speaker.

Do not confuse the p-m speaker with older types of magnetic speakers which operate on the principle of a movable iron armature. The latter have practically passed into history.

INSTALLATION OF THE SPEAKER

If good reproduction is desired from a speaker, it must be mounted against a baffle, or in a cabinet. The reason for this is that sound waves, developed at the front or at the back of the speaker will cancel each other, unless a fairly long path is provided around which the sound waves have to travel before they react upon each other with such a cancelling effect.

As you know, movement of any surface will cause the air in front of it to be set in motion. Now, a speaker cone is similar to the piston of a pump. As the cone moves forward, the air in front of the cone is compressed and pushed outward. This forward movement of the cone creates a momentary rarefaction or vacuum in the air behind it.

The air that has been compressed in front of the cone tends to rush back immediately and occupy the rarefied space behind the cone surface. As a result, the forward movement of the cone is not transmitted to the original or full volume of air extending outward from its front; consequently, no sound or very little sound is produced. The transmission of sound through air is a direct function of the movement of a volume of air in the form of compressions and rarefactions.

This cancelling effect is most noticeable on low-frequency notes, mainly because the movement of the cone is much slower than at the higher frequencies. Thus, the air has <u>more time</u> in which to move back over the edge of the cone and occupy the rarefied area behind the cone surface. At high frequencies, the movement of the cone is more rapid; therefore, the air does not have sufficient time to flow to the back of the cone before the cone finishes its forward movement.

For this reason, a marked absence of the low notes can be noted immediately when a speaker is operated without a baffle, or extension of the surface area around which the compressed air must flow. However, the high notes are reproduced without much loss.

The question is: How can this condition be eliminated? The answer is -- by mounting the speaker against a large piece of solid material, such as a baffle board, or in a cabinet. The dimensions of the baffle, or the cabinet, must be such that the path, which the compressed air from in front of the speaker must take to arrive at the rear of the speaker, is long enough to allow the cone to finish its forward motion before the compressed air reaches the rear surface of the cone.

Fig. 14 shows two methods of mounting the speaker so that this requirement can be satisfied. In the upper illustration, the heavy arrow shows that the air must travel a relatively long distance in order to reach the back of the cone. From this it is evident that the larger the area of the baffle, the greater will be the distance which the sound wave must travel in order to reach the rear of the speaker.

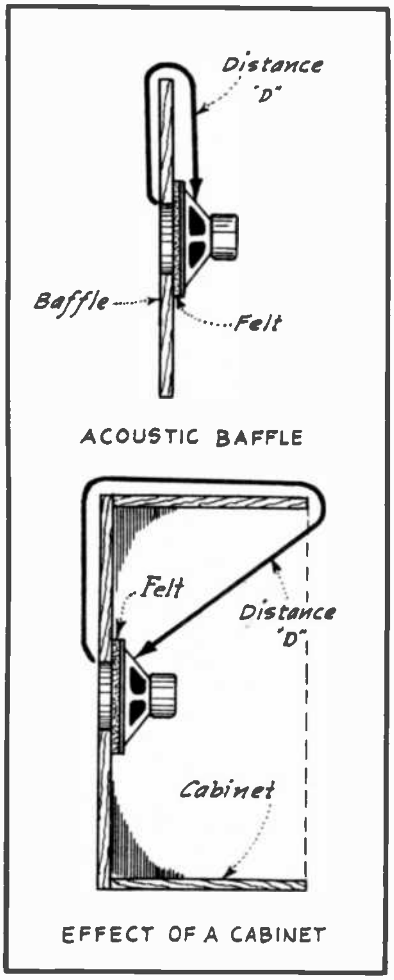

FIG. 14
MOUNTING SPEAKER AGAINST BAFFLE

If we now add sides, a top and bottom to the straight baffle, we will have a box or cabinet as shown in the lower illustration of Fig. 14. The air path has thus been greatly increased, as indicated by the heavy arrow. This is the reason why receiver chassis are nearly always installed in a boxlike cabinet.

In order to obtain faithful reproduction of the very low notes, the distance "D" in Fig. 14 must have a certain minimum length, according to the following formula:

$$D = \frac{282}{F}$$

"D" is the distance in feet which the sound wave must travel from the front to the rear of the cone. "F" is the frequency in cycles of the lowest note that is to be reproduced.

For example, suppose that the lowest note to be reproduced is 40 cycles. Applying the formula, we have:

$$D = \frac{282}{40} = 7.05 \text{ feet}$$

Therefore, the required baffle length is approximately seven feet. (Note: In the above equation 282 is a constant, and never varies.)

It is to be noted and remembered that the sole object of a baffle or cabinet is to increase the length of the air path from the front to the rear of the speaker cone. The baffle or cabinet must be constructed so that it will have no natural vibration period of its own, which is of audio frequency. A cabinet or baffle is not a resonating box as that for a guitar or similar stringed instrument. Resonance in a speaker cabinet will cause serious distortion at one or more audio frequencies; in other words, cabinet resonance will impair fidelity of reproduction.

To prevent the cabinet from vibrating, the baffle portion, or the front board against which the speaker is mounted, must be made of fairly heavy material. In addition, it often helps to use a heavy ring, made of thick felt, between the speaker rim and the baffle. Generally, electrodynamic speakers come equipped with a thick fiber or cardboard ring which effectively insulates speaker vibration from the baffle.

CLOSED CABINETS

From the explanations given concerning the necessity of keeping the air path from the front of a speaker to the rear as long as possible, you have no doubt come to the conclusion that the problem would be solved satisfactorily by simply installing the speaker in a completely enclosed box. However, this will not always solve the problem, because so enclosing the speaker will cause a pressure to be built up on the rear surface of the speaker cone with each backward motion. This would prevent the cone from having proper freedom of movement.

Additional difficulties would arise through complete enclosure of the cabinet due to resonant vibrations being set up in the walls of the cabinet. These spurious vibrations of the cabinet cause considerable distortion of the sound at certain frequencies, usually during the reproduction of the low notes in a musical program. Mechanical vibrations of this type, in a closed cabinet, are caused by the alternate compression and rarefaction of the air within the enclosure, which action would be similar to that which would occur if a small toy balloon were attached to the end of an air piston. Any movement in or out of the piston would cause the balloon to alternately inflate and deflate.

To prevent these mechanical vibrations from occurring, several small holes are cut in the rear cover of the enclosure. The back pressure against the rear of the cone can be relieved by the movement of air through these small holes. The method of cutting these holes in the rear cover of the cabinet is shown clearly in Fig. 15.

In addition to the holes in the rear cover of the cabinet, the inside surface of the box should be covered or lined with a sound absorbent material such as thick felt, rock wool, Celotex, or one of several other types of materials which absorb sound.

An enclosed cabinet is particularly desirable for small receivers, because the low-frequency response of such receivers is increased considerably through its use. Likewise, a cabinet of this type often helps to provide good fidelity from an extension type speaker, especially in such cases where the speaker must be mounted in a small enclosure.

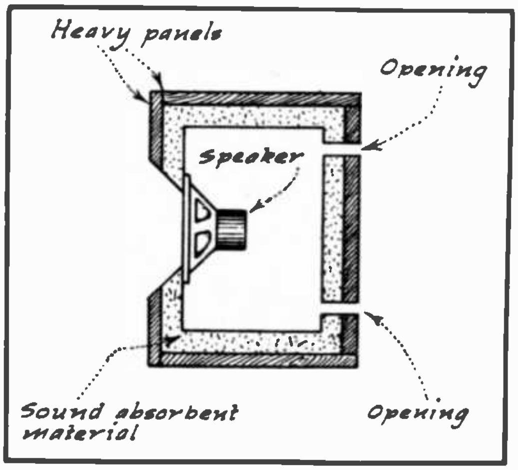

FIG. 15
ENCLOSED SPEAKER CABINET

In most common commercial receivers, the acoustical portion of the cabinet also includes the support or mounting for the chassis. To enclose a cabinet of this type and line it with sound-absorbent material, would require a considerable amount of material, and the cost would be fairly high. If a cabinet of this type suffers from disagreeable resonant conditions, the trouble can often be cured by placing the receiver in a different location in the room, usually against the wall.

At times, moving the receiver cabinet away from the wall will cause the reproduction of certain notes to sound hollow. This results from the reflection of certain frequencies within the space between the wall and the speaker baffle. Some notes are thus reinforced by the reflection while others suffer a decrease of intensity. This effect is most pronounced in the frequency range of the human voice. Often, it causes an announcer to sound as though he were speaking into an empty barrel; that is, his voice will sound hollow and "boomy." This effect can sometimes be stopped by placing the receiver at a distance from the wall, or in a corner. Thus, it is apparent that the quality of reproduction will vary with the position of a receiver in a room.

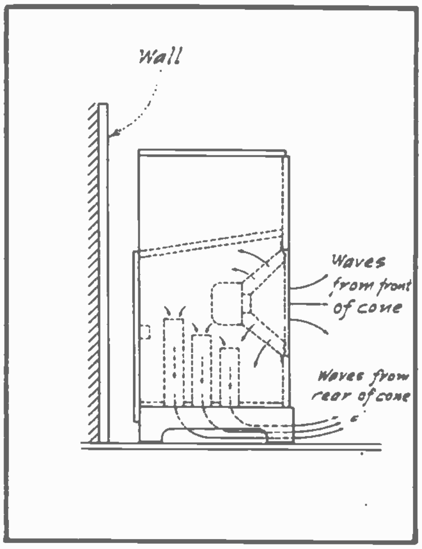

FIG. 16
"MAGIC VOICE" ACOUSTICAL SYSTEM

Frequently, best quality reproduction is never realized from a receiver, because it can be placed in only one certain position in a room and must be left there indefinitely. To prevent a situation as this, some receiver manufacturers have designed special acoustical chambers into their cabinets. These cabinets can be placed in any position without affecting the quality of sound reproduction.

In Fig. 16 is shown the R.C.A. Victor acoustic system, known as the "magic voice" cabinet. The acoustic chamber is completely enclosed, and a group of resonant pipes or tubes is placed in the bottom of the enclosure. The natural resonant frequency of these tubes is established so that those frequencies which suffer the most loss, due to discrimination in the receiver amplifier and reflection within the sound chamber, are reinforced.

THE ACOUSTIC LABYRINTH

Large console-style Stromberg-Carlson receivers employ a folded acoustic labyrinth. This acoustical device eliminates all the resonant difficulties of the closed cabinet, and at the same time, permits the reproduction of the lowest notes with complete fidelity.

Three smaller illustrations (A), (B), and (C) of Fig. 17 show the evolution of the labyrinth acoustic chamber. At (A) is shown the typical receiver trouble -- a booming, hollow sound on low notes. Illustrations (B) and (C) show how this condition can be eliminated by increasing the effective length of the baffle.

The theory behind this method of increasing the baffle area is the same as has already been studied. That is, a speaker is placed at the end of a long square tube, but instead of the tube extending straight out from the back of the receiver as at (B), it is folded in the manner illustrated at (C). Thus, it can be made into a size and shape which will fit in the small space available within the cabinet.

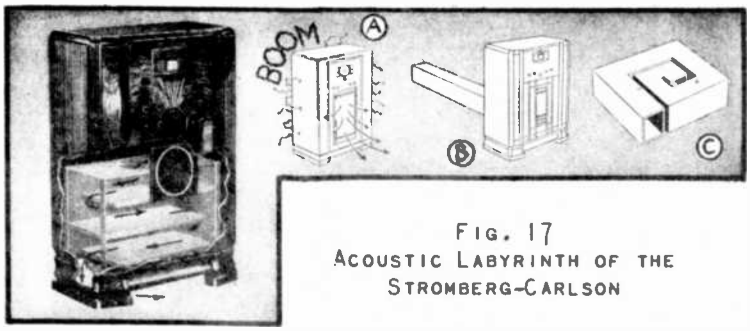

FIG. 17
ACOUSTIC LABYRINTH OF THE STROMBERG-CARLSON

The manner in which this acoustical labyrinth is installed in the larger Stromberg-Carlson models is shown at the left of Fig. 17. Observe how the sound waves from either the front or back of the speaker must follow a zig-zag course back and forth through a special partitioned chamber -- a path several times longer than would be the case if the speaker were mounted against the front of an ordinary cabinet. The walls of this sound chamber are lined with a sound-absorbent material to prevent them from vibrating.

Other manufacturers employ various types of closed sound chambers in large console receivers. The most popular of these is called the "bass reflex" system. This system makes use of a sound chamber which is completely closed at the back. An opening or port is cut in the speaker baffle directly under the opening provided for the speaker cone, as shown in Fig. 18. The inner surfaces of the chamber are lined with sound-absorbent material.

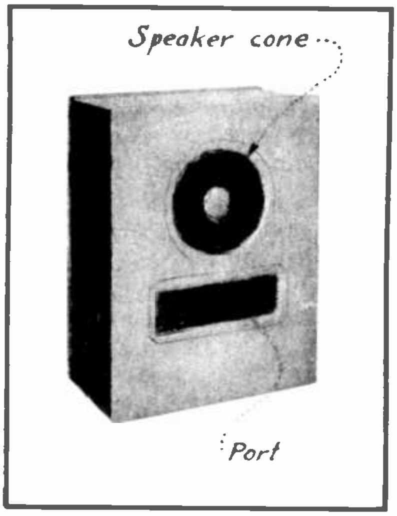

FIG. 18
BASS REFLEX SYSTEM

The theory of operation is that the sound waves from the back of the cone reach the opening or port underneath the speaker by two different paths: one of these paths is directly from the cone; the other, by reflection from the sides and back of the enclosure. Due to the different lengths of these paths, the waves cancel any movement of sound pressure in or out of the port at certain frequencies. If the dimensions of the cabinet have been chosen correctly, and the port is of the proper size and position, the reflection and phase addition of sound waves will occur mainly at the low frequencies. These frequencies will therefore be reproduced at greater intensity than ordinarily.

Special sound chambers have been devised for small receivers. These fit around the back of the speaker and increase the length of the sound path, thus eliminating disagreeable cabinet resonance and loss of low-frequency response. However, these small sound chambers do not give the same results as much larger and more elaborate systems.

Now, it cannot be assumed that the fidelity or quality of sound reproduction of a receiver is totally a function of the speaker and acoustic conditions of the cabinet. The quality of sound is also determined in a great measure by the frequency response and amplification of the receiver's a-f section. In other words, if a high-grade speaker is mounted in a cabinet which is acoustically correct, the quality of sound reproduction will still not be satisfactory if the audio-frequency amplifier is not capable of amplifying the audio frequencies properly.

In reproduction of sound by radio, each of the component parts of the system forms a link with the next. Thus, any deficiency in one part or section may be amplified by the next. As a specific example, let us suppose that the detector tube is not operating correctly and is therefore producing distortion in its output. This distortion will be amplified by the audio-frequency stages that follow, and will be passed on to the speaker. Thus, no matter how good the speaker and acoustic system may be, the quality of sound will still be undesirable.

REPAIRING OR REPLACING THE SPEAKER CONE

Most modern speaker cones are molded in a single piece, the only joint in the surface of the cone being at the apex where the cone is cemented to the voice coil form. Many of the older cones were cut from a pattern, and a glued seam used to form the cone into the desired shape. In time, the cement which holds this joint together gradually decomposes or crystallizes,permitting the seam to come apart, which often results in a rattle or grating noise being emitted by the speaker.

To rejoin the seams or joints of any type of speaker cone, a special cement is required. The best cement for this purpose is made by dissolving celluloid in acetone. This cement is known by such names as "ambroid", "collodion", and many other names.

Rubber cement can also be used with satisfactory results for speaker cones. However, it is slower drying than the collodion type; also, it requires considerable pressure to be applied to the two surfaces being joined in order to obtain a perfect joint.

Never use gum tape or ordinary glues on a speaker cone. Tapes add weight to the cone in one spot and cause distortion due to spurious vibrations being set up in the cone. Ordinary glues crystallize quickly and therefore permit the joint to break open again.

At times, the voice coil will be found to be partially broken away from the apex of the speaker cone. This is especially true of old speakers. The first symptom of such a condition, usually, is considerable distortion -- more so on the low notes than on the high-frequency notes. The remedy is to cement the voice coil form back in position, using collodion or rubber cement.

Tears or breaks in a speaker cone can often be repaired by cementing the torn edges together with collodion cement. Rubber cement is not suitable for this type of repair, because it does not dry quickly enough. If the tear or break is extensive, narrow strips of tough tissue paper can be cemented over the break. The tissue paper should be cemented on both the front and the rear surfaces of the cone, so as to hold the break in correct alignment at its edges. Small holes in the cone can be repaired in a similar manner. Do not use heavy paper for a repair of this nature.

If the damage to the cone is so bad that repairs are impossible, the only satisfactory remedy is to install a new cone or to buy a new speaker. Usually, installing a new cone is much cheaper than buying a new speaker, but some speaker manufacturers have made it a policy not to supply replacement cones for their speakers. They suggest that the complete speaker be replaced; this recommendation being based on the theory that the price of a new speaker is usually only slightly higher than would be the cost for buying a new cone and installing it. Also, installing a new speaker is much easier than replacing a cone.

While this may be true for certain makes of cheap speakers, it is certainly not true for a good grade of speaker. Manufacturers of the latter will always supply replacement cones for any of their speakers, and at a moderate price. Ordinarily, cone replacements for well-known and recommended speakers can be bought from any radio supply house. If such concerns do not have the proper cone on hand, they will usually order it for you from the factory.

When obtaining a new cone from a radio parts dealer, the make and model number of the speaker should always be given. This is necessary in order to be assured that the new cone will be the same size and possess the same voice coil impedance as the original cone. The make and model number of the receiver is not of much help in securing a speaker cone replacement because receiver manufacturers often change types and models of speakers several times during the course of a year's assembly of some particular model of receiver.

To remove the damaged cone and voice coil assembly, first unsolder the voice coil leads. Then remove the screws which hold the spider in position. Finally, cut the outer rim of the cone loose from the frame, using a knife. If a thick cardboard ring is glued over the outer edge of the cone, it is often necessary to retain this ring intact so that it can be employed again when the new cone is installed. To prevent tearing this ring, the knife blade should be thin and sharp. Sometimes, it is possible to loosen the ring by generously applying an acetone solution around the joint, between the ring and the rim of the speaker. A small brush can be employed for this purpose.

Before the new speaker cone is installed, the voice coil well should be cleaned thoroughly to remove any dirt or pieces of metal that may have collected between the surface of the pole piece and the retainer plate. The next step is to place the cone in its proper position in the speaker frame and to center the voice coil form and winding in the voice coil well.

This job of centering can be done correctly only by employing small narrow flat pieces of fiber or steel called "speaker shims." These shims come in sets of four each and of different thickness to fit various spacings between the wall of the voice coil form and the central pole piece. If a speaker cone, of the type illustrated in Fig. 19, is to be centered, only three shims are necessary. These are spaced at equal distances around the voice coil form as shown.

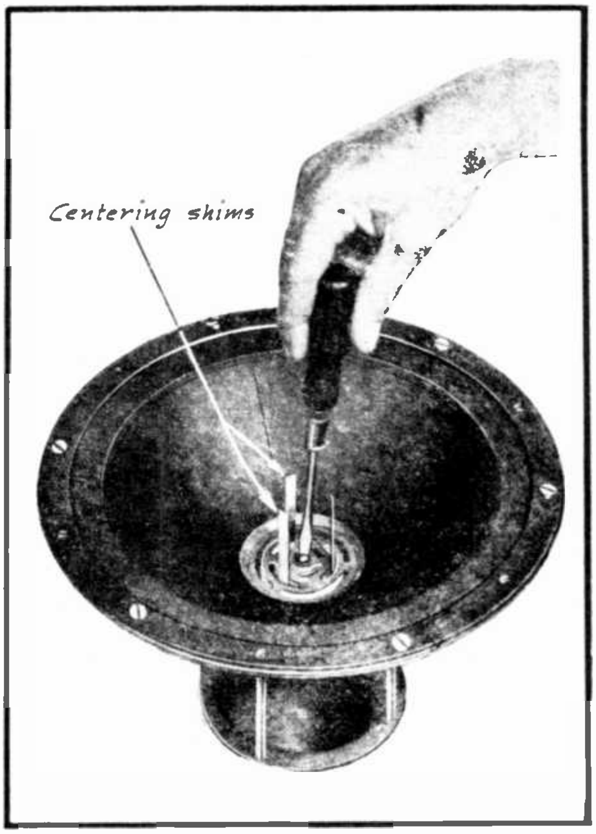

FIG. 19
CENTERING THE SPEAKER VOICE COIL

Having spaced the voice coil and centered it correctly, the next step is to tighten the screw or screws which hold the spider in its correct position. For a speaker of the type illustrated in Fig. 19, this is the screw shown being turned by the screw driver. After the spider has been fastened securely, the outer edge of the cone can be cemented to the rim of the speaker frame. Lastly, the cardboard ring is cemented in the recess of the rim. Some of the older types of speakers had a ring fastened to the rim by means of screws, as shown in Fig. 19. Practically all modern speakers employ a cardboard or felt ring.

When cementing the outer edge of the speaker cone to the recessed rim of the speaker frame, a generous amount of cement should be applied both to the under surface of the cone-edge and to the metal of the rim. Then, after the cardboard ring has been glued over the cone edge, the speaker should be turned face downward on a flat surface, and a weight placed on it. The speaker should be left weighted in this manner for at least an hour to allow the cement adequate time to become thoroughly dry and hard.

When the cone is held in position by a spider which is fastened to the front retainer plate of the speaker field assembly, the work of centering and fastening the cone is often rather difficult. This is largely due to the fact that the holding screws for the spider are located in such a position that they cannot be reached by an ordinary type of screw driver. In such cases, special types of offset screw drivers or small offset speaker socket wrenches are a necessity. By means of these special screw drivers and wrenches, the heads of the screws can be reached and turned through the openings in the side of the cone housing.

Some speaker manufacturers who employ this latter method of spider suspension, often supply the cone and voice coil assembly in two or three parts. Usually, the parts consist of the spider as one separate unit, and the cone and voice coil as another separate unit. In a case such as this, the spider is mounted and centered in position first, then tightened down securely. Next, the cone and voice coil are placed in position and centered with the aid of speaker shims. Now, with a small brush, apply cement at the junction of the spider with the voice coil form. Special care must be exercised to be certain that none of the cement runs down the voice coil form into the speaker well.

RE-CENTERING A SPEAKER CONE

Very often, a speaker cone will work out of position, or out of center, to the extent where it will rub against the inside surfaces of the speaker well. Sometimes, this is due to the spider screws becoming loose, or to a gradual change in the length of the spider arms. In cases such as this, it becomes necessary to re-center the cone. This is done in the same manner as was described for centering a new cone.

To re-center a speaker of the type illustrated in Fig. 19, it is seldom necessary to use speaker shims. The spider screw is then simply loosened while the speaker is in operation, and the voice coil moved slightly until a position is found where it does not rub against the surface of the pole piece. This position can usually be determined by listening to the sound.

There are times when the voice coil form loses its cylindrical shape and becomes slightly oval or egg-shaped. This results in the form rubbing against the pole piece or against the inside surface of the retainer plate. Such a condition cannot be repaired or remedied. The only practical solution is to purchase a new cone, or a new speaker.

When re-centering a voice coil which is suspended by means of a spider and screw assembly fastened to the front plate of the field frame, two small cuts can be made in the cone, directly over the head of the spider screw. These cuts are made in the shape of a "V". The V-shaped section of the cone can then be bent down or up out of the way, so that a screw driver can be inserted through the opening. After the screws have been tightened, the cut section of the cone can be cemented back in place with collodion cement. Small patches of tissue paper are often used to strengthen and hold the cut section in position.

MISCELLANEOUS SUGGESTIONS

Most new p-m speakers, and a great many of the modern electrodynamic speakers, have a special type of spider or voice coil suspension system. This consists of a circular, concentrically-corrugated, paper plate. The outer edge of this circular spider is cemented to a raised metal rim. The replacement of this type of assembly is no more difficult than any other type. In fact, it is much easier to replace a cone of this type than it is to replace a cone which is suspended by means of a laterally extended spider.

Collodion cement should be used exclusively for replacement work with this type of speaker cone. Before the new cone is installed, the surface of the spider suspension rim, and the surface of the cone housing rim, should both be cleaned thoroughly with a knife and acetone.

The spider should be cemented and centered first. This requires fast work because collodion cement dries quickly. Cement should be applied to both the surface of the spider suspension rim and to the under-surface of the outer edge of the paper spider. This done, quickly set the cone in position and insert the speaker shims in their proper position, thus automatically centering the voice coil. Next, press down the edge of the paper. By this time, the collodion will usually be in a partially dry state so that the paper edge readily sticks to the top surface of the suspension ring. Make sure that the edge of the paper is pressed down tightly all the way around.

Now, lift up the outer edge of the cone and apply a generous amount of cement all the way around, between the paper and the recessed rim of the cone housing. Press the cone edge down firmly and apply more cement to its surface. Apply cement to the bottom surface of the cardboard ring and place it in position on the rim. Turn the speaker face down on a flat surface and leave it until the cement has dried thoroughly. After the cement is dry, the voice coil leads can be soldered to their terminals, and the speaker is again ready for use.

Sometimes, a scraping noise in a speaker can be traced to a loose voice coil winding. Usually, the first suspicion is that the voice coil is rubbing against the pole piece, but on re-centering the voice coil, the noise is found to persist. This indicates that the trouble is due to the voice coil winding having become loose on its form. In such a case, the only remedy is to replace the cone.

At other times, a noisy speaker may be caused by particles of iron or steel becoming lodged between the voice coil and the surface of either the pole piece or the front plate. Often, these particles can be removed with the aid of speaker shims. A magnetized screw or thin piece of steel can also be used as a means for pulling the particles out from between the voice coil and pole piece. But this can only be done when no current is flowing through the speaker field, or when there is no magnetism in the pole piece. Thus, the only practical method for dislodging metal particles from a p-m type speaker is to blow them out with compressed air or to force them out with a speaker shim. If either of these methods fail, the speaker cone must be removed.

A speaker field winding very rarely develops trouble. If trouble does occur in a speaker field, it is usually possible to replace the defective winding with a new one. However, if it is impossible to remove the old field, the whole speaker will have to be replaced.

In many cases, the operation of the speaker will cause the field winding to become hot. This is due to the dissipation of electrical energy in the resistance of the winding. A warm or fairly hot field winding does not mean that something is wrong with the field, unless it begins to smoke, or smell as if insulation were burning. The latter indicates that the winding is being overloaded -- usually, due to a shorted filter condenser. A partial short circuit in the field winding will only cause a decrease in speaker volume.

Insufficient volume, when two speakers are being operated in the same room, is due to out-of-phase operation of the speaker cones. That is, the cones of both speakers do not move in synchromism, or do not move exactly in the same direction at the same time. This is nearly always due to reversed connections at the voice coil of the extension speaker. The remedy is to change the connections at the voice coil of the extension speaker.

The application of large, special speakers for public address amplifier systems is explained in a later lesson. At that time, you will also receive more detailed instruction regarding the use of multiple speakers, such as the combinations best suited for certain installations, their methods of connection, etc. Additional information, in the nature of speaker troubles, their symptoms, and remedies is given in your Job Sheets. All of this material, together, will provide you with a good basic knowledge of the constructional features, operating principles, and problems associated with the various types of loudspeakers now being used.

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EXAMINATION QUESTIONS

LESSON NO. 22

1. - What baffle length is required for a speaker so that it will faithfully reproduce a 50-cycle note?

2. - Draw a simple circuit diagram, showing how the field of an a-c electrodynamic speaker may be energized from the a-c line.

3. - What are the most probable causes for scraping noises in an electrodynamic speaker?

4. - What is the essential difference between a p-m speaker and a conventional electrodynamic speaker?

5. - What factors should be considered in selecting a speaker for a given receiver?

6. - What is an acoustic labyrinth?

7. - Explain briefly how you would proceed to determine the value of speaker field resistance required for a given receiver.

8. - How would you proceed to center the speaker voice coil?

9. - Why is it not advisable to mount a speaker in a cabinet which is completely enclosed?

10. - How would you repair a tear in a speaker cone?

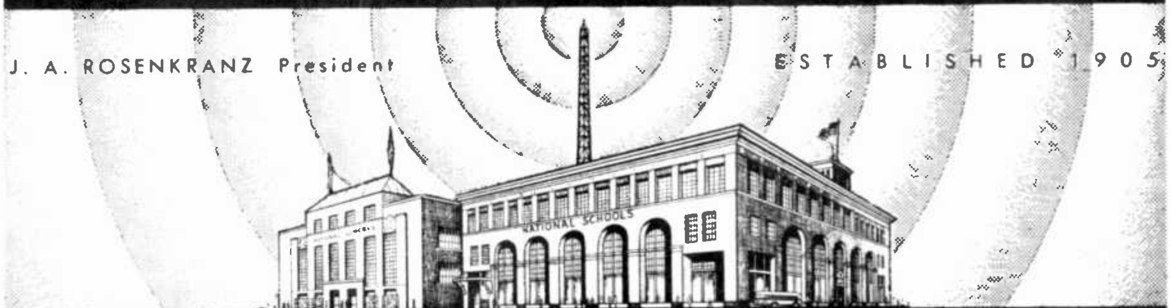
HE IS wise who does not put off until tomorrow what he can do today...he is wiser still who does not put off until today what he could have done yesterday.

J. A. ROSENKRANZ,

Practical Technical Training In

RADIO·TELEVISION

AND ALLIED ELECTRONICS



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LESSON NO. 23

RADIO INTERFERENCE

IN THIS LESSON, YOU ARE GOING TO STUDY ABOUT THE TYPE OF RADIO INTERFERENCE THAT CAUSES CRASHING, CRACKLING, AND RASPING NOISES TO BE PRODUCED BY THE LOUD SPEAKER. SINCE THIS IS A COMMON COMPLAINT OF RADIO LISTENERS,YOU SHOULD LEARN AS MUCH ABOUT IT AS POSSIBLE SO AS TO BE ABLE TO CORRECT THE CONDITION WHENEVER THIS IS PRACTICABLE.

LOCATING SOURCES OF INTERFERENCE AND ELIMINATING SUCH DISTURBANCES HAS BECOME AN IMPORTANT AND PROFITABLE FIELD OF SPECIALIZATION FOR RADIO TECHNICIANS.

FIG. 1
LOCATING THE SOURCE OF INTERFERENCE

THE MEANING OF "RADIO INTERFERENCE"

THE TERM "INTERFERENCE" IS USED RATHER FREELY IN RADIO. FOR EXAMPLE, WHEN TWO STATIONS ARE HEARD SIMULTANEOUSLY, WE SAY THAT THEY ARE INTERFERING WITH EACH OTHER, OR THAT THE RECEIVER IS TROUBLED BY INTERFERENCE. THIS IS DUE TO LACK OF SELECTIVITY IN THE RECEIVER; BUT IN THIS LESSON, WE ARE NOT PARTICULARLY INTERESTED IN THIS KIND OF INTERFERENCE. AT THIS TIME OUR ATTENTION IS CENTERED ON THAT TYPE OF INTERFERENCE WHICH CAUSES NOISY RECEPTION.

THE INTERFERENCE, WHICH WE ARE STUDYING ABOUT NOW, IS CAUSED BY ELECTRICAL DISTURBANCES ORGINATING EITHER NEAR OR AT SOME DISTANCE FROM THE RECEIVER;BUT REGARDLESS OF WHERE IT COMES FROM,THE LISTENER EXPECTS THE RADIO TECHNICIAN TO GET RID OF IT. THERE IS, HOWEVER, ONE TYPE

OF INTERFERENCE OVER WHICH WE HUMANS HAVE NO CONTROL AND THESE ARE THE ELECTRICAL DISTURBANCES, WHICH HAVE THEIR ORIGIN WITHIN THE ATMOSPHERE. THIS ATMOSPHERIC ELECTRICITY IS GENERALLY REFERRED TO AS STATIC AND SOMETIMES THESE STATIC CHARGES PILE UP AND SUDDENLY DISCHARGE THEMSELVES WITH A TREMENDOUS FLASH, WHICH WE KNOW AS LIGHTNING. "STATIC" IS ONE OF NATURE'S ENEMIES AGAINST PERFECT RADIO RECEPTION AND ALTHOUGH ITS EFFECTS CAN BE REDUCED, YET IT CANNOT BE ELIMINATED ENTIRELY.

STATIC DISCHARGES CAUSE A CRASHING SOUND TO BE EMITTED FROM THE RECEIVER AND IN SOME LOCALITIES AND AT CERTAIN SEASONS OF THE YEAR, THESE STATIC DISTURBANCES ARE VERY BOTHERSOME. SOMETIMES, ONE WILL BE LISTENING TO A BEAUTIFUL SELECTION BEING PLAYED BY SOME FAMOUS SYMPHONY ORCHESTRA, WHEN ALL OF A SUDDEN AND WITHOUT ANY WARNING WHATEVER, A LOUD CRASHING NOISE WILL COME OUT OF THE RECEIVER, WHICH SOUNDS AS THOUGH THE WHOLE ROOF HAD CAVED DOWN UPON THE ORCHESTRA. THIS NOISE, HOWEVER, IS SIMPLY DUE TO ONE OF NATURE'S TRICKS WITH STATIC SOMEWHERES UP IN THE ATMOSPHERE, PROBABLY MILES AWAY FROM THE POINT WHERE YOU ARE "LISTENING-IN."

MAN-MADE INTERFERENCE

NOT ONLY DO WE HAVE NATURE'S INTERFERENCE TO DEAL WITH BUT WE HAVE TO FIGHT "MAN-MADE" INTERFERENCE AS WELL. YOU SEE, ANY ELECTRICAL DISCHARGE, SUCH AS A SPARK IN THE AIR, WILL SEND RADIO WAVES OUTWARD IN ALL DIRECTIONS. FORTUNATELY, THESE EMITTED WAVES ARE SOMETIMES SO FEEBLE THAT THEY ARE NOT RADIATED VERY FAR AND FOR THIS REASON ARE NOT VERY BOTHERSOME. AT OTHER TIMES, HOWEVER, SUCH A SPARK WILL RADIATE WAVES WITH SUFFICIENT FORCE TO CAUSE THEM TO TRAVEL FOR MILES AND MILES, THEREBY NOT LOCALIZING THE DISTURBANCE BUT PROBABLY RUINING RADIO RECEPTION FOR A WHOLE COMMUNITY.

THE WAVES RADIATED BY SUCH SPARK DISCHARGES EFFECT THE RECEIVER IN MUCH THE SAME WAY AS A REGULAR RADIO WAVE BUT THEY ARE UNTUNED AND CONSEQUENTLY CANNOT AS A RULE BE ELIMINATED BY TUNING IN SOME OTHER STATION.

EVEN WHEN AN ALTERNATING CURRENT IS FLOWING THROUGH A CONDUCTOR, ELECTRIC WAVES WILL BE RADIATED FROM THE CONDUCTOR, WHICH MAY AFFECT SOME NEARBY RECEIVER AND THE HIGHER THE FREQUENCY OF THIS ALTERNATING CURRENT, THE MORE PRONOUNCED WILL BE THE INTERFERENCE EFFECT UPON A RADIO RECEIVER. A GREAT MANY OF THE PRODUCERS OF THIS RADIO INTERFERENCE MAY BE LOCATED WITHIN THE SAME BUILDING IN WHICH THE RECEIVER IS BEING OPERATED AND IN FIG. 2, YOU WILL SEE SOME COMMON ELECTRICALLY OPERATED HOUSEHOLD APPLIANCES, WHICH CERTAINLY DO THEIR PART IN CAUSING INTERFERENCE.

BY ADDING THESE EVERY DAY HOUSEHOLD APPLIANCES TO THE MANY OTHER POSSIBLE CAUSES OF INTERFERENCE, WHICH MAY BE LOCATED ELSEWHERE OUTSIDE OF THE HOME, IT IS OBVIOUS THAT OUR LIST OF INTERFERENCE PRODUCERS WILL BE QUITE LARGE.

BEAR IN MIND, THAT ANY APPLIANCE, WHICH USES AN ELECTRIC MOTOR, OR VIBRATING INTERRUPTER POINTS IS A GOOD INTERFERENCE PRODUCER. IN FACT, EVEN A LOOSE ELECTRICAL CONNECTION INSIDE A LAMP IS APT TO ARC AND THEREBY PRODUCE INTERFERENCE.

THE FOLLOWING LIST GIVES YOU AN IDEA OF THE MANY THINGS WHICH ARE LIKELY TO CAUSE INTERFERENCE NOISES:

DOOR BELLS OR BUZZERS
ELECTRIC SEWING MACHINES
ELECTRIC VACUUM CLEANERS
ELECTRIC FANS
ELECTRIC WASHING MACHINES
ELECTRIC VIBRATOR OR MASSAGING MACHINES
ELECTRIC TOASTERS
ELECTRIC IRONS
ELECTRIC CURLING IRONS
ELECTRIC SOLDERING IRONS
ELECTRIC RANGES
ELECTRIC WAFFLE IRONS
DEFECTIVE INSULATORS ON POWER LINES
DEFECTIVE POWER TRANSFORMERS
ELECTRIC PERCOLATORS
ELECTRIC HAIR CLIPPERS
ELECTRIC REFRIGERATORS
ELECTRIC SIGNS
ELECTRIC ELEVATORS
ELECTRIC RAILWAYS
X-RAY MACHINES
MOTION PICTURE EQUIPMENT
ARC LAMPS
FLASHER SIGNS
ELECTRIC MOTORS
ELECTRIC GENERATORS
DEFECTIVE ELECTRIC SWITCHES OF ALL TYPES ETC.

WE COULD GO ON PRACTICALLY INDEFINITELY, NAMING ALL KINDS OF POSSIBLE SOURCES OF INTERFERENCE BUT THOSE MENTIONED WILL AT LEAST GIVE YOU AN IDEA OF WHAT TO LOOK FOR.

NOW THAT YOU KNOW WHERE VARIOUS INTERFERENCE NOISES ORIGINATE, THE NEXT STEP IS TO FIND THEIR CAUSE AND LOCATION AND THIS, OF COURSE, IS THE HARDEST PART OF THE JOB. HOWEVER, WHEN TRACING SUCH NOISES IN A SYSTEMATIC

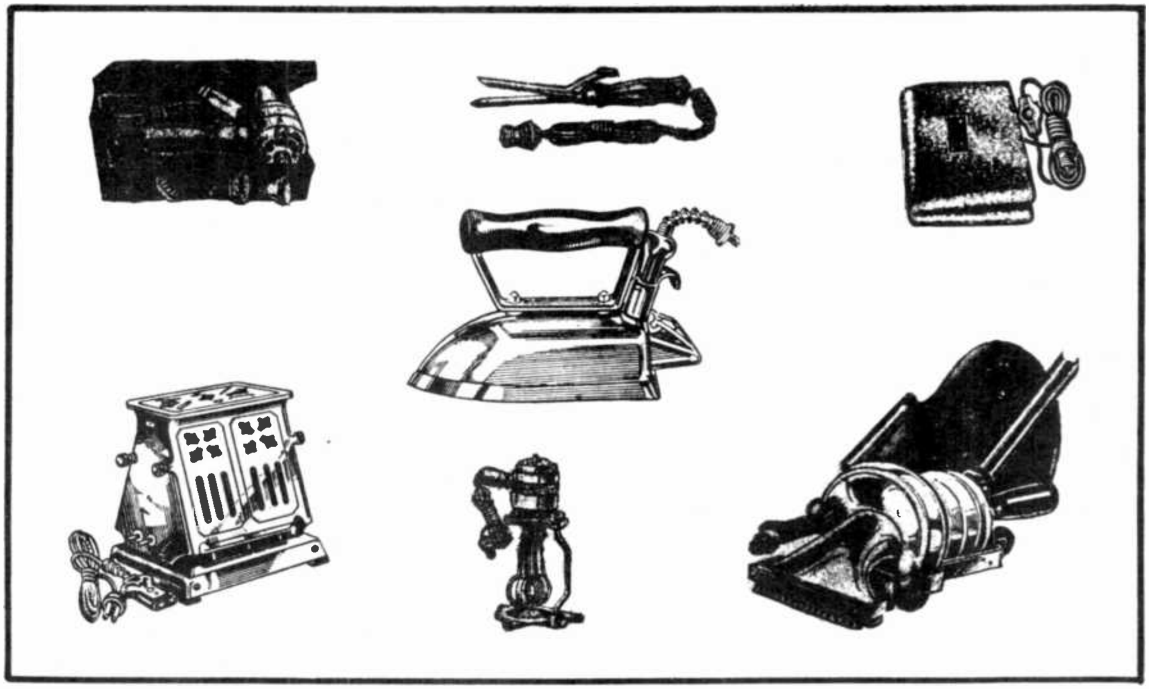

FIG. 2
Some Common Causes for Interference in the Home.

WAY, IT REALLY ISN'T AS DIFFICULT AN UNDERTAKING AS ONE MIGHT FIRST EXPECT.

LOCATING INTERFERENCE

SINCE TROUBLE WITHIN THE RECEIVER ITSELF MAY ALSO CAUSE VARIOUS TYPES OF SCRATCHING AND CRACKING SOUNDS, ONE MUST NOT JUMP TO HASTY CONCLUSIONS AND BLAME IT UPON INTERFERENCE THE FIRST THING, BEFORE EVEN STOPPING FOR A MOMENT TO CONSIDER THE SITUATION IN A MORE THOROUGH AND SEN-

SIBLE MANNER. TO DETERMINE IN A GENERAL WAY WHERE THESE UNDESIRABLE NOISES ARE COMING FROM IT IS BEST TO FIRST DISCONNECT THE ANTENNA LEAD-IN WIRE FROM THE RECEIVER WHILE THE RECEIVER IS IN OPERATION AND BRINGING IN A STATION, AS WELL AS THE NOISE YOU ARE LOOKING FOR.

SHOULD THE NOISE DISAPPEAR THE INSTANT YOU DISCONNECT THE ANTENNA LEAD-IN WIRE, THEN YOU KNOW THAT THE DISTURBING NOISES WERE ENTERING YOUR RECEIVER BY WAY OF THE ANTENNA. HOWEVER, IF THE NOISES ARE STILL HEARD, EVEN WITH THE ANTENNA DISCONNECTED, THEN CONTINUE YOUR INVESTIGATION BY NEXT DISCONNECTING THE GROUND WIRE FROM THE RECEIVER. IN CASE THE NOISE DISAPPEARS WITH ITS REMOVAL, THEN THE TEST INDICATES THAT THESE NOISES WERE EITHER PICKED UP AND DELIVERED TO THE RECEIVER BY THE GROUND WIRE, OR ELSE A POOR GROUND CONNECTION WAS BEING USED.

IF THE SAME NOISE STILL PERSISTS WITHIN THE RECEIVER WITH THE ANTENNA AND GROUND BOTH DISCONNECTED, THEN THE TROUBLE IS WITHIN THE RECEIVER ITSELF—PROVIDED IT IS A BATTERY OPERATED SET. HOWEVER, IF THE RECEIVER IS BEING OPERATED FROM AN A.C. LIGHTING SUPPLY, THEN THE SOURCE OF NOISE MAY EITHER BE WITHIN THE RECEIVER OR ELSE SOMEWHERES IN THE LIGHTING OR POWER LINE, WHICH IS SUPPLYING THE RECEIVER WITH ITS OPERATING POWER.

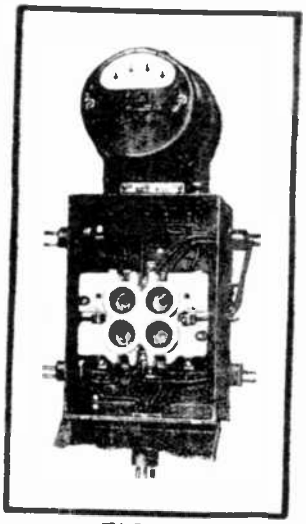

FIG. 3
Service Cabinet

SINCE IT IS NOT AN UNCOMMON OCCURRENCE FOR A FAULTY CONNECTION WITHIN THE RECEIVER TO PRODUCE SCRATCHING SOUNDS, IT IS ADVISABLE TO CHECK THE RECEIVER IN A GENERAL WAY BEFORE LOOKING FOR LINE TROUBLE. TO DO THIS, LEAVE THE RECEIVER IN OPERATION AND TUNED TO A STATION. THEN TAKE A STRIP OF BAKELITE OR HARD RUBBER AND PROD THE DIFFERENT CIRCUIT CONNECTIONS WHILE THE RECEIVER IS IN OPERATION. SHOULD A POORLY SOLDERED JOINT BE MOVED IN THIS WAY, THE EFFECT WILL BE NOTICEABLE AT THE SPEAKER IMMEDIATELY.

ALSO MAKE SURE THAT THE TUBE PRONGS ARE ALL CLEAN AND THAT THEY MAKE A GOOD FIRM CONTACT WITH THE SPRINGS IN THEIR RESPECTIVE SOCKETS. SEE TO IT THAT SUCH PARTS AS THE VARIABLE CONDENSERS ARE FREE FROM DUST AND DON'T FORGET THAT A POOR SWITCH CONTACT OR DIRTY VOLUME CONTROL IS FREQUENTLY RESPONSIBLE FOR SCRATCHING NOISES. WORKING THESE PARTS BACK AND FORTH WILL READILY INDICATE THEIR CONDITION.

HAVING MADE THIS GENERAL INSPECTION OF THE A.C. RECEIVER AND BEING CONVINCED THAT THE NOISES ARE COMING IN OVER THE POWER LINES, THEN YOU ARE READY TO SET ABOUT THE TASK OF TRACING THEM TO THEIR SOURCE. TO DO THIS, GO TO THE ENTRANCE OR SERVICE SWITCH OF THE LIGHT SUPPLY IN THE BUILDING, IN WHICH THE RECEIVER IS BEING OPERATED. ONE OF THESE SWITCHES IS SHOWN IN FIG. 3 AND NO DOUBT YOU WILL IMMEDIATELY RECOGNIZE IT AS BEING THAT FAMILIAR LOOKING SWITCH BOX, WHICH IS MOUNTED EITHER NEAR OR TOGETHER WITH THE METER. IN A GREAT MANY CASES, YOU WILL FIND IT ON THE BACK PORCH OF THE HOME.

ALL THE LIGHTING CURRENT, WHICH COMES INTO A BUILDING, MUST PASS THROUGH SUCH A MAIN SWITCH AND IF THIS SWITCH IS OPENED, ALL OF THE CIRcuits within the building are put out of operation. The lighting circuits in most buildings are divided into groups which are known as branch circuits and all of these branch circuits are fed by the main supply line, with the branches having their origin either in this service switch cabinet or else in a separate cabinet. Each circuit is protected with a separate set of fuses, which may be either of the plug or cartridge type, both of which are shown in Fig. 4. A plug fuse is shown at the top of Fig. 4 and a ferrule type cartridge fuse is shown at the bottom of this illustration. Now with the radio receiver in operation, remove the branch circuit fuses one at a time until you find one, which when removed, causes the receiver to stop operating. This then, is the fuse which protects the branch circuit to which the receiver is connected. Knowing this, replace this fuse so that the receiver can operate again and with a program coming in, together with the undesirable noise you are looking for, remove the other branch circuit fuses one at a time and listen for the effect upon the receiver.

Should the interfering noise disappear when a certain fuse is removed, then the noise has its origin in this particular branch circuit. The thing to do then is to disconnect all of the appliances from this one troublesome branch circuit but do this in a routine way. That is, turn off the different appliances such as lamps, the vacuum cleaner, the electric fan, the electric heater etc. one at a time and if the noise disappears, then the disconnection of the unit causing its disappearance is responsible for the interference. You can readily determine which appliances are operated from a single branch circuit, by simply turning on all the lights etc. in the entire building and noting which group goes out when one particular branch circuit fuse is removed. Those appliances, which are put out of commission by removing a single fuse are all connected to the same branch circuit. Should, however, all of the circuits be "killed" when you remove a fuse, then it simply means that you have removed a main circuit fuse instead of a branch circuit fuse, so watch for this.

FIG. 4
Fuses.

If you have removed a branch circuit fuse without eliminating the interfering noise, then remove the balance of the branch fuses, one at a time. Should none of these tests remove the interference, it is very likely that the trouble may be in the branch circuit to which the receiver is connected and to check up on this possibility, simply connect the receiver to another branch circuit and note how it performs. If the interference has disappeared, it indicates that the source of the noise is in that particular branch circuit from which the receiver was originally being operated. So check the troublesome branch circuit carefully and this means for defective circuit connections, as well as for defective appliances which may be connected to the circuit. Frequently, you will find this interference being caused by loose wires at lamp sockets, wall switches, outlet sockets, etc. and even a loose lamp bulb may be responsible for the interfering noise.

INTERFERENCE VIA THE POWER LINES

NOW IF NONE OF THESE FUSE REMOVAL TESTS STOP THE INTERFERENCE, THEN YOU KNOW THAT THE NOISES ARE ENTERING THE BUILDING BY WAY OF THE MAIN SUPPLY LINES. IT MAY BE DUE TO FAULTY LINE INSULATORS ON THE POLES, A DEFECTIVE LINE TRANSFORMER ETC. AND IN SUCH CASES, IT IS ADVISABLE TO NOTIFY THE POWER COMPANY AND THEY WILL SEE TO IT THAT THEIR EQUIPMENT IS ALL CHECKED AND PUT BACK IN PROPER WORKING ORDER. IN FACT, YOU WILL FIND MOST POWER COMPANIES VERY ACCOMODATING, WHEN IT COMES TO RUNNING DOWN LINE TROUBLE AND VERY OFTEN THEY WILL FIND CONDITIONS IN WHICH THE INTERFERENCE SOURCE IS LOCATED IN A DIFFERENT BUILDING, WHICH HAPPENS TO BE CONNECTED TO THE SAME POWER DISTRIBUTING LINES.

BEFORE BRINGING YOUR TROUBLES BEFORE THE POWER COMPANY, HOWEVER, MAKE SURE THAT THE TROUBLE IS NOT LOCALIZED AROUND OR WITHIN THE BOTHERED RECEIVER. THAT IS, ASK DIFFERENT PEOPLE IN THE NEIGHBORHOOD IF THEY TOO ARE TROUBLED WITH THIS INTERFERENCE AND ALSO TRY TO DETERMINE THE TIME OF DAY OR NIGHT WHEN THESE NOISES ARE MOST PRONOUNCED. IN THIS WAY IT MAKES IT MUCH EASIER TO FIND WHETHER THE POSSIBLE CAUSE IS IN SOME FACTORY, WHICH ONLY OPERATES DURING CERTAIN HOURS OF THE DAY, OR IN A THEATER OR FLASHER ELECTRIC SIGN, WHICH ONLY OPERATE AT NIGHT ETC. ALL OF THIS INFORMATION IS OF A GREAT HELP TO YOU, AS WELL AS TO THE POWER COMPANY AND OFFERS A SYSTEMATIC METHOD OF ATTACKING THE PROBLEM IN LOCATING THE SOURCE OF THE INTERFERENCE.

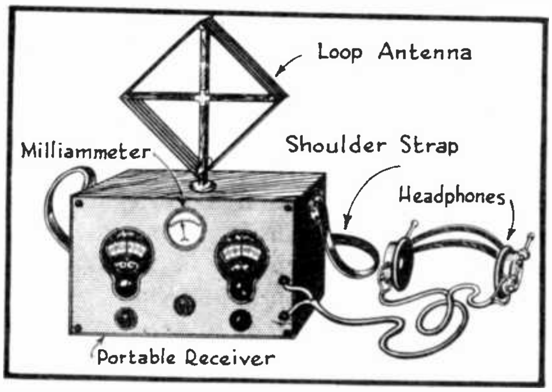

FIG. 5
Interference Locator

SEARCHING A DISTRICT FOR INTERFERENCE PRODUCER

SOMETIMES YOU MAY BE CALLED UPON TO LOCATE INTERFERENCE WHICH IS BOTHERING A WHOLE DISTRICT OF RADIO FANS AND WHICH MIGHT BE ACTING UPON THEIR RECEIVERS THROUGH EITHER THE ANTENNA, GROUND CONNECTION OR LIGHTING LINES. THIS OFFERS A CONSIDERABLY LARGE TERRITORY IN WHICH TO LOOK FOR THIS TROUBLE AND THE EASIEST WAY TO LOCATE THE SOURCE OF SUCH INTERFERENCE IS BY MEANS OF THE APPARATUS SHOWN IN FIG. 5.

THIS OUTFIT CONSISTS OF A SENSITIVE LOOP OPERATED RECEIVER, EQUIPPED WITH A SHOULDER STRAP SO THAT IT CAN BE CARRIED ABOUT WITH EASE AND COMFORT. IN ADDITION TO HAVING THE CONVENTIONAL RADIO RECEIVING CIRCUITS WITHIN THIS CABINET, AN EXTRA VISUAL INDICATING DEVICE IS ALSO USED AND IT IS FOR THIS REASON THAT THE MILLIAMMETER IS MOUNTED ON THE PANEL OF THE INTERFERENCE LOCATER.

THE CIRCUIT DIAGRAM FOR THE VISUAL INDICATING DEVICE IS SHOWN IN FIG. 6 AND THIS PORTION OF THE TESTER IS COUPLED TO THE OUTPUT OF THE REGULAR RECEIVER CIRCUIT BY MEANS OF THE 1 TO 1 RATIO IRON CORE TRANSFORMER. A PAIR OF PHONES ARE ALSO CONNECTED TO THE OUTPUT OF THE RECEIVER CIRCUIT SO THAT THE INTERFERENCE AND BROADCAST SOUNDS CAN BE HEARD. THAT PORTION OF THE CIRCUIT, WHICH IS SHOWN IN FIG. 6 IS WHAT IS KNOWN AS A SIMPLE TYPE VACUUM TUBE VOLTMETER.

BY STUDYING FIG. 6, YOU WILL NOTE THAT THE SECONDARY OF THE COUPling transformer is connected across the grid circuit of a radio tube and a potentiometer is used with which the grid bias on this tube can be controlled. A separate set of batteries should be used in the indicator circuit from those used in the receiver circuit, in order to provide correct meter readings. The milliammeter, you will note, is connected in the plate circuit of the tube and it has a range of from 0 to 25 milliamperes.

The bias voltage of the tube is so adjusted that with the least amount of interference received, the deflection of the milliammeter needle should be at a minimum. With the adjustment thus made, it will be found that the meter reading will increase as the receiver is brought closer to the source of the interference and it will decrease when moved farther from the source of interference.

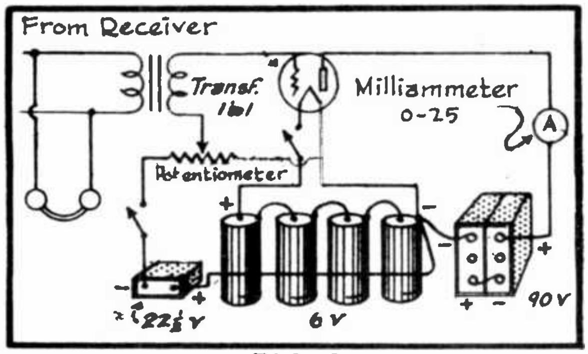

FIG. 6
Circuit Diagram of the Visual Indicator

Thus by having the phones also connected in the circuit, one can compare the results of the meter indications with the audible indications, for the interference will also increase in loudness as one brings the receiver closer to the source.

In order to have an idea in which direction to travel when running down interference, a great deal of time can be saved through the use of an adjustable loop aerial. This can be accomplished by mounting the loop in a bearing as shown in Fig. 5 or else the loop can be carried by hand.

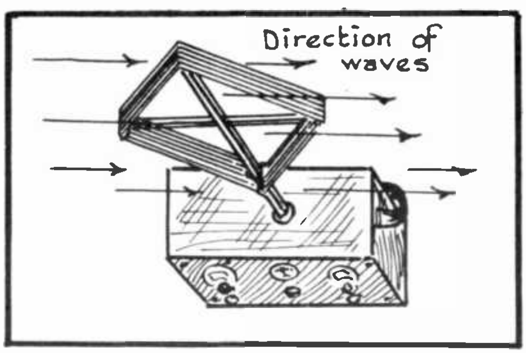

FIG. 7
Position of Loop for Strongest Signal.

The loop antenna has directional qualities and the sounds from a station will be loudest when the waves therefrom pass over the loop wires as shown in Fig. 7. The same condition holds good when looking for interference because when the interference waves pass across the loop in the direction shown in Fig. 7, they too will come in with maximum force.

Due to this quality of the loop antenna, it becomes quite a simple problem to centralize the location of the interference down to an approximate point and we do this in the manner illustrated in Fig. 8.

Here you will see a portion of a street map in a district troubled with radio interference. The seat of the trouble is at one spot but it spreads out throughout this entire section and becomes a nuisance to the whole neighborhood. You are the man chosen to find where this interference is coming from and the first thing you do is to set up your interference locating equipment at some such point as #1 in Fig. 8.

NOW YOU TUNE YOUR PORTABLE RECEIVER UNTIL THE INTERFERENCE BECOMES BARELY AUDIBLE IN YOUR PHONES. SET YOUR POTENTIOMETER SO THE MILLIAMMETER READS MINIMUM AND THEN WITHOUT MOVING YOUR POSITION, SLOWLY ROTATE YOUR LOOP ANTENNA UNTIL YOU FIND A POINT WHERE THE INTERFERENCE NOISE COMES IN LOUDEST AND WHERE THE MILLIAMMETER SHOWS THE GREATEST DEFLECTION.

IT IS A GOOD PLAN TO DRAW A ROUGH SKETCH OF THE SURROUNDING TERRITORY, SOMEWHAT LIKE THAT SHOWN IN FIG. 8 AND ALSO MARK UPON IT THE POSITION YOU JUST OCCUPIED (STATION #1) AND ALSO DRAW IN THE POSITION OF THE LOOP ANTENNA WHERE THE LOUDEST RESPONSE FROM THE INTERFERENCE WAS OBTAINED FROM THIS FIRST SET UP.

THIS DONE, YOU NOW MOVE TO SOME OTHER LOCATION, A FEW BLOCKS AWAY FROM THE FIRST AND HERE YOU AGAIN SET UP YOUR APPARATUS. THIS IS STATION #2 IN FIG. 8 AND WITH THE SAME CONTROL SETTINGS AS AT STATION #1, NOTE THE RESPONSE OF YOUR APPARATUS WITH THIS NEW SET UP AT #2. (YOU MIGHT HAVE TO READJUST THE VOLUME CONTROL BIAS POTENTIOMETER.) NOW ROTATE THE LOOP SLOWLY UNTIL THE INTERFERENCE NOISE COMES IN LOUDEST AND THE MILLIAMMETER READING MAXIMUM. MARK THIS NEW POSITION ON YOUR MAP AND ALSO THE DIRECTION IN WHICH THE LOOP WAS POINTING.

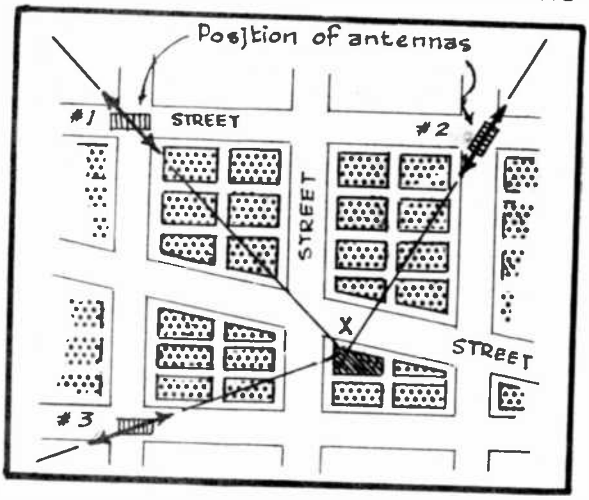

FIG. 8
Locating Interference

NOW MOVE TO SOME OTHER POSITION A FEW BLOCKS AWAY, SUCH AS SET UP #3 IN FIG. 8. DO THE SAME THING HERE AS AT THE PREVIOUS TWO SET UPS, AGAIN MARKING THE POSITION OF THE LOOP AND LOCATION OF THE SET UP. MAKE SEVERAL OF THESE TESTS, WORKING EITHER AROUND A LARGE SQUARE OR CIRCLE AND THEN BY DRAWING DOTTED LINES THRU ALL THE LOOP DIRECTION ARROWS ON YOUR MAP AS IN FIG. 8, YOU WILL FIND SOME POINT WHERE THESE PROJECTED LINES WILL VERY NEARLY ALL INTERSECT OR CROSS EACHOTHER. THIS IS THE POINT FROM WHERE THE INTERFERENCE IS COMING AND IT IS MARKED WITH AN "X" IN FIG. 8.

THIS GIVES YOU THE APPROXIMATE POSITION OF THE INTERFERENCE SOURCE AND WILL GIVE YOU A GOOD IDEA OF THE DIRECTION IN WHICH YOU SHOULD MOVE IN ORDER TO FIND IT. THEN AS YOU COME CLOSER AND CLOSER TO IT, THE INTERFERENCE NOISE WILL CONTINUALLY INCREASE IN YOUR HEADPHONES AND THE MILLIAMMETER WILL ALSO CONTINUE TO REGISTER AN INCREASED READING. GRADUALLY, YOU WILL HAVE WORKED YOUR WAY RIGHT TO THE SEAT OF THE TROUBLE WHERE YOUR MILLIAMMETER READING AND RESPONSE FROM THE PHONES WILL BE AT THEIR MAXIMUM.

GOOD, SENSITIVE AUTOMOBILE RECEIVERS HAVE ALSO BEEN USED TO ADVANTAGE IN RUNNING DOWN INTERFERENCE. IN THIS CASE, THE INTERFERENCE NOISE INCREASES IN INTENSITY AS THE CAR IS DRIVEN CLOSER TO THE SOURCE. TO ENSURE STILL GREATER EFFICIENCY, AN OUTPUT METER CAN BE CONNECTED TO THE AUTOMOBILE RECEIVER AND IT WILL OFFER AN INCREASED READING AS THE INTERFERENCE SOURCE IS APPROACHED.

THE ELIMINATION OF INTERFERENCE

HAVING GONE INTO THE DISCUSSION OF THE METHODS USED TO LOCATE THE CAUSE OF INTERFERENCE, OUR NEXT PROBLEM WILL BE TO ELIMINATE THE INTERFERENCE AFTER WE HAVE FOUND IT. IN A GREAT MANY CASES, YOU WILL FIND THAT THE DISTURBANCE IS CAUSED BY SOME FAULTY ELECTRICAL APPARATUS, WHICH WOULD NOT ORDINARILY CAUSE THIS TROUBLE WERE IT IN PROPER OPERATING CONDITION. THE THING TO DO HERE, OF COURSE, IS NOT TO DOCTOR UP THE APPARATUS BY ATTEMPTING TO REDUCE THE EFFECTS OF THE DISTURBANCES BUT IT IS MUCH WISER TO REMEDY THE CAUSE OF THE DISTURBANCE.

FOR EXAMPLE, YOU MIGHT TRACE THE INTERFERENCE TO EXCESSIVELY SPARKING BRUSHES ON A GENERATOR. SO THE LOGICAL THING TO DO HERE IS TO STOP THE SPARKING AT THE BRUSHES BY EITHER REPLACING THE WORN BRUSHES WITH NEW ONES, CLEANING THE COMMUTATOR OF THE ARMATURE WITH SAND PAPER OR ANY OTHER REPAIR, WHICH MAY BE REQUIRED TO OVERCOME THE TROUBLE. MAJOR REPAIRS ON ELECTRICAL MACHINERY ARE GENERALLY OUT OF THE RADIO MAN'S LINE AND CONSEQUENTLY SHOULD BE TURNED OVER TO AN ELECTRICIAN, WHO IS SPECIALLY TRAINED ALONG THIS LINE OF WORK.

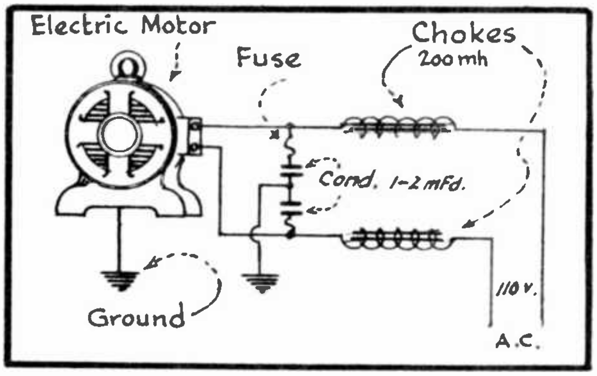

FIG. 9

Filter Connections for an Electric Motor.

THERE ARE, HOWEVER, CASES WHERE ELECTRICAL EQUIPMENT WILL PRODUCE A GREAT DEAL OF INTERFERENCE, EVEN THOUGH IT BE IN A NORMAL OPERATING CONDITION AND SINCE NO EFFECTIVE REPAIRS CAN BE MADE IN THIS INSTANCE, WE HAVE TO DO THE NEXT BEST THING, WHICH IS TO REMOVE THE EFFECTS RATHER THAN THE CAUSE OF THE INTERFERENCE AND IN THIS WAY PREVENT THE INTERFERENCE NOISES FROM BEING TRANSMITTED TO NEARBY RADIO RECEIVERS.

TO REDUCE INTERFERENCE NOISES, WE USE FILTERS, CONSISTING OF CHOKES AND CONDENSERS, WHICH ARE SIMILAR IN OPERATION TO THOSE YOU USED IN A.C. POWER PACKS. FIG. 9 SHOWS YOU HOW SUCH A FILTER SYSTEM WOULD BE CONNECTED UP TO AN ELECTRIC MOTOR, WHICH IS CAUSING INTERFERENCE.

NOTICE THAT WE FIRST MAKE SURE THAT THE METAL HOUSING OF THE MOTOR IS WELL GROUNDED. THEN WE INSTALL A 200 MILLI-HENRY CHOKE IN EACH OF THE SUPPLY LINES. TWO 1 OR 2 MFD. CONDENSERS ARE CONNECTED IN SERIES AND SHUNTED ACROSS THE LINES AS SHOWN AND THEIR CENTER CONNECTION IS GROUNDED. THIS GROUND CONNECTION CAN BE MADE EITHER AT A COLD WATER PIPE OR ELSE TO THE CONDUIT CARRYING THE POWER LINES. (CONDUIT IS THE IRON PIPING IN WHICH ALL MODERN POWER WIRING IS CARRIED AND THIS CONDUIT IS ALWAYS GROUNDED SOMEWHERE ALONG ITS RUN, SO BY MAKING YOUR GROUND CONNECTION TO THE GROUNDED CONDUIT, YOU WILL AT THE SAME TIME HAVE AN EFFECTIVE GROUND CONNECTION FOR YOUR FILTER. BE SURE, HOWEVER, TO SCRAPE OFF ALL DIRT OR PAINT FROM THE POINT ON THE CONDUIT AT WHICH YOU MAKE YOUR GROUND CONNECTION AND USE AN APPROVED GROUND CLAMP.)

IF THE POWER LINES, WHICH SUPPLY THE MOTOR, ARE WORKING AT AN A.C. VOLTAGE OF 110 OR 220 VOLTS, AS IS GENERALLY THE CASE, THEN EACH OF THE FILTER CONDENSERS SHOULD HAVE A RATED D.C. WORKING VOLTAGE OF 500 VOLTS.

AND IT IS PREFERABLE THAT THEY BE OF THE MICA DIELECTRIC TYPE RATHER THAN PAPER. SHOULD THE LINE VOLTAGE BE 550 VOLTS A.C. THEN EACH OF THE CONDENSERS IN FIG. 9 WOULD BE REPLACED BY TWO SERIES CONNECTED CONDENSERS, EACH HAVING A RATED D.C. WORKING VOLTAGE OF 500 VOLTS AND THE CONNECTIONS WOULD THEN BE MADE AS ILLUSTRATED IN FIG. 10.

ALSO NOTICE IN FIG. 9 THAT A FUSE IS CONNECTED IN SERIES WITH EACH OF THE FILTER CONDENSERS. THESE FUSES OFFER AN ADDITIONAL PROTECTION IN CASE THE CONDENSERS SHOULD BECOME SHORT CIRCUITED. IF THIS WERE TO HAPPEN, THE MOTOR CIRCUIT WOULD ALSO BE SHORTED AND THEREBY DRAW AN EXCESSIVE CURRENT OF DANGEROUS PROPORTIONS. HOWEVER, BY INCLUDING FUSES IN THE CONDENSER CIRCUIT, THE FUSES WILL BLOW OUT AND THUS INTERRUPT THE CIRCUIT, THE INSTANT THAT THE DAMAGING CURRENT COMMENCES TO FLOW AT THE TIME OF A CONDENSER'S BREAKING DOWN.

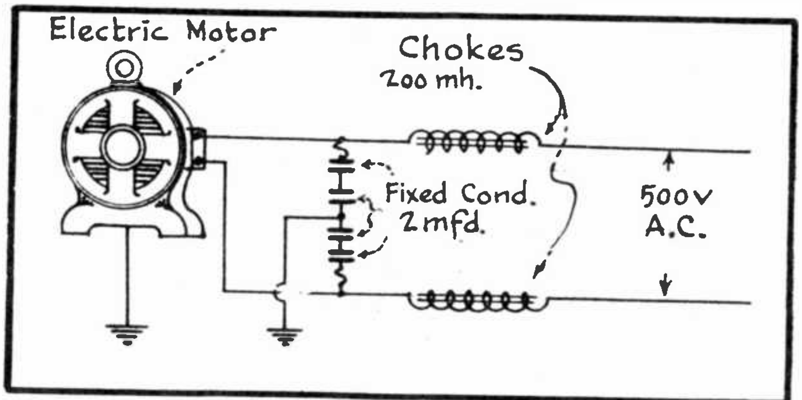

FIG. 10
Filter for 550 volt A.C. Circuit.

THE ELECTRICAL DISTURBANCE OF THE MOTOR, WHICH IS CAUSING THE INTERFERENCE IS OF A HIGH FREQUENCY AS YOU WERE ALREADY TOLD. THEREFORE, BY HAVING THE CHOKES CONNECTED IN SERIES WITH THE LINES, THEY WILL OFFER A GREAT DEAL OF OPPOSITION TO THE FLOW OF THE HIGH FREQUENCY INTERFERENCE CURRENT BUT NOT TO THE LOW FREQUENCY A.C. CURRENT, WHICH OPERATES THE MOTOR.

THE CONDENSERS, ON THE OTHER HAND OFFER FREE PASSAGE TO THE HIGH FREQUENCY INTERFERENCE CURRENT BUT A TREMENDOUS OPPOSITION TO THE LOW FREQUENCY A.C. MOTOR OPERATING CURRENT. CONSEQUENTLY, THE CHOKE COILS FORCE ALL OF THE HIGH FREQUENCY INTERFERENCE CURRENT INTO GROUND BY WAY OF THE CONDENSERS AND IN THIS WAY PREVENT THEM FROM GETTING INTO THE POWER LINES WHERE THEY COULD BE RADIATED OVER WHOLE DISTRICTS.

TO INSTALL SUCH A FILTER, ALL THAT IS NECESSARY IS TO DISCONNECT THE POWER LINES WHILE THE LINE WIRES ARE DISCONNECTED FROM THE SOURCE OF E.M.F. AND THEN TO CONNECT THE FILTER BETWEEN THE MOTOR AND POWER LINES. IN ORDER FOR THE FILTER TO OPERATE PROPERLY, THE CONDENSERS MUST BE CONNECTED ON THE MOTOR SIDE OF THE FILTER CIRCUIT AND THE FILTER CIRCUIT AS A WHOLE, SHOULD BE CONNECTED AS CLOSE AS POSSIBLE TO THE MOTOR OR SOURCE OF INTERFERENCE.

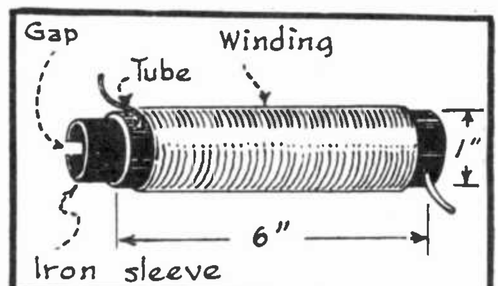

FIG. 11
Choke Coil of Approx. 200 Milli-Henries.

CONSTRUCTION OF CHOKES

THE CONSTRUCTION OF THE CHOKES USED IN FIGS. 9 AND 10 IS ILLUSTRATED FOR YOU IN FIG. 11. EACH OF THESE CHOKES IS MADE UP OF 180 TURNS OF

DOUBLE COTTON COVERED WIRE. THIS WIRE IS WOUND ON A PORCELAIN OR BAKELITE TUBING, WHICH IS 6" LONG AND HAVING A DIAMETER OF 1".

THE ENTIRE COIL IS MADE UP OF TWO LAYERS, WITH 90 TURNS OF WIRE TO EACH LAYER AND A PIECE OF EMPIRE CLOTH IS INSERTED BETWEEN THE TWO LAYERS. THE WHOLE COIL IS VARNISHED AND THEN SOME MORE EMPIRE CLOTH IS WRAPPED OVER THE OUTER LAYER AND OVER THIS YOU CAN WRAP SOME FRICTION TAPE AND LIKEWISE APPLY A FINAL COATING OF VARNISH OVER THE TAPE.

THE CORE CONSISTS OF A PIECE OF #18 GAUGE SHEET IRON (STOVE-PIPE IRON) WHICH IS CUT TO SUCH A SIZE, SO THAT IT CAN BE BENT INTO THE SHAPE OF A SLEEVE AND BE SLIPPED INTO THE HOLLOW WINDING TUBE. ITS ENDS, HOWEVER, SHOULD NOT OVERLAP OR EVEN TOUCH BUT THERE SHOULD BE A SEPARATION OF ABOUT 1/8" BETWEEN THEM.

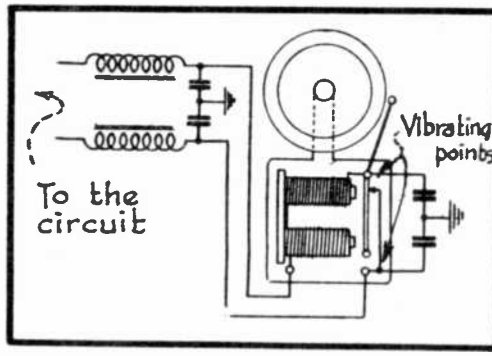

FIG. 12
Filter System for an Electric Bell.

WHEN CHOOSING WIRE SIZES FOR CHOKES, ONE MUST BE CAREFUL TO USE WIRE WHICH IS LARGE ENOUGH TO CARRY THE REQUIRED LOAD CURRENT, AS TOO SMALL A WIRE WILL HEAT UP AND THEREBY OFFER THE POSSIBILITY OF A FIRE. THE FOLLOWING TABLE GIVE YOU THE SAFE CARRYING CAPACITY OF VARIOUS SIZES OF WIRE, WHICH ARE SUITABLE FOR CHOKE USE.

TABLE I
SAFE CURRENT CARRYING CAPACITY OF COPPER WIRE

WIRE SIZE B&S GAUGE	ALLOWABLE CURRENT FOR RUBBER INSULATION	ALLOWABLE CURRENT FOR OTHER INSULATION
#18	3 AMP.	5 AMP.
#16	6 AMP.	10 AMP.
#14	15 AM.	20 AMP.
#12	20 AMP.	25 AMP.
#10	25 AMP.	30 AMP.
#8	35 AMP.	50 AMP.
#6	50 AMP.	70 AMP.
#4	70 AMP.	90 AMP.
#3	80 AMP.	100 AMP.

IN FIG. 12, YOU WILL SEE A DIAGRAM OF AN EFFECTIVE FILTER CIRCUIT FOR USE ON AN ELECTRIC BELL, WHICH PRODUCES INTERFERENCE. HERE, TWO SERIES-CONNECTED 1 MFD. CONDENSERS ARE CONNECTED ACROSS THE VIBRATING POINTS OF THE BELL AND THEY ARE GROUNDED AT THEIR MID-POINT. WHENEVER, YOU ARE WORKING ON AN APPLIANCE OF ANY TYPE, WHICH USES A SET OF VIBRATING POINTS SIMILAR TO THIS BELL EXAMPLE, YOU WILL FIND THAT THIS CONDENSER CONNECTION ACROSS THE POINTS WILL AID MATERIALLY TO REDUCE INTERFERENCE.

IF THIS ALONE DOES NOT ELIMINATE THE INTERFERENCE ENTIRELY, THEN AN ADDITIONAL FILTER SHOULD BE INSTALLED IN THE LINE AS SHOWN IN FIG. 12, SO AS TO PREVENT THE INTERFERENCE CURRENTS FROM BEING DISTRIBUTED THROUGH THE LINES. REMEMBER, THAT THE REQUIRED WORKING VOLTAGE OF THE CONDENSERS AND WIRE SIZE OF THE CHOKES WILL DEPEND ENTIRELY UPON THE VOLTAGE AND CUR-

RENT USED BY THE APPLIANCE.

OTHER FILTER SYSTEMS

IN FIG. 13, YOU WILL SEE AN EXAMPLE OF HOW A FILTER SYSTEM IS INSTALLED IN A BUILDING BETWEEN THE ELECTRIC METER AND THE MAIN SERVICE SWITCH. THIS ARRANGEMENT PREVENTS INTERFERING NOISES, WHICH ORIGINATE WITHIN THE BUILDING, FROM BEING TRANSMITTED TO SURROUNDING BUILDINGS. AT THE SAME TIME, IT ALSO PREVENTS INTERFERING NOISES FROM ENTERING THIS SAME BUILDING BY WAY OF THE POWER LINES.

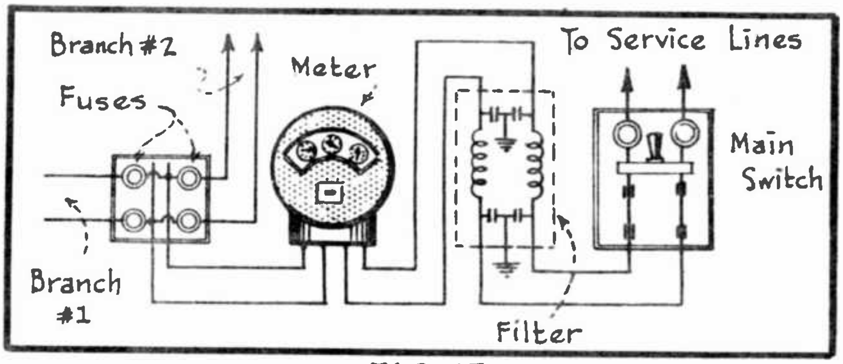

FIG. 13
Filter Installed in Lighting Circuit.

ON SMALL GENERATORS AND MOTORS, WHERE BUT LITTLE INTERFERENCE IS BEING PRODUCED, YOU WILL VERY OFTEN FIND THAT THE TROUBLE CAN BE RELIEVED SIMPLY BY ATTACHING TWO SERIES CONNECTED 1 MFD. CONDENSERS OF THE REQUIRED VOLTAGE RATING ACROSS THE TERMINALS OF THE APPLIANCE OR ACROSS THE LINE CLOSE TO THE APPLIANCE. THE MID-POINT OF THIS CONDENSER CONNECTION CAN THEN BE GROUNDED TOGETHER WITH THE METAL HOUSING OF THE APPLIANCE.

IF THIS PROVES TO BE INSUFFICIENT, THEN THE CHOKES MUST BE USED IN ADDITION AS WAS ALREADY SHOWN YOU.

THE SAME PLAN OF FILTERING, AS OUTLINED FOR YOU, IS CARRIED OUT IN PRACTICALLY ALL CASES. THERE ARE, HOWEVER, CASES THAT NOW AND THEN COME UP, WHICH ARE RATHER COMPLEX IN THEIR NATURE AND CONSEQUENTLY SOMEWHAT HARD TO HANDLE. IT IS THEN SIMPLY A MATTER OF EXPERIMENTING, IN TRYING OUT DIFFERENT FILTER CIRCUITS AND THEREBY DETERMINING WHICH OF THEM OVERCOMES THE TROUBLE.

ALTHOUGH THE FILTER SYSTEMS, WHICH WE HAVE SO FAR CONSIDERED, ARE READILY MADE BY THE RADIO SERVICE MAN, YET SPECIAL FACTORY BUILT RADIO INTERFERENCE FILTERS CAN BE PURCHASED FROM ANY GOOD RADIO STORE OR WHOLESALE HOUSE.

FACTORY-BUILT INTERFERENCE FILTERS

AN EXAMPLE OF SUCH A COMMERCIAL TYPE OF RADIO INTERFERENCE FILTER IS SHOWN IN FIG. 14. THESE UNITS ARE MADE IN DIFFERENT SIZES AND SHAPES AND EACH OF THEM HAS A DIFFERENT MODEL NUMBER. THEREFORE, IF ONE NEEDS A FILTER SYSTEM TO HANDLE A CERTAIN JOB, THEN ALL THAT IS NECESSARY IS TO DESCRIBE YOUR REQUIREMENTS TO THE DEALER AND

FIG. 14
A Commercial Filter for Interference.

HE WILL GIVE YOU THE PARTICULAR FILTER, WHICH HAS BEEN ESPECIALLY DESIGNED FOR THAT PARTICULAR JOB. THAT IS, IF YOU WANT A "TOBE FILTERETTE" (TRADE NAME FOR INTERFERENCE FILTER'S MANUFACTURED BY TOBE DEUTSCHMANN CORP.) TO INSTALL IN THE CIRCUIT OF AN ELECTRIC REFRIGERATOR, WHICH IS BEING OPERATED AT 110 VOLTS A.C. AND DRAWING NOT MORE THEN 5 AMPERES, YOU WOULD STATE THESE FACTS TO YOUR DEALER AND HE WOULD PROVIDE YOU WITH A MODEL #110 TOBE FILTERETTE. THESE FILTERS ALL OPERATE ON THE SAME PRINCIPLES AS THE ONES WE HAVE BEEN DISCUSSING RIGHT ALONG.

NO MATTER WHAT KIND OF COMMERCIAL FILTER YOU BUY, FULL INSTRUCTIONS AS TO THE PROPER METHOD OF ITS INSTALLATION ALWAYS COME WITH IT AND THUS MAKES IT EASY FOR ANYONE TO CONNECT UP.

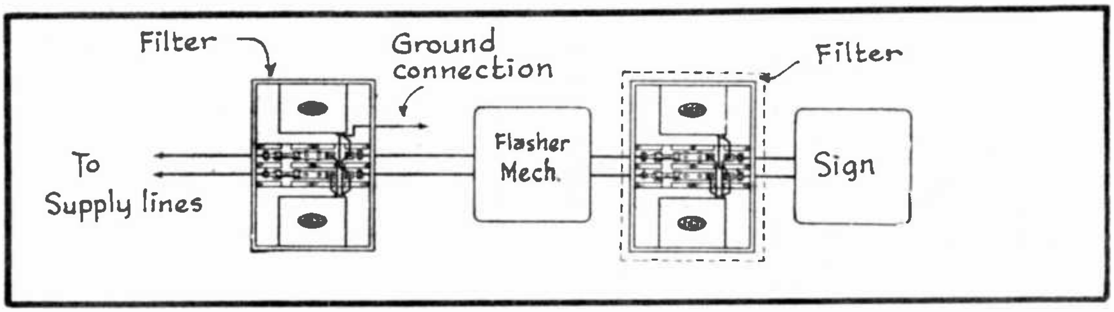

FIG. 15
Filter Installation In Flasher Sign Circuit.

FIG. 15 SHOWS YOU A TYPICAL EXAMPLE OF HOW SUCH A COMMERCIAL INTERFERENCE FILTER IS CONNECTED IN THE CIRCUIT OF A FLASHER TYPE SIGN, WHICH IS CAUSING INTERFERENCE. THESE FLASHER SIGNS ARE EXTREMELY BOTHERSOME AS AN INTERFERENCE PRODUCER AND SINCE THEY OPERATE AT NIGHT WHEN MOST PEOPLE ARE LISTENING TO THEIR RADIO, IT IS EVIDENT THAT CARE MUST BE TAKEN TO ELIMINATE ALL POSSIBLE CHANCE OF INTERFERENCE FROM THIS DEVICE.

ALL OF THE INTERFERENCE FILTERS, WHICH WE HAVE SO FAR CONSIDERED, WERE PERMANENTLY CONNECTED IN THE LINE, EITHER AT THE SOURCE OF THE INTERFERENCE NOISE OR IN THE HOUSE LIGHTING CIRCUIT, TO PREVENT THERE ENTRY. NOW IN FIG. 16, YOU WILL SEE A FACTORY BUILT INTERFERENCE ELIMINATOR, WHICH IS ESPECIALLY BUILT FOR INSTALLATION OF A PERMANENT OR TEMPORARY NATURE, EITHER AT THE SOURCE OF THE INTERFERENCE OR ELSE DIRECTLY AT THE RECEIVER.

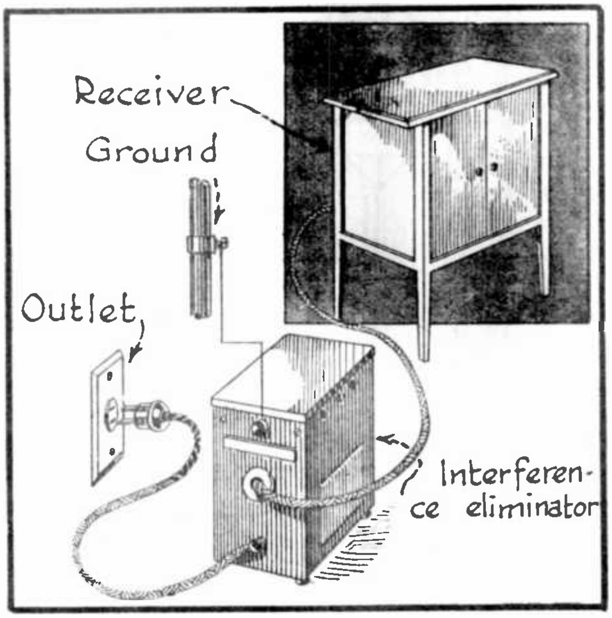

FIG. 16
Connecting Interference Eliminator to A.C. Receiver.

THESE DEVICES ARE ESPECIALLY SUITABLE FOR USE IN APARTMENT HOUSES ETC. WHERE LIGHTING CIRCUITS ARE CONTINUALLY BEING SWITCHED ON AND OFF THROUGHOUT THE ENTIRE BUILDING. EVERYTIME THAT THIS IS DONE, THERE IS A TENDENCY FOR A CRACKING SOUND TO COME OUT OF SOME OPERATING RECEIVER ELSEWHERE IN THE BUILD-

ING. TO PREVENT THIS, THE INTERFERENCE FILTER CAN BE CONNECTED IN SERIES BETWEEN THE RECEIVER AND THE LIGHTING OUTLET FROM WHICH IT IS BEING OPERATED. THIS IS CLEARLY ILLUSTRATED IN FIG. 16.

THE REMAINING TERMINAL OF THE INTERFERENCE ELIMINATOR IS THEN GROUNDED TO SOME NEARBY COLD WATER PIPE OR OTHER SUITABLE POINT AND RECEPTION WILL NOW BE GREATLY IMPROVED.

IN ACTUAL PRACTICE, IT IS OF COURSE GENERALLY DESIRABLE TO HOUSE THE INTERFERENCE ELIMINATOR WITHIN THE CABINET, SO THAT IT IS CONCEALED FROM VIEW. IT IS READILY INSTALLED AND DISCONNECTED AND IS THEREFORE IDEAL FOR PORTABLE USE AND CAN BE CARRIED AWAY WITH THE RECEIVER IN CASE THE TENANT SHOULD DECIDE TO MOVE.

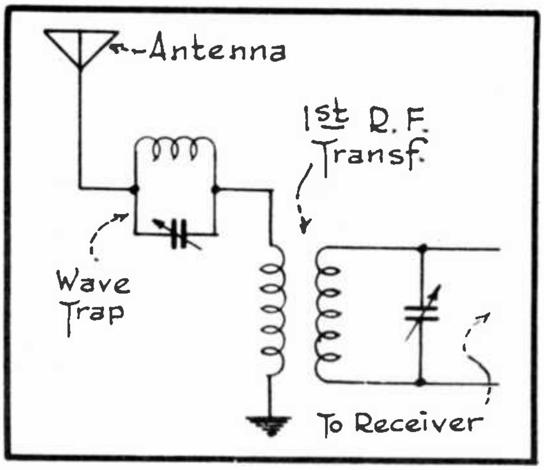

FIG. 17
A Series Connected Wave Trap.

REDUCING STATIC NOISES

NOW THAT WE HAVE INVESTIGATED THE MANNER OF SUPPRESSING MAN-MADE INTERFERENCE AT THE SOURCE, LET US NEXT SEE WHAT WE CAN DO ABOUT NATURE'S INTERFERENCE, NAMELY "STATIC." AS YOU WERE TOLD BEFORE, WE CANNOT ELIMINATE STATIC BUT THERE ARE METHODS WHEREBY WE CAN REDUCE THE AUDIBLE EFFECTS OF STATIC UPON OUR RECEIVER, DURING THE TIME WE ARE LISTENING TO A PROGRAM. THE SAME SUGGESTIONS WHICH ARE TO BE OFFERED YOU NOW, APPLY EQUALLY WELL TOWARDS REDUCING THE AUDIBLE EFFECTS OF MAN-MADE INTERFERENCE NOISES WHICH ARE PICKED UP BY THE RECEIVING ANTENNA.

THE FIRST THING TO CONSIDER IN THIS RESPECT IS THE ANTENNA INSTALLATION BECAUSE THE HIGHER AND LONGER THE ANTENNA AND THE LONGER THE LEAD-IN, THE GREATER WILL BE THE DISTURBANCE OF STATIC.

THE REASON FOR THIS IS THAT ALTHOUGH THE SIGNAL BECOMES WEAKER AS THE HEIGHT AND LENGTH OF THE ANTENNA WIRE IS DECREASED, YET THIS CONDITION HAS A STILL MORE MARKED EFFECT UPON THE STATIC BECAUSE IT CAUSES THE STATIC STRENGTH TO DECREASE MORE RAPIDLY THAN SIGNAL STRENGTH. CONVERSELY, WE HAVE THAT THE HIGHER AND LONGER WE MAKE OUR ANTENNA, THE STATIC STRENGTH WILL INCREASE AT A MORE RAPID RATE THAN OUR SIGNAL STRENGTH MEANING THAT WITH A GIVEN VOLUME OF BROADCAST PROGRAM, WE WILL NOW HAVE A GREATER PERCENTAGE OF STATIC NOISE AS COMPARED TO THE RESULTS OBTAINED WITH THE LOW AND SHORT ANTENNA.

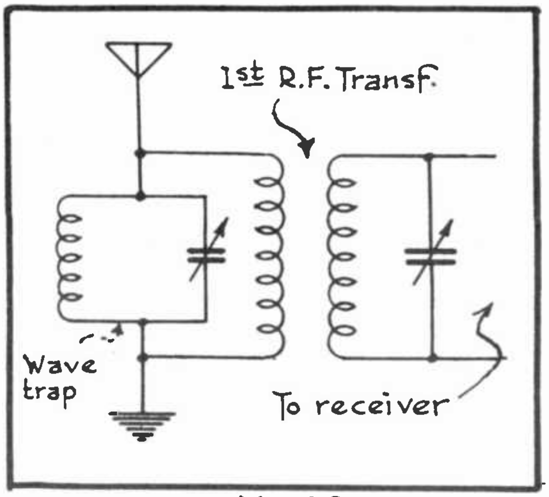

FIG. 18
A Parallel Connected Wave Trap.

TO TAKE ADVANTAGE OF THIS CONDI-

TION, IT IS ADVISABLE TO USE AN ANTENNA CONSISTING OF A SINGLE WIRE, WHICH IS NOT MORE THAN 50 FT. LONG AND ELEVATED AT A HEIGHT OF NOT MORE THAN 30 FT. THIS WILL CAUSE A MARKED DECREASE IN STATIC COMPARED TO SIGNAL STRENGTH.

WAVE TRAPS

ANOTHER IDEA, WHICH HAS BEEN WORKED OUT AND WHICH FREQUENTLY PRODUCES THE DESIRED RESULTS IN REDUCING STATIC NOISES IS SHOWN IN FIG. 17. HERE WE HAVE A WAVE TRAP CONNECTED IN SERIES BETWEEN THE ANTENNA AND PRIMARY WINDING OF THE RECEIVER'S 1ST R.F. TRANSFORMER.

THIS WAVE TRAP IS NOTHING MORE THAN A SINGLE TUNING CIRCUIT, CONSISTING OF A COIL AND VARIABLE CONDENSER. BY TUNING THIS TRAP TO A CERTAIN FREQUENCY, THIS PARTICULAR FREQUENCY WILL FIND IT VERY DIFFICULT TO GET INTO THE PRIMARY WINDING OF THE FIRST R.F. TRANSFORMER BUT ALL OTHER FREQUENCIES PASS THROUGH THE TRAP QUITE READILY.

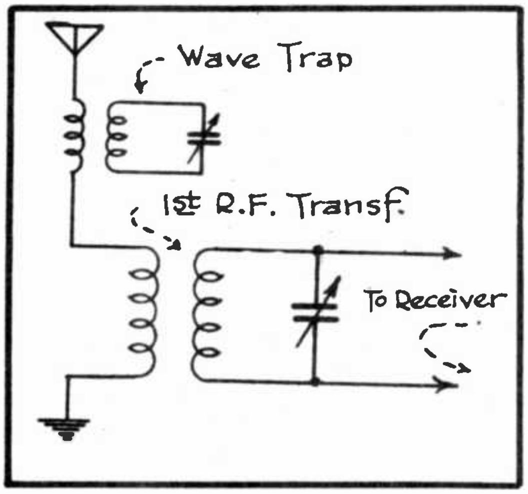

FIG.19
Absorption Type Wave Trap.

NOT ONLY DOES SUCH A TRAP AID IN IN REDUCING STATIC NOISES BUT IT ALSO AIDS IN MAKING A POORLY DESIGNED RECEIVER MORE SELECTIVE IN THAT IT TENDS TO REJECT SOME POWERFUL STATION WHICH IS CAUSING FORCED OSCILLATIONS IN THE REGULAR TUNED CIRCUITS, WHEN THESE ARE TUNED TO AN ENTIRELY DIFFERENT FREQUENCY.

ANOTHER INSTALLATION FOR A WAVE TRAP IS SHOWN IN FIG. 18 AND HERE THE TRAP IS CONNECTED PARALLEL TO THE PRIMARY WINDING OF THE 1ST. R.F. TRANSFORMER. IN THIS CASE, THE FREQUENCY TO WHICH THE TRAP IS TUNED, WILL BE FORCED THROUGH THE PRIMARY WINDING OF THE R.F. TRANSFORMER AND ALL REMAINING FREQUENCIES WILL FIND QUITE AN EASY PATH THROUGH THE TRAP.

STILL ANOTHER WAVE TRAP IS SHOWN IN FIG. 19. THIS IS THE ABSORPTION TYPE AND HERE YOU WILL NOTE THAT AN EXTRA R.F. COIL IS CONNECTED IN SERIES BETWEEN THE ANTENNA AND PRIMARY WINDING OF THE 1ST. R.F. TRANSFORMER. THE EXTRA WINDING IS THEN INDUCTIVELY COUPLED TO A TUNED WAVE TRAP AND WHEN THE WAVE TRAP IS TUNED TO SOME CERTAIN FREQUENCY, IT WILL ABSORB A GREAT DEAL OF POWER FROM THE ANTENNA CIRCUIT CAUSED BY THIS UNDESIRED FREQUENCY. THE RESULT IS THAT PRACTICALLY NO POWER OF THE FREQUENCY TO WHICH THE TRAP IS TUNED WILL EVER REACH THE RECEIVER AND WHAT LITTLE DOES ENTER THE RECEIVER, ITS STRENGTH IS REDUCED SUFFICIENTLY SO AS TO PREVENT IT FROM CAUSING MUCH TROUBLE.

THE ABSORPTION TYPE WAVE TRAP IS ABOUT THE MOST EFFECTIVE OF THOSE SHOWN YOU BUT ALL OF THEM HELP SOMEWHAT TO REDUCE STATIC NOISES AND FORCED OSCILLATIONS FROM UNWANTED STATIONS. THESE TRAPS CAN EITHER BE CONTAINED WITHIN A SEPARATE CASE AND CONNECTED TO THE RECEIVER ONLY AT THE TIME ONE CARES TO USE IT OR ELSE THEY CAN BE INCORPORATED AS A PERMANENT PART OF THE RECEIVER CIRCUIT.

INTERFERENCE-REJECTING ANTENNA SYSTEMS

CONTINUAL RESEARCH IS IN PROGRESS TO OVERCOME THE UNDESIRABLE EFFECTS OF INTERFERENCE NOISES UPON RADIO RECEPTION AND CONSTANT IMPROVEMENTS ARE BEING MADE.

EXPERIMENTS HAVE SHOWN THAT MOST OF THE SO-CALLED "MAN-MADE STATIC" IS PICKED UP BY THE ANTENNA LEAD-IN WIRE AND FROM HERE CARRIED TO THE RECEIVER, RATHER THAN BEING MOSTLY PICKED UP BY THE ELEVATED PORTION OF THE ANTENNA AS WAS FORMERLY GENERALLY SUPPOSED. CONDITIONS BEING SUCH, IT IS NO MORE BUT LOGICAL TO BELIEVE THAT A CONSIDERABLE PORTION OF THE INTERFERENCE NOISE CAN BE PREVENTED FROM ENTERING THE RECEIVER BY SIMPLY PROVIDING THE ANTENNA LEAD-IN WIRE WITH A GROUNDED SHIELD. IN THIS WAY, THE LEAD-IN WIRE WOULD SERVE SOLELY AS A CONDUCTOR OF RADIO FREQUENCY ENERGY FROM THE ELEVATED ANTENNA WIRE TO THE RECEIVER WITHOUT POSSESSING ANY SIGNAL PICK-UP CHARACTERISTICS OF ITS OWN.

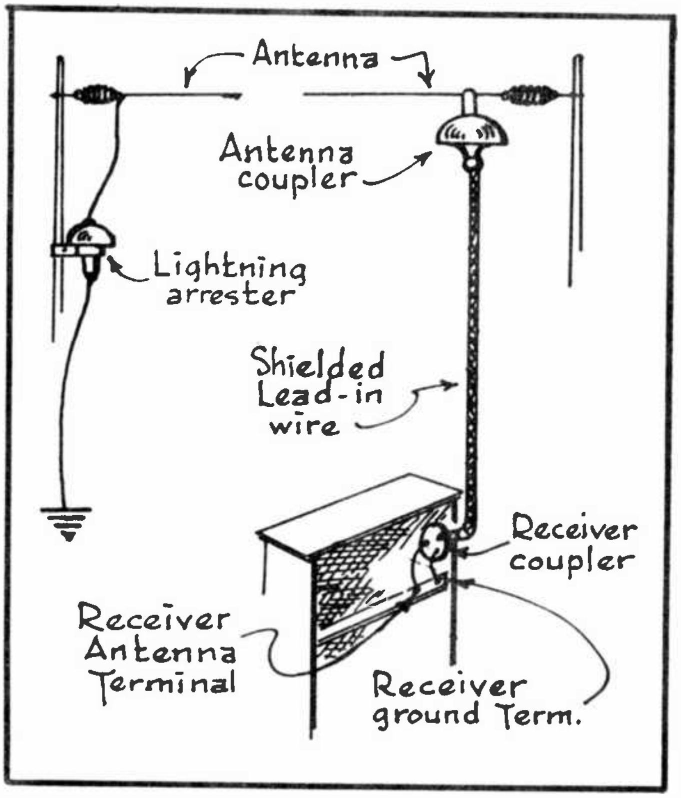

FIG. 20
A Noise-Rejecting Antenna System

SINCE THE TIME THIS DISCOVERY WAS MADE, SHIELDED LEAD-IN WIRE HAS BEEN GAINING IN POPULARITY. IT CONSISTS OF THE CUSTOMARY STRANDED COPPER CONDUCTOR. THIS IS SURROUNDED BY A LAYER OF COTTON OVER WHICH A LAYER OF RUBBER IS PROVIDED. THE RUBBER INSULATION IS IN TURN COVERED WITH A TINNED COPPER OR ALUMINUM BRAID.

THE COPPER CONDUCTOR IS THUS USED IN THE NORMAL MANNER TO CONDUCT THE SIGNAL ENERGY FROM THE ANTENNA TO THE RECEIVER AND BY SOLDERING A WIRE TO THE METALLIC BRAID COVERING AND THEN GROUNDING THIS WIRE, THE LEAD-IN WIRE WILL BE THOROUGHLY SHIELDED.

ALTHOUGH THE SHIELDED LEAD-IN WIRE WILL PREVENT CONSIDERABLE PICK-UP OF INTERFERENCE NOISE, YET IT OFFERS UNDESIRABLE CHARACTERISTICS AS WELL. THE CHIEF DISADVANTAGE OF THE PLAIN SHIELDED LEAD-IN WIRE IS THAT CONSIDERABLE CAPACITY IS INTRODUCED BETWEEN THE LEAD-IN CONDUCTOR AND ITS GROUNDED SHIELD COVERING. THIS CAPACITY PERMITS CONSIDERABLE RADIO FREQUENCY OR SIGNAL ENERGY TO PASS FROM THE LEAD-IN WIRE TO GROUND WITHOUT REACHING THE RECEIVER AND THIS NATURALLY RESULTS IN A CONSIDERABLE LOSS OF SIGNAL ENERGY.

TO OVERCOME THIS LOSS, SPECIAL ANTENNA COUPLING TRANSFORMERS HAVE

BEEN DEVELOPED BY SEVERAL CONCERNS. TWO OF THESE COUPLERS ARE GENERALLY USED TO COMPLETE THE INSTALLATION——ONE OF THEM BEING USED TO COUPLE THE ANTENNA TO THE SHIELDED LEAD-IN WIRE AND THE OTHER TO COUPLE THE LEAD-IN WIRE TO THE ANTENNA TERMINAL OF THE RECEIVER.

TO MAKE AN ANTENNA INSTALLATION AS THIS, IT IS PREFERABLE TO ERECT THE ANTENNA AS HIGH AS POSSIBLE AND OUT IN THE CLEAR SO THAT IT WILL BE LOCATED AS FAR AWAY AS PRACTICAL FROM ALL NEARBY KNOWN SOURCES OF MAN-MADE STATIC.

THE ANTENNA COUPLER IS ATTACHED TO THE ANTENNA AND FROM THIS COUPLER THE SHIELDED LEAD-IN WIRE IS RUN TO THE RECEIVER. THE RECEIVER COUPLER IS THEN MOUNTED WITHIN THE RECEIVER CABINET AND THE LEAD-IN WIRE ATTACHED TO IT, WITHOUT MAKING ANY ADDITIONAL CONNECTIONS IN THE ENTIRE LENGTH OF THE LEAD-IN. THE RECEIVER COUPLER IS IN TURN CONNECTED TO THE ANTENNA AND GROUND TERMINALS OF THE RECEIVER, THUS COMPLETING THE INSTALLATION. IT IS IMPORTANT THAT THE SHIELDING OF THE LEAD-IN WIRE BE SECURELY GROUNDED.

A NUMBER OF THESE NOISE-REDUCING ANTENNA COUPLING DEVICE ARE BEING MANUFACTURED BY DIFFERENT CONCERNS AND CAN BE PURCHASED READY FOR INSTALLATION FROM ANY GOOD RADIO SUPPLY HOUSE. THE MANUFACTURERS SUPPLY COMPLETE INSTRUCTIONS REGARDING THE INSTALLATION OF THEIR PARTICULAR UNITS SO AS TO INSURE SATISFACTORY PERFORMANCE.

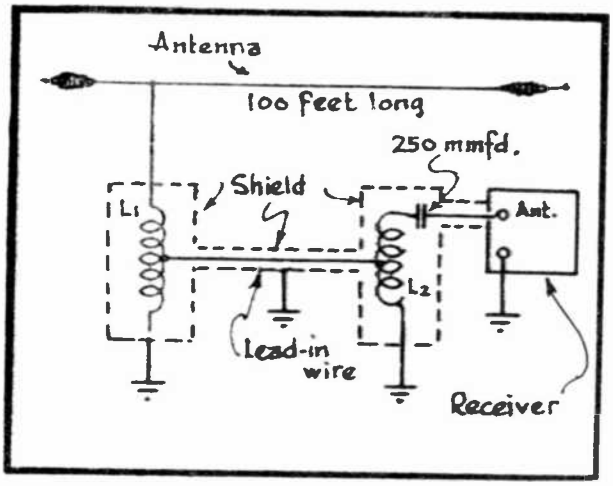

FIG. 21
Construction of the Antenna System.

SO AS TO GIVE YOU A BETTER IDEA OF THE CONSTRUCTIONAL FEATURES OF SUCH AN ANTENNA COUPLING SYSTEM, WE HAVE PREPARED FIG. 21 FOR YOU. HERE THE ANTENNA COUPLER IS REPRESENTED BY L_1 AND THE RECEIVER COUPLER BY L_2. COILS L_1 AND L_2 EACH CONSIST OF 150 TURNS OF #30 B&S DOUBLE COTTON COVERED WIRE SCRAMBLE-WOUND ON A $\frac{1}{2}$" DIAMETER FORM. THE WIDTH OF THE FINISHED COILS IS $\frac{1}{4}$" AND THEY ARE EACH TAPPED AT THE 25TH TURN.

ONE END OF L_1 IS CONNECTED DIRECTLY TO THE ANTENNA AND ITS OTHER END IS GROUNDED. ONE END OF L_2 IS GROUNDED WHILE ITS OTHER END IS CONNECTED TO THE ANTENNA TERMINAL OF THE RECEIVER THROUGH A .00025 MFD. FIXED CONDENSER.

EACH OF THE COILS IS HOUSED IN AN INDIVIDUAL METALLIC CAN, WHICH IS GROUNDED SO AS TO FORM A SHIELD AND THE CANS ARE FILLED WITH PARAFFINE TO PROTECT THE COILS AGAINST MOISTURE.

THE LEAD-IN WIRE IS CONNECTED TO THE TAPS OF THE TWO COILS. THE SHIELDING OF THE LEAD-IN WIRE IS ALSO THOROUGHLY GROUNDED.

THIS PARTICULAR SYSTEM IS DESIGNED TO BE USED IN CONJUNCTION WITH AN ANTENNA OF 100 FT. LENGTH AND A LEAD-IN OF 100 FT. LENGTH. SUCH A LONG

LEAD-IN IS NOT SO DETRIMENTAL WITH A COUPLED INSTALLATION AS IN THE ANTENNAS SYSTEMS WITHOUT THIS FEATURE DUE TO THE ABSENCE OF NOISE PICK-UP WITH THE SHIELDED LEAD-IN, AND THE BOOSTING EFFECT OBTAINED FROM THE COUPLING DEVICES.

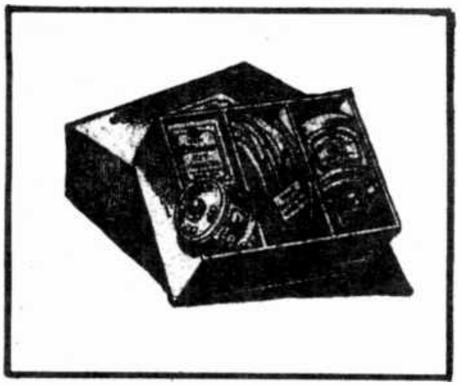

FIG. 22
Noise Rejecting Kit.

IN FIG. 22 YOU ARE SHOWN A TYPICAL ANTENNA NOISE-REJECTING KIT SUCH AS OFFERED BY SEVERAL MANUFACTURERS. THESE ATTRACTIVELY PACKED KITS CONTAIN THE ANTENNA COUPLER, THE RECEIVER COUPLER, 75 FT. OF SHIELDED LEAD-IN WIRE AND COMPLETE INSTRUCTIONS FOR INSTALLATION. ALL UNITS ARE BUILT UP FOR IMMEDIATE USE AND ALL THAT YOU HAVE TO DO IS TO CONNECT THEM INTO THE SYSTEM.

THE INFORMATION GIVEN YOU IN THIS LESSON SHOULD BE OF CONSIDERABLE VALUE TO YOU BECAUSE THERE IS A GREAT DEMAND FOR TRAINED RADIO MEN, WHO KNOW HOW TO OVERCOME THESE DIFFICULTIES OF INTERFERENCE. TAKE ADVANTAGE OF THE OPPORTUNITIES OFFERED YOU IN THIS BRANCH OF RADIO WORK AND HELP IN THIS LARGE UNDERTAKING TO MAKE RADIO RECEPTION STILL MORE ENJOYABLE FOR THE MILLIONS OF RADIO LISTENERS THROUGHOUT THE WORLD.

YOU WILL BE WELL REPAID FOR YOUR EFFORTS IN THIS FASCINATING SEARCH AND ELIMINATION OF ONE OF RADIO'S WORST ENEMIES—"INTERFERENCE."

"EXAMINATION QUESTIONS"
LESSON #23

1. - WHAT DO WE MEAN BY "MAN-MADE INTERFERENCE?"

2. - DESCRIBE A SIMPLE METHOD WHEREBY YOU CAN DETERMINE WHETHER OR NOT THE INTERFERENCE NOISE IS BEING PICKED UP BY THE ANTENNA OR GROUNDING SYSTEM.

3. - HOW CAN YOU DETERMINE WHETHER OR NOT THE INTERFERENCE NOISE ORIGINATES OUTSIDE OF THE BUILDING IN WHICH THE RECEIVER IS BEING OPERATED?

4. - DESCRIBE HOW IT IS POSSIBLE TO LOCATE THE SOURCE OF INTERFERENCE IF IT ORIGINATES OUTSIDE OF THE BUILDING IN WHICH THE RECEIVER IS BEING OPERATED.

5. - HAVING FOUND AN ELECTRIC MOTOR AS PRODUCING INTERFERENCE, WHAT WOULD YOU DO TO PREVENT RADIATION OF THIS DISTURBANCE?

6. - DESCRIBE HOW A CHOKE MAY BE CONSTRUCTED IN ORDER TO SUPPRESS INTERFERENCE.

7. - WHAT SHOULD BE DONE TO PREVENT A SET OF VIBRATOR POINTS OF SOME ELECTRICAL APPLIANCE FROM PRODUCING INTERFERENCE?

8. - WHY IS IT ADVISABLE TO INCLUDE A SET OF FUSES WHEN INTERFERENCE FILTER CONDENSERS ARE CONNECTED ACROSS A POWER LINE?

9. - DESCRIBE ONE FORM OF WAVE TRAP AND EXPLAIN HOW IT WORKS.

10.- DESCRIBE AN INTERFERENCE--REJECTING ANTENNA SYSTEM.

"Opportunity Knocks at a Man's Door But Once"

Many a time you have heard that expression and perhaps it is true, but there is no law of God or man that prohibits a man from knocking at Opportunity's door just as often as he may wish. If he knocks often enough, sooner or later, he is sure to find opportunity at home. If he is ready it will mean Success.

Opportunity means nothing to the man who is not ready. If he is not prepared he won't even be recognized. Whatever we amount to in this world depends entirely upon ourselves, and our own efforts. If we make no effort we get nothing. If we make a big effort to get ahead we can and will succeed. In other words, we are going to be rewarded for exactly what we do.

Success will not come by merely wishing for it. It is something we must fight for. We have got to conquer every obstacle—we cannot give in to pleasures or idle dreams. And the harder we fight the greater will be our success.

Opportunity waits for no one—it's up to us to make ourselves ready and catch her.

Practical Technical Training In
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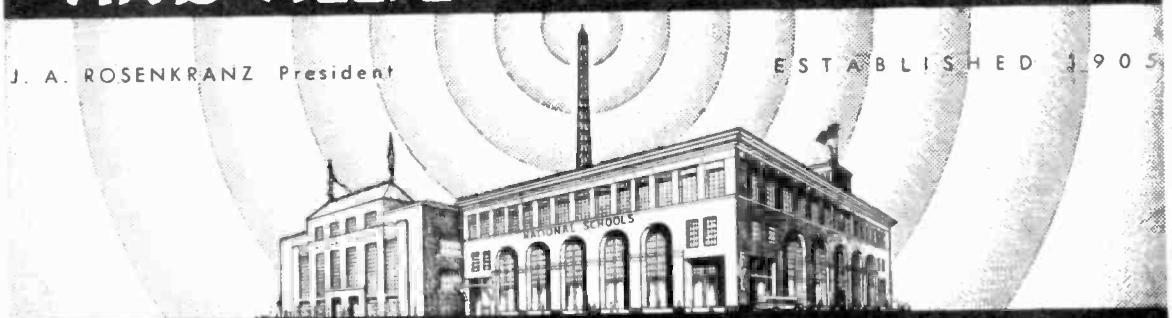
J. A. ROSENKRANZ President   ESTABLISHED 1905



NATIONAL SCHOOLS ★ LOS ANGELES 37, CALIF.

LESSON NO. 24

A-C TABLE MODEL RECEIVERS -- PORTABLE RECEIVERS

This lesson is the first of a series treating with specific types of circuits, as used in small table-model a-c, portable, d-c, ac-dc, automobile, shortwave, and all-wave receivers. Each of these

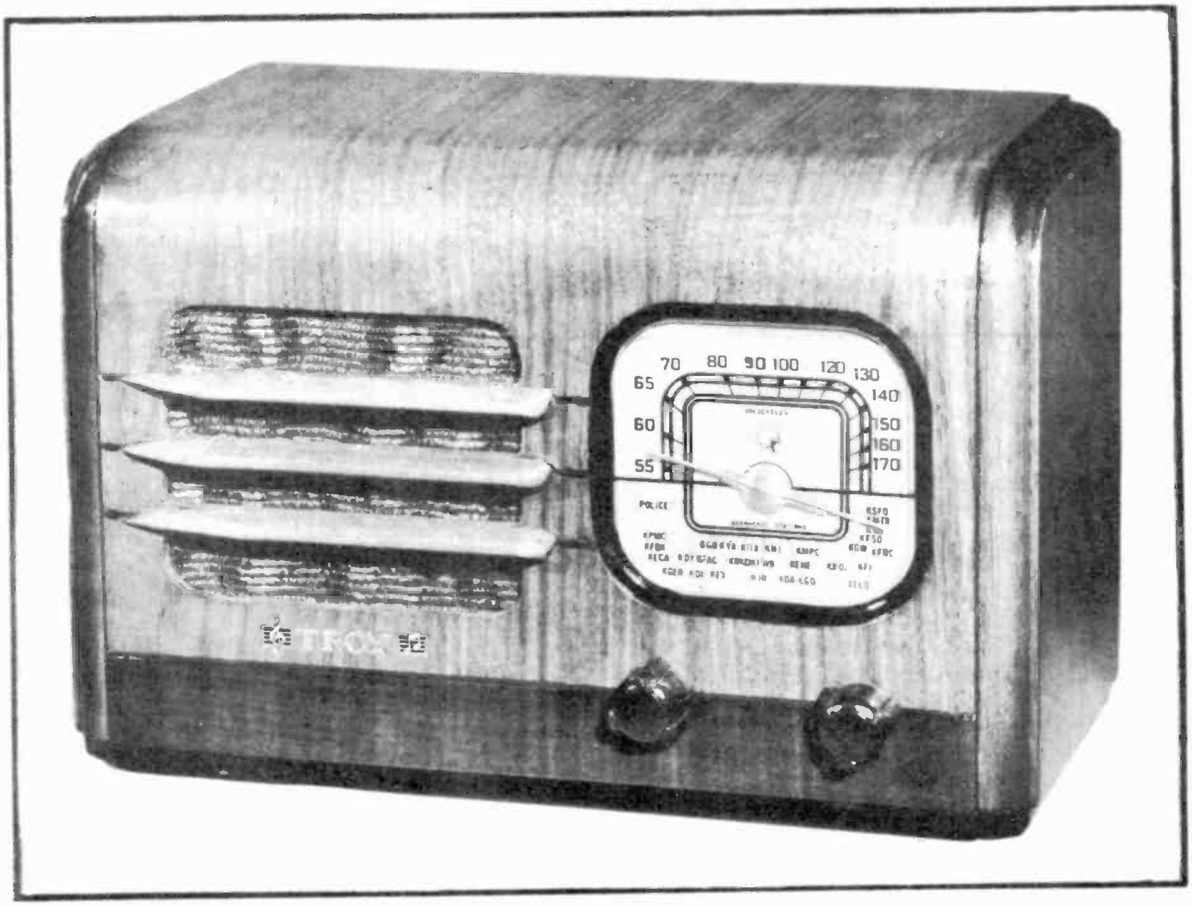


FIG. 1
TYPICAL TABLE-MODEL RECEIVER

receiver types contains special features which are particularly well adapted to them, and it is important that you become intimately acquainted with these variations in design. We commence this specialized study of receivers in this lesson with the small table-model a-c sets.

A-C Table Model Receivers

In Fig. 1 you are shown a typical table-model receiver, housed in an attractive cabinet. The main reason that this type of circuit has been accepted so favorably by the public is that the unit is compact in design and therefore requires no more room-space than the average mantel-clock; in addition, its sales-price can be kept at a value well below that of the console or "full-size" receiver. Although the table-model receiver is an abbreviated design, when compared to the larger console radios, it is nevertheless complete in every detail.

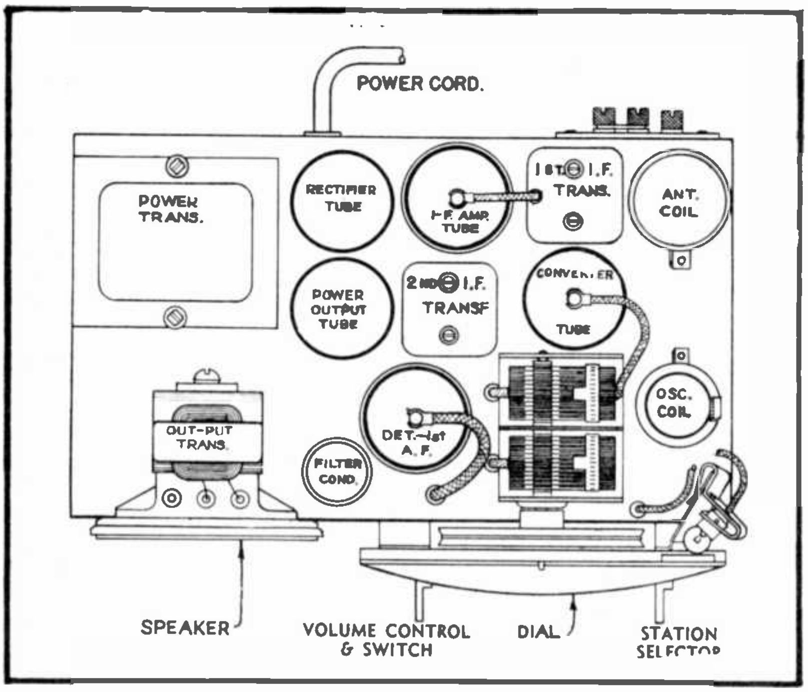


FIG. 2
PARTS ARRANGEMENT OF TYPICAL TABLE-MODEL SUPERHETERODYNE

Most "full-size" receivers provide greater sensitivity and better tone quality, in addition to being more selective than the average table-model receiver. The reason for this is that the compact design of table-model sets calls for a reduction in the number of tubes and tuning circuits, a smaller speaker, less speaker baffle area, etc. However, these deficiencies of the table-model receiver are not so great but that the unit is capable of performing remarkably well. Many of these smaller receivers are being used today.

Fig. 2 will give you somewhat of an idea of the manner in which the parts are arranged in a typical table-model a-c superheterodyne. Study this lay-out carefully and note especially that the relative positions of the various parts are such as to make possible a compact but efficient design. Notice also that a two-gang variable condenser is used to control the first-detector and oscillator sections of the pentagrid converter tube; considerable space is saved by omitting preselection. For the present, we shall leave the circuit details, as these are fully covered later in this lesson.

Great care must be used in laying out these small receivers so that the compact arrangement of the parts will not produce undesirable coupling between the various sections of the set.

It is, of course, true that the circuits of small a-c receivers as a whole are quite conventional. However, certain details are associated with such circuits that might confuse you,were they not brought to your attention. It is therefore the purpose of this lesson to point out to you the important details concerning such circuits; we do this by analyzing for you popular circuit designs, commencing with the more simple t-r-f types and gradually advancing through the more elaborate designs.

FOUR-TUBE T-R-F RECEIVER

In Fig. 3 is illustrated the circuit diagram of the first table-model circuit which we shall study. In general appearance, you will find it to be quite conventional, employing a pentode tube in the r-f stage, a triode as a power-detector and a pentode resistance-capacity coupled audio power tube. However, closer inspection of the circuit will reveal several special features which are not generally found in the larger receivers. We shall now investigate these differences in detail.

To begin with, a single secondary winding on the power transformer furnishes the filament voltage for all three of these tubes. This permits the use of a smaller power transformer, which in addition to saving space, also reduces the cost. You will further observe that one side of this filament winding and also one filament terminal of each of the tube sockets is connected to ground, thus saving one of the filament circuit wires.

While we are discussing this part of the circuit, it is well to point out to you the simplified method of representing the filament circuit in this wiring diagram, by marking with an "X" one side of the

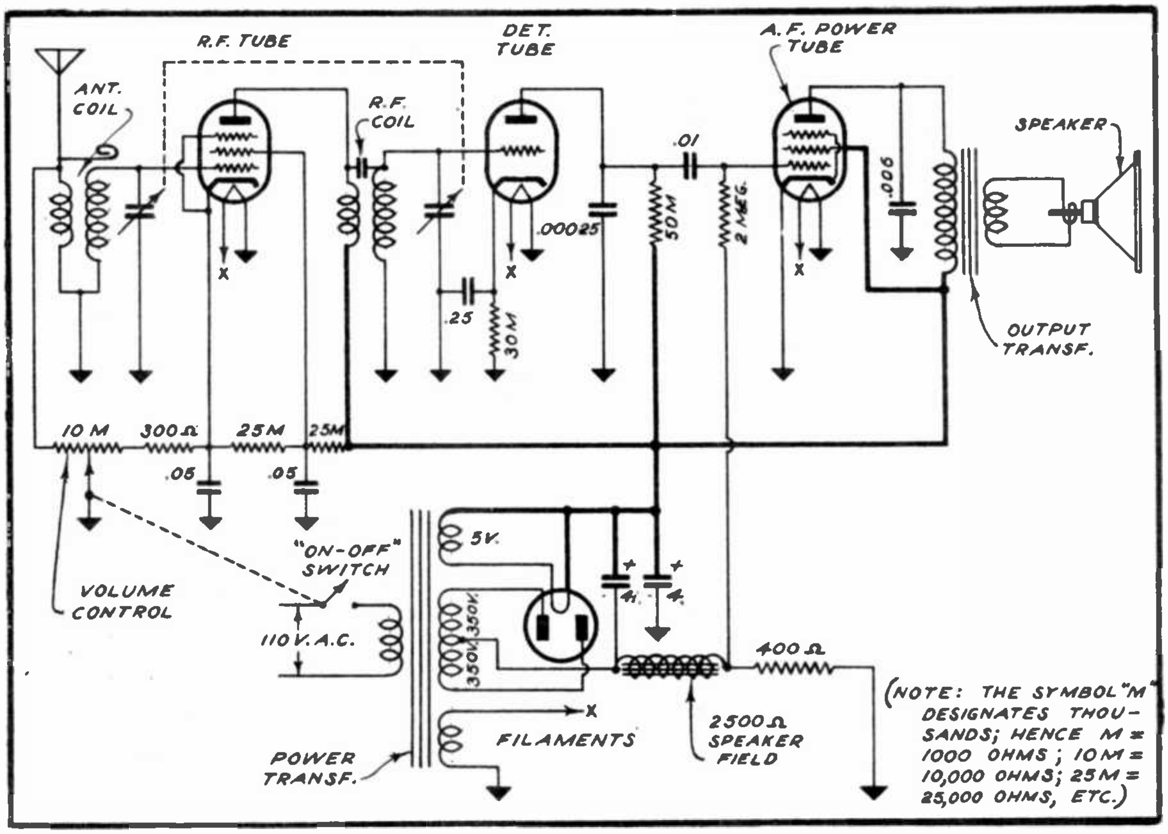


FIG. 3
FOUR-TUBE T-R-F MIDGET CIRCUIT

filament of each tube and also one end of the power transformer low-voltage secondary winding. This manner of marking designates that in the wiring of the actual receiver,point "X" of the transformer winding is connected to points "X" at the tube filaments. By adopting this system,it is not necessary to connect these points together with lines. This is common practice in all fields of radio and it is therefore advisable for you to accustom yourself to it.

The speaker field in Fig. 3 serves as the only filter choke, and is connected in the negative side of the "B" supply. It is connected between the center tap of the power transformer's high voltage winding and ground, with a 400-ohm resistor in series. Therefore, all "B" current will flow through the 400-ohm resistor and the 2500-ohm speaker field coil in order to complete the circuit between the center tap of the high voltage transformer winding and ground (the chassis).

The plate current for the r-f and detector tubes flows through their cathodes, and also through resistors included between these cathodes and ground. This will produce the bias voltages for these tubes in the customary manner. However, the bias voltage for the power tube is obtained in a different manner, as explained in the following paragraphs.

The voltage-drop developed by current flowing through the 400-ohm resistor is used to supply the negative bias for the power tube. The direction of current flow through this resistor is such as to make its ground-end positive with respect to the other end. Therefore, since the negative end of this resistor is connected to the grid of the power tube through the 2-megohm leak resistor, and the cathode of the tube is grounded to the chassis, a negative bias voltage will be impressed upon this tube.

This method of obtaining the bias for the power tube allows the cathode of this tube to be grounded directly, thereby eliminating the expensive bypass condenser that would be necessary at this point were the bias resistor placed in the cathode circuit.

Although the screen and plate voltage in the stages preceding the power amplifier is reduced by an amount equal to the voltage drop across the 400 ohm resistor, when the speaker field is placed in the negative side of the line, the saving of this bypass condenser was instrumental in causing this method to be used extensively in receivers where cost is an important factor.

A 10,000-ohm potentiometer is used to control the volume by offering a means whereby the bias voltage for the r-f tube and also the signal input to the circuits can be varied.

The .006 mfd condenser, which is connected between ground and the plate of the power tube, bypasses some of the higher audio frequencies so that they will not be effective in the primary winding of the output transformer. In this way, the average pitch of the sound reproduction will be lowered somewhat and thereby provides a more mellow tone quality.

HIGH-GAIN COILS

Another important fact which should be noted, relative to the circuit of Fig. 3, is the use of constant-gain type r-f transformers, or as they are often called, "constant-gain coils." These constant-gain coils are intended to introduce two important features into the circuit; the first being to provide as great an amplifying ability as possible (high-gain), and second, to provide practically uniform amplification throughout the entire broadcast band.

Conventional tuned r-f amplifiers, employing the ordinary types of r-f transformers, have a natural tendency to furnish greater amplification at the higher frequencies than at the lower frequencies of the broadcast band. The reason for this is that the magnetic field of the r-f transformer's primary winding is more active at the higher frequencies than at the lower frequencies and thereby causes greater induction in the secondary winding, with a corresponding increase in amplification at the higher frequencies. This variation in amplifying ability at different frequencies is undesirable.

Another reason for this is that the amplifying ability of a vacuum-tube circuit increases as the load in its plate circuit is increased. This being true,it is apparent that the amplifying ability of the circuit will be increased by using an r-f transformer having a primary winding of considerable inductance (many turns). However, too great an r-f plate circuit load may cause the circuit to oscillate due to excessive feed-back through the plate-to-grid capacitance of the tube.

It is also interesting to note than when using a primary winding of large inductance value, it is possible to design the coil so that its distributed capacitance will tune or cause the primary winding to resonate at a frequency slightly below the lowest broadcast frequency. As a result, the amplifier will have a tendency to amplify very well at the lower broadcast frequencies which are somewhat near the resonant frequency of the high-inductance primary winding. Conditions being such, the amplifying ability of the circuit will be reduced at the higher broadcast frequencies.

Several refinements have been made in the design and construction of modern r-f coils so as to retain the advantages of good amplification at the lower frequencies, while at the same time maintaining the amplifying ability at an EQUAL value at the higher frequencies. The first of these is shown you in Fig. 4.

In Fig. 4 you will see that the primary winding consists of a small honeycomb or lattice-wound coil which is similar in appearance to an r-f choke. This winding of comparatively high inductance value is wound on a wooden dowel and placed in the lower end of the coil form.

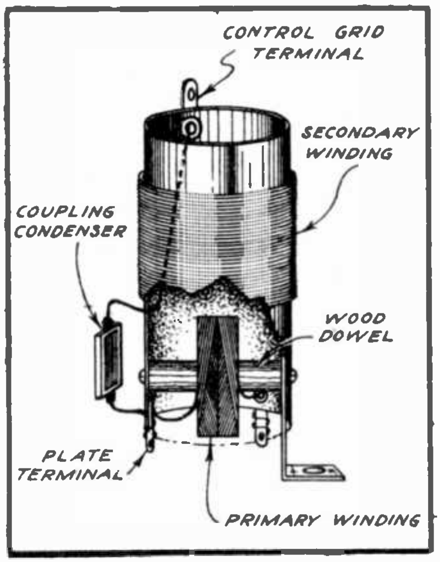


FIG. 4
CONSTANT-GAIN R-F TRANSFORMER WITH COUPLING CONDENSER

The secondary is wound on the coil form in the conventional manner. A small condenser is mounted on the side of the coil-form, near its base; one of its terminals is connected to the plate-end of the primary winding and the other to the control grid terminal to which one end of the secondary winding is also attached. This condenser may have a value of about 3 to 10 mmf.

The purpose of this condenser is to produce a capacitive relation or condenser-coupling between the primary and secondary windings. You will remember that the capacitive reactance of a condenser decreases with an increase in frequency -- just the opposite to the effect of an inductance.

Witn these facts in mind, and returning to the transformer of Fig. 4, we find the capacitive reactance offered by the small coupling condenser to be very great at the time the receiver is tuned to the lower broadcast frequencies; consequently, this condenser is of no particular value when the receiver is tuned to frequencies in the lower regions of the broadcast band. At this time, the primary is transferring its maximum energy because it is operating near its natural resonant frequency.

Now, if the receiver is tuned to one of the higher broadcast frequencies, far removed from the primary winding's resonant frequency, we find that the inductive energy-transfer between the primary and secondary has a tendency to decrease. Such energy-transfer also decreases at this time because of the primary winding's axis being placed at right angles to the axis of the secondary. However, the capacitive reactance of the coupling condenser decreases at the higher frequencies, and therefore, greater energy-transfer between the primary and secondary windings now takes place through the coupling condenser. This will compensate for the decrease in the energy-transfer by induction.

In practice, the capacitive value of the coupling condenser is selected so that the energy-transfer through this condenser will increase at approximately the same rate as the decrease in energy-transfer by induction, while tuning across the band. It can be seen readily that a proper balance between these two couplings can thus be attained so that the amplification will remain practically constant throughout the broadcast band. Also, the over-all amplification of the unit will be greater than that of a simple type coil. It is for the latter reason that coils of this type are frequently referred to as "high-gain" coils.

The presence of the coupling condenser, as used on this type of coil, is indicated in the diagram of Fig. 3 by the standard condenser symbol interconnecting the two windings of the r-f coil.

R-F TRANSFORMERS WITH CAPACITY-LOOP

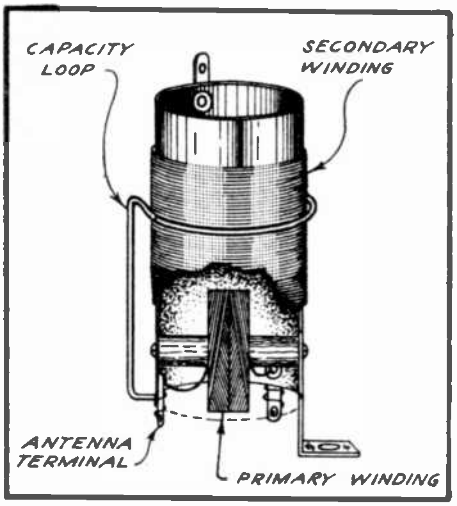


FIG. 5
APPLICATION OF THE CAPACITY LOOP

Another form of constant-gain or high-gain r-f transformer is illustrated in Fig. 5. The primary and secondary windings in this case are practically the same as used on the transformer in Fig. 4, the essential difference being that the coupling condenser is replaced by a heavy, stiff, bare wire. The lower end of the wire is connected to the antenna or plate terminal of the transformer, while its upper end is bent into the shape of an incomplete loop that surrounds the grid-end of the secondary winding.

This loop acts as one plate of a small condenser, while the secondary winding serves as the other plate of the condenser. The winding insulation and the spacing between the secondary winding and the loop act as the dielectric.

The operation of this transformer is exactly the same as already described relative to the unit illustrated in Fig. 4, except that capacity coupling between the primary and secondary windings in this case is furnished by the loop-capacity instead of by the usual condenser.

The presence of a capacity-loop, as used on this type of coil, is indicated on the antenna stage r-f transformer appearing in Fig. 3.

ANOTHER HIGH-GAIN COIL DESIGN

Another form of high-gain r-f transformer is illustrated in Fig. 6. This design is used even more extensively than either of the two types just described. In this case, the primary is wound on the lower end of the coil form, and usually consists of many more turns of wire than is used on the secondary. This primary coil design is often referred to as a"duo-lateral"wound type. In many instances, the primary winding is wound on movable slip-over forms to provide convenient coupling adjustment.

The coupling-loop for this coil consists of an insulated wire of small diameter, one end of which is connected to the antenna terminal of the transformer. The other end of this wire is wrapped around the coil form, next to the grid-end of the secondary. Two or three turns are generally used, and no circuit connection is made at its upper end.

This small winding will supply the necessary capacity-effect between the primary and secondary windings. The operation of this transformer is exactly the same as already described relative to the unit illustrated in Fig. 5.

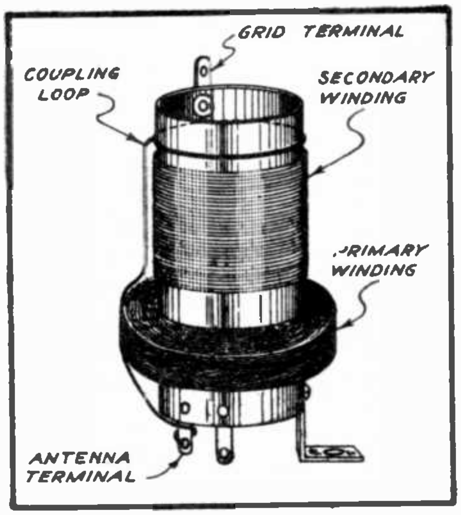


FIG. 6
HIGH-IMPEDANCE R-F TRANSFORMER

While antenna coils with low-impedance primaries are cheaper to manufacture than those using the high-impedance primaries, they are, nevertheless, seldom used in modern table-model and midget-type receivers.

The latter coil design provides reasonable gain, and when properly designed, permits almost negligible misaligning of the first tuned circuit when connecting the receiver to antenna systems of differing characteristics.

It is to be noted that capacity coupling can either reduce or increase the gain of a high-impedance, magnetically-coupled transformer; the effect depends largely upon the polarity of the windings. If capacity coupling is to aid the magnetic coupling, current entering the antenna terminal of the primary winding must flow around the coil-form in a direction opposite to the current-flow in the grid winding, and the coupling capacity must be connected between the antenna and grid terminals of the coil. This means that circuit connections to such coils must be made correctly if satisfactory performance is to be expected.

Although we have described these particular coil designs relative to table-model receiver circuits, this does not mean that these types of coils are used only in such receivers. The truth of the matter is that coils of these types are also used extensively in the circuits of full-size receivers.

CIRCUIT USING PENTODES

In Fig. 7 you are shown the circuit diagram of a table-model receiver in which pentode-type tubes are used in the r-f,detector, and power stages, while a type 80 tube is used as the rectifier. It is advisable that you study this circuit very carefully, comparing its features of design with conventional circuits with which you are familiar.

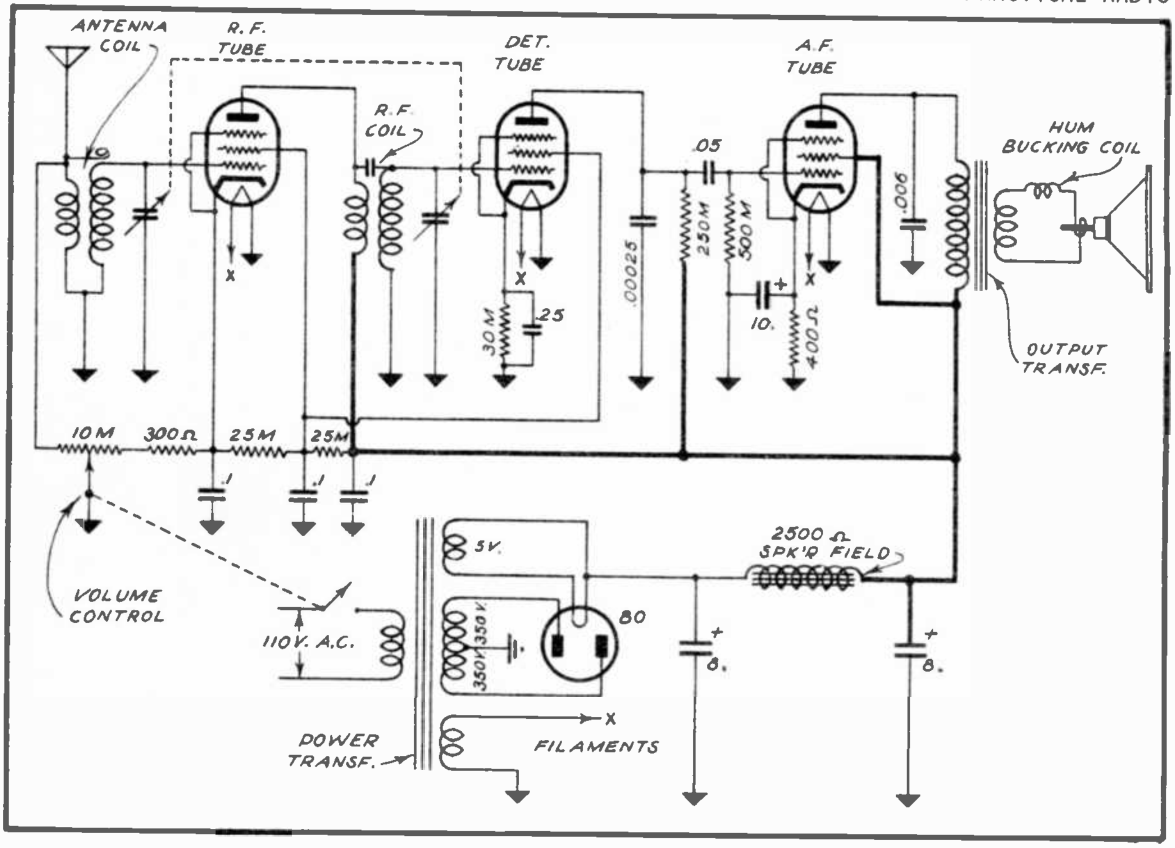


Fig. 7
Four-tube t-r-f Midget Circuit

The circuit of this receiver is very similar to the other receiver presented to you earlier in this lesson. The essential difference between these two circuits is that the circuit in Fig. 7 is designed to accommodate a pentode detector tube;the method of biasing the power tube follows conventional practice.

As a rule, small table-model receivers are equipped with only two operating controls; one for the station-tuning and the other serving as the volume control and "on-off" switch. A tone control is seldom used, as it increases the cost.

There are two reasons why a-v-c is not employed in the two circuits shown thus far: first, the addition of a-v-c would increase the cost of the receiver materially, and second, this feature is only practical where the frequency of the controlled stages is constant, as in a superheterodyne receiver. In the latter case, the a-v-c system controls the i-f channel which operates at a definite frequency. This is explained more fully in later lessons that treat with a-v-c systems.

Also note the use of high-gain r-f transformers in the antenna and detector stages of the receiver diagrammed in Fig. 7.

In this circuit, the speaker field is placed in the positive side of the filter system. This arrangement provides higher screen and plate voltages for the stages preceding the a-f tube, for the reason that the 400 ohm biasing resistor is connected in series with the cathode circuit of the a-f tube only; instead of being in the B-return circuit of all tubes, as in Fig. 3. These increased voltages in the r-f and detector stages increase the sensitivity of the receiver. Observe the use of an additional 10 mfd condenser for bypassing the 400-ohm resistor.

While this procedure is somewhat more expensive than the system outlined in Fig. 3, the higher plate voltage available from this method makes this system more desirable in table-model receivers of the higher price-class.

You will also observe that the capacities of the various bypass and filter condensers used in this circuit have in most instances been increased over those of the other example shown. This will increase the stability of the receiver as a whole, and will reduce any "hum" that might be present in the filter system due to inadequate filtering.

THE R-F COIL MOUNTING

The antenna and r-f coils are frequently unshielded in receivers of this type. However, when such is the case, their positions are selected so that they will be well separated from each other. The usual practice is to mount the antenna coil above the chassis base and the r-f coil below the chassis base; the metal chassis thus serves as an effective shield between the two coils. Were this precaution not taken, r-f coupling might occur between the two tuned circuits, and in this way result in undesirable feed-back and oscillations.

MIDGET-TYPE SUPERHETERODYNE RECEIVERS

You learned about the principles of superheterodyne receivers in a previous lesson, and now you will see how this type of receiver is adapted to table-model specifications. A typical midget superheterodyne receiver is shown in Fig. 1.

The first circuit to be described and discussed is diagrammed in Fig. 8. It is typical of the lower priced variety, wherein several ingenious but practical features are incorporated for conserving space

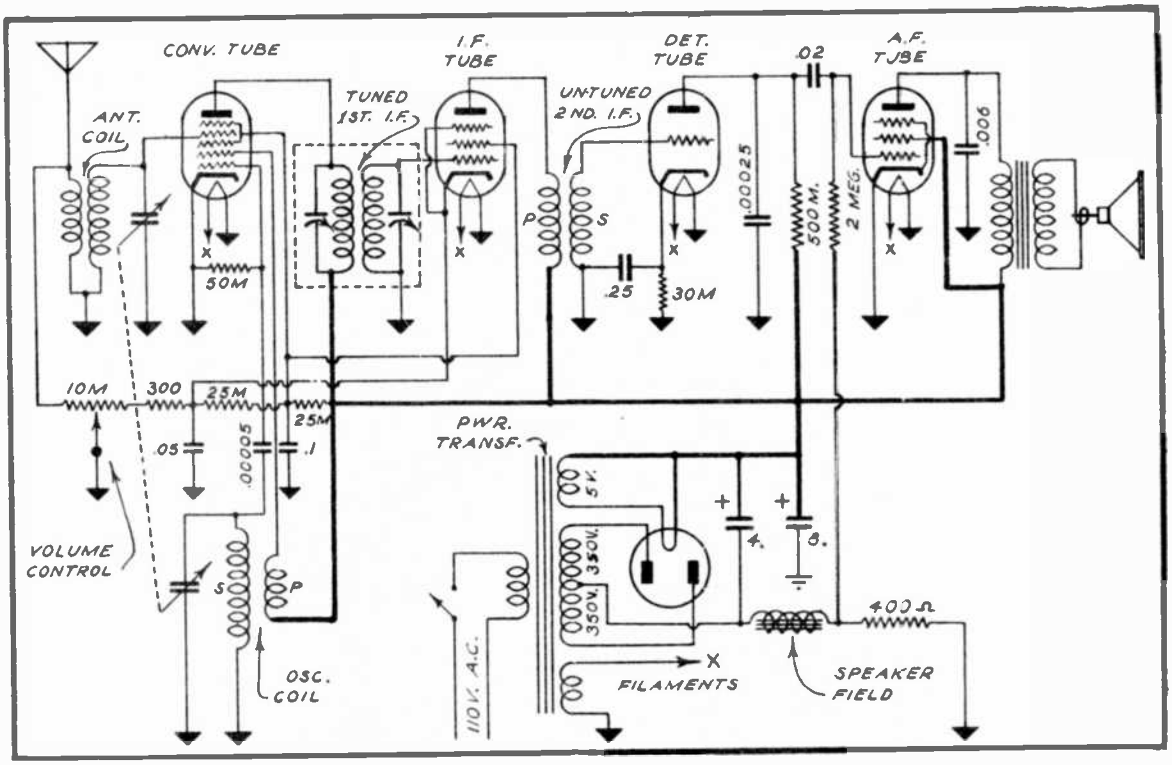


Fig. 8
Five-tube Midget Superheterodyne Circuit

and keeping the cost at a minimum. Here you will observe that five tubes are used, consisting of a combination first detector and oscillator, followed by a pentode i-f tube and a triode second detector. The latter feeds into a pentode power tube. An 80 type tube is used as the rectifier.

Returning to the converter tube,you will notice that the cathode of this tube is connected to ground directly, thus eliminating the customary bias resistor and bypass condenser. The elimination of these parts will not allow the tube to operate at its best, but nevertheless performance is still satisfactory.

You will further observe in Fig. 8 that no padding condenser is included in the ground-return circuit of the oscillator coil's secondary winding. This is possible because specially-cut plates are used in the oscillator section of the gang tuning condenser. This feature makes it unnecessary to use an expensive mica condenser, which for all practical purposes would require a capacity-tolerance within close limits.

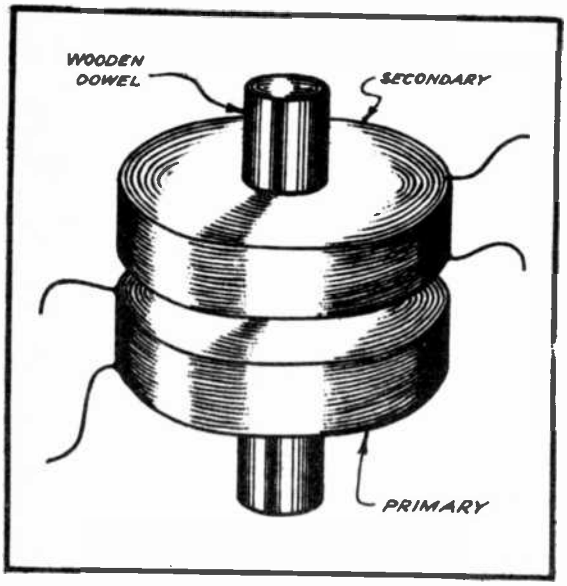


FIG. 9
UNTUNED I-F TRANSFORMER

The next point of interest is the second i-f transformer used in Fig. 8. By close inspection of this unit you will observe that it is untuned and unshielded. Such an i-f transformer is shown in Fig. 9.

While the gain and selectivity of this transformer do not compare too favorably with the transformer which has both its primary and secondary windings tuned to exact resonance, it does operate satisfactorily. Furthermore, the cost of such an i-f transformer is considerably less than one having both windings tuned and housed in a shield can.

As we have already mentioned, the second detector is a triode, and while not having the gain and sensitivity of a pentode, will perform satisfactorily,especially when the coupling of the i-f transformer is quite close. Close coupling must necessarily exist when untuned i-f transformers are used.

It should also be noted that the use of a triode in the second detector stage is practical when no a-v-c system is employed in the receiver. The omission of a-v-c in the circuit of Fig. 8 reduces the cost materially.

The remainder of this circuit is quite conventional, and similar to others which we have described in earlier paragraphs of this lesson.

HIGH-QUALITY FIVE-TUBE TABLE-MODEL SUPERHETERODYNE RECEIVER

Not all table-model superheterodyne receivers are so radical in design as the one just described. Many of these receivers feature the very latest developments heretofore found only in the high-priced console sets. The circuit of a high-quality table-model superheterodyne is shown in Fig. 10.

From a close inspection of this receiver, you will observe that two dual-purpose tubes are employed. You will further notice that an a-v-c system is included, operating in conjunction with a diode-triode tube. To assure perfect tracking of the oscillator tuning section, a variable padding condenser is employed. A variable tone control is also included.

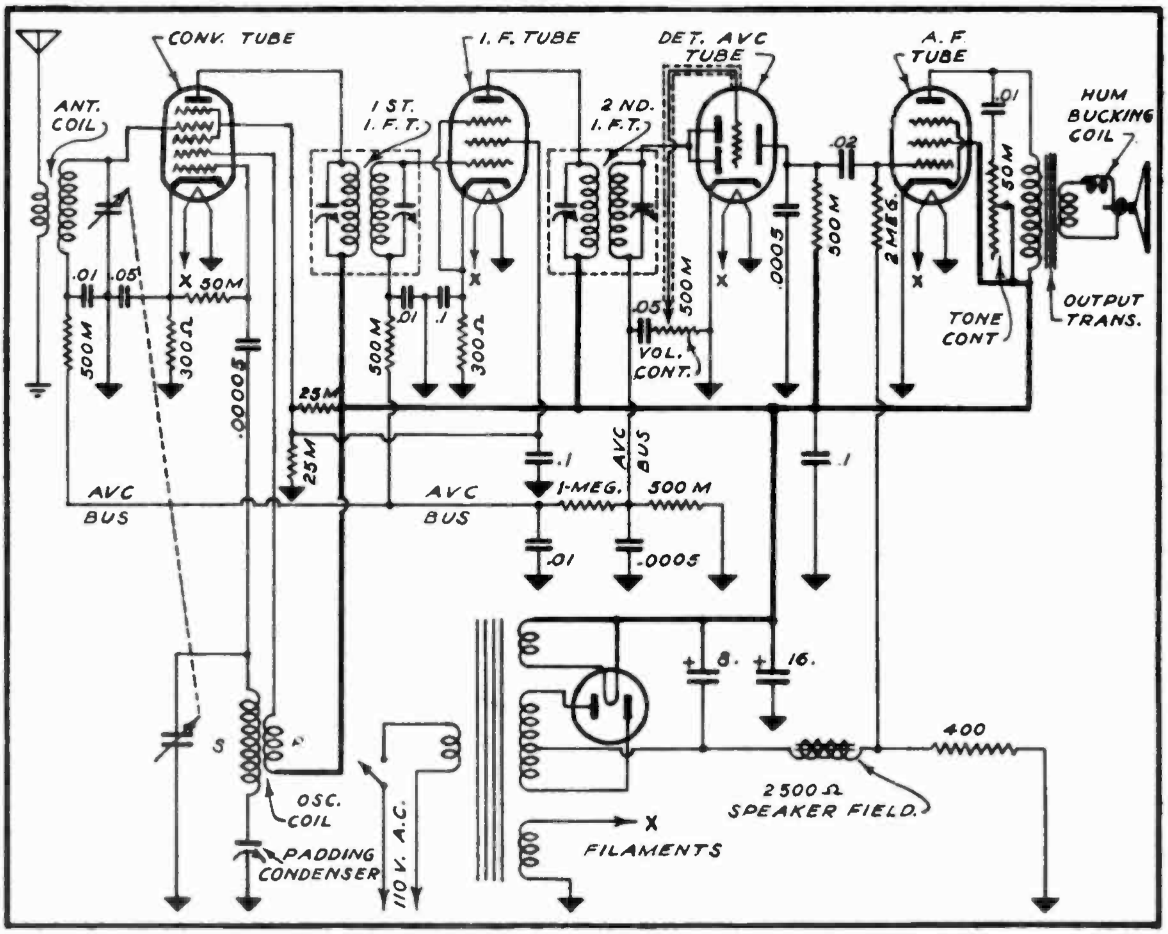


Fig. 10
High-quality Five-tube Midget-type Superheterodyne Circuit

To realize the greatest possible sensitivity, gain and selectivity, the input and output i-f transformers both employ dual-tuned circuits. These units are all enclosed in shielded containers so as to be fully shielded.

You will further observe in Fig. 10 that an adequate number of r-f and rectifier filter condensers are employed; also, the proper bias resistor and condenser are installed in the cathode circuit of the converter tube to insure maximum operating efficiency of the tube. Although this receiver does not employ many tubes, no "trick" methods are used to reduce the cost, and the efficiency of the circuit as a whole is of a high order.

Another feature of the circuit diagrammed in Fig. 10 is the diode-triode tube which is used as a combination second detector, a-v-c and first audio amplifier tube. The action of this tube is quite similar to the system explained to you in an earlier lesson, where a diode tube served as a combination second detector and a-v-c tube in a superheterodyne receiver, feeding its audio output to a separate triode for further amplification. This system operates in exactly the same manner as does the corresponding section in the circuit illustrated in Fig. 10 of this lesson. The only difference is that in the latter circuit, the diode and triode tube-sections are combined into a single glass envelope, thus forming what is known as a "diode-triode" tube.

So that you may understand more readily how the diode-triode tube functions in Fig. 10, let us first review quickly the equivalent system illustrated at "A" of Fig. 11, the operation of which you are already familiar. Here we find that a-c signal voltages appearing across the extremities of the output i-f transformer's secondary cause the diode plates of the second detector tube to be charged alternately to a positive and negative potential.

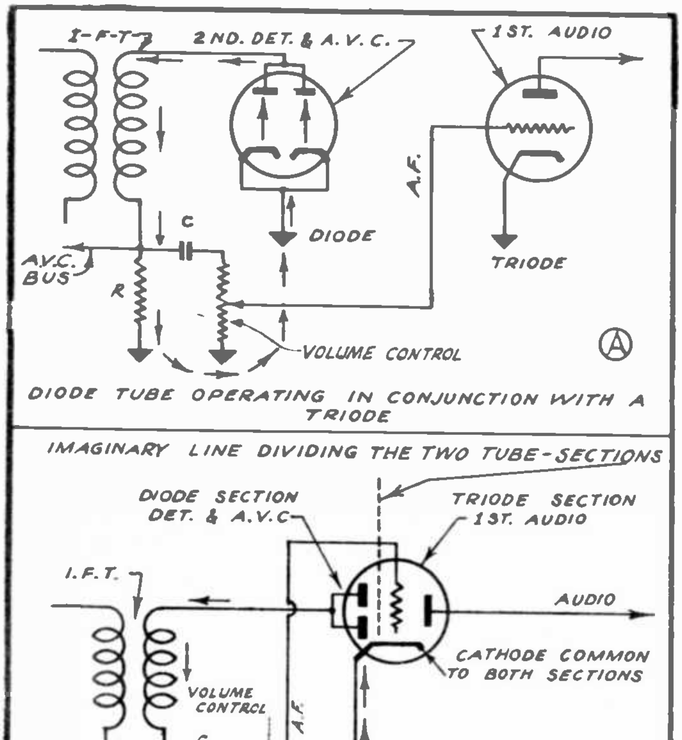


FIG. 11
ANALYSIS OF DIODE-TRIODE OPERATION

Each time that the diodes become positively charged, the electron-flow through this tube and circuit will be in the direction indicated by the arrows. Whenever the diodes are charged to a negative potential, no current will flow through the diode circuit. Thus the tube functions as a half-wave rectifier in this circuit.

This rectified current flows through resistor R and produces voltage-changes of corresponding frequency across its extremities. These voltage-changes occur at an audio frequency rate, and react through condenser C, whence they are used to excite the grid of the first audio tube. The volume control serves as the leak resistor for the audio tube.

Turning now to the equivalent circuit illustrated at "B" of Fig. 11, you will find the action of the circuit to be identical. Here the rectified signal current also flows through resistor R, producing a-f voltage fluctuations across it. These a-f voltage fluctuations react through condenser C to excite the grid of this tube's triode section. The setting of the volume control determines to what extent these a-f voltages excite the grid; and the grid, in turn, controls the plate current flow through this tube and thereby provides a means for transferring the audio signal variations to succeeding stages.

The a-v-c bus is connected to the upper end of resistor R, and leads to the control grid circuits of the preceding tubes. At present, we will not spend any more time discussing the a-v-c system, as it was already explained in a previous lesson and will be treated in detail later on.

Portable Receivers

Sometimes, radio installations on ships, aircraft, automobiles, etc., are considered as being portable equipment. However, this is not strictly true, for the installation in these cases is generally made in such manner that the radio is actually a part of the craft's equipment.

Strictly speaking, a portable set is one that is self-contained, including its power supply and all auxiliary apparatus, so that it can be carried much the same as a suitcase and set up for operation at any point desired.

In Fig. 12 you are shown typical uses for the portable receiver, while others might be in the home, the camp, at the office, in a hotel room, on a fishing trip, or even carried by a person while hiking as shown in Fig. 13. In the particular case illustrated in Fig. 13, the shoulder-strap serves as the loop-antenna for the portable receiver. The directional properties of the self-contained loop antenna also makes the portable receiver practical for tracing possible sources of electrical interference.

FIG. 12
TYPICAL APPLICATIONS OF PORTABLE RECEIVERS

FIG. 13
COMPACT CAMERA-CASE PORTABLE

In the following paragraphs you will find many valuable suggestions and circuit diagrams which will familiarize you with these types of circuits.

THE LOOP ANTENNA

Before entering the detailed discussion on portable receiver circuits, it is advisable that you first become more familiar with the construction and operation of the loop type antenna, used in conjunction with portable receivers.

A typical loop antenna is shown in Fig. 14. As a rule, you will find such antennas having four sides, as here illustrated. In order for this type of antenna to be effective, it is necessary that it be used with a sensitive receiver.

Capacity is the chief characteristic of the ordinary L-type outdoor antenna. Antennas of this type collect signal-energy because electrical charges are developed on the antenna system -- the elevated aerial wire acting as one plate of a large condenser and ground acting as the other plate. On the other hand, inductance is the chief characteristic of the loop antenna, and this type of antenna collects its energy because it acts the same as any other coil, in that lines of force cutting through its wires generate voltage-changes in these wires.

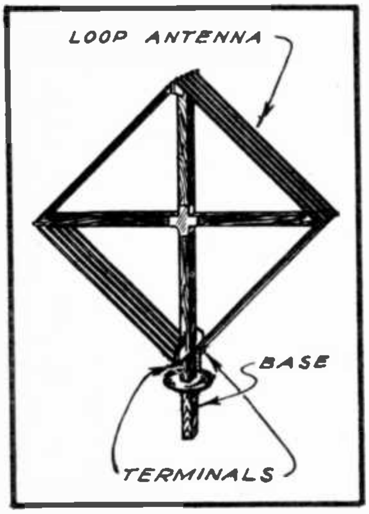


FIG. 14
TYPICAL LOOP ANTENNA

THE EFFECTS OF THE LOOP'S POSITION AND LOCATION

Maximum signal-energy will be picked up when the loop antenna is adjusted to such a position that its sides are in the same plane as the passing wave-train (see upper illustration of Fig. 15). In this illustration signals of equal strength will be obtained whether the wave-train be moving from right to left or from left to right, as long as the edges of the loop are in the same plane as the wave. The least signal-energy is picked up when the loop is turned, as illustrated at the bottom of Fig. 15.

Another interesting feature concerning the loop-type antenna is that the loop will at times be pointed directly toward a station as far as geographical direction is concerned,but yet the signals of this station will not "come in" with as much strength as when the loop's position is shifted slightly. The reason for this is that the radiated radio waves do not always follow a true course as they leave the transmitter. Instead,they are frequently deflected one way or another by various natural objects, until they finally reach the loop antenna. This phenomena frequently deceives the operator as to the directional relation between the transmitter and the receiver.

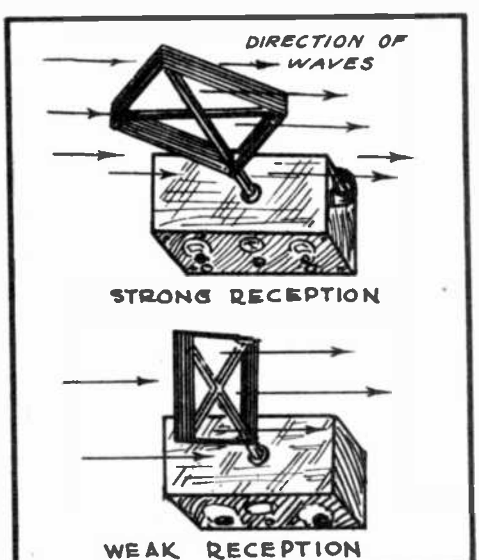


FIG. 15
DIRECTIONAL QUALITIES OF A LOOP ANTENNA

When operated inside of buildings, loop antennas will very often produce peculiar results. This is especially true if considerable metal is included in the building's structure; in this case the metal acts as a shield, thereby preventing the signal-energy from reaching the antenna or else causing the signal to follow an erratic course after once entering the building.

TUNING THE LOOP ANTENNA

Since this type of antenna is chiefly an inductance, it quite naturally opposes the flow of high frequency currents. In your studies of tuned radio frequency circuits,you learned that the maximum voltage will be generated across a coil and condenser combination when the capacity is adjusted so that the circuit is tuned to resonance. A similar condition exists in the case where a loop-type antenna is coupled to the input of a receiver, as illustrated in Fig. 16.

Notice in Fig. 16 how a regular variable tuning condenser is connected across the ends of the loop antenna. Here we have a tuned circuit, the same as when connecting a tuning condenser across the ends of an r-f transformer's secondary winding. Furthermore, this tuned circuit is connected across the grid circuit of the receiver's input tube, thereby providing a tuned oscillating circuit, with which to excite the grid of this first tube, the same as though it were connected to a conventional aerial system and tuned r-f stage.

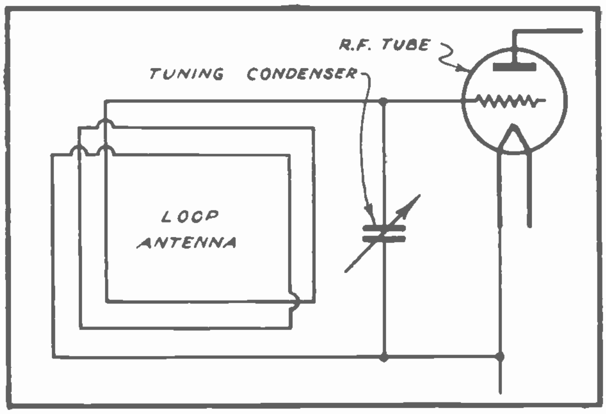


FIG. 16
COUPLING THE LOOP ANTENNA TO THE INPUT OF RECEIVER

The inductance of the loop antenna must be màtched to the tuning range of the condenser so as to permit tuning the system through the entire broadcast range. By adding more turns, the inductance of the loop antenna will be increased; more inductance requires a smaller tuning condenser in order to tune through a given band of frequencies. Another point to be considered is the fact that the addition of more turns to the loop increases the distributed capacity of the antenna; this in turn prevents the circuit from tuning to the higher frequencies.

We also find that the loop's distributed capacity is reduced by spacing its turns, and by using wire of smaller size. However, wider spacing between turns decreases the inductance of the loop. Also, the voltage generated across a certain inductance by a given frequency decreases with a decrease in inductance; therefore, a certain amount of signal strength will be sacrificed when spacing the turns.

FIG. 17
TYPICAL PORTABLE RECEIVER

So much for the fundamental properties of loop antennas. Let us now continue our analysis of portable receiver circuits.

MODERN PORTABLE RECEIVERS

The economy and successful operation of modern self-contained portable receivers has been due chiefly to the development of a complete new line of low-voltage, small current-consuming tubes. These tubes possess operating and performance characteristics that compare very favorably with corresponding a-c tubes. This means that portable superheterodyne receivers, employing four of these new tubes, will perform practically as well as a-c operated "home radios" equipped with an equal number of tubes and connected to a conventional outdoor antenna.

A typical modern portable receiver is shown in Fig.17. Here you will observe that the entire receiver, together with the speaker and batteries, is housed in a beautiful carrying case;the loop antenna is built into the detachable back cover.

A rear-view of the arrangement is shown in Fig. 18, where also is shown the position of the batteries and the method of mounting the loop antenna. In this particular type of loop antenna, the wire is wound in the form of a pan-cake or flat surface arrangement that fits flush against the inner surface of the back-cover. The receiver here shown weighs only sixteen pounds, including batteries; some of the "pee-wee" models, such as the t-r-f types, weigh as little as seven pounds, depending upon the type and size of batteries used.

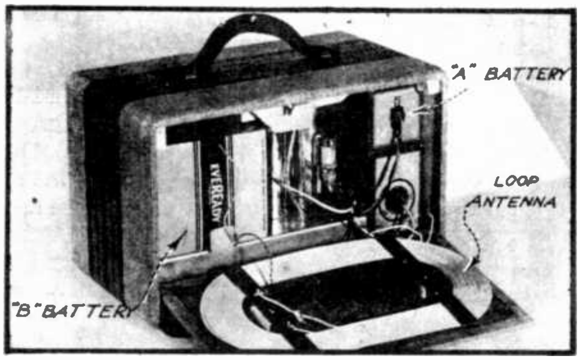


FIG. 18
REAR VIEW, SHOWING LOCATION OF BATTERIES AND LOOP ANTENNA

THREE-TUBE PORTABLE T-R-F RECEIVER

The superheterodyne principle is used most extensively in the better class portable receivers because of the greater sensitivity and selectivity offered by this type of circuit. Nevertheless, many of the cheaper competitive portables use a t-r-f circuit, which feature restricts satisfactory operation to metropolitan areas where numerous broadcast stations are located.

The circuit diagram of a typical three-tube t-r-f portable receiver is shown in Fig. 19. Upon close inspection of this circuit you will observe several interesting things.

Notice that pentode type tubes are used in the r-f, detector and audio power stages. Also observe that the volume is controlled by means of varying the filament voltage of the r-f tube, and that the "on-off" switch interrupts the "A" and "B" battery circuits simultaneously. This switch arrangement is necessary because of the extensive use of electrolytic condensers which would slowly drain the B-batteries, even while the receiver is not in use. Although this precaution is taken, high-quality electrolytic condensers must nevertheless be used to minimize the drain while the receiver is in operation.

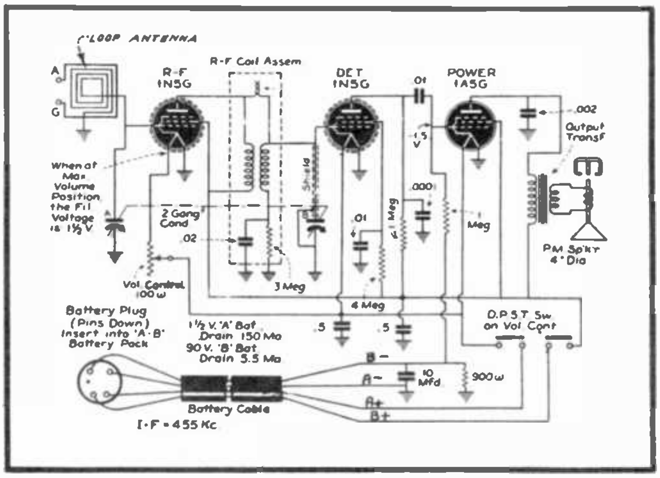


FIG. 19
CIRCUIT DIAGRAM OF TYPICAL PORTABLE T-R-F RECEIVER

Upon studying the circuit more closely, you will be quick to realize that this arrangement is similar to the four-tube, a-c, t-r-f receiver appearing in Fig.7 of this lesson. The only difference is that filament-type tubes are used in Fig.19; the filament serving both as the cathode and heater element. Beside this, there is no need for a rectifier tube and its associated power and filter circuits in the battery receiver.

THE AUDIO SECTION: As you will observe from the schematic diagram shown in Fig. 19, no "C" battery is employed in this receiver. The power tube obtains its bias voltage from the voltage-drop appearing across the 900-ohm resistor which is connected in the negative lead between the "B" battery and the chassis,to which A- is also connected. While this arrangement over-biases the tube, it nevertheless reduces the B-battery drain. Although it increases the percentage of harmonics, this practice seems justified, as the quality is quite acceptable.

This receiver is equipped with a permanent-magnet type dynamic speaker, more commonly known as a "p-m speaker." The field of this speaker does not require an electric current for its excitation as is the case with other types of dynamic speakers. Furthermore, in this particular circuit, a p-m speaker is even more satisfactory than the type requiring field excitation, because better sound reproduction can be obtained from a good p-m speaker than from an electrodynamic unit which is under-excited (the one-half watt of field-exciting power available for field-type dynamic speakers in this type of receiver, would constitute gross under-excitation).

THE ANTENNA: Upon further referring to the circuit diagram in Fig.19, you will observe that the loop antenna is connected directly across the input grid circuit of the r-f tube; no conventional antenna-stage transformer is employed.

The single-turn antenna coupling coil (shown with heavy lines in Fig. 19) is wound around the outside of the loop and serves as a connection to an external antenna and ground, if such be used. This antenna and ground may be connected to the "A" and "G" terminal posts which are placed on the back of the carrying case.

FOUR-TUBE PORTABLE SUPERHETERODYNE RECEIVER

Let us now continue our discussion of portable receivers by noting how the superheterodyne principle is applied in such sets.

The circuit diagram of a typical four-tube superheterodyne portable receiver is shown in Fig. 20. This is the basic superheterodyne circuit which is used by practically all manufacturers of portable superheterodyne receivers,and therefore warrants your most careful study.

Notice that a converter tube is used as a combination first detector and oscillator. This is followed by a pentode i-f tube and a diode-triode second detector. The audio output tube is also of the pentode type.

You will further observe that the two i-f transformers and oscillator coil windings are wound on iron-core forms. This is done to increase the gain and sensitivity of the circuit. Full a-v-c action is also employed -- the system being energized by the diode circuit of the second detector.

Upon studying the combination second detector, a-f and a-v-c sections in Fig. 20 more closely, you will be quick to realize that this arrangement is a duplicate of the corresponding section used in the circuit appearing in Fig. 10. The only difference is that filament-type tubes are used in Fig.20 -- the filament serving both as the cath

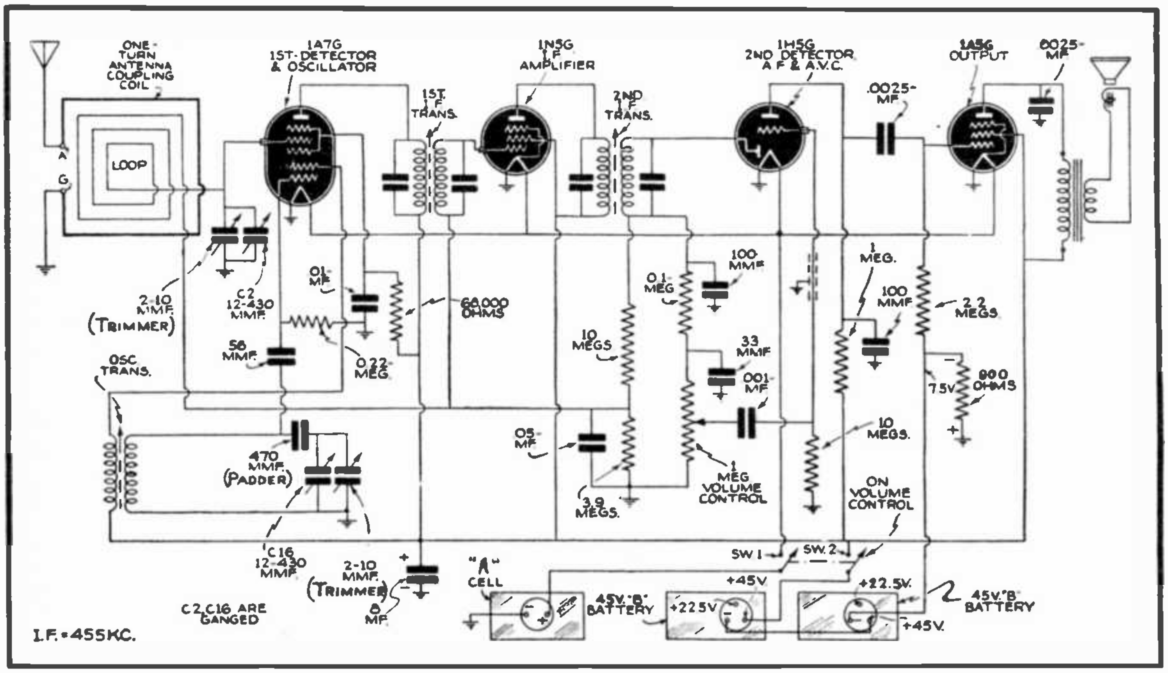


FIG. 20
CIRCUIT DIAGRAM OF TYPICAL PORTABLE SUPERHETERODYNE RECEIVER

ode and heater element. Therefore, the explanation already given you relative to Figs. 10 and 11 of this lesson will apply equally as well to the second detector stage in Fig. 20.

This portable receiver is typical of receivers of this type. Practically all of them use the same tube combinations and are also alike in all other respects except the design of the cabinet.

The same basic circuit arrangement illustrated in Fig.20 is also being used for battery-operated home radios, in which case the chassis and battery equipment are installed in a table-model or console-type cabinet. In some instances,the loop antenna is retained for home use, while some manufacturers replace the loop antenna input with a conventional r-f transformer,operating in conjunction with a standard tuning condenser.

BATTERY-LIFE

Battery-life is the main factor in the service requirements of these receivers. Assuming a typical four-tube set to be used three hours daily, the A and B batteries will furnish about three months of service. Thus,both batteries have the same approximate life-span. In "pack-units" combining A and B batteries, it is desirable that both battery sets "run down" simultaneously. The end-point of utility is considered to be 1.1 volts for the A-battery and 66 volts for the B batteries,these voltages being measured while the set is in operation.

COMBINATION ELECTRIC -- BATTERY PORTABLE RECEIVERS

Many manufacturers of portable receivers have designed "Universal-type receivers" that include a rectifier tube and other accessories so as to adapt these sets for operation from either batteries, a 110-volt a-c power line, or a 110-volt d-c power line. By so doing, battery-life is conserved when operating the set in localities where power is available. Of course, these sets are somewhat heavier than the more conventional battery models.

In Fig. 21 is shown a typical circuit diagram for one of these popular sets. No effort will be made at this time to explain the operating principle of the 35Z5GT type rectifier employed in this circuit, as in a later lesson you will receive complete and thorough instruction on all types of ac-dc receivers. However, we do point out at this time that no power transformer is employed in ac-dc type receivers; all B-current flows directly from the line through the 35Z5GT rectifier tube and filter system.

The "off-on" switch S-1 is mounted on and operated by the volume control. When closed, it connects the B voltage supply to the receiver circuit, regardless of whether the receiver is being operated from the lighting system or batteries. When open, it disconnects the "B" voltage supply from the receiver. It also serves to disconnect the "A" battery from the receiver at such times that the receiver is to be shut down while being operated on batteries; and to interrupt the filament circuit when shutting off the receiver while connected to the lighting system.

Switch S-2 is a two-position change-over switch, which when closed to the left, connects the batteries to the receiver. When switch S-2 is closed to the right, the batteries are disconnected and power obtained from the lighting circuit is supplied to the receiver circuits.

Switch S-3 is a cut-off switch, by means of which power to the receiver can be turned on or off while the line cord is connected to the lighting system.

The 545 ohm resistor element in the ballast tube is connected in series with the filament of the 35Z5GT tube and the lighting circuit so as to maintain the filament voltage of this tube at the correct value. The filaments of the other tubes are in series with each other, and are connected across the B+ circuit through the 2500 ohm resistor element in the ballast tube. Because of the low filament current drawn by the battery-type tubes, such a connection is possible. The filament of the 35Z5GT tube is tapped, thus making available a drop of 5.5 volts between terminals 2 and 3 for operating the pilot lamp P-1.

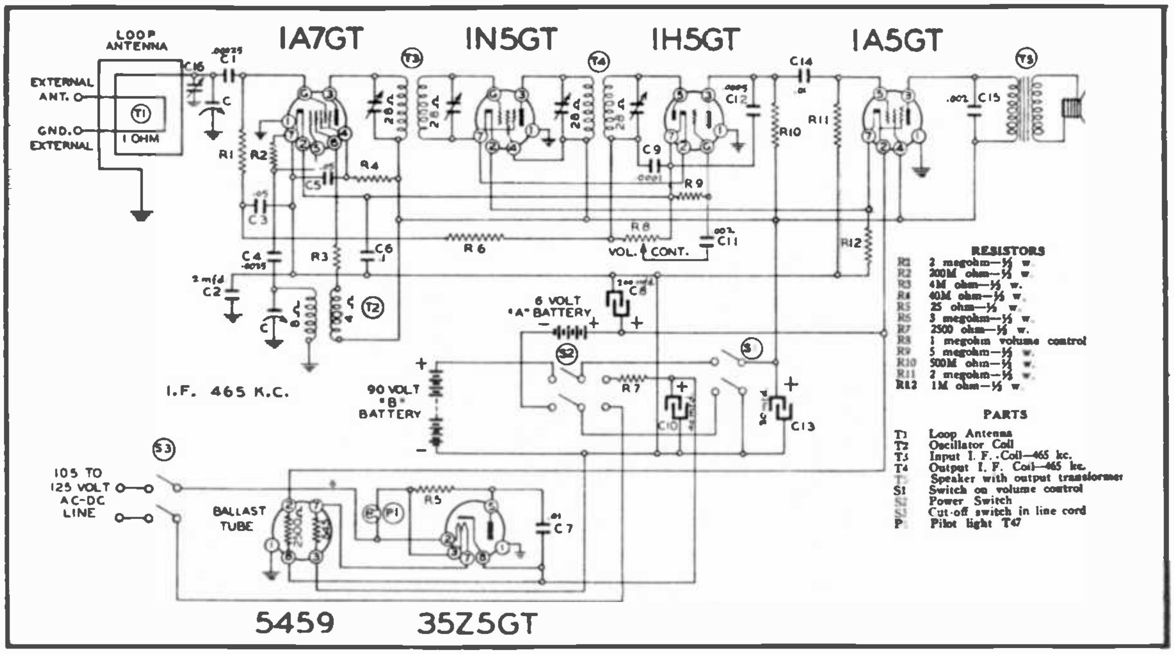


FIG. 21
BATTERY OR AC-DC OPERATED PORTABLE SUPERHETERODYNE RECEIVER

Aside from the ac-dc feature, which will be more fully explained in a later lesson, the operation of the converter, i-f, detector and audio circuits in Fig. 21 is identical to that in the other superheterodynes just described.

When operation from an electric line is contemplated over an extended period, it is advisable to remove the batteries from the cabinet,as their life is shortened considerably when they are subjected to even moderately increased temperatures.

LESSON NO. 24

1. - What method is usually used in connecting together the filament circuits in a-c table-model receivers?

2. - What two methods are used for obtaining bias voltages in a-c receivers?

3. - (a) Describe briefly the constructional features and operating principle of one type of high impedance or constant-gain r-f transformer.
   (b) What advantages do coils of this type offer over the simple type of r-f transformer?

4. - Describe the constructional features and explain the operating principle of the loop antenna.

5. - What is the most important technical factor that is responsible for the success of modern portable receivers?

6. - (a) What change-over method is employed in combination battery,ac-dc, portable receivers so that the set can be operated from either one of these power supplies?
   (b) What precaution should be exercised relative to the batteries when operating such receivers from the power-line over long periods of time?

7. - (a) What type of dynamic speakers are usually employed in portable receivers?
   (b) Why is this the practice?

8. - Name at least four important factors that control the design and construction of a-c table-model receivers.

9. - Mention at least five common practices which are followed by manufacturers to reduce the cost of a-c table-model receivers.

10. - Describe the construction and explain the operation of a diode-triode type tube.

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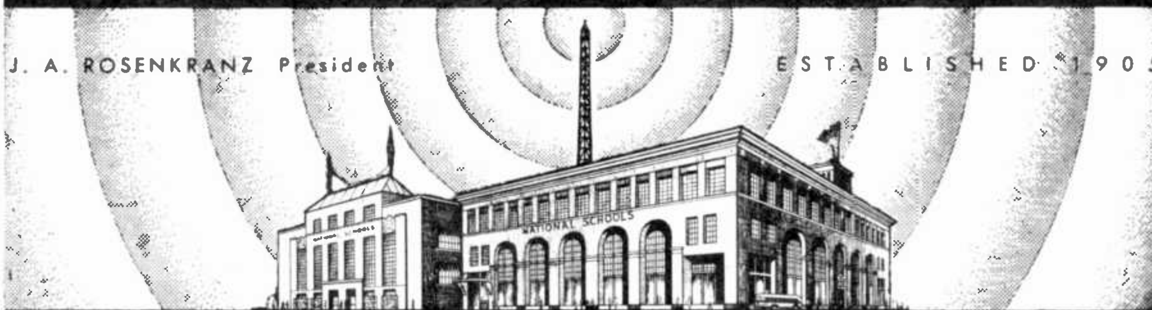

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LESSON NO. 25

D-C AND AC-DC RECEIVERS

The chief difference between a-c receivers and d-c receivers is that the latter require no rectifying system nor power transformer. The elimination of the rectifier in the d-c receiver is an advantage, as it makes possible a saving in the cost of constructing such a receiver. However, in direct contrast, the absence of a power transformer in d-c receivers makes it impossible to obtain B-voltages exceeding the line voltage -- that is, if the d-c line voltage is only 110 volts, the highest B-voltage available will be somewhat less than 110 volts.

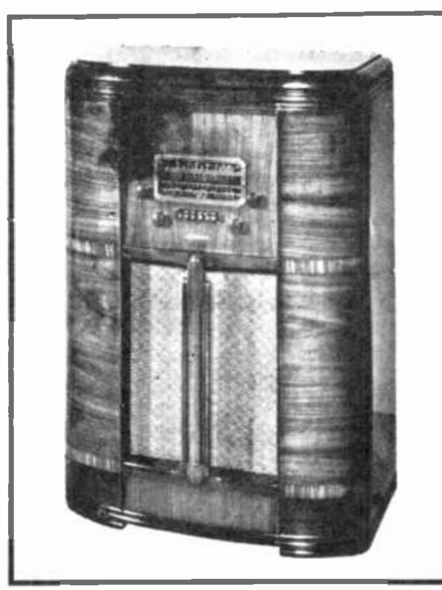

FIG. 1
CONSOLE TYPE D-C RECEIVER

Another interesting point for comparison is that in a-c receivers a parallel filament connection is used, whereas a SERIES filament connection is employed in d-c receivers.

SERIES FILAMENT CONNECTIONS

The filament circuit shown in Fig.2 is typical of d-c receivers. Here, the tubes used in the r-f, converter, i-f, detector, and first a-f stage all have filaments designed for 6.3 volts operation, and when so operated, draw a filament current of 0.3 amp. You will recall that these particular tubes are also suitable for a-c receivers.

The power stage, of the particular receiver being discussed, employs two type 48 tubes in a push-pull arrangement. The type 48 tube was developed primarily for use in d-c receivers -- the chief aim being to produce a power tube that will furnish appreciable amplification and power output with only about 100 volts applied to its plate. Another factor which makes the type 48 tube particularly well adapted to d-c receivers is that its filament is designed to operate at 30 volts, which feature aids materially in reducing the line voltage for the combined filament circuit. When operated at 30 volts, the 48 tube draws a filament current of 0.4 ampere.

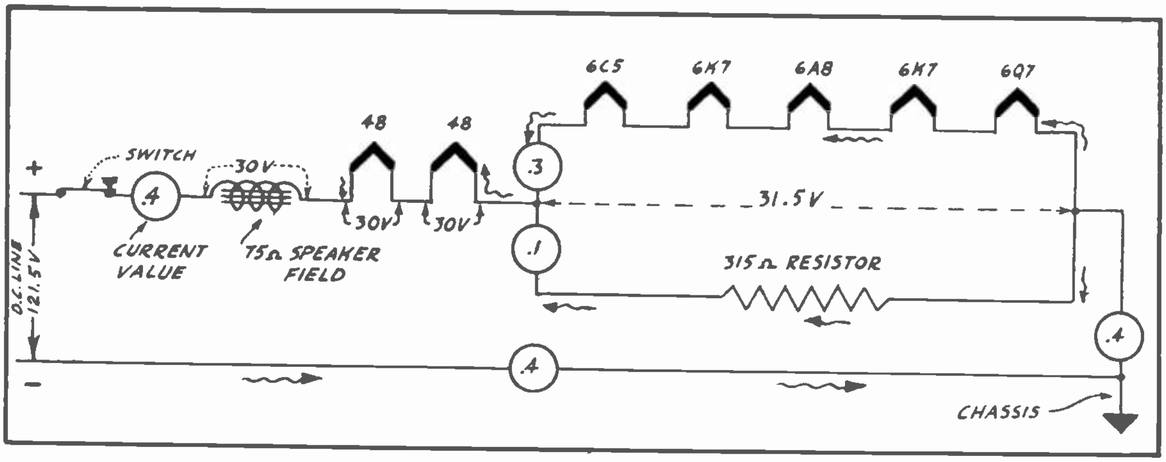

FIG. 2
FILAMENT CONNECTIONS IN A SEVEN-TUBE D-C SUPERHETERODYNE RECEIVER

Returning to our diagram of Fig. 2, we note that the line voltage,as determined by actual measurement, is 121.5 volts. The combined voltage-drop of all the tube filaments in the series arrangement is equal to the sum of the individual filament voltages, or --

$$6.3 + 6.3 + 6.3 + 6.3 + 6.3 + 30 + 30 = 91.5 \text{ volts}$$

Since a line voltage of 121.5 volts is available and only 91.5 volts are required by the combined filament circuit, it is clear that some additional means must be provided whereby another voltage-drop of 121.5 minus 91.5 or 30 volts can be produced. This additional voltage drop could be furnished by a resistor connected in series with the filament circuit and the line. Since this resistor should be expected to carry a current of 0.4 amp (as demanded by the filaments of the 48 tubes), and to develop a voltage-drop of 30 volts, its value would be determined by applying Ohm's Law in the form $R = \frac{E}{I} = \frac{30}{0.4} = 75$ ohms.

Although such a resistor will meet our requirements, it is nevertheless true that the power dissipated by a resistor is a direct waste. It is for this reason that a specially designed 75-ohm speaker field is used in Fig. 2 to replace this resistor.

In the event that all of the tube filaments in Fig. 2 required the same current, it would not be necessary to use the 315-ohm resistor here shown. However, the filaments of the two 48 tubes require a current of 0.4 amp, while the remaining tubes require only 0.3 amp. Therefore, some means must be provided whereby the extra 0.1 amp can flow through the filaments of the 48 tubes without flowing through the filaments of the other tubes -- and such is the purpose of the 315 ohm resistor.

The value for this resistor is determined in the following manner: The voltage, as measured between the negative side of the line and a point between the 6C5 and 48 tubes in the positive side of the line, is 31.5 volts, as shown. Therefore, to bypass a current of 0.1

ampere at this point will require a resistor having a value of 315 ohms. ($R = \frac{E}{I} = \frac{31.5}{0.1} = 315$ ohms.)

Notice in Fig. 2 that the heater of the detector tube is connected to the ground-end of the series circuit. This is done in many d-c and ac-dc receivers to reduce hum.

COMPLETE D-C SUPERHETERODYNE RECEIVER

In Fig. 2 we show only the filaments of the various tubes; the other elements have all been eliminated to simplify the analysis. The complete circuit diagram appears in Fig. 3. To point out clearly in Fig. 3 the basic difference between d-c receivers and a-c receivers, we have again illustrated the filament circuit individually. Notice especially in Fig. 3 how the filaments of all tubes are connected in series with each other,as well as with the 75-ohm speaker field. Also, observe how this series-group is connected directly across the d-c lighting circuit through the receiver's "off-on" switch and a 2-ampere fuse. The chassis is used as the ground-return side of the circuit, and the 315-ohm,20-watt resistor is used in the same manner as explained relative to Fig. 2.

THE B-CIRCUITS: Since the power company in this case furnishes d-c, no rectifying system is required by this receiver. Instead, the B+ feeder for this circuit is connected directly to the positive side of the line.

The d-c power, as supplied by the company,is not absolutely uniform in value. That is, considerable ripple-voltage is present, similar to that experienced at the output of the rectifier in a-c sets. For this reason, it is necessary to include in this circuit a conventional filter, consisting of a 30-henry choke and two 8 mf filter condensers.

All "B" current furnished the r-f, converter, i-f, second detector,and first a-f stages must flow through this filter,as these stages

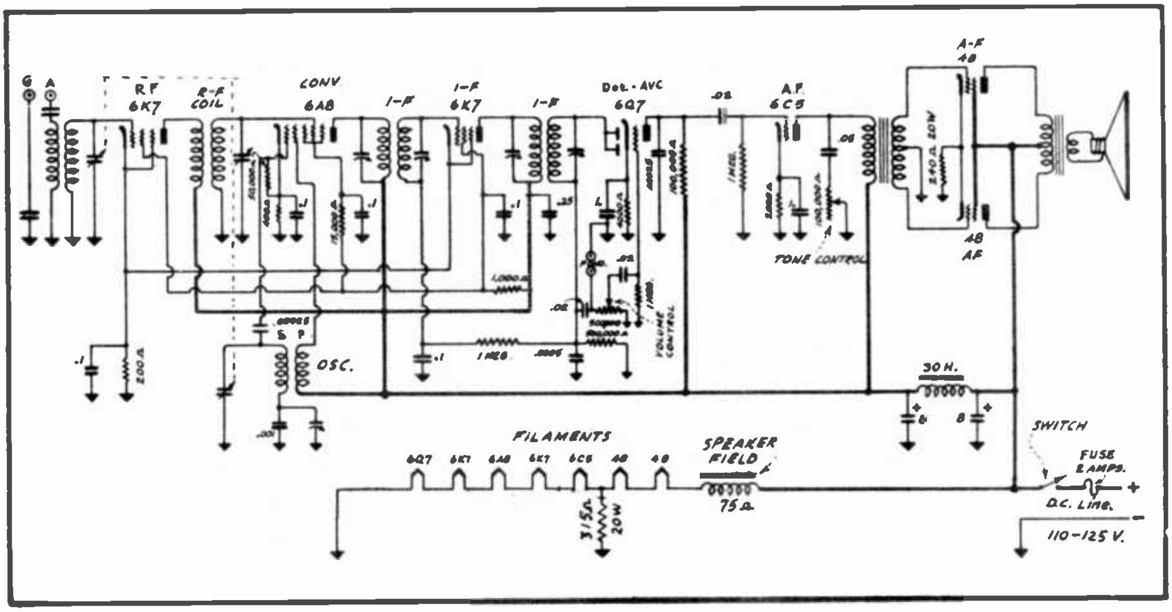

FIG. 3
D-C SUPERHETERODYNE RECEIVER

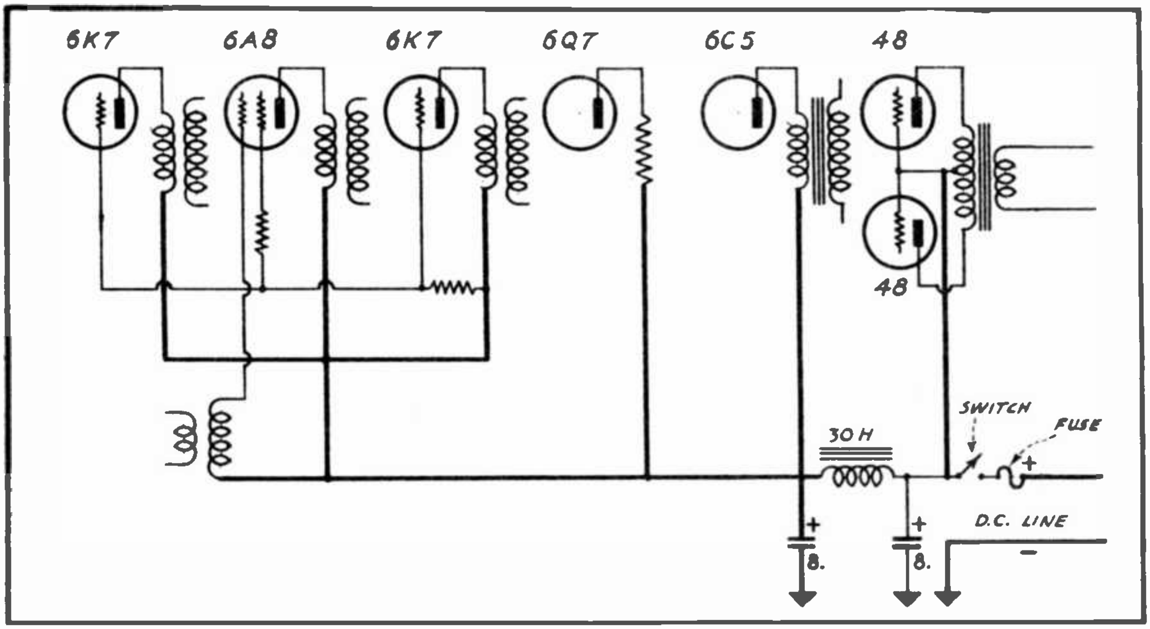

FIG. 4
SCREEN AND PLATE CIRCUITS IN THE D-C RECEIVER

are more susceptible to hum voltage than is the final power stage. In other words, any hum picked up in any stage preceding the power output stage would be amplified considerably, and we must therefore take every precaution to prevent such an occurrence. The detailed drawing of the screen and plate connections, shown in Fig. 4, illustrates this point clearly.

Perhaps, you are wondering by this time why the plate and screen circuits of the 48 output tubes are connected to the input end of the filter. There are definite reasons for this and they can be explained as follows:

The combined plate and screen current drawn by the power tubes is much greater than that required by the remaining tubes. Therefore, if the B-circuits for the power stage were connected to the output end of the filter system, the greatly increased current-flow through the filter choke would result in a high voltage-drop at this point. This in turn would mean that all B-voltages throughout the circuit would be much lower in value than is the case when using the connections illustrated, and the performance of the receiver would suffer accordingly. Also, the cost of a choke capable of carrying so great a current would be appreciable.

Even though the B-current for the power output stage is not filtered, its use at this point can be tolerated, as any small amount of hum-voltage introduced at this section of the circuit will not be amplified sufficiently to be annoying.

Also observe in Figs. 3 and 4 that a reversal in the line plug connection will prevent the receiver from operating, as by so doing a negative instead of a positive potential will be applied to the plate and screen elements of the various tubes.

INSULATED GROUND AND ANTENNA CONNECTIONS: Another important point to be noted in Fig. 3 is the use of a fixed condenser between the receiver's antenna terminal and primary winding of the antenna stage coil, as well as between the ground terminal and the chassis. These condensers serve to insulate the antenna and ground circuits from the chassis so far as the d-c line voltage is concerned, but do not interfere with the high-frequency voltages and currents.

Power companies generally ground the negative side of their d-c lines. Upon studying the circuit diagram in Fig. 3, it is apparent that an accidental reversal of the line plug connection would cause the chassis proper to be connected to the positive or"hot-side" of the line. Then if the ground terminal were to connect the chassis directly to ground without having the condenser included in series, the ground connections would produce a direct short across the power line. Including a fixed condenser in this circuit prevents such an occurrence.

The fixed condenser in the antenna circuit serves a similar purpose in preventing line-current passing through the antenna coil in case that the line plug should be momentarily reversed while the antenna is partially grounded through faulty installation. Line-current passing through the antenna coil would burn it out instantly.

EFFECT OF LOW B-VOLTAGE: It is of course true that the tubes used in the circuit illustrated in Fig. 3 operate at B voltages which are considerably less than the normal values used for similar tubes when installed in a-c receivers. This will naturally reduce the amplifying ability of the receiver somewhat, but not enough to prevent satisfactory performance.

Aside from the points thus far discussed relative to Fig. 3, the circuit proper is quite conventional. Hence, since all other sections of this receiver are similar to corresponding sections in a-c receivers that have already been explained thoroughly, there is no need for us to spend any more time on this particular d-c circuit. Also, bear in mind that this circuit is typical of receivers of this type.

220-VOLT D-C RECEIVERS

The receiver just described was designed for so-called 110-volt operation. Since 110-volt power lines are used more extensively than 220-volt systems, it is the more common practice among receiver manufacturers to design their equipment for 110-125 volt operation. Then, if a 110-volt d-c receiver is to be operated from a 220-volt supply, it is only necessary to install an additional resistor of the proper value in series with the receiver and the 220-volt line. This will reduce the line voltage of 220 to 110 volts, and the receiver then operates at 110 volts.

The value of this resistor is determined by dividing the voltage drop to be developed across this resistor (220 minus 110,or 110 volts) by the total current drawn by the receiver. For example, if the receiver draws 0.45 ampere, including all filament and B-current, the resistor must have a resistance value of approximately 244.44 ohms ($R = \frac{E}{I} = \frac{110}{0.45} = 244.44$). Its watt-rating should be 49.50 watts ($W = E \times I$), plus a safety factor -- the actual watt-rating amounting to approximately twice the calculated value or 99 watts. (A standard 250-ohm, 100-watt resistor would serve the purpose.)

There are some exceptions to the rule just given, as in a case where the receiver is designed especially for 220 volts. In the latter case, the higher voltage is used advantageously for the "B" voltages which are applied to the various circuits. The general construction and operating theory for the 220-volt d-c receiver is the same as already described for the 110-volt d-c sets.

N

AC-DC Receivers

For some time, receiver manufacturers have been constructing receivers that are designed to permit operation from either an a-c or d-c power supply. Receivers which will meet these requirements are known as AC-DC RECEIVERS. The line plug of such a receiver can be inserted directly into a lighting circuit that is supplied with either 110-volt a-c or d-c energy, and no auxiliary equipment is required. Most of the commercial combination ac-dc receivers are of the compact midget design, such as illustrated in Fig. 5 of this lesson, although larger console types are also available.

There are several reasons why this type of receiver is widely used. In the first place, this circuit is especially adaptable to the "midget" or "pee wee" sizes, as there is no need for a power transformer nor any other large, heavy-duty parts,as are required in conventional a-c sets.

The saving of many costly parts will obviously allow a set of much smaller size to be built, and will also permit selling such sets at a much lower price. As a rule, the average ac-dc set will sell for about one-quarter less than an equivalent set designed for straight a-c operation.

The tubes used in the earlier ac-dc receivers were designed primarily to operate at maximum efficiency in a-c receivers, where comparatively high B-voltages were available. Using these same tubes in "transformerless" ac-dc sets, where B-voltages are below 110 volts, prevented efficient operation. Therefore,to enable the performance of the ac-dc receivers to compare more favorably with the a-c receivers, special tubes and parts were designed that would improve their performance, efficiency and amplifying ability when operated at the lower plate voltages prevailing in the ac-dc type of receiver. This has made it possible for the average modern ac-dc set to compare quite favorably with an equivalent set designed for straight a-c operation. These factors,plus the reduced size, weight and cost of ac-dc receivers, have been primarily responsible for this type of set being used extensively throughout the world.

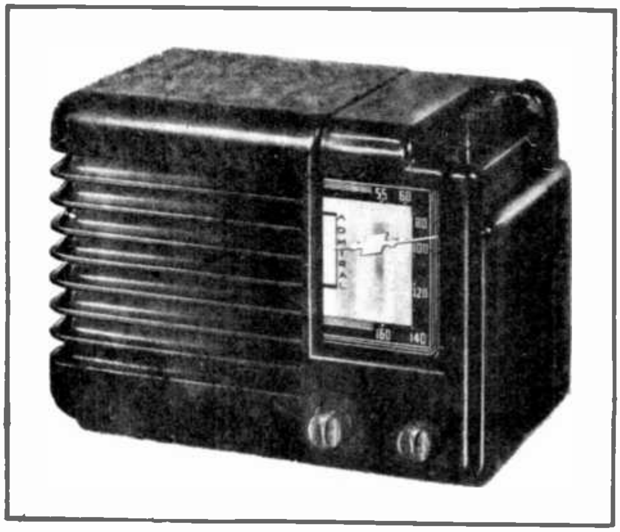

FIG. 5
A MODERN AC-DC MIDGET TYPE RECEIVER

CONSTRUCTIONAL FEATURES

In Fig. 6 you are shown a "bird's-eye-view" of a typical ac-dc receiver chassis. As you will observe, it is of compact construction which is characteristic of all midget designs. In the majority of cases, the speaker is mounted at the front and to one side of the chassis, as here shown.

By using a chassis layout as is here illustrated, the cabinet can be constructed along the lines of the one shown in Fig. 5.

In a great many ac-dc receivers, the metal chassis acts as the common ground and negative return-side of the wiring system. In such cases, the correct polarity must be established when inserting the line plug for operation from a direct current circuit. Should the line plug be reversed in the receptacle, the set will fail to operate because at such time a negative instead of a positive potential will be applied to the plates of the rectifier. This in turn will prevent passage of B-current thru this tube, with the result that B-voltages will not be available in the various circuits of the set.

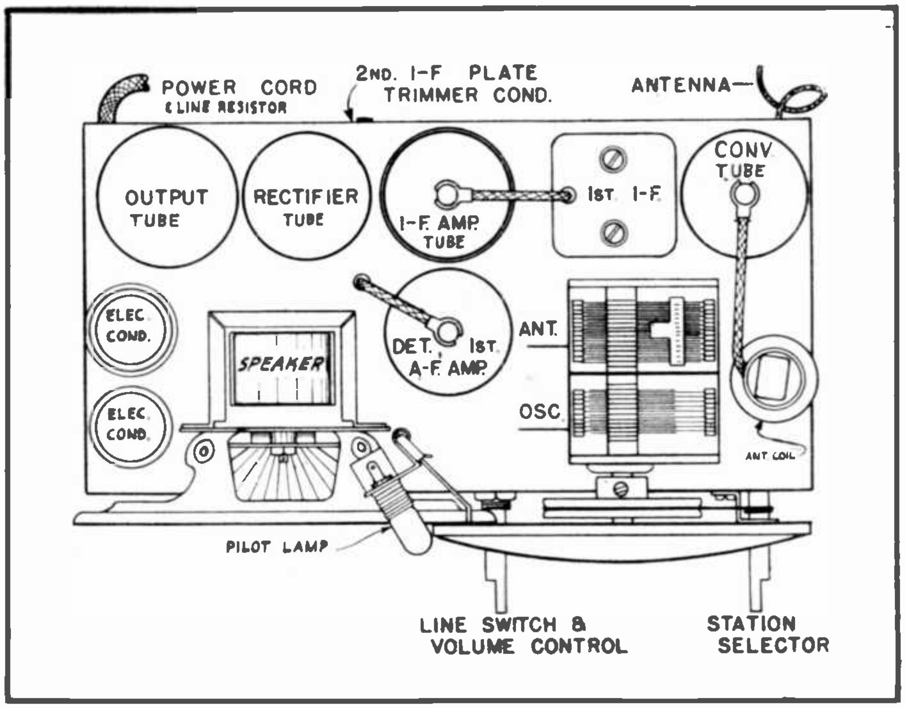

FIG. 6
TYPICAL AC-DC CHASSIS-ARRANGEMENT

Notice in the various diagrams of this lesson that protective bypass condensers are usually connected in series with the antenna, ground or both terminal posts of ac-dc receivers. This is done in the same manner and for the same reasons as already explained in this lesson relative to d-c receivers.

RECTIFIERS FOR AC-DC RECEIVERS

As ac-dc receivers increased in popularity, it became necessary to design rectifier tubes especially adapted to these sets. In other words, it was desirable to have a rectifier tube whose filament or heater draws the same current as the other tubes generally used in such receivers, as this would make a series heater circuit practical. It was also desirable that the rectifier tube, as used for this purpose, be capable of passing adequate "B" current with a rather low impressed plate voltage.

Several of such tubes are now available. Generally speaking, tubes of this type consist of two tube-sections housed in a single enclosure which may be of either a glass or metal structure.

The application of such a tube in the "B" circuit of an ac-dc receiver is shown in Fig. 7. Here you will observe that the tube has two plates, two cathodes and a series connected dual-section filament. Although such a tube structure is actually of the full-wave type, it is nevertheless used as a half-wave rectifier in the majority of ac-dc receivers.

In the circuit of Fig. 7 we are using the 25Z5 as an example, as this is one of the first tubes of this type as well as being typical of the tubes used for this service.

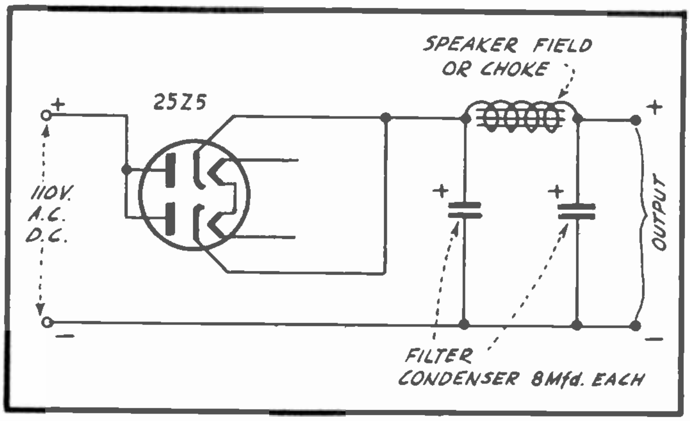

FIG. 7
CIRCUIT APPLICATION OF THE 25Z5 TUBE

Notice in Fig. 7 how the two plates of the tube are both connected to one side of the lighting circuit (the positive side, if a d-c line is available). The two cathodes are also connected together, and placed in the positive side of the filter system. The negative side of the line is connected directly to the negative side of the filter system. In other words, the two halves of the tube are connected in parallel.

When the circuit of Fig. 7 is connected to a d-c power line, a positive potential will at all times be applied to the plates of the tube, while a negative potential is applied to its cathodes thru the wiring of the receiver circuit. Such being the case, the heated cathodes will continually emit a stream of electrons that are attracted steadily toward the positively-charged plates. Thus, we have a continuous flow of B current furnished the receiver circuits, and the tube at this time serves as nothing more than a resistance element of comparatively low value, permitting d-c line current to pass through the system.

Upon connecting the system in Fig. 7 to an a-c lighting circuit, the plates of the tube will be changed alternately from a positive to a negative potential. Each time that the plates are charged positively, electrons will be attracted from the cathodes, and a surge of current will pass through the tube. The following alternation of the a-c supply will charge the plates negatively, causing them to repel electrons emitted by the cathodes and thereby preventing any flow of current between these elements. The tube thus functions as a half-wave rectifier and furnishes a B-current and voltage of corresponding characteristics.

CONNECTING THE SPEAKER FIELD IN THE CATHODE CIRCUIT

In Fig. 8 is shown another arrangement, which is sometimes used in ac-dc receivers. Here, the two plates of the rectifier tube are both connected to one side of the line. One of the cathodes is connected to the filter system, consisting of the choke and the two filter condensers. The other cathode, at the same time, conducts the energizing current for the speaker field which

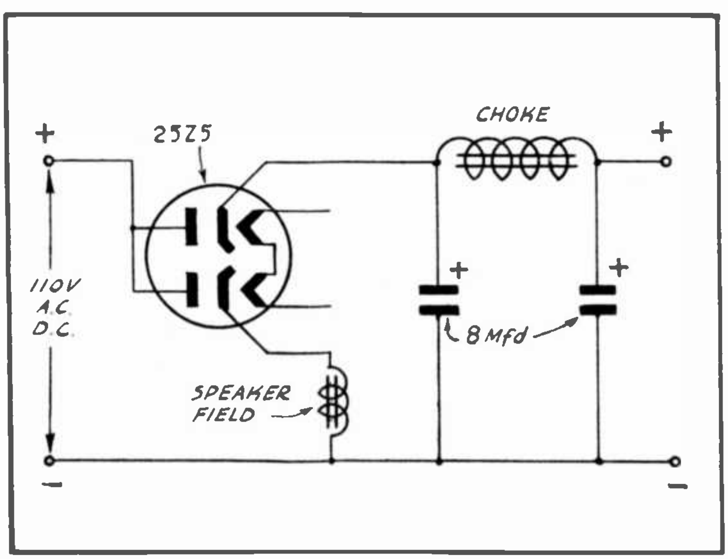

FIG. 8
THE SPLIT HALF-WAVE RECTIFIER

is connected between this cathode and the negative side of the circuit. Upon applying a-c to the input, the tube functions as a half-wave rectifier, furnishing d-c for both the B circuits and the speaker field.

TYPICAL AC-DC T-R-F RECEIVER

In Fig.9 we have the circuit diagram of a typical four-tube ac-dc, t-r-f receiver, using the 25Z5 tube in conjunction with a 6D6 pentode r-f tube, a 6C6 pentode detector, followed by a 25L6 pentode a-f amplifier. To simplify matters, the filament circuit is shown separately, apart from the tube symbols.

By studying this circuit diagram, you will immediately notice that the heaters of the four tubes are all connected in series with a line cord ballast resistor, 25-ohm pilot lamp resistor and 110-volt line. The circuit is so designed that a 25-volt drop will be produced across the rectifier's heater,another 25 volts across the power tube's heater and 6.3 volts across the r-f and detector tube heaters. This accounts for a total voltage drop of 62.6 volts across the filaments of all four tubes. The remaining 47.4 volts of the line voltage is dissipated or "dropped" across the ballast resistor and the 25-ohm resistor across which the pilot lamp is connected. Ballast resistors,as here used, are generally rated at 25 watts.

Regardless of whether the 110-volt power supply be d-c or a-c, the voltage distribution for the heater circuit is exactly the same. Furthermore, since all of the tubes are of the heater-cathode type, they are equally well adapted to both d-c and a-c heater supplies.

Notice especially that the 25Z5 tube is being used in a half-wave rectifying arrangement, as already described in this lesson. The

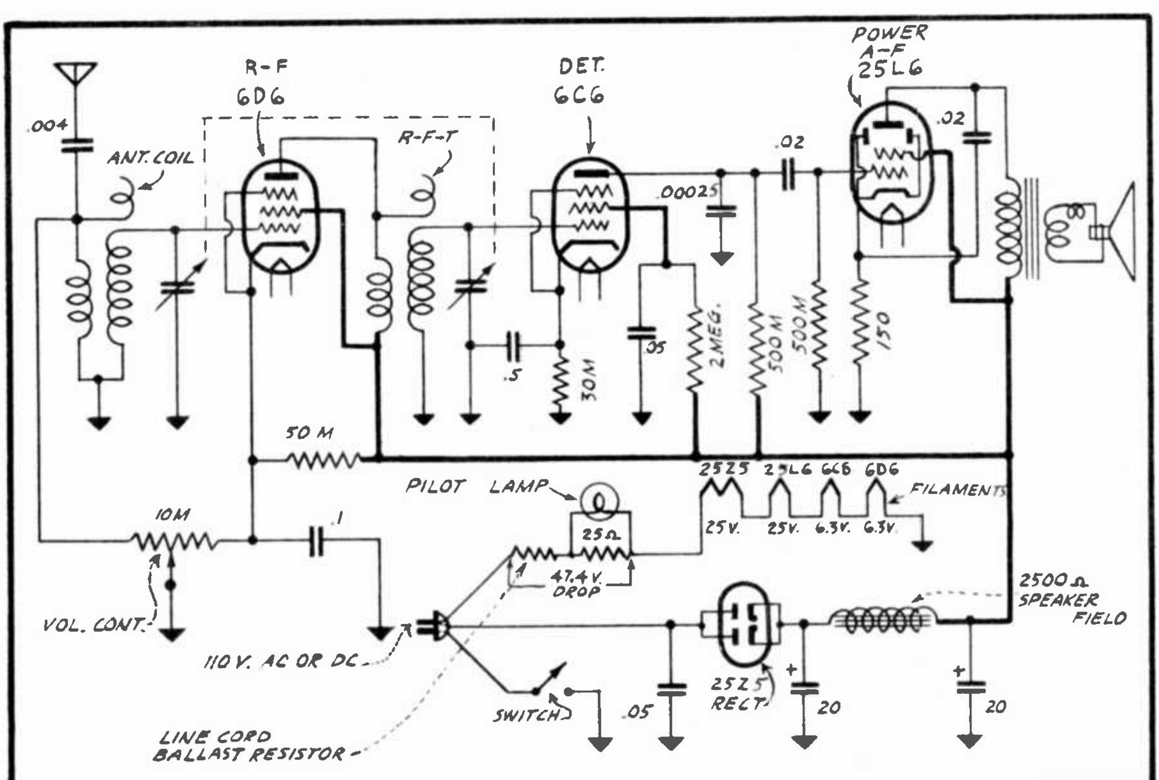

FIG. 9
TYPICAL FOUR-TUBE, AC-DC RECEIVER CIRCUIT OF T-R-F DESIGN

2500-ohm speaker field is connected in the positive side of a conventional filter circuit and thereby serves as the choke for the filter system.

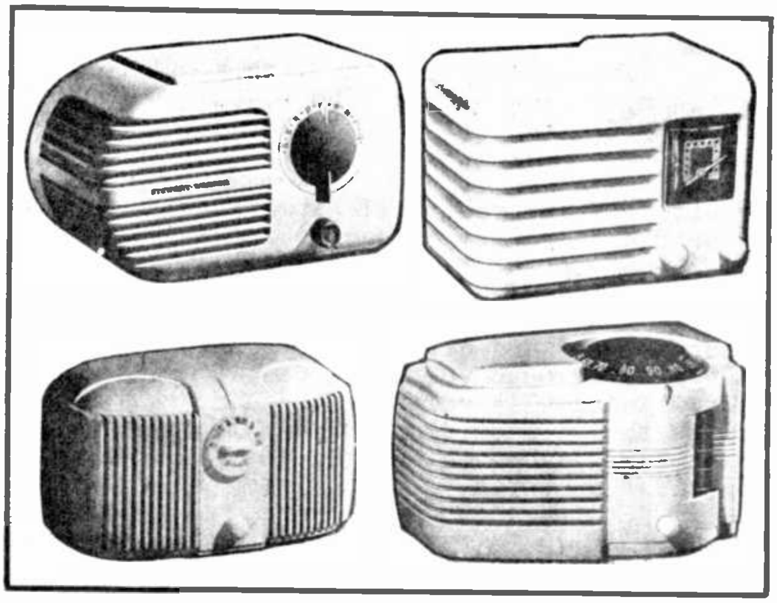

FIG. 10
TYPICAL MIDGET AC-DC RECEIVERS WITH MOULDED CABINETS

The reason for the 0.05 mf condenser across the line is to bypass line noises. Notice also in Fig. 9 how the pilot lamp derives its filament voltage by utilizing the voltage-drop developed by the flow of filament current passing through the 25-ohm resistor. All other components of this receiver are quite conventional and therefore require no additional explanations.

In Fig. 10 you are shown a group of typical four-tube, ac-dc midget t-r-f receivers. The cabinets shown are of a moulded material, which is used quite extensively for receivers of this type, particularly in the small compact designs known as "pee-wee" receivers.

LINE-CORD BALLAST RESISTOR CABLES

In the earlier ac-dc receivers, the line resistor for the series connected tube filaments was usually constructed in the form of a heavy duty wire-wound resistor. The large size of this resistor made it difficult to mount on the chassis proper; also, the intense heat radiated by it caused damage to other parts of the receiver. To overcome this undesirable condition, line-cords were designed in which the ballast resistor was incorporated directly within the line-cord, together with the negative line and rectifier-plate leads. Fig. 11 illustrates how this is done.

This line-cord resistor is wound in the form of a spiral, approximately one foot long, and placed parallel with the other two wires. Thus, being somewhat exposed to atmosphere, it dissipates more readily the intense heat generated by the current flowing through it.

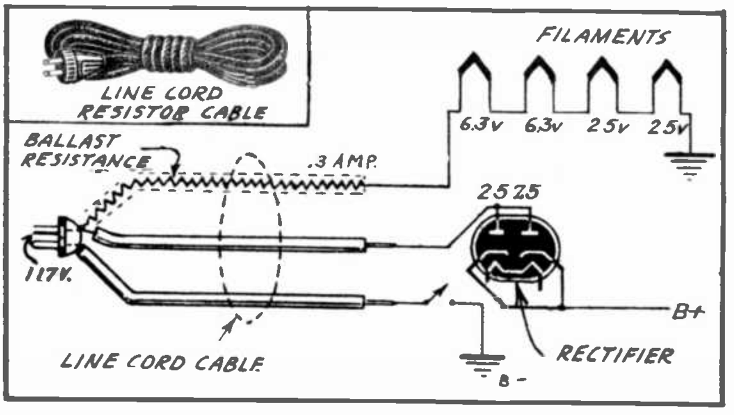

FIG. 11
CIRCUIT CONNECTIONS OF LINE-CORD BALLAST RESISTOR

CALCULATING THE RESISTANCE AND WATTAGE VALUES OF BALLAST RESISTORS

It is possible to calculate the resistance and wattage requirements of ballast resistors by applying Ohm's Law in the form, $R = \frac{E}{I}$. For example, in the circuit illustrated in Fig. 11 four tube-filaments are connected in series with the ballast resistor; the entire series combination being connected across a 117-volt line. To determine the ballast resistor value in this case, we proceed as follows: The voltage requirements for these tubes are 6.3, 6.3, 25, and 25 volts respectively -- the accumulative filament voltage therefore amounts to 6.3 + 6.3 + 25 + 25 = 62.6 volts.

Since the supply-line voltage is rated at 117 volts, we subtract 62.6 volts from 117 volts in order to determine the required voltage-drop. Thus, 117 minus 62.6, or 54.4 volts must be developed across the ballast resistor. Knowing that a filament-current of 0.3 ampere will flow through this resistor, we divide 54.4 (voltage-drop) by 0.3 (current) to determine the resistance required. Upon so doing, we obtain 181.3 (54.4 ÷ 0.3) as the resistance value for the ballast.

The nearest standard resistance to this figure is 185 ohms, which would be the resistor-value selected for this particular receiver. While this figure is slightly higher, it is better practice to use a ballast of slightly greater resistance than the minimum requirements. This prevents an excessive voltage being applied to the tube filaments in case that the line-voltage should increase slightly. This is also the reason why the value 117 volts has been adopted by the industry as the standard line-voltage for working out the design of 110-volt receiver circuits.

Line cords containing a ballast resistor should never be cut, as this will shorten the resistance wire and reduce its resistance. Such reduction in resistance value will cause the tube filaments to burn out.

CALCULATING THE WATTAGE RATING

In the ballast resistor problem under discussion, the voltage-drop (E) has been determined as 54.4 volts and the current (I) as 0.3. Therefore, to determine the watts dissipated, we simply multiply the voltage by the current as follows: 54.4 x 0.3 = 16.3 watts.

Now, 16.3 watts is the absolute minimum requirement for our ballast resistor. It is desirable to use a resistor of four times the calculated watt-rating; however, to reduce the cost, manufacturers generally use a resistor of only twice the calculated watt-rating, which in this instance would be approximately 32 watts. Here again, we would select the nearest standard watt-rating available.

Thus, we have determined that a ballast resistor rated at 185 ohms and 32 watts (approximately) would be suitable for the circuit diagrammed in Fig. 11.

THE PLUG-IN RESISTOR BALLAST TUBE

Not all of the ac-dc receivers have the ballast resistor incorporated in the line-cord. In fact, in the more modern sets, this ballast resistor is enclosed in a standard radio tube shell, and mounted on a base that can be plugged into a conventional tube socket. This method of handling the ballast resistor problem has proven very satisfactory and is used today in the majority of ac-dc receivers.

It is quite apparent that the tube-type ballast resistor offers several advantages over the line-cord resistor. The advantages are as follows:

(1) The ballast resistor tube reduces to an absolute minimum the fire hazard incurred by the abnormally high temperature of the line-cord which is caused by the flow of current through the line-cord resistor.

(2) The ballast resistor tube can be replaced very easily in case of burn-out.

(3) Placement of the ballast tube on the chassis provides adequate ventilation for dissipating the heat generated by the resistor.

Fig. 12 illustrates one of these ballast resistor tubes,and also the method for connecting it in the circuit. While the resistor shown is enclosed in a metal envelope, many ballast elements are housed in glass envelopes, the appearance of the unit then being similar to an ordinary glass radio tube. The usual socket connections are for the octal-type base.

THERMOSTATIC PILOT-LAMP BALLAST RESISTORS

The more modern ac-dc receivers that are equipped with pilot lamps generally use another resistance in addition to the ballast, for protection against pilot lamp burn-outs.

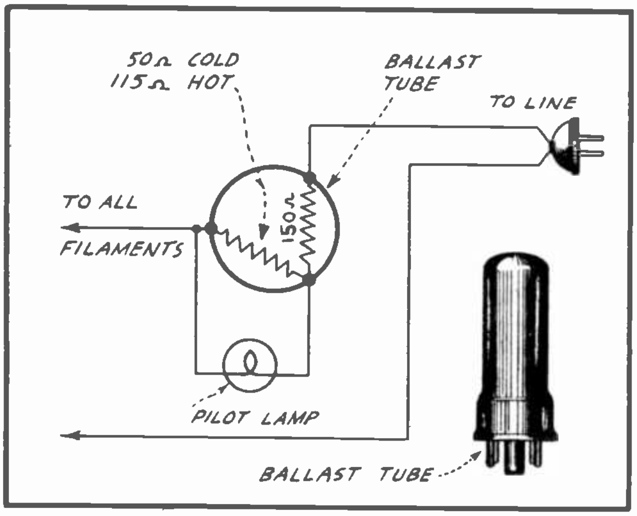

FIG. 12
BALLAST RESISTOR TUBE WITH THERMOSTATIC PILOT LAMP RESISTOR

The connections of a combination ballast resistor and pilot lamp circuit are shown in Fig. 12. The 150-ohm resistor is a conventional ballast resistor for furnishing the necessary voltage-drop in the filament circuit, and is made of ordinary resistance wire. The 50-ohm section, across which the pilot lamp is connected,is made of pure nickel.

The effect of temperature upon the 50-ohm nickel-wire resistor is such that its value increases to about 115 ohms, after it has attained its normal operating temperature. Thus, when the set is first turned on, the cool resistor provides its rated 50 ohms of resistance, which value is sufficiently low that a minimum voltage-drop will be produced across the resistor, with which to light the pilot lamp. As the set approaches normal operating temperature, the pilot lamp resistor gradually increases its value and causes the lamp to burn at increased brilliance. At normal operating temperatures, the resistance value will have increased sufficiently to cause the pilot lamp to light up at full brilliance.

Having thus analyzed the operation of this arrangement, it can be seen readily that the initial surge of current flowing through the pilot lamp will be at a reduced value for the first few seconds after setting the receiver in operation. The pilot lamp voltage then builds up gradually as the circuit attains normal operation temperature,which action causes the brilliance of the pilot lamp to increase gradually rather than flashing suddenly to full brilliance the instant that the switch is turned on. The latter condition causes the filaments in pilot lamps to burn out. The values of the resistances in Fig.12 are typical only, and should not be taken as standard for all ballast resistor tubes.

In Fig.13 is shown a typical chassis-layout for an ac-dc superheterodyne receiver, employing a ballast tube.

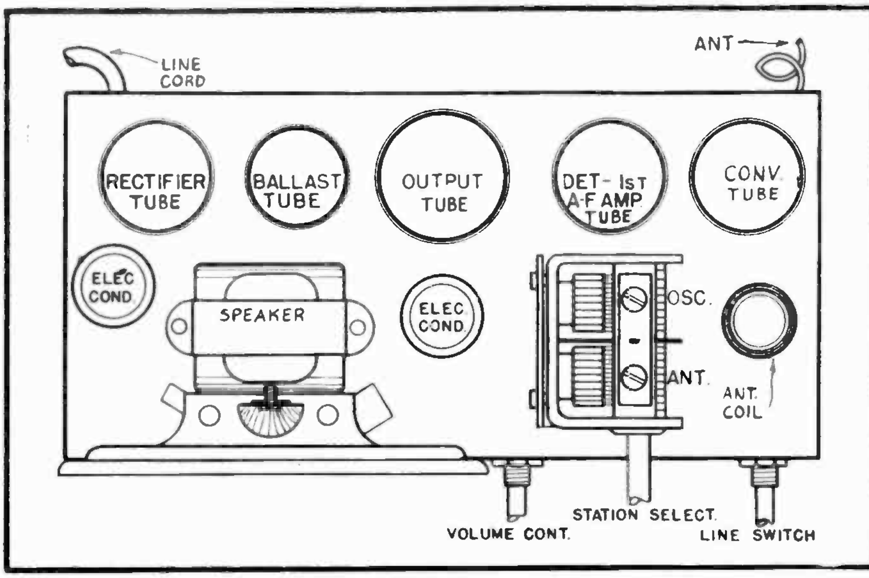

FIG. 13
PLACEMENT OF BALLAST RESISTOR TUBE ON TYPICAL AC-DC CHASSIS

SIX-TUBE, AC-DC SUPERHETERODYNE WITH BALLAST TUBE

In Fig. 14 is shown a circuit diagram of a six-tube, ac-dc superheterodyne, employing one of these ballast tubes. In reality, this receiver is only a five-tube set; nevertheless, it is the general practice among some manufacturers to count the ballast tube as one of the

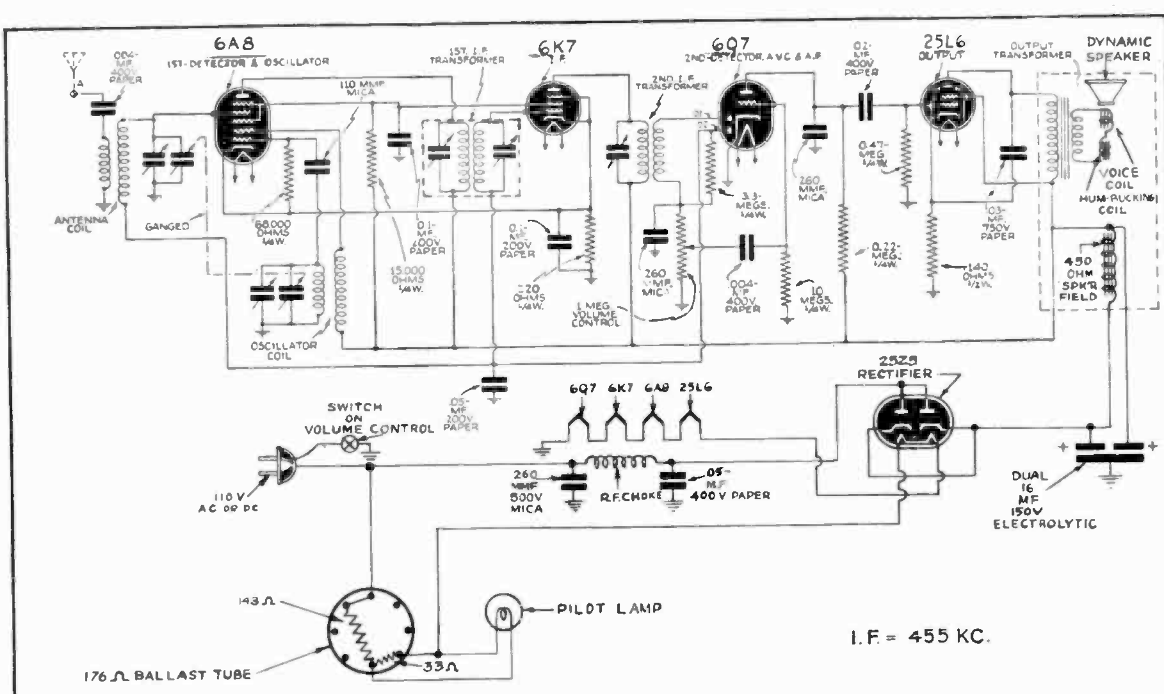

FIG. 14
CIRCUIT DIAGRAM OF SIX-TUBE, AC-DC SUPERHETERODYNE

tubes included in the set, although many persons believe this method of specifying the number of tubes to be misleading.

The r-f and a-f stages of this receiver are conventional and similar in operation to circuits already studied.

FIVE-TUBE, AC-DC PORTABLE SUPERHETERODYNE RECEIVER

The recent success of small self-contained loop-antennas,as used in portable battery receivers described in a previous lesson, has resulted in incorporating this convenient feature in electric table-model receivers as well. Thus,the necessity of installing an external antenna and grounding system is eliminated.

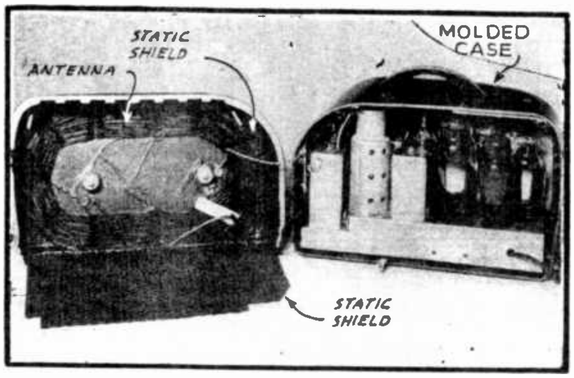

FIG. 15
TYPICAL PANCAKE-WOUND LOOP ANTENNA

In Figs. 15 and 16 you are shown illustrative views of two typical loop assemblies, as used with ac-dc receivers. This feature makes this type of receiver also quite portable.

In Fig. 17 is shown a circuit diagram of an ac-dc portable superheterodyne, employing a loop-antenna. You will observe that the loop inductance takes the place of the conventional antenna-stage transformer. However, provisions have been made for connecting an external antenna to the receiver so as to provide greater station pick-up.

THE STATIC SHIELD: Some loop-antennas are used in conjunction with an electrostatic or Faraday shield,consisting of a cage of parallel wires grounded to a plate or bus at one end. The other ends are left free and unconnected. It is important that there be no closed loops in the wires forming the shield.

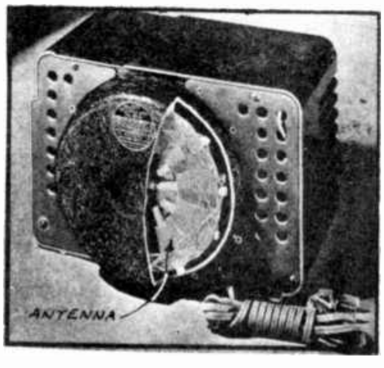

FIG. 16
SPIDERWEB LOOP ANTENNA

In Figs. 15 and 17 you will observe how a typical static shield is applied for this purpose. Static shields provide several advantages: first, they reduce pick-up from the electrostatic field that surrounds many sources of man-made static disturbances, particularly devices that cause sparking, such as electric motors, razors, ignition systems, X-ray equipment, high-tension leakage, etc. This is a very important feature in the large cities, especially if the receiver is to be operated in an apartment house or hotel. Upon comparing the performance of a receiver using a shielded loop-antenna, with that of an identical receiver using the flexible ac-dc type antenna-cord strung around the room, the improvement in the signal-noise ratio will be most noticeable.

The second advantage of the static shield is that it eliminates electrostatic reaction between the loop-antenna and various parts of the receiver. Still another advantage is that it improves the directional qualities of the loop-antenna.

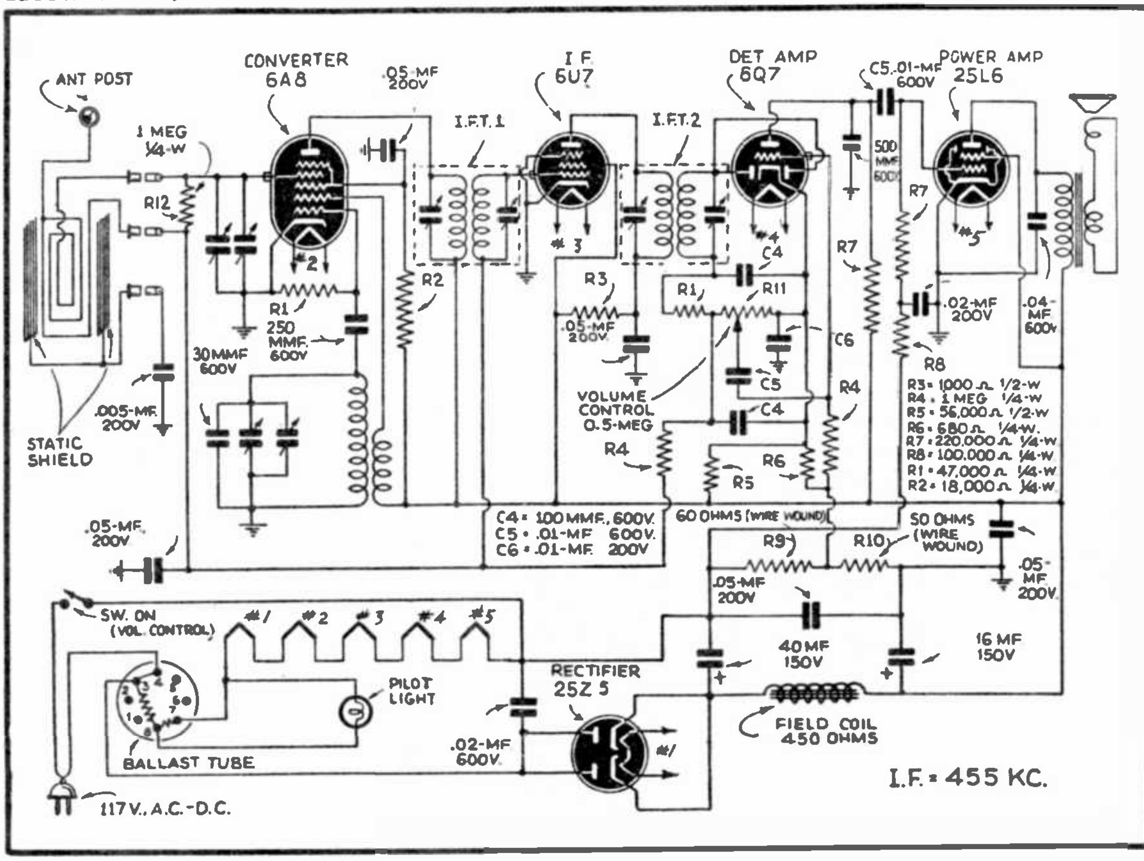

FIG. 17

CIRCUIT DIAGRAM OF FIVE-TUBE AC-DC PORTABLE RECEIVER

The receiver diagrammed in Fig.17 also includes a modern ballast resistor tube, and a field-coil type dynamic speaker, along with many other modern circuit refinements, such as a-v-c, dual-tuned i-f transformers and two dual-purpose tubes. This receiver (including the ballast) is equivalent in actual performance to a standard eight-tube rereceiver in which individual tubes perform the various functions.

OBTAINING THE BIAS VOLTAGES: By referring to the circuit diagram in Fig. 17, you will observe that the cathodes of all the tubes, with the exception of the second detector, are connected directly to ground. Therefore, some other method besides a cathode-resistor must be employed to obtain the bias voltages required by these tubes.

There are two accepted methods of obtaining the required negative grid bias voltage required for each tube. One method being, as we have previously explained, to insert a resistor in the cathode circuit of the tube and thereby automatically obtain a voltage-drop across the resistor. The other method is to place a negative potential directly on the grid of the tube.

There are two ways of obtaining the latter -- either by batteries or by inserting a dropping-resistor in series with the negative or common ground-return side of the receiver circuit. Each system has its advantages and disadvantages which will be discussed from time to time throughout your lessons.

Since there are no batteries employed in the receiver diagrammed in Fig. 17, it is obvious that the grid bias voltage in this receiver must be obtained from fixed dropping-resistors placed in the negative or common ground-return side of the line. By closely inspecting the circuit, you will observe how this is done.

By tracing through the return-side of the 117-volt supply line, you will notice that when the "on-off" switch is closed, the current will flow through resistors R_9 and R_{10} in order to complete the ground side of the circuit. This current-flow will produce a voltage-drop across these resistors, which can be used for biasing the 6Q7 and 25L6 tubes.

The bias voltage for the 6Q7 tube is furnished by the voltage-drop appearing across resistor R_b , whereas the bias voltage for the 25L6 tube is furnished by the voltage-drop appearing across the combined resistors R_9 and R_{10} . Thus, a greater bias voltage will be applied to the grid of the 25L6 tube than to the grid of the 6Q7 tube.

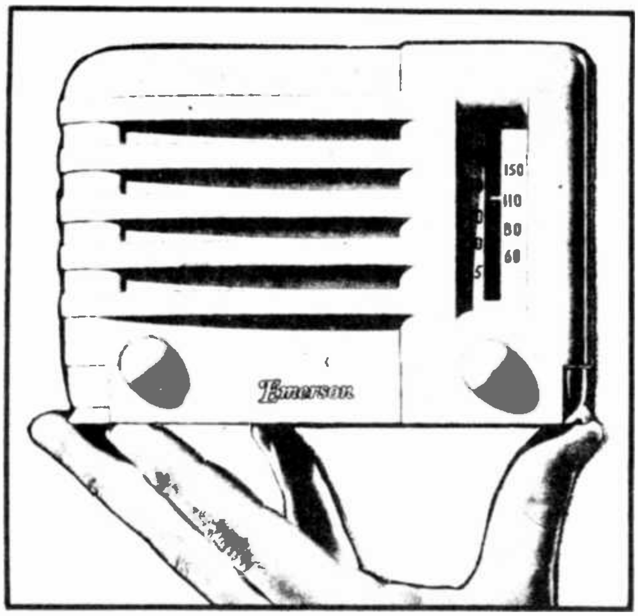

FIG. 18
TWO-TUBE T-R-F "PEE-WEE" AC-DC RECEIVER

TWO-TUBE AC-DC MIDGET RECEIVER

In Fig. 18 you are shown a compact two-tube, t-r-f midget type ac-dc receiver which is contained in an attractive moulded cabinet made of insulative material. Upon comparing the size of this receiver with the hand holding it, you will appreciate its very small size.

The circuit diagram for this "pee-wee" receiver is shown diagrammatically in Fig. 19, where you will observe that two dual-purpose tubes are used for the same purpose as four individual tubes. One of these dual-purpose tubes is a duplex triode pentode, employed as a combination r-f amplifier and detector; the other tube consists of an a-f beam output section combined with a rectifier section. The dotted lines in our diagram point out the dual sections in the two tube-envelopes.

The operating principle of this two-tube receiver is identical to the four-tube receiver shown in Fig. 9, where separate tubes are used for the individual circuit sections. The performance of the receiver diagrammed in Fig. 19 is equivalent in every respect to that of the four-tube receiver previously described. However, the chief aim of many manufacturers of ac-dc midget type receivers is to build the most efficient receiver with the least number of tubes and parts, in order to reduce the cost and size of the completed set.

THE R-F, DETECTOR AND A-F CIRCUITS: In our analysis of these operations, we will start with the r-f signal as it appears in the secondary winding of the antenna coil. At this point the r-f signal voltages excite the input control grid of the 25B8 tube's pentode section. This r-f signal will then be amplified in the plate circuit of this tube-section, the amplified signal variations flowing through the primary winding of the r-f coil.

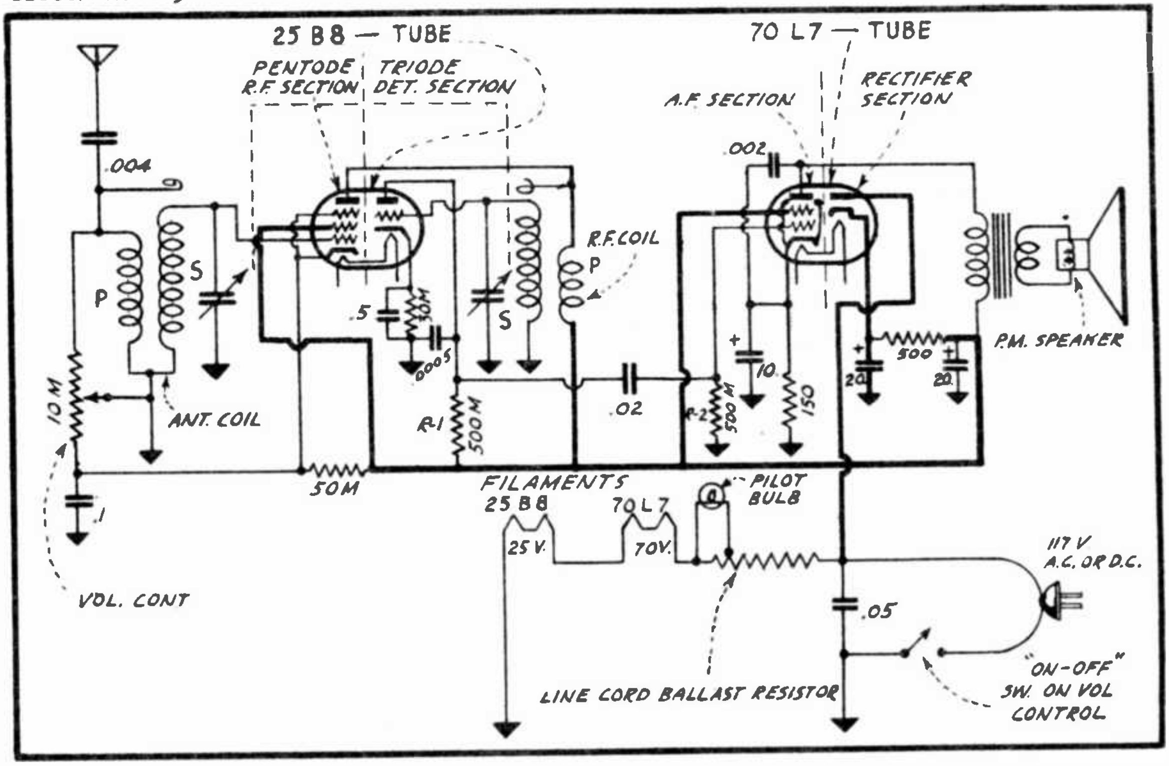

FIG. 19
CIRCUIT DIAGRAM OF TWO-TUBE T-R-F, AC-DC MIDGET RECEIVER

The pulsating magnetic field established by the flow of these amplified r-f current variations through the primary winding will cause voltage-changes of corresponding frequency to be induced in the secondary winding of this r-f transformer. The r-f signal appearing in this tuned secondary circuit is now applied to the control grid of this same tube's triode section, the circuit of which is arranged to function as a detector. Detection or rectification of the r-f signal will now take place in this tube section.

The resulting rectified signal will produce corresponding audio variations in the plate circuit of the triode detector section, which will flow through the plate circuit resistor R-1. The voltage variations produced across the extremities of R-1 by these a-f current variations will react through the .02 mf condenser and then be applied to the grid of the 70L7 tube's a-f beam section. These audio variations will then be further amplified and will appear in the plate circuit of this tube section, where they are used to energize the windings of the output transformer, across which the p-m type speaker is connected.

It is to be noted that resistors R-1 and R-2 are the detector plate and audio grid resistors which, together with the .02 mf condenser, complete the resistance-capacity coupled audio-amplifier stage. The .0005 mf condenser is the conventional detector-plate r-f bypass condenser. By comparing this circuit with the conventional circuit shown in Fig. 9, you will recognize readily their exact electrical similarity.

<u>OPERATION OF THE RECTIFIER SECTION</u>: Upon inspecting the 70L7 tube further, you will observe that the rectifier elements are enclosed within the same envelope as the a-f beam section. This rectifier section consists of a filament, cathode, and plate elements, and operates

as follows: The a-c line potential is imposed upon the plate of this tube-section. During positive alternations of the cycle, current will flow between the cathode and plate, resulting in a pulsating half-wave d-c current which is filtered by the 500-ohm resistor and the two 20-mf filter condensers. The output of this filter system furnishes the B-supply to the various circuits in the usual manner.

The reasons for using a resistor in place of a conventional filter choke are that the resistor is cheaper and requires less space for mounting. Also, since receivers of this type generally employ a p-m dynamic speaker instead of a field-coil type dynamic speaker, no field coil is available to serve as a filter choke. It is, of course, true that a resistor does not provide as efficient filtering as does a choke, but the use of high-capacity condensers therewith provides performance that is sufficiently satisfactory to be practical.

Should this receiver be plugged into a d-c line, then the plate of the 70L7 tube's rectifier-section will be subjected continually to a positive potential. The tube will then function as a resistance element of low value, as already explained relative to the 25Z5 tube when operating under similar conditions.

Upon further inspection of the circuit diagram appearing in Fig. 19, you will observe that a line-cord ballast resistor is used to reduce the line potential to 95 volts, which is the combination filament voltage required by the two series-connected tubes.

You will notice also, that one of these tubes requires 70 volts for its filament, while the other requires 25 volts.

AC-DC SUPERHETERODYNE USING DUPLEX TUBES

The midget-type receiver, just described, was of the t-r-f type. Now let us see how a midget-type superheterodyne circuit is adapted to either a-c or d-c line-voltage applications.

In Fig. 20 is shown a typical circuit for such a receiver. Upon close inspection of the diagram, you will observe that several very interesting and modern features have been incorporated.

Although only three tubes are used, this receiver is equivalent actually to a six-tube set. The set-up of this receiver follows: A converter tube is followed by a dual-purpose i-f and detector tube, while the output-tube consists of an a-f section combined in the same envelope with the rectifier. Thus, we have in three tubes a "full-fledged" modern superheterodyne receiver, with the exception of a-v-c; and even this feature, in some instances, is incorporated in receivers of this type. However, since the majority of such receivers do not use a-v-c, we have omitted it from our sample circuit.

The operating principle of this three-tube superheterodyne is identical to that of the six-tube receiver circuit shown in Fig. 14 of this lesson, in which individual tubes are used for the various circuit functions. In performance, this three-tube receiver is equivalent in every respect to the six-tube set. However, as is the usual practice in many ac-dc midget-type receivers, a minimum number of tubes is employed in order to reduce the cost and size of the set.

CIRCUIT FEATURES: Commencing with the converter tube in Fig. 20, you will observe that it is of conventional design and therefore functions as described in previous lessons. The second tube in this circuit is a dual-purpose type 25B8 tube, consisting of two separate tube-sections within the same envelope; these two sections comprise the i-f and second detector stages of the receiver.

You will further notice that the first i-f transformer is of the shielded type, while the second i-f transformer is of the unshielded type. Both, however, employ dual-tuned circuits. The operation of this dual-purpose tube is as follows:

The i-f signal-voltage appearing in the secondary winding of the first i-f transformer excites the control grid of the 25B8 tube's pentode-section. The i-f signal will then be amplified as it is transferred to the plate circuit of this tube-section. Amplified versions of the i-f signal thus appear in the primary winding of the second i-f transformer, and are in turn transferred by induction into the secondary winding of the second i-f transformer. These i-f signal-voltage changes are then used to excite the grid of the 25B8 tube's detector-section, so that rectification or detection will then take place in the usual manner.

The resulting pulsating rectified current (a-f) will produce corresponding audio variations in the plate circuit of the triode-section of the 25B8 tube, which will produce corresponding voltage-drop variations across the 500,000-ohm plate circuit resistor, causing the signal to react through the .02 mf coupling condenser of the resistance-capacity audio stage and thereby excite the grid of the 70L7 tube's beam a-f section.

The signal is then amplified further and transferred to the p-m speaker in the same manner as already explained relative to the 70L7

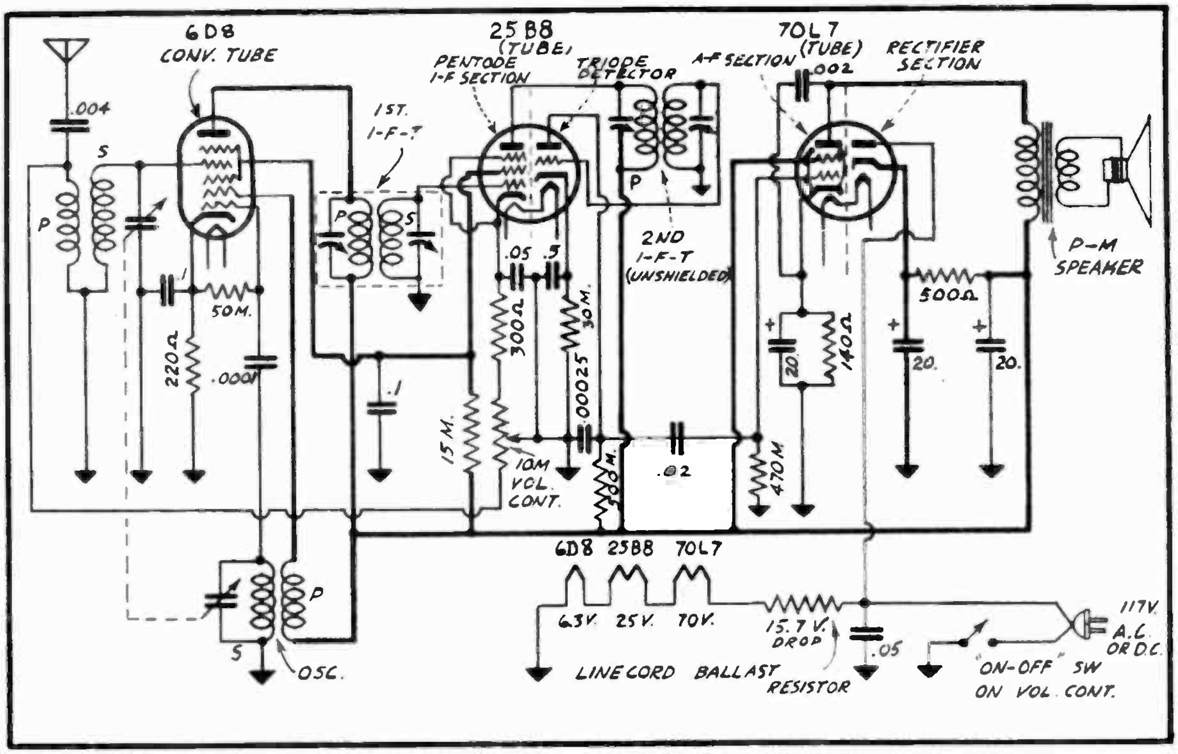

FIG. 20

CIRCUIT DIAGRAM OF THREE-TUBE, AC-DC SUPERHETERODYNE RECEIVER tube used in the circuit diagrammed in Fig. 19. The rectifier-section of this tube also functions in the same manner as already explained.

The combined filament voltages required for the three series-connected tubes amounts to 6.3 + 25 + 70 volts, or 101.3 volts. Therefore, since the line-supply is considered as being 117 volts, this value must be reduced to 101.3 volts. To accomplish this, a ballast resistor is inserted in series with the line-supply to produce a voltage drop of 15.7 volts.

In this lesson we have covered the outstanding features which are to be found in d-c and ac-dc receivers. This should serve to give you a good general knowledge of the workings of such sets so that you will be better able to solve their service problems.

EXAMINATION QUESTIONS

LESSON NO. 25

1. - Why is a filter choke (or speaker field coil) sometimes not used in the main B+ lead of ac-dc receivers, and what means is employed to compensate for the omission of the choke or field coil at this point?

2. - Describe briefly how the 25Z5 tube functions in a conventional ac-dc receiver which is connected to an a-c circuit.

3. - In a certain ac-dc receiver the filaments of five tubes are connected in series with each other and also with a ballast resistor and the line. The filament voltage requirements of these tubes are 6.3, 6.3, 6.3, 25 and 25 volts, respectively, while the total current drawn is 0.3 ampere. What value of ballast resistor should be used, assuming the line voltage to be 117 volts?

4. - Why is it not advisable to cut a line cord containing a ballast resistor?

5. - What is a static shield, as applied to a receiver antenna, and why is it used?

6. - Briefly describe the construction and operation of a thermostatic pilot-lamp ballast resistor.

7. - How does the circuit of a 110-volt d-c receiver differ from the circuit of a conventional a-c receiver?

8. - Explain briefly how a single tube can function simultaneously as an i-f amplifier and second detector.

9. - Why is it important not to reverse the line-plug connection when connecting an ac-dc receiver to a d-c circuit?

10. - Explain briefly how it is possible for one tube to function simultaneously as a rectifier and a-f amplifier.

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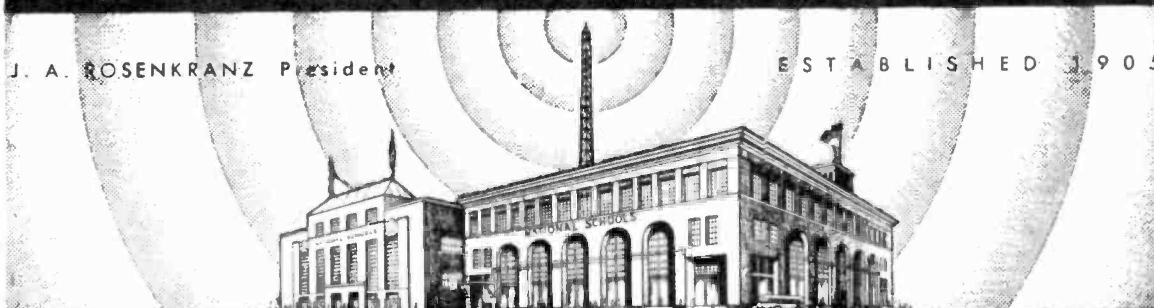

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LESSON NO. 26

AUTOMOBILE RECEIVER EQUIPMENT

Aside from the mechanical construction, control mechanism and power supply, there is little difference between "home radios" and automobile receivers. Therefore, our discussions on automobile receivers will center primarily on the points of difference with which you must be acquainted

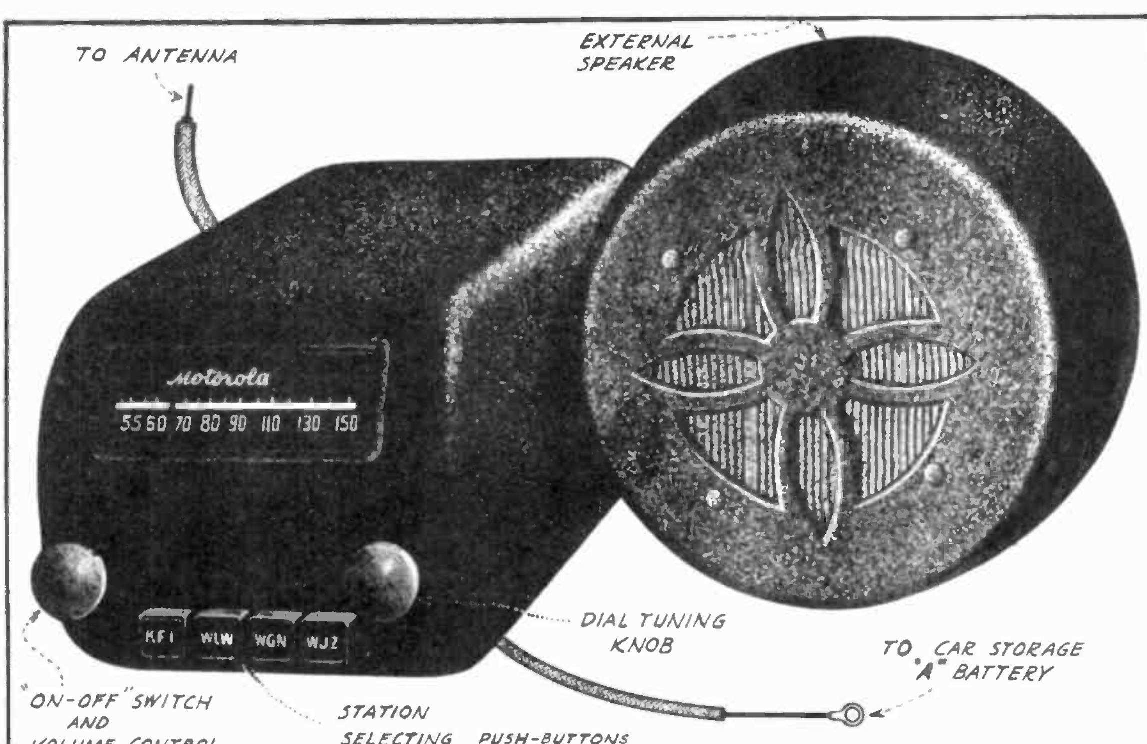

FIG. 1
COMPLETE AUTOMOBILE RECEIVER ASSEMBLY

in order to install and service such receivers intelligently. However, we will also point out to you certain special features which are incorporated within their circuits to best adapt them for this particular service.

AUTOMOBILE RECEIVER INSTALLATION

We will begin our discussion of automobile receivers by considering a typical installation, and the basic features of construction as found in the earlier models. We will then progress in logical steps with the study of the more modern assemblies and their related accessory equipment. Such a procedure will give you a broader knowledge of these receivers, in that you will thus have the opportunity to become acquainted with the field in general, and better informed on the progress made in this particular branch of radio during the past few years.

Fig. 2 gives you a good idea of how a typical early model automobile receiver was installed -- this arrangement of the various component parts was used in a great many cases.

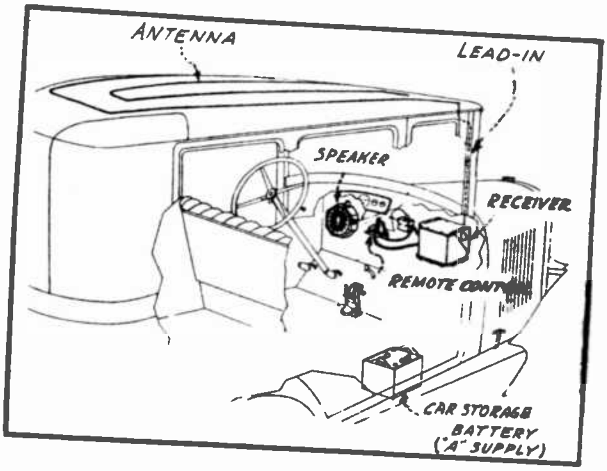

FIG. 2
TYPICAL AUTO RADIO INSTALLATION

Notice that in this illustration the receiver is mounted under the cowl. The speaker is also mounted under the cowl, at a level sufficiently low for the emitted sound to be transmitted to the seating quarters. The remote control assembly, consisting of the tuning control,volume control and switch is mounted on the instrument panel of the car so as to be within easy reach of the driver.

The receiver derives its operating power from the car's storage battery. The antenna in this particular case is in the form of a tin-foil ribbon,placed in the fabric top of the car and connected to the antenna terminal of the receiver. The metallic mass of the car, consisting of the frame, engine, body, etc., serves as the "ground" side of the system.

Later, we will discuss the installation of automobile receivers in a thorough manner, but with this general picture of the installation in mind you are ready to investigate in detail each of the various units of the assembly.

CONSTRUCTIONAL FEATURES OF AUTOMOBILE RECEIVERS

Since the automobile receiver is more or less portable, it must be constructed as light and compact as possible. However, strength should not be sacrificed to obtain these qualities, for we must not overlook the fact that the automobile receiver is subject to vibration and road shocks during the course of driving.

Special midget-size condensers,resistors,as well as other parts, are manufactured to facilitate constructing automobile receivers in a compact manner. These parts, although being of the same electrical value and of the same high quality as corresponding parts of conventional size, are constructed to occupy but very little space, and will withstand vibration remarkably well.

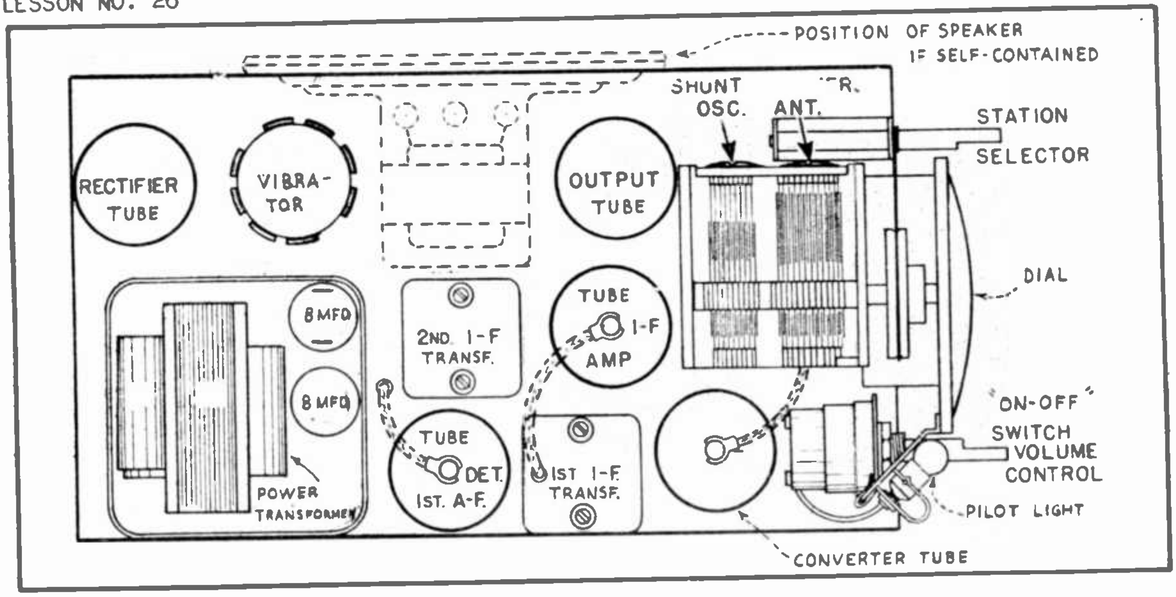

FIG. 3
TOP VIEW OF AUTO RECEIVER CHASSIS

In Fig. 3 is shown the arrangement of the major parts on the chassis of a typical automobile receiver. You will note that the entire assembly is complete, yet its overall dimensions are reasonably proportioned, so that the unit can be mounted underneath the dash of the car.

The receiver chassis here shown is housed in a box-like metallic container, similar to the one appearing in Fig. 1. While the receiver in Fig. 1 employs a separate speaker unit, it is now the more common practice to include the speaker within the same metal cabinet that houses the receiver chassis. This form of construction is shown in Fig. 4, where you will observe that the speaker grill is inclined downward -- in many cases the speaker grill is placed at the side of the cabinet.

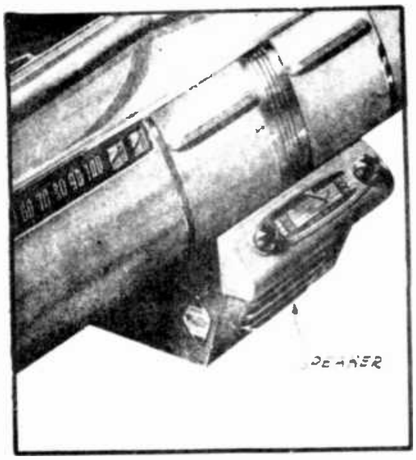

FIG. 4
DASHBOARD RECEIVER MOUNTING

In Fig. 4 the complete receiver assembly is mounted below the instrument panel of the car, and requires only a single bolt for mounting. This feature of compactness enables one to install, remove, or inspect the set with comparative ease.

When a separate speaker is used, it can be mounted on the bulkhead underneath the instrument panel or overhead as shown in Fig. 5. So much for receiver mountings -- now, let us see how remote-control systems are employed.

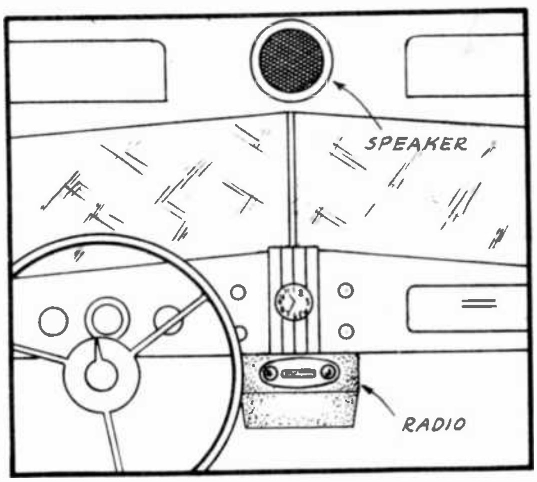

FIG. 5
OVERHEAD SPEAKER MOUNTING

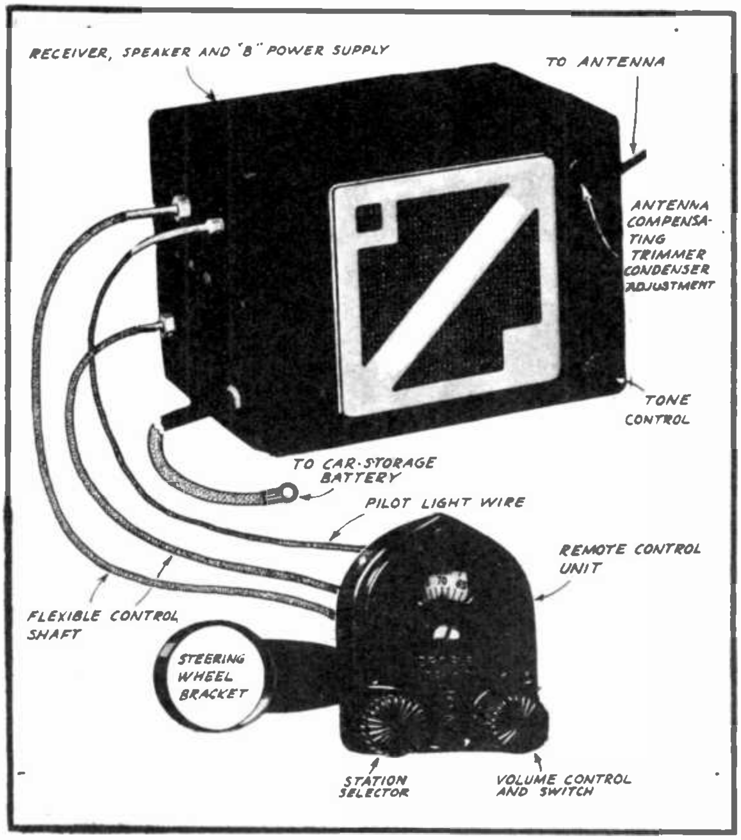

FIG. 6
AUTO RECEIVER WITH REMOTE CONTROL

STEERING-WHEEL REMOTE CONTROLS

The operating controls for the receivers thus far described are of the direct-operated type; that is, they are mounted directly in the receiver cabinet. However, in a great many instances, these controls are placed several feet from the receiver and must then operate the receiver through a special drive system. This permits placing the operating controls in a more convenient position for the operator.

In Fig. 6 you are shown a remote-control assembly that permits the driver to operate the receiver directly from the steering-wheel. This type of remote control is commonly referred to as a UNIVERSAL TYPE CONTROL, because it is adaptable to all types of cars.

CUSTOM-BUILT REMOTE CONTROLS

A more recent trend of automobile manufacturers is to build into the instrument panel of their cars a special compartment to accommodate the remote-control tuning assembly.

Since nearly all automobile manufacturers have adopted this practice, it is only natural that a variety of remote control panel designs and sizes would have to be available for the many different cars. In Fig. 7 you are shown several typical custom-built control panel assemblies that are designed to harmonize with the instrument panels of the cars for which they are intended. They are styled to become a part of the instrument panel.

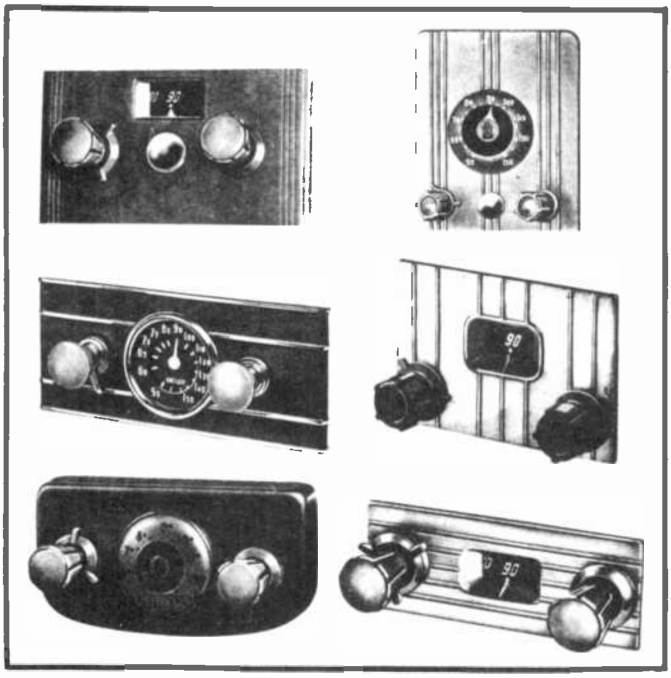

FIG. 7
TYPICAL CUSTOM-STYLED REMOTE CONTROL PANEL ASSEMBLIES

DETAILS OF THE REMOTE CONTROL SYSTEM

The steering wheel type and custom-built remote-control units are provided with both tuning mechanism and volume control knobs.

A flexible cable (shaft) completes the connection between the control unit and the receiver parts to be controlled, as shown in Fig. 8. The success of remote-control assemblies has been due chiefly to the perfection of the flexible cable.

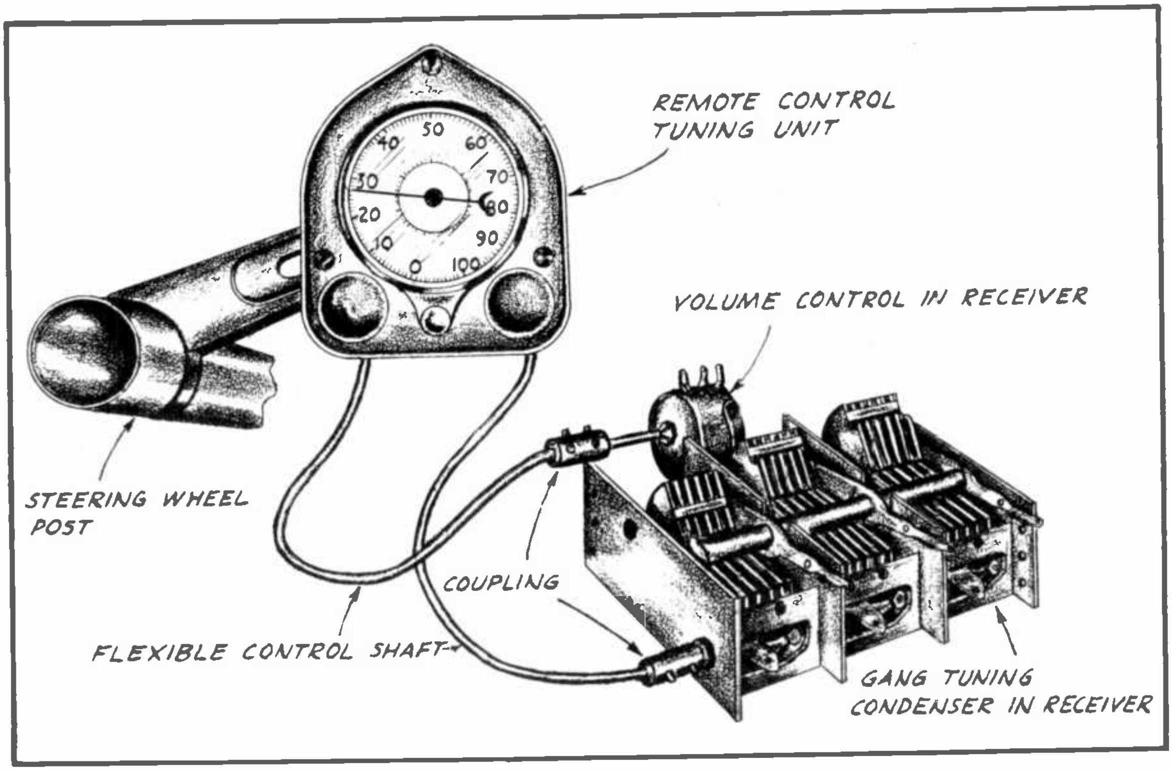

FIG. 8
BASIC PRINCIPLE OF REMOTE CONTROL TUNING

In Fig. 9 you are shown a sectional-view of a typical flexible cable, fastened to the unit which it drives or by which it is driven. You will observe that the cable assembly consists of a flexible metal control cable, housed in a flexible metallic casing -- the arrangement is the same as the speedometer cable used on automobiles.

In the particular example illustrated in Fig. 9, a set-screw is used to anchor the flexible casing to the stationary body of the control unit or receiver. The end of the flexible control cable is locked to the shaft from which or to which the rotating motion is to be transmitted. Hence, the flexible casing remains stationary while the flexible control cable is free to rotate.

Set-screws are not always the means for fastening the control

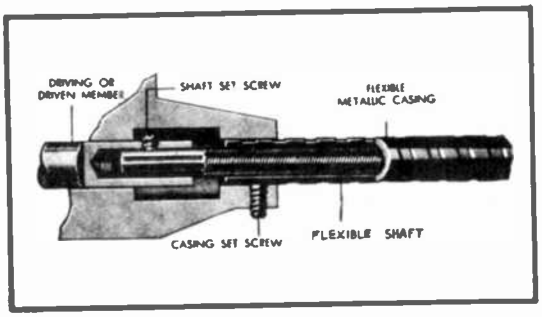

FIG. 9
METHOD OF ATTACHING REMOTE CONTROL SHAFT AND CASING, USING A SET-SCREW

cable in place -- sometimes, special coupling nuts are used. Various typical flexible cable designs are shown in Fig. 10, together with several coupling devices.

The cable shown at the extreme left in Fig. 10 is equipped with a threaded and knurled coupling nut (collar) that slides over the flexible casing, and screws into a fitting on the receiver cabinet or control housing. The shoulder at the end of the casing prevents it from being pulled out of the coupling device.

The second cable toward the right is designed for use of a set-screw locking device and therefore has no coupling nut. Here you are also shown how the drive gear is fastened to the end of the cable.

The cable appearing at the center of the group shown in Fig. 10 features an internally-threaded coupling nut that butts the shoulder of the cable's casing to the receiver cabinet or control casing.

The remaining two cables are each designed for set-screw locking, while the unit farthest to the right also has an enlarged end that fits into a recess in the coupling fitting that is attached to the receiver cabinet. In the latter case, the set-screw will bear against the casing at the point where its diameter is reduced, thus the enlarged section prevents the cable from being pulled out of its fitting.

In Fig. 11 you are shown the mechanism used in a typical remote control unit. In this particular example, you are looking down upon the unit from above -- (the stub shafts for the knobs point toward the driver's seat). The dial scale is of the horizontal drum-type and rotates past a small window that faces the driver, but which is not in

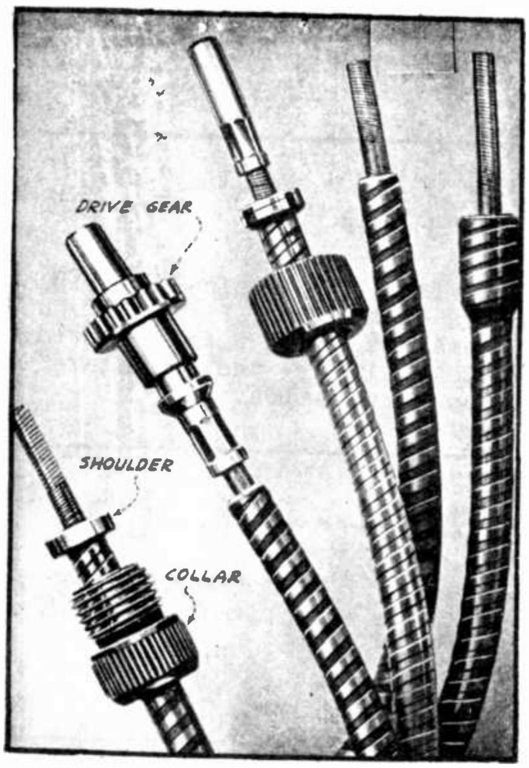

FIG. 10
FLEXIBLE CONTROL SHAFTS

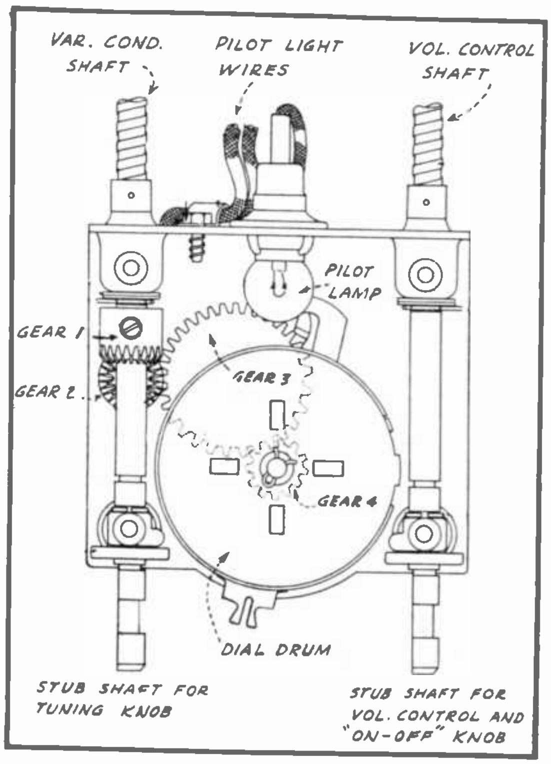

FIG. 11
REMOTE-TUNING CONTROL ASSEMBLY

N

the range of vision in Fig. 11. The dial in the remote-control panel, shown at the lower right of Fig. 7, is of this type.

Returning to Fig. 11 again, you will note that any rotation of the volume control knob will be transmitted through a flexible cable to the combination volume control and "on-off" switch that is located in the receiver proper. (See Fig. 8 also.)

Rotating the tuning knob will cause the flexible cable to rotate the rotor section of the tuning condenser, and at the same time will cause gear #1 in Fig. 11 to rotate. This gear drives gear #2 which in turn causes gear #3 to rotate. Gear #3 then rotates gear #4 which is locked to the dial drum, causing it to rotate. The purpose of this train of gears is to furnish a speed-reduction between the tuning knob and dial scale.

When no reduction gears are contained in the remote control unit for decreasing the speed at which the tuning condenser is driven, the reduction gears are mounted at the tuning condenser. Therefore, to apply the control unit shown in Fig. 11, reduction gears are required at the condenser.

Notice, also, in Fig. 11 how the pilot lamp is mounted in the remote-control unit.

Another remote-control assembly is shown in Fig. 12. In this case,a control knob drives the volume control through a flexible cable, the same as in our previous example. The tuning knob in Fig. 12 controls a set of gears contained in a special housing and thus provides a speed reduction at this point for both the dial and the tuning condenser. Notice how a separate flexible cable of short length transmits motion from this gear housing to the needle of an airplane type dial. A large flexible cable (not shown) transmits motion at reduced speed from this gear housing to the tuning condenser.

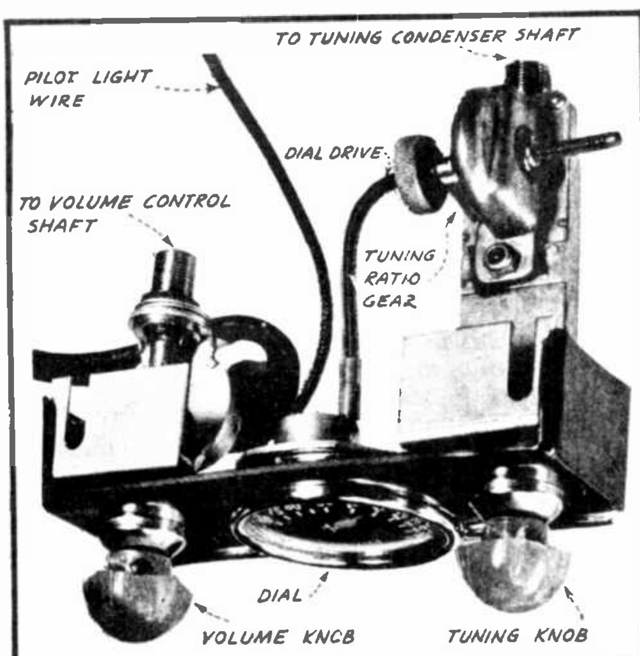

FIG. 12
CUSTOM-BUILT REMOTE CONTROL MECHANISM

AUTOMOBILE ANTENNAS

Two of the most important properties required of the auto antenna are for it to possess good signal pick-up and not be directional in its response to signal energy. (A directional-type antenna has a tendency to pick up signals coming from a certain direction, without being affected very favorably by those coming from other directions.) Other important qualities of an automobile antenna are that it must be simple to install and must not detract from the appearance of the car. Several different antennas are being manufactured commercially which, to some extent, meet the requirements presented at the beginning of this paragraph. We will now describe them to you, commencing with the earlier types.

THE SCREEN-TYPE ANTENNA

In Fig. 13 is shown a very effective type of auto antenna that was used extensively with the earlier model receivers. You will observe that a copper screen is used to pick up the signal energy. Such an arrangement is suitable only for cars equipped with a fabric top. It is not applicable to all-metal tops.

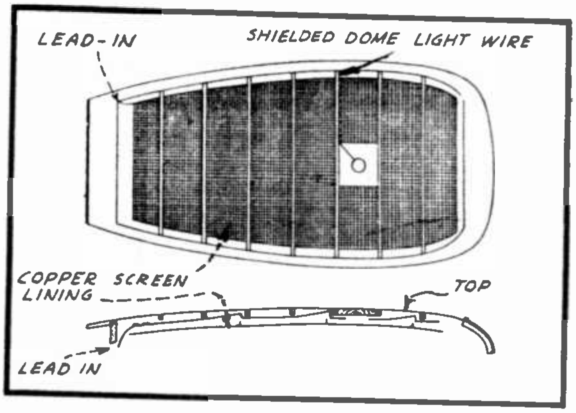

FIG. 13
COPPER-SCREEN ANTENNA INSTALLATION

The installation in Fig. 13 was made by first removing the cloth covering from the ceiling of the car. The copper screen was then fastened into position securely, and was separated from the dome-light and metal body of the car by at least three inches. The upper illustration of Fig. 13 shows how a square hole was cut into the copper mesh in order to clear the dome-light. In this illustration, the antenna installation is shown as viewed from above, whereas the lower illustration shows a side-view of the same installation.

The antenna lead-in was soldered to the right front corner of the copper screen, and was run thru a non-metallic insulative housing down the right front corner-post of the car body. The cloth covering was then replaced on the ceiling of the car to complete the antenna installation.

THE AXLE-TYPE ANTENNA

In Fig.14 you are shown two special forms of axle-type antennas. The earlier model shown at (A) consists of a water-proof fabric envelope in which a copper screen is contained. An eyelet is provided at each end. A coil spring is fastened to one eyelet and a web-strap to the other. This arrangement permits the antenna to be suspended between the front and rear axles. A 10-foot rubber-covered lead-in wire is usually furnished with the antenna.

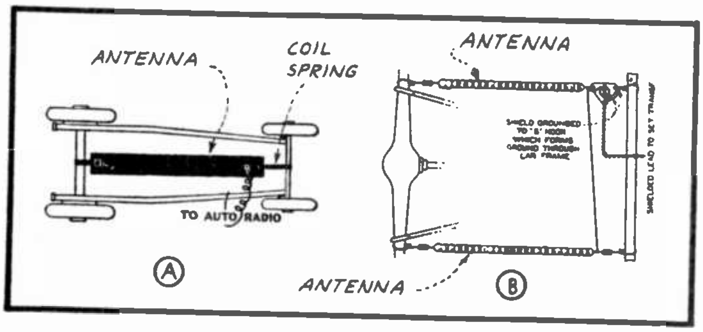

FIG. 14
AXLE-TYPE ANTENNAS

The model shown at (B) of Fig. 14 is an improvement over the one shown at (A). Here two lengths of wire are wound in the form of a coil and are enclosed in a water-proof fabric envelope. They are connected between the rear axle and the center cross-member of the car's frame, as shown in the illustration.

RUNNING-BOARD ANTENNAS

When the car antenna is placed quite near to a metal top, the "grounding effect" of the metallic mass reduces the sensitivity of the antenna system. The increasing popularity of turret-top cars has stimulated the demand for efficient under-car aerials. To meet this demand, the low-capacity, ruggedly built bar or strap type has been used extensively. Ease of installation on existing bolts under the running board is largely responsible for the popularity of these types.

An early model, as well as an improved version of this type of antenna, is shown in Fig. 15. The earlier model shown at (A) offered a rather large area of metallic surface for signal pick-up, and was suspended slightly below the car's running board and parallel to it. A splash guard was usually hung at the front end to help prevent excessive accumulation of refuse that is thrown upward by the wheel.

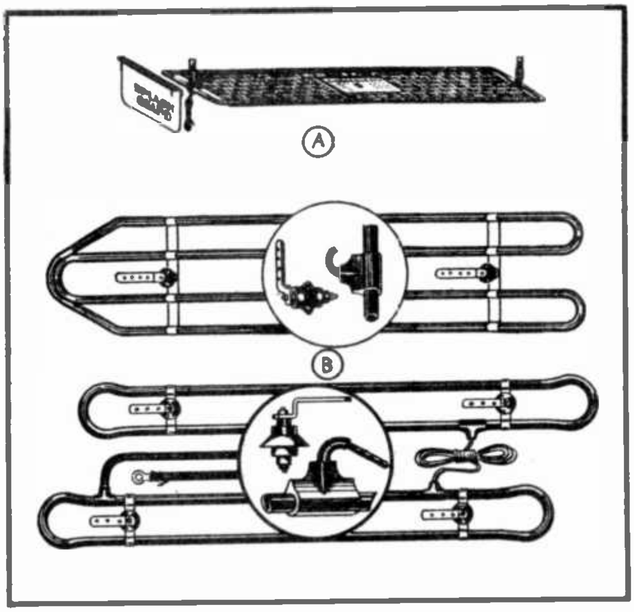

FIG. 15
RUNNING-BOARD ANTENNAS

Later models of running board type antennas are shown at (B) of Fig. 15. Here the aerial wire is completely sealed in rubber, thus eliminating losses caused by moisture, snow or ice. The lead-in is a low-loss, water-proof, shielded, loom-covered wire.

ROOF AND VERTICAL-TYPE ANTENNAS

In Fig. 16 is shown a type of auto antenna used in a great many installations -- particularly on cars with steel turret-tops. This antenna is quite effective; it is streamlined in appearance. The usual construction is of a chrome-plated, non-ferrous metal, mounted on bakelite and chrome fittings.

Another type of extensively used antenna is known by such trade names as the "Vertical," "Telescope," "Fish Rod," "Fish pole," and "Hinge" type antenna. The only difference between these various classifications lies in the particular position in which the antenna is mounted on the car.

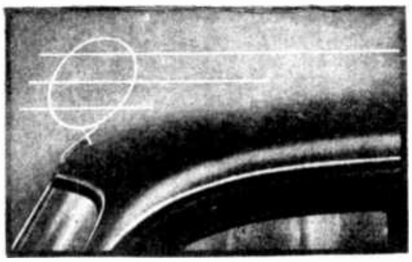
FIG. 16
ROOF ANTENNA

The telescope or fish-pole antenna, shown in Fig. 17, is made of seamless, rust-proof metal and is assembled in telescope form. It is usually constructed in either three or four sections, and is approximately 24 inches long when collapsed. With two sections extended it is 43 inches long; with three sections extended it is 62 inches long. Being built in several sections, it may be adjusted to meet the exact requirements of the receiver and the location, thereby assuring maximum reception under all conditions. When traveling in cities, where several broadcasting stations are centralized, satisfactory pick-up will be obtained with the aerial in the collapsed position.

Several manufacturers have developed ingenious methods for automatically lowering or raising the telescopic sections of such antennas.

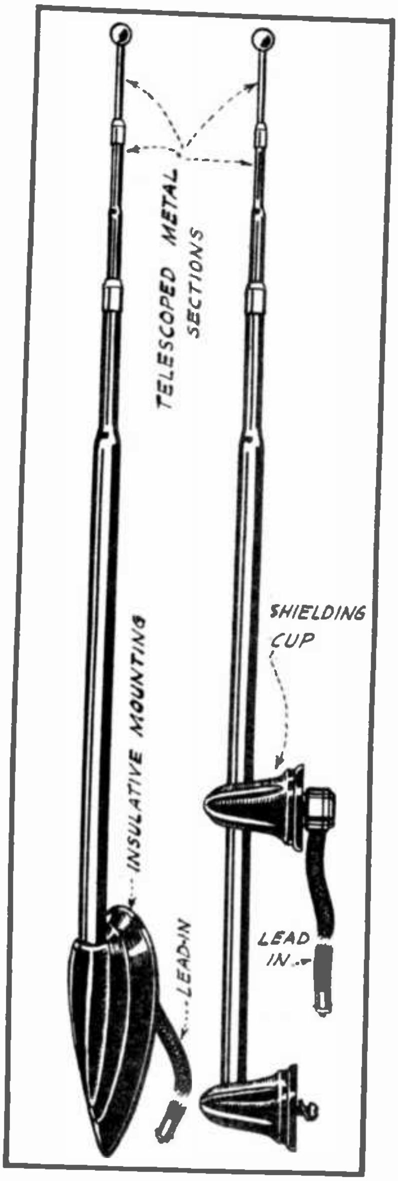

FIG. 17
TELESCOPE OR "FISH POLE" VERTICAL ANTENNAS

In one particular case, the intake manifold of the engine is connected to the antenna by a tubing of small bore. A suitable control valve is mounted in the driver's compartment, the operation of which will cause the engine-vacuum to either lower or raise the different telescope sections. The principle is similar to that employed in vacuum-type windshield wipers.

The lead-in supplied with these antennas is usually 30 inches long, and is made of material which not only prevents loss of signal, but because of its adequate shielding, also prevents noise pick-up. A plug is usually attached to the end of the lead-in, and fits into the standard aerial socket of the radio. The connection between the lead-in and the antenna proper is housed in a shielding cup or box so that there will be no pick-up of noise at this point. By referring to the constructional details shown in Fig. 18, you will observe the method employed in mounting the telescoping rod.

"B" POWER SUPPLIES

Our next step is to survey the construction and operation of the various types of automotive B-power supplies. These may be classified in the following two main groups:

(1) Motor-generator or dynamotor types.
(2) Vibrator types.

A motor-generator and a dynamotor both accomplish the same purpose, although they differ in construction. A motor-generator consists of two independent units --- a motor and a generator. The motor is operated by electrical power furnished by the car's battery. The armature shafts of the motor and generator are coupled mechanically so that the motor's rotation drives the generator which in turn furnishes d-c of a much higher voltage than that supplied by the battery.

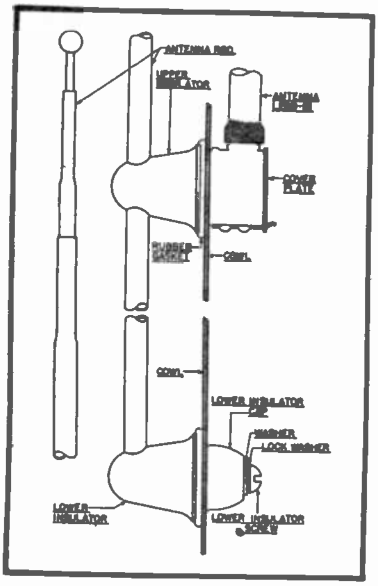

FIG. 18
DETAILS OF TELESCOPE COWL ANTENNA

In the case of the dynamotor, the motor and generator features are incorporated in a single unit. This is accomplished by providing a single armature with two sets of windings. One of these windings is connected to the battery circuit, the current of which causes the armature to rotate the same as in a conventional motor. The rotation of the armature causes the other armature winding to generate a high d-c voltage, the same as does the armature winding of an ordinary generator. The generator winding is connected to the output circuit through a separate set of brushes than those used for the motor section.

B-power supplies, using vibrators, may be further sub-divided into non-synchronous and synchronous types.

The first B-power supply units to be described will be of the motor-generator or dynamotor type. Such units are used most extensively, and almost exclusively, by Police and other law-enforcing agencies where auto receivers must perform at utmost efficiency and provide reliable service over a long period of time.

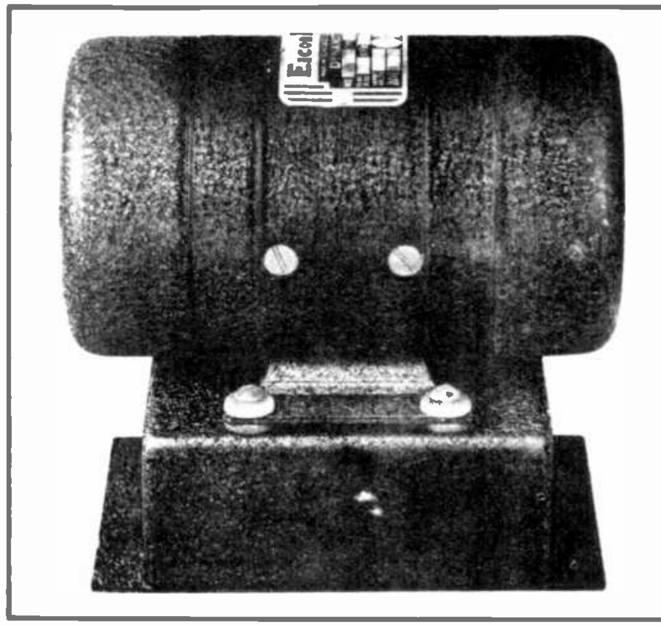

FIG. 19
TYPICAL DYNAMOTOR-TYPE B-POWER UNIT

DYNAMOTOR B-POWER SUPPLIES

In Fig. 19 you are shown a dynamotor of compact design. It is designed to be connected across the battery circuit of the car and is driven thereby as a motor. An additional winding is included in this unit so that while operating as a motor, it will at the same time generate high d-c voltage that is suitable for "B" use. A filter circuit is housed within the base of the unit, serving to reduce ripples in the generated d-c output before delivering it to the receiver. A terminal strip (not shown) is provided on the side of the base to which the circuit connections can be made.

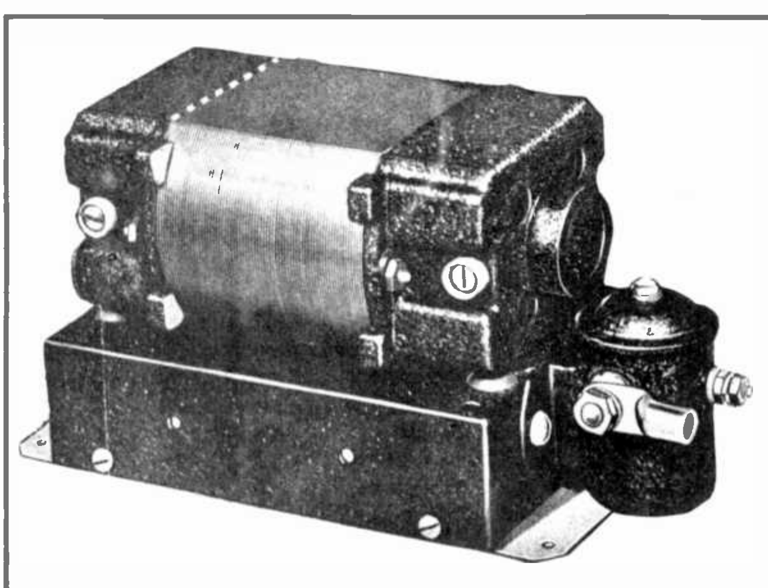

FIG. 20
HEAVY-DUTY DYNAMOTOR B-POWER SUPPLY

This unit can be mounted at any convenient point on the car, such as under the front or back seat, under the instrument board, etc. Special rubber mountings prevent vibration and the production of locally-generated interference noises -- the unit is thus operated practically noiselessly.

The particular dynamotor shown in Fig. 19 draws approximately 2.2 amperes of storage battery current and delivers an output of 180 volts d-c at 40 ma, while the larger unit shown in Fig. 20

draws 33 amperes of storage battery current and provides an output of 500 volts d-c at 200 ma. The latter unit is particularly suitable for heavy-duty, two-way, police communication work.

THE MOTOR GENERATOR CIRCUIT

Having familiarized yourself with the general structural features of typical motor-generator and dynamotor B-supply devices, we shall now proceed with the study of the circuit employed therein.

In Fig. 21 is shown the circuit diagram of one type of dynamotor. In this particular example, you are shown how the motor brushes are connected to the car's storage battery circuit through the A+ and A- leads. The 1 mf condenser which is connected across these leads, as well as across the motor brushes, is incorporated within the unit and is used to bypass any interference noises that might have their origin at the brushes.

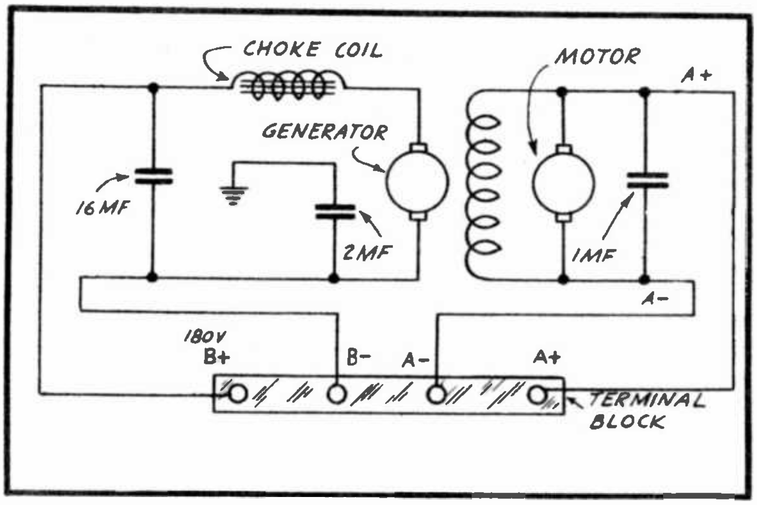

FIG. 21
TYPICAL DYNAMOTOR CIRCUIT

The generator brushes, on the other hand, lead to the output terminals which are marked on this diagram as B+ 180 volts and B-. Also observe the filter circuit, which is included in the generator circuit to minimize any ripple in the "B" output due to the action of the generator's commutator segments.

Because of the current demands of the motor section of such a unit, it is important that the A+ and A- leads be made of a wire size not smaller than #12 B&S. All wires to the unit should be shielded, and the shielding should be grounded to the car frame at intervals not exceeding six inches.

When mounting motor-generator or dynamotor type B-power units, the manufacturer's instructions should be followed exactly, because some of these units are not adapted for mounting in such positions that will place their rotor shaft on a vertical plane.

Besides the example shown you, there are various other types of motor-generator and dynamotor units on the market. For instance, one particular type operates as a motor off the 6-volt storage battery, and in turn furnishes a 110-volt a-c supply that is suitable for operating a standard 110-volt a-c receiver or public address amplifier. In another case, a 110-volt a-c generator is designed to be driven by the fan belt of the engine, and thus operates 110-volt a-c equipment.

The a-c generator units, just described, are not intended for operating standard automobile receivers as used in pleasure cars, and will therefore not be treated in detail at this time. However, it is well that you be aware of their existence.

VIBRATOR TYPE B-POWER SUPPLIES

The vibrator is literally the heart of every auto receiver that uses this type of B-power supply, and because of its importance in the modern receiver, servicemen should be thoroughly familiar with its operation. It is true that the motor-generator was and still is being used to a certain extent, but the large size and high price of motor generators is responsible for vibrator type B-power units being used most extensively in common receivers that are installed in pleasure cars.

The purpose of the vibrator is to change the continuous or direct-current, as furnished by the 6-volt automobile battery, into a current of varying intensity. Once this has been accomplished, a-c voltage of the desired high potential may be obtained with the aid of a transformer. This done, it can be rectified and filtered so as to furnish a uniform direct current, ready to be used wherever high d-c voltages are required in the radio receiver.

It is of interest to note that only two basic vibrator circuits have been used in automobile receivers since 1933. These are the non-synchronous or interrupter type vibrator, used in conjunction with a vacuum-tube rectifier, and the synchronous or self-rectifying (mechanical) type vibrator. These two types will now be described in the order mentioned.

NON-SYNCHRONOUS VIBRATOR TYPE B-POWER SUPPLY

In Fig. 22 you are shown how the non-synchronous vibrator is connected in series with the car's storage battery and the primary winding of the power transformer. Considering current as electron flow and moving from the battery's negative to positive terminal, the system operates in the following manner:

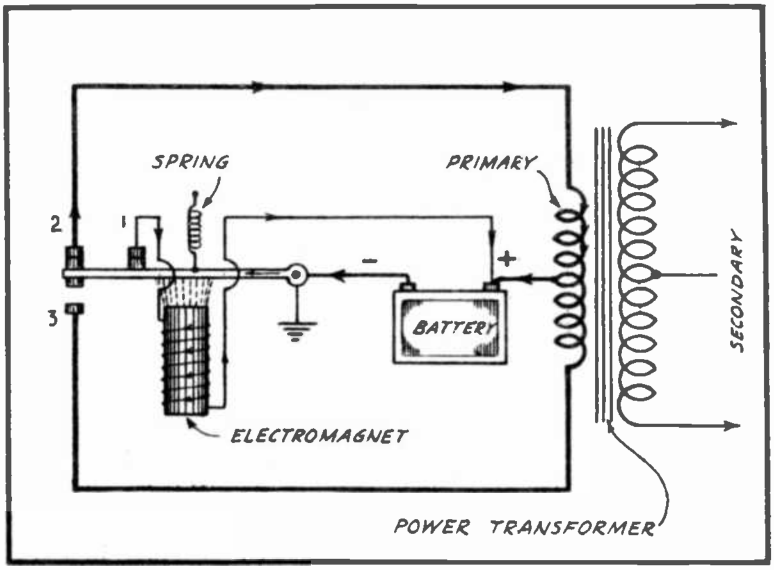

FIG. 22
FIRST POSITION OF ARMATURE

With spring tension holding the armature in the position illustrated, contact sets #1 and #2 will be closed. Battery voltage will therefore cause electrons to flow through the contacts #1 and the electromagnet winding. At the same time, there will be an electron flow through contacts #2 and the upper-half of the transformer's primary winding, as indicated by the arrows.

As the electromagnet core becomes magnetized and attracts the armature downward, contacts #1 and #2 will separate while contacts #3 will close. The electron flow will now be through contacts #3 and from the lower end of the primary winding toward its center tap, as indicated by the arrows in Fig. 23. Absence of current through the electromagnet will permit the spring to pull the armature up again.

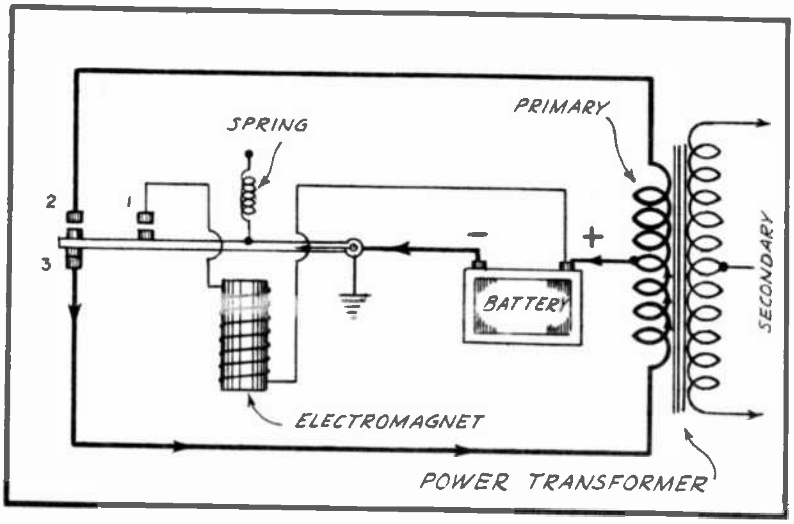

FIG. 23
SECOND POSITION OF ARMATURE

Notice especially in Fig. 23 that the electron flow (current) thru the primary winding is now in the OPPOSITE DIRECTION than formerly. Consequently, as the armature undergoes a vibrating movement, this action is repeated at a rate of about 115 cycles per second, and the current will reverse its direction of flow through the primary winding accordingly. Thus, we have in effect an alternating current flowing through the primary winding. A-c voltages of corresponding frequency will therefore be induced in the secondary winding of the transformer, and by using more turns of secondary winding than primary winding the required step-up in voltage can be obtained.

The next job is to rectify the high voltage a-c appearing in the secondary winding. One method of accomplishing this is to employ a rectifier tube as illustrated in Fig. 24, where you are shown the B-power supply in its complete form.

THE COMPLETE CIRCUIT ACTION

Observe in Fig. 24 how the extremities of the transformer's secondary winding are connected to the plates of a rectifier tube. This tube is a full-wave rectifier of the heater-cathode type, the cathode serving as the electron-emitter and B+ side of the system. The heater element of this tube is of such design that it can be connected directly across the car's storage battery circuit. The cathode is necessary due to the fact that there is but one source of current supply for all filaments in automobile receivers, including the rectifier tube.

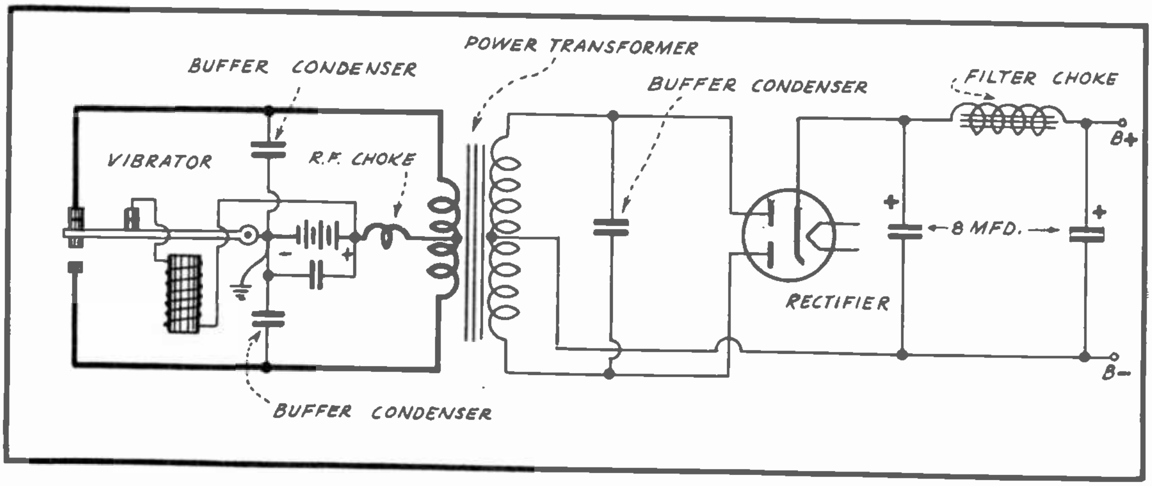

FIG. 24
COMPLETE B-POWER SUPPLY, USING NON-SYNCHRONOUS VIBRATOR

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The center-tap of the high voltage winding serves as the negative side of the "B" circuit, the same as in home radios. A conventional filter circuit is included in the output circuit of the rectifier.

Cathode-type tubes are comparatively slow to warm up to the point where they will draw sufficient plate current to place a normal load upon the secondary winding of the transformer. If no load at all is applied across the power transformer's secondary winding during the warm-up period, the resulting abnormally high secondary voltage might puncture the insulation of this winding and thus damage the transformer. To prevent such an undesirable occurrence, it is customary to include a buffer condenser in the secondary circuit, as shown in Fig. 24.

This buffer condenser acts somewhat as a "shock absorber"by accepting energy from the transformer, reversing its charge in accordance with the reversals in secondary voltage and current. The counter-emf thus furnished by the buffer condenser opposes the excessively high peak voltages produced by the transformer and prevents the peak voltage from rising to abnormally high values.

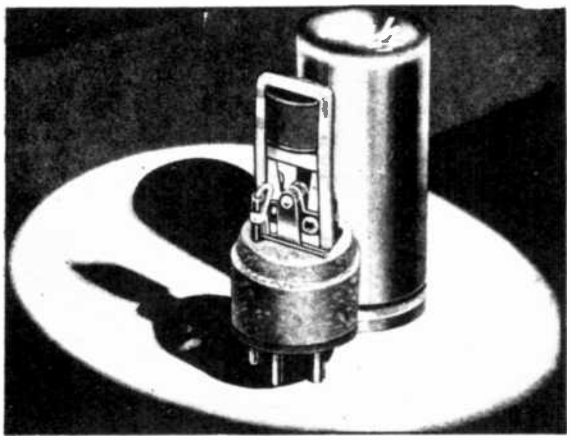

FIG. 25
NON-SYNCHRONOUS VIBRATOR

As soon as the rectifier draws current, the flow of "B" current serves as a sufficient load to act as a control upon the secondary voltage and thus keeps this voltage within safe limits. The value of the condenser used for this purpose is approximately 0.005 mf.

The purpose of the buffer condensers in the primary circuit -- and also the r-f choke and its bypass condenser --- is to filter out all sources of interference noises which are likely to be produced by the vibrating points. The average capacitive value of these buffer condensers is approximately 0.01 mf. These same condensers also increase the useful life of the vibrator points by reducing arcing across them. Sometimes, 100-ohm resistors are used in place of these buffer condensers. However, one or the other is always employed, for the reasons just mentioned.

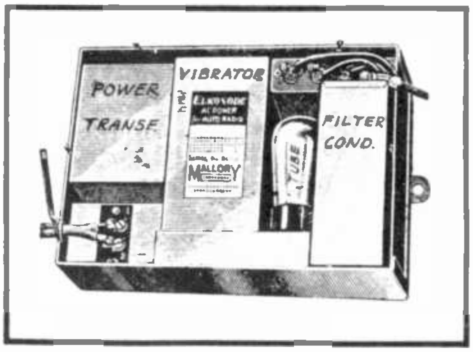

FIG. 26
COMPLETE TUBE-RECTIFIER
TYPE B-POWER UNIT

In Fig. 25 you are shown a non-synchronous type vibrator as used in the system just described. Its cover has been removed so as to expose the working parts. Notice that this unit is fitted with a standard tube-base, and that when the cover is placed in position, its general appearance is quite similar to a metal tube.

A complete B-power unit, based on this principle of operation, is shown in Fig. 26. This unit is completely enclosed in a compact metal cabinet of which the overall dimensions are 10 x 7 x 3½ inches -- it weighs 5 pounds. It can be mounted in any position at any convenient point, and is constructed in two models, one offering a d-c output of 135 volts at 30 milliamperes, and another with an output of 180 volts at 50 milliamperes. It draws approximately 2 amperes of battery current. In most automobile receivers, this entire B-power unit is built into, and as a part of, the main receiver chassis. The B-power unit is then well shielded and packed in sponge rubber so as to reduce mechanical vibration and vibrator interference noises to a minimum.

SYNCHRONOUS VIBRATORS

The synchronous type of vibrator is somewhat different from the non-synchronous vibrator as regards rectification of the high voltage a-c. This will become more apparent as we continue our analysis of the fundamental circuit illustrated in Fig. 27, wherein a synchronous vibrator is used.

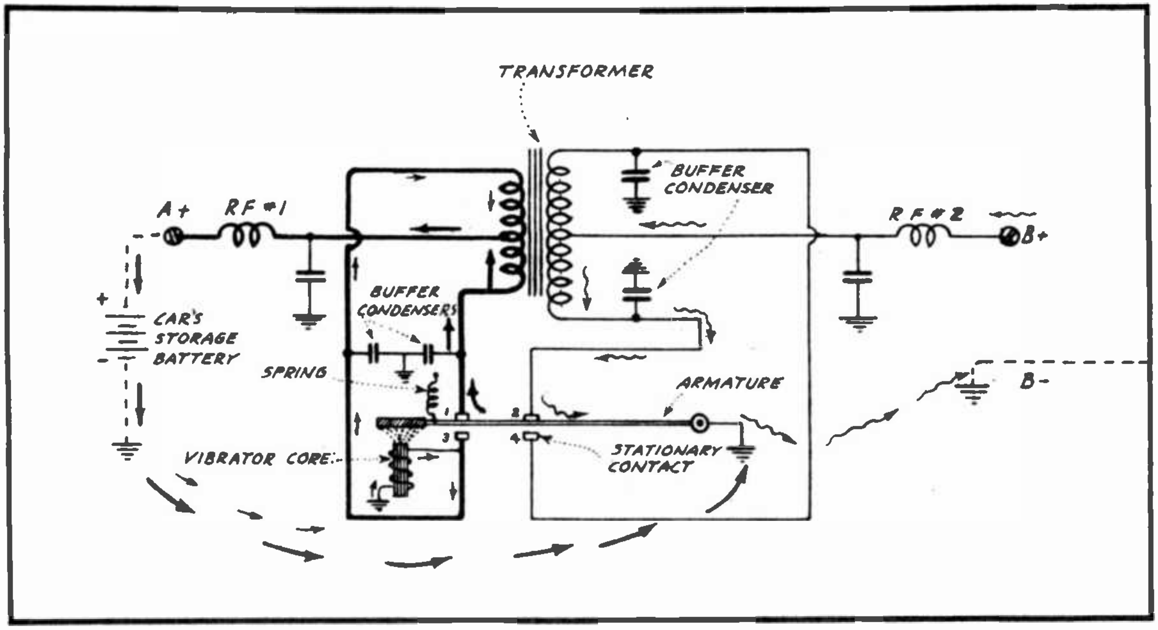

FIG. 27
FIRST ALTERNATION OF B-POWER UNIT'S CYCLE

The chief advantage of a synchronous vibrator system over a non-synchronous system is that the synchronous vibrator serves to "chop up" the battery current to produce the effect of a-c in the primary circuit, and at the same time serves to rectify the high voltage a-c. Thus, no rectifier tube is needed. However, the synchronous vibrator will not provide as long trouble-free service, and is more costly than the non-synchronous type.

Directing our attention to the system diagrammed in Fig. 27, we find it to operate in the following manner:

With the armature in the position shown in Fig. 27, electrons will flow from the negative terminal of the car's storage battery through "ground" to the armature of the vibrator. The electron-flow then continues through contact #1, the lower-half of the transformer's primary winding, and returns to the battery by way of its positive terminal. At this same time, electrons flow from the negative battery terminal, through the winding of the vibrator core and back to the battery by way of the upper-half of the transformer's primary winding.

(This flow of current is indicated in Fig. 27 by the small arrows.) The winding on the vibrator core consists of many turns of small wire, the resistance of which is sufficiently great to limit the flow of current through this path to a very low value.

The momentary surge of battery current through the lower-half of the primary winding will induce a high voltage in the secondary winding. Contact #2 is at this time closing the secondary circuit in such manner that "B" current will flow through the lower-half of the secondary winding and over the external circuit, as indicated by the wavy arrows.

The current flow through the winding of the vibrator core magnetizes the core sufficiently so that it will attract the armature, thereby interrupting the circuit at contacts #1 and #2, but completing it at contacts #3 and #4, as shown in Fig. 28. Observe in Fig. 28 that the electron flow is now from the negative terminal of the storage battery through "ground" and the armature, whence it passes through contact #3 and the upper-half of the primary winding, back to the battery. Notice, especially, that the main flow of electrons through the primary winding is reversed to that occurring in that part of the cycle illustrated in Fig. 27.

The surge of primary current pictured in Fig. 28 induces a high voltage in the secondary winding of the transformer, causing an electron flow through the upper-half of this winding in the direction indicated by the wavy arrows. Contact #4 completes the secondary circuit at this time. No current flows through the winding of the vibrator during this half of the cycle, as the closing of contact #3 grounds the upper end of this winding through the armature, thereby short-circuiting it.

It is especially important to notice that the surge of primary current reverses as the armature moves from one position to the other, and that contacts #2 and #4 operate in such manner that the high-

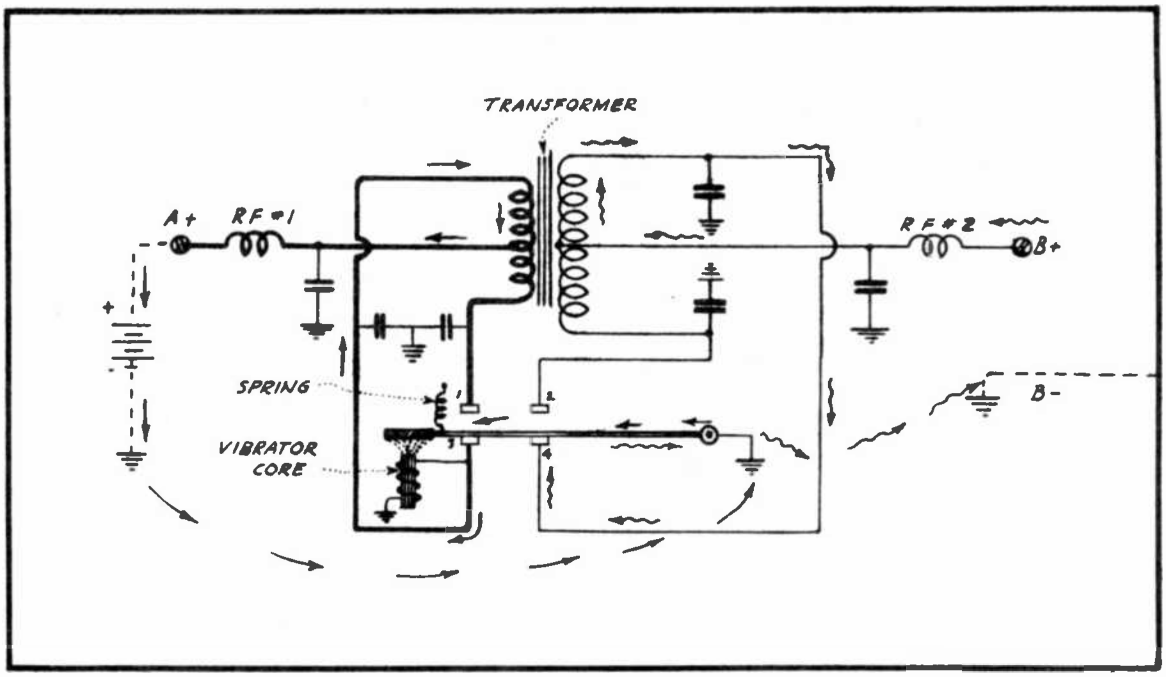

FIG. 28
SECOND ALTERNATION OF B-POWER UNIT'S CYCLE

voltage current always flows through the external circuit in the same direction, regardless of the armature's position. In other words, full-wave rectification takes place in the secondary circuit.

Short-circuiting the vibrator winding during the period illustrated in Fig. 28 causes the vibrator core to lose its attraction for the armature. Spring tension then returns the armature to the position pictured in Fig. 27.

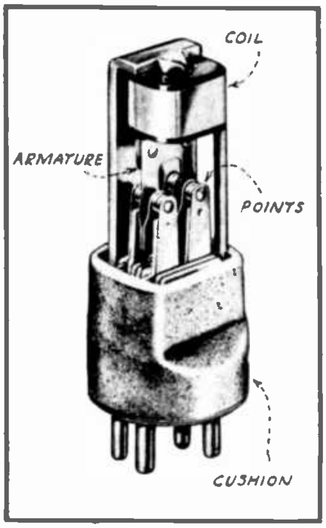

FIG. 29
SYNCHRONOUS TYPE VIBRATOR

The two alternations of the cycle, just described, repeat themselves in rapid succession as the armature undergoes a vibrating action.

Although it is true that the "B" current in the secondary winding is in the form of surges or "spurts", the action of the vibrator is so rapid that the "B" output appears as a somewhat steady flow, and the filter helps to make it still more uniform. We classify this form of rectification as being of the synchronous or self-rectifying type -- sometimes, such a device is called a "mechanical-type rectifier."

The purpose of buffer condensers used with this system is to reduce arcing at the contact points and thus prolong their useful life. At the same time, in conjunction with the r-f chokes, they aid in filtering out any sources of interference noise.

In Fig. 29 you are shown a typical synchronous type vibrator, with its cover removed. The various sets of contact points, armature and coil are clearly shown. Also, observe that this unit is fitted with a standard tube-base so that it can be installed or removed from the power unit with ease. The vibrator mechanism is mounted on a sponge-rubber cushion to protect it against vibrations of the car, and also to prevent its causing any rattling sound.

The same vibrator is shown in Fig. 30, with its cover in place. Comparing it with the hand will give you an idea of its size. Vibrators vary somewhat as to their details of design and construction. However, in a lesson of this type, we are chiefly interested in the PRINCIPLE rather than in the design variations of the various commercial models. The examples presented in this lesson are typical of automotive B-power supply units in general.

FIG. 30
TYPICAL VIBRATOR

EFFECT OF BATTERY-POLARITY UPON THE VIBRATOR

On car radios equipped with a B-power supply using a non-synchronous vibrator, it makes no difference whether either the positive or negative battery terminal be grounded. In this case, the rectifier will always cause the cathode to act as the positive terminal of the "B" system.

However, in systems employing synchronous vibrators this is not true. For instance,

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in Figs. 27 and 28 we show the operation of such an apparatus when the negative terminal of the car battery is grounded, at which time you will observe the center-tap of the secondary winding serving as the B+ terminal.

Should the battery connections now be reversed, as shown in Fig. 31, the direction of secondary current will also become reversed, causing the center-tap of the transformer's secondary winding to become B- instead of B+. Such a condition will prevent the receiver from operating.

Radio manufacturers generally supply the receiver connected for installation in a car wherein the negative battery terminal is grounded. Should the battery be installed with the positive terminal grounded, then it is a simple matter to alter the connections so as to make possible the correct operation of the synchronous vibrator. This may be done in the following manner:

(1) If the vibrator assembly is of the interchangeable type, having polarity markings, simply insert the vibrator in its socket so that its A+ terminal is connected to the positive "A" battery lead.

(2) If the vibrator is not interchangeable as to polarity connections, reverse either the primary or secondary leads between the vibrator and the transformer.

Manufacturers generally furnish information with each set, instructing one of the circuit changes necessary in case of a reversed battery installation.

VIBRATOR REPLACEMENTS

It is not generally the practice to attempt to repair defective vibrator units. Defective vibrators should always be replaced with a new unit of the same mechanical and electrical characteristics.

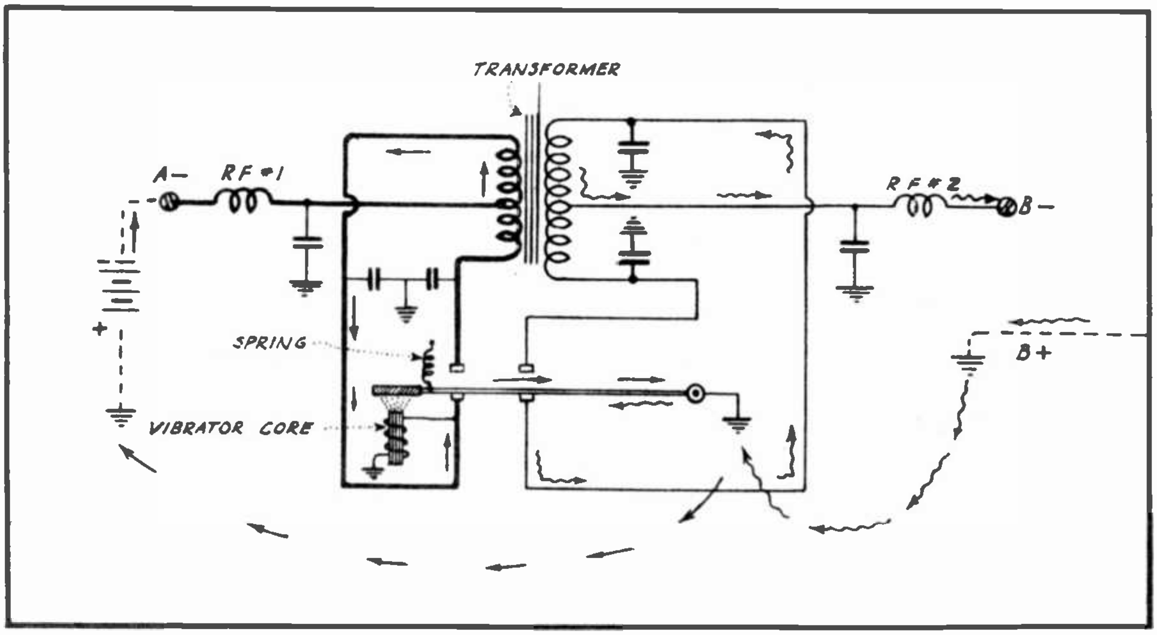

FIG. 31
EFFECT OF REVERSED BATTERY CONNECTIONS

Vibrator manufacturers have assigned "type numbers" to the large variety of designs used, so that by referring to this number identical replacements can be made conveniently.

In the next lesson, we continue our discussion of automobile receivers with an analysis of the receiver circuits and installation problems.

EXAMINATION QUESTIONS

LESSON NO. 26

1. - Explain briefly the dual function of the synchronous type vibrator.

2. - What two important properties are required of an automobile antenna?

3. - Explain the chief differences as regards the synchronous and non-synchronous types of vibrator units.

4. - Describe briefly the operating principles and method of installing the "Genemotor" or dynamotor type B-power supply.

5. - What are the effects of battery polarity upon the synchronous vibrator?

6. - What serves as the conventional "ground" in an auto receiver installation?

7. - Describe briefly the purpose and operating principle of the remote control tuning unit.

8. - Generally speaking, how does the automobile receiver differ from the conventional type of receiver such as used in the home?

9. - Describe one type of automobile antenna.

10. - (a) Draw a circuit diagram of an automobile B-power supply unit, using a vibrator in conjunction with a rectifier tube.
(b) Explain briefly how this unit operates.

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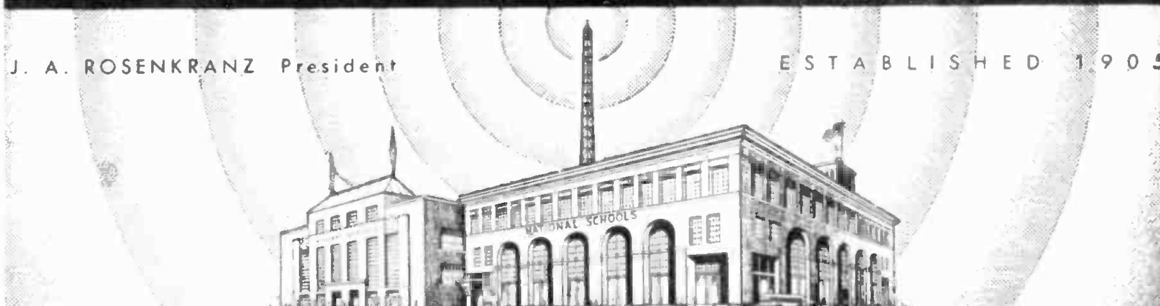

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LESSON NO. 27

AUTO RADIO CIRCUITS - INSTALLATION PROBLEMS

Let us begin our study of automobile receiver circuits with an analysis of the wiring diagram appearing in Fig. 2. Notice that this receiver is of the superheterodyne type, which is typical of automobile receivers in general. The mixer, i-f, detector and audio circuits are of conventional design, and are similar to those employed in a-c receivers designed for use in the home.

FIG. 1
HERE THE RECEIVER AND SPEAKER-UNIT ARE PLACED BEHIND A GRILLE ON THE INSTRUMENT PANEL

It is also of interest to note that the same 6.3 volt tube-series is used as is employed in a-c receivers. This is true, regardless of whether the tubes are of the glass, metal or "G" type.

On cars equipped with a 6-volt storage battery, the battery circuit operates at voltages near this value. Therefore, the 6.3-volt tubes are ideally suited for automotive use. The heater-cathode construction of these tubes is also advantageous in automobile receivers because it will withstand the vibration of driving much better than will the conventional filament structure used in filament-type tubes.

Upon further inspection of the circuit appearing in Fig. 2, you will observe that the antenna input, speaker field, and power supply circuits are somewhat different from those used in any of the receivers that you have studied thus far. Since automobile receivers differ chiefly from a-c superheterodynes with respect to the antenna input, speaker field, and power supply circuits, we will at this time confine our attention to these points only.

ANTENNA NOISE-REJECTION FILTER CIRCUITS

The design and installation of the antenna lead-in is one of the most critical points to be considered in affecting a good noise-free installation. To aid in the reduction of noise pick-up at this point, it has become the practice to keep the lead-in out of all high-intensity electric fields, such as might exist in the engine compartment. In addition, the lead-in wire is shielded, and the shield covering is grounded to body members of the car at several effective points. This is discussed more fully later on. For the present, we are interested in the FILTER CIRCUITS as used in the antenna system only.

In the receiver circuit shown in Fig. 2 you will observe how such a noise-filter is included in the antenna input line, whereas several such filter circuits are illustrated in detail in Figs. 3 to 7, inclusive. By comparing the basic circuits shown in these illustrations you will note that there are several variations of antenna filter designs, although they are all intended to serve the same fundamental purpose

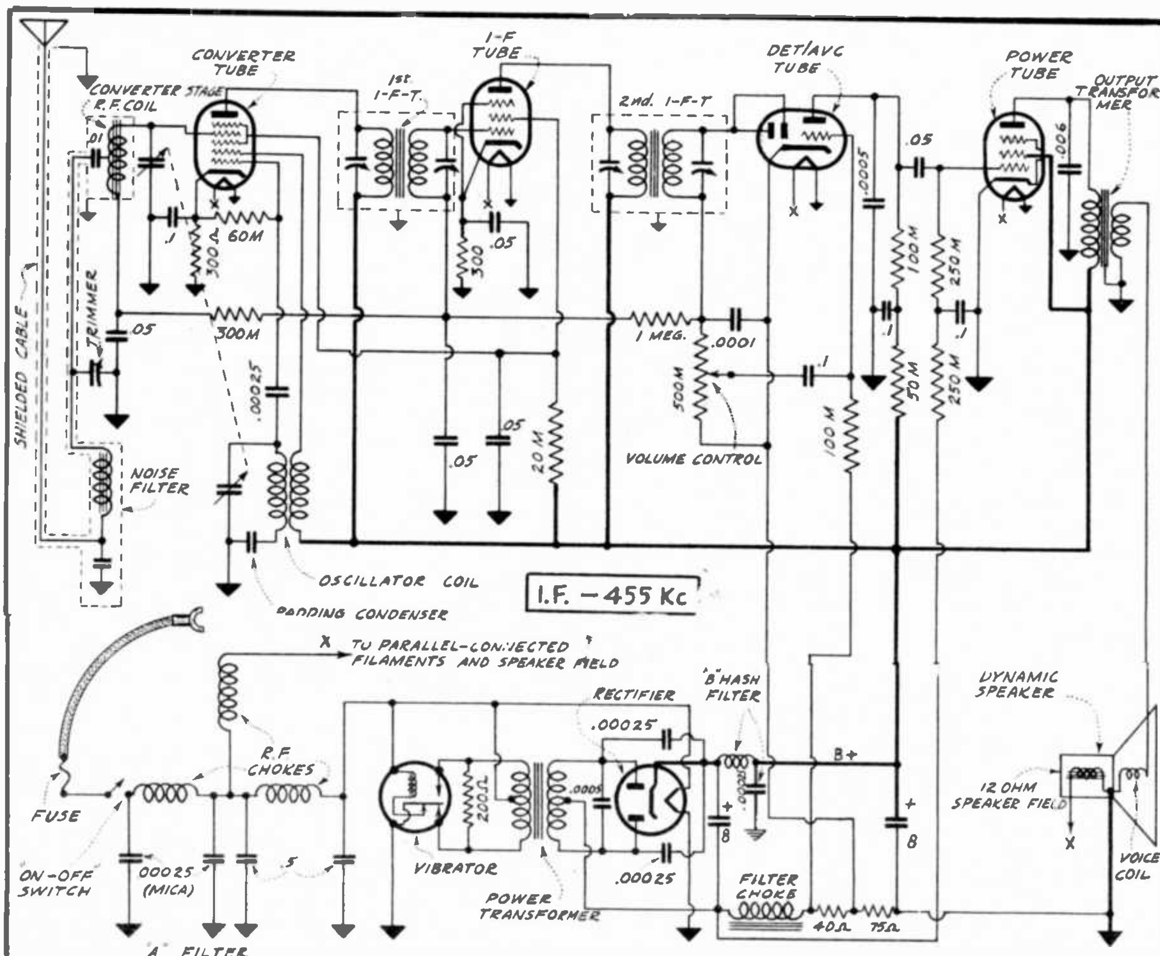

FIG. 2
FIVE-TUBE AUTOMOBILE RECEIVER WITH NON-SYNCHRONOUS VIBRATOR

The filter circuits used for this purpose will permit currents below a certain critical frequency to flow through the antenna circuit, while at the same time rejecting currents of higher frequencies. The interference or noise-producing frequencies, as generated by the car's electrical system, are around 50 mc -- a much higher frequency than are the broadcast signal frequencies. This difference in frequency between the desired and undesired "signal" makes it possible for the antenna filter to perform its duties in the manner explained in the following paragraphs.

SIMPLE LOW-PASS FILTER: The basic principle of the circuit shown in Fig. 3 is the same as that used in the filter system of "B" power supplies in a-c receivers -- the only difference being that low values are chosen for the inductance and capacity in the antenna filter so as to handle currents of radio frequency, while high inductance and capacity values are used in B-supply filters to handle currents of rather low audible frequencies.

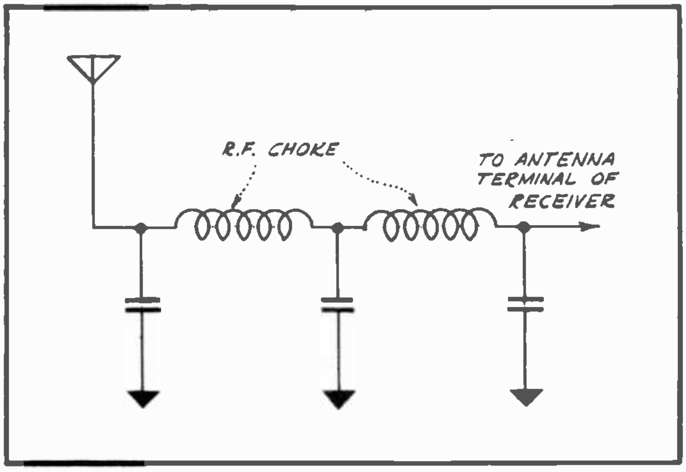

FIG. 3
SIMPLE LOW-PASS FILTER

Being familiar with B-power filters, you will readily understand how the higher noise-producing frequencies will be forced by the inductive reactance to be bypassed to ground through the condensers. The broadcast frequencies, being of a much lower frequency value, will reach the antenna circuit of the receiver with little attenuation (reduction in strength).

AUTO TRANSFORMER WITH CAPACITY INPUT: In the input filter circuit appearing in Fig. 4, the antenna coil is in the form of an auto-transformer, wherein the primary and secondary sections are two parts of one continuous winding. Condenser "C" is a coupling condenser that serves as the connecting medium between the antenna and the input circuit of the receiver, and its value is such that it will pass with ease both the broadcast frequencies and the interference frequencies.

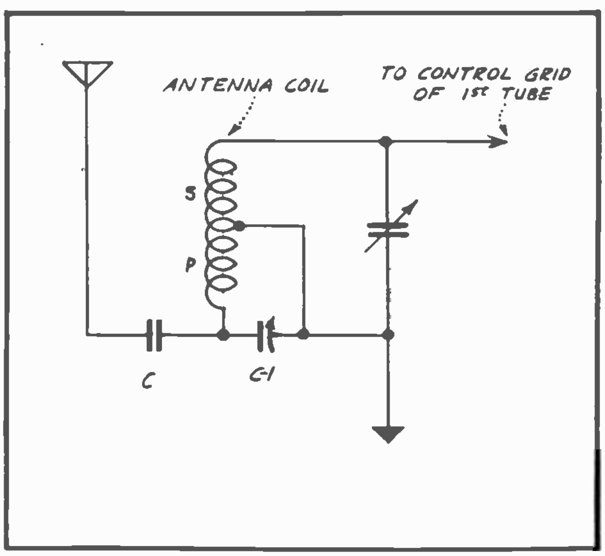

FIG. 4
AUTO-TRANSFORMER INPUT

The primary section of the antenna coil, together with the adjustable trimmer condenser C-1, constitutes a parallel resonant circuit that is connected in series with the antenna and grounding system. This circuit is rather broad-tuning and is tuned to a frequency near the lower end of the broadcast band; therefore, it offers more opposition to frequencies throughout the broadcast range than to frequencies far removed from this band. Such being the case, maximum signal voltage will be generated across this circuit at the broadcast frequencies, thereby causing maximum energy-transfer by induction to appear in the secondary section of this coil. The latter circuit is tuned to resonance with the desired signal-frequency.

Since the primary circuit as well as the antenna circuit as a whole is tuned to the broadcast band, all frequencies far removed therefrom (particularly the higher frequencies) will pass readily through condenser C-1 to ground and thus fail to impress any appreciable voltage upon the control grid of the first tube.

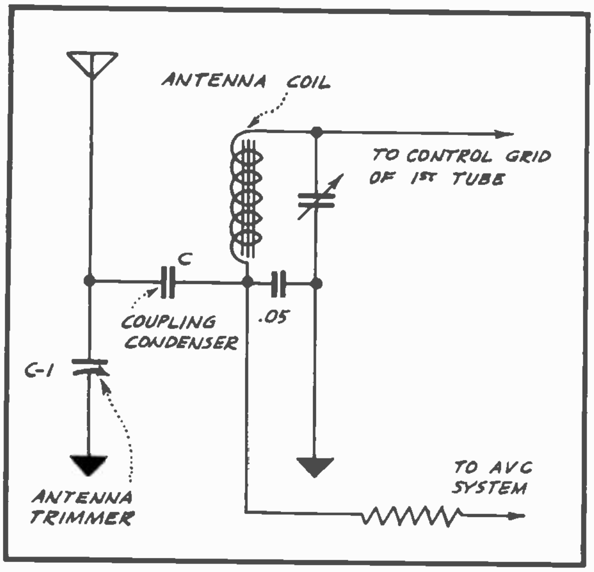

FIG. 5
CAPACITY INPUT

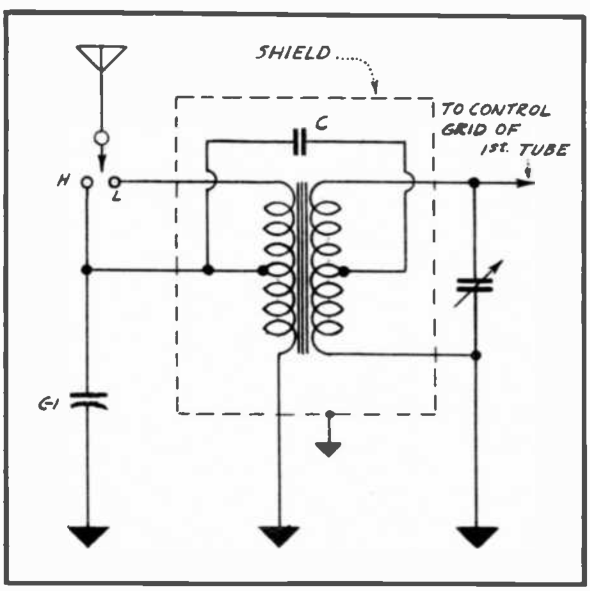

FIG. 6
TRANSFORMER-COUPLED INPUT

CAPACITY INPUT: The arrangement illustrated in Fig. 5 is quite similar, though somewhat different, to that appearing in Fig.4. In Fig. 5 the antenna is connected to ground through trimmer condenser C-1, while at the same time being connected through coupling condenser "C" to the parallel resonant circuit consisting of the antenna coil and main tuning condenser. The value of the grid-isolating condenser (.05 mf) is sufficiently large so as not to affect the tuning characteristic of the antenna stage to any appreciable extent. It does serve to isolate the control grid of the first tube from ground so far as d-c is concerned, and thus makes a-v-c possible.

The antenna stage of the receiver tunes in the desired stations in the conventional manner. The undesired high-frequency noise signals are bypassed to ground through the low-capacity trimmer condenser C-1,which path offers considerable opposition to the broadcast frequencies. This same trimmer condenser also assists in matching antennas of various capacitive values to the receiver's input tuning circuit. This condenser is adjusted so that a minimum amount of noise and maximum station signal intensity is obtained.

Since the circuit in Fig. 5 provides no step-up in signal voltage due to the absence of a transformer, this lack of amplification is compensated for partially by using an iron-core r-f coil at this point. Using an iron-core in this manner makes it possible to obtain the required inductance value with a minimum amount of resistance being introduced into the circuit, and thus makes the circuit more efficient.

TRANSFORMER COUPLED INPUT: The system illustrated in Fig. 6 provides a very marked improvement in the signal-to-noise ratio, as well as in sensitivity. The use of an iron-core r-f transformer in this case causes the energy-transfer to the first tube to be considerably higher than is possible with the more simple systems thus far described. This increased signal-gain ahead of the first tube is largely responsible for the remarkable improvement in noise-to-signal ratio. Basically, this system is a refined version of that illustrated in Fig. 4, a two-winding iron-core transformer replacing the air-core auto-transformer.

A tap is provided on the primary winding of the transformer used in Fig. 6. This is done so as to best adapt the receiver installation to the characteristics of the particular antenna being used -- more inductance being used for a shorter effective length of the antenna system.

The impedance characteristic of iron-core r-f transformers is such that these units transfer low-frequency broadcast signal energy most satisfactorily, but they are less responsive to the signals of stations at the high-frequency end of the broadcast band. To compensate for this deficiency, condenser "C" is connected between the taps of these two windings. The response of the transformer then becomes more like that of a conventional high-gain r-f coil, where the natural transformer characteristic is to handle the lower frequencies best, while the coupling condenser provides better energy-transfer for stations operating at the higher frequencies.

In Fig. 6 the high reactance value of the transformer's primary winding forces the "noise-currents" of very high-frequency value through condenser C-1 and into ground. The latter also serves to assist in more nearly resonating the antenna circuit to the broadcast band.

IMPEDANCE-MATCHING SYSTEM: Let us now consider the noise-rejection arrangement shown in Fig. 7. This system features a low-impedance transmission line between the receiver and the antenna. Here, the energy

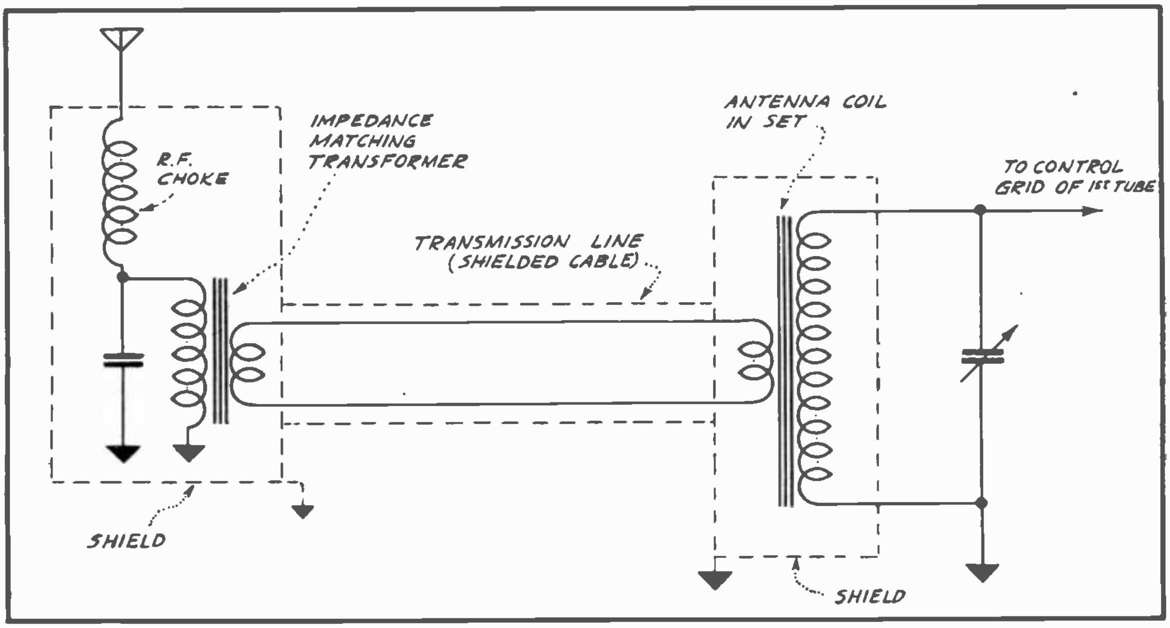

FIG. 7
IMPEDANCE-MATCHING INPUT

picked up by the antenna passes through the motor-noise rejector system, comprising an r-f choke and a bypass condenser of small capacity.

The latter forms a series-resonant circuit that is tuned to resonance with the high-frequency noise-producing energy. Therefore, currents of such frequencies will be bypassed to ground readily through the condenser, without acting upon the transformer's primary winding to any noticeable extent. In fact, the rather high inductance of the latter winding serves still further to force the undesired frequencies to ground through the condenser. The inductance value of the primary winding and the capacity of its shunting condenser are selected so that this winding is tuned broadly to the broadcast band.

The broadcast signals, being of a rather low-frequency value, pass through the primary winding of the transformer in the usual manner and induce corresponding voltage-changes in the secondary winding of this transformer. This unit is located near the antenna, and is enclosed in a grounded metal shield.

The secondary winding of this transformer consists of comparatively few turns so as to have a rather low impedance characteristic. This winding is connected through a two-wire transmission line to a similar winding that is used as a primary to provide coupling with the receiver's antenna-stage tuned winding,as well as to furnish a step-up voltage at this point. Thus, the transmission line serves as the "link" between the noise-rejecting filter and the receiver.

The transmission line is shielded, but because of its extremely low impedance characteristic, little loss is experienced due to the proximity of the shield. Using a transmission line of this type, in conjunction with efficient terminating or impedance-matching transformers, increases the signal-to-noise ratio materially.

ANOTHER CAPACITY INPUT: The receiver circuit illustrated in Fig. 2 has included in its antenna input circuit a filter similar to the systems already described, with the exception that the noise-rejection filter is coupled to the converter stage coil through a condenser instead of by transformer coupling. Thus, no impedance-matching transformers are necessary in Fig. 2.

In this case, the high inductive reactance of the filter choke forces the noise frequencies to ground, but permits the broadcast frequencies to react upon the r-f coil of the converter stage. The trimmer condenser serves to more nearly resonate the antenna system to the broadcast band, and it is adjusted so that the receiver will provide the greatest possible signal strength with the least noise.

It is to be noted that none of these antenna filter systems reject the noise frequencies entirely, and that they also reduce the signal strength somewhat. However, the relation between the reduction of noise and signal strength is such that the noise is affected more than the signal. Therefore, the signal-to-noise ratio is favorable for satisfactory reception.

"A" FILTERS

A filter network is included in the A-battery circuit of modern automobile receivers so as to reduce still further the probability of interference noises entering the receiver circuits. An example of such an A-filter is shown in Fig. 8.

Here, the car's battery circuit is connected to the filter at the point labeled "To hot A." Therefore, any noise-frequency picked up by the A-lead will be opposed by the r-f choke which is installed at this point, and forced to ground through the bypass condensers that precede this choke. In this particular case, a small .00025 mf mica condenser is placed directly at the point where the hot A-lead enters the metal cabinet, while the other condensers of the system are of the 0.5 mf size.

The output end of this first r-f choke leads directly to the filament circuit of the receiver, but an additional filter section is placed between the speaker field and this point so as to prevent interference noise picked up by the speaker cable from entering the receiver circuits.

A dual-section filter arrangement is included between the output of the input filter, vibrator and the rectifier filament. This is done to isolate the vibrator system from the receiver's filament and speaker circuits. Therefore, any interference noise originating in the vibrator system will not find its way into the receiver proper.

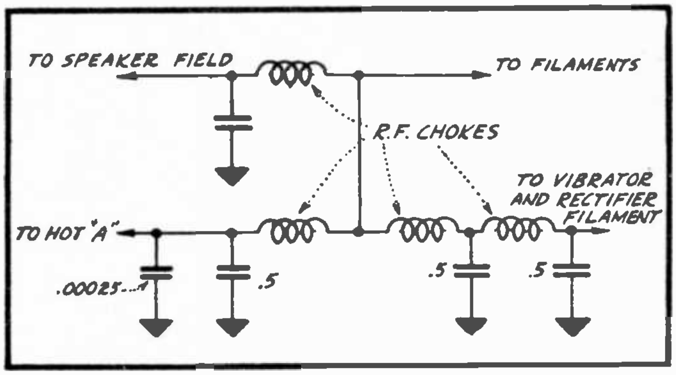

FIG. 8
A-FILTER WITH SEPARATE SPEAKER-FIELD LEG

The principle of condenser-choke filter circuits has already been covered in other lessons of the course, and since the A filter circuits here shown do not differ in principle from r-f filters in general, there is no need to repeat the explanations that were given previously. However, it is well that you pay special attention to the manner in which the various receiver circuits branch out from the filter network. This is the main point of difference between the A-filters of various receivers.

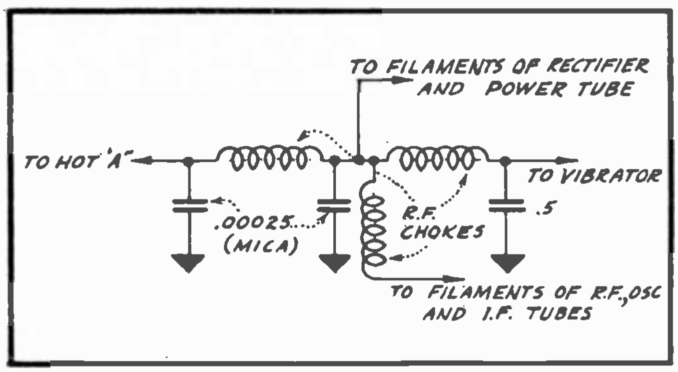

FIG. 9
A-FILTER WITH INDEPENDENTLY-FILTERED "R-F LEG"

Another example is shown in Fig. 9. In this case, a master filter section is placed at the input end of the network. The circuit then divides through three paths so that there is no possibility for interference reaction between the hot A-lead, filament circuit of the power and rectifier tubes, nor the circuit that feeds the filaments of the r-f, oscillator and i-f tubes.

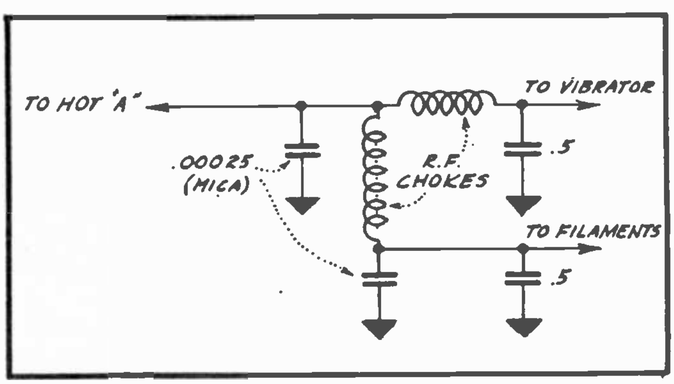

FIG. 10
SIMPLE A-FILTER

Notice, particularly, that the filament circuit of the latter tube-group is filtered separately. The reason for this is that the latter circuit is highly sensitive to noise -- any noise introduced therein being amplified considerably.

The A-filter appearing in Fig. 10 is less elaborate than those already described and consists of only two filter sections that are included in the vibrator and filament circuits, respectively.

Upon comparing Figs. 8, 9 and 10 you will find them to be fundamentally alike, and that the more elaborate systems endeavor to divide the receiver circuit into as many individually-filtered branches as possible. Naturally, the greater the number of sections used, the more expensive will be the system. The various receiver diagrams appearing in this lesson will show you how A-filters form a part of the complete circuit.

While we are on the subject of filters, it is also well to take note of the "B" hash filter that is installed in the B+ lead of the rectifier used in Fig. 2. The nature of the dielectric used in electrolytic condensers is such that condensers of this type constitute practically pure resistance to the high-frequency "noise-signals" that may be introduced into this circuit by the vibrator. Such being the case, the 8-mf filter condenser in the B-supply filter is of little value in bypassing the high-frequency noise disturbances. Therefore, a .00025-mf mica condenser is connected in parallel with the 8-mf condenser, which together with the r-f choke also used at this point, reduces the vibrator's so-called "hash" (noise) quite effectively.

SPEAKER FIELDS

In automobile receivers, one must necessarily deal with limited voltages and currents. Therefore, if a 1500 or 2500-ohm speaker field coil should be connected in series with the B+ side of the circuit as in conventional a-c receivers, the voltage-drop across it would be so large as to cause the rest of the set to operate at abnormally low plate and screen voltages. For this reason, the majority of the dynamic speakers used with automobile receivers are equipped with fields ranging from 4 to 15 ohms so as to adapt them for connection directly across the 6-volt storage battery circuit as shown in Fig. 2. Notice in this illustration that all points marked as "X" are connected to the ungrounded side of the "A" circuit. Such speakers are also often said to contain a "6-volt field coil."

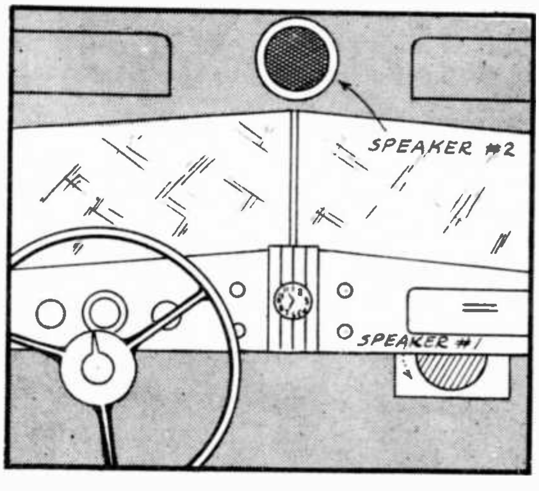

FIG. 11
APPLICATION OF TWIN-SPEAKERS

Permanent-magnet type dynamic speakers are also used extensively with automobile receivers -- the advantage of these units being that no battery energy is required to excite their fields. As already explained in the previous lesson, the speaker may be an integral part of the receiver, or else a separate unit mounted independently of the receiver.

The complete receiver diagrams appearing later in this lesson show you several variations in speaker connections as used by various prominent receiver manufacturers.

TWIN SPEAKERS

Sometimes, two speakers are used in auto-radio installations,one of the speakers being included in the radio compartment below the dash of the car and the other overhead or above the windshield as illustrated in Fig. 11. The latter speaker is known as a "header-type" speaker, its chief purpose being to furnish more uniform sound distribution throughout the car than is provided by the master speaker alone. The obstruction and sound absorbing properties of the upholstered seats, as well as other physical obstructions within the car, frequently prevent a single speaker from providing satisfactory sound distribution to both the front and rear seating compartments. In some cases, one speaker is contained within the receiver cabinet to meet the requirements of the passengers in the front seat, while the second speaker is mounted at some convenient point in the rear compartment for the convenience of the passengers seated therein.

In Fig. 12 are shown the circuit connections for two speakers as used by one well-known manufacturer. By closely inspecting this circuit diagram, you will observe that two dynamic speakers with 12-ohm field coils are used. Plate current for the final audio tube flows thru the primary winding of the master speaker's transformer, while the primary winding of the extra speaker's output transformer is coupled to the plate of the power tube through the 0.01-mf condenser. An r-f choke, in combination with a .00025-mf condenser, is connected in the primary circuit of the extra speaker's transformer to keep any radiated noise out of this relatively long lead.

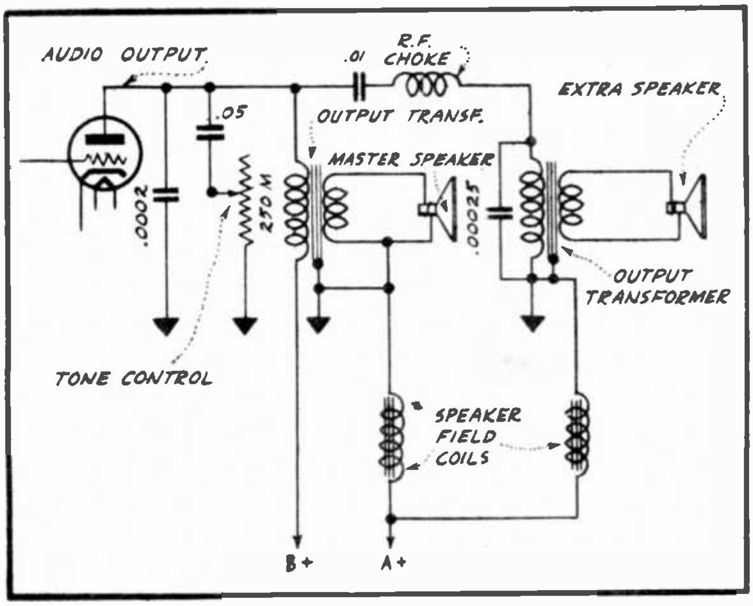

FIG. 12
TWIN-SPEAKER CIRCUIT CONNECTIONS

In many installations, this extra or "header" speaker is of the permanent-magnet (PM) type,which requires no battery current for field coil energizing. The absence of field coil wiring also simplifies the connections to and from the extra speaker.

A SIX-TUBE RECEIVER

Let us now turn our attention to another typical automobile receiver. This time, to the six-tube receiver whose circuit is diagrammed in Fig. 13. Here again, you will observe that the receiver is of the conventional superheterodyne type, and that a push-pull output is furnished by a single duplex-triode that is installed in the final audio stage. The noise rejection filter networks, as used in the antenna and "A" input circuits, are similar to those already explained. Also observe that an r-f choke is used in combination with a 0.5-mf condenser in the "B" output circuit so as to eliminate vibrator "hash."

Another point of interest is that the receiver diagrammed in Fig. 13 employs a synchronous vibrator in the B-power unit, whereas the circuit shown in Fig. 2 uses a non-synchronous vibrator in conjunction with a cathode-type rectifier tube.

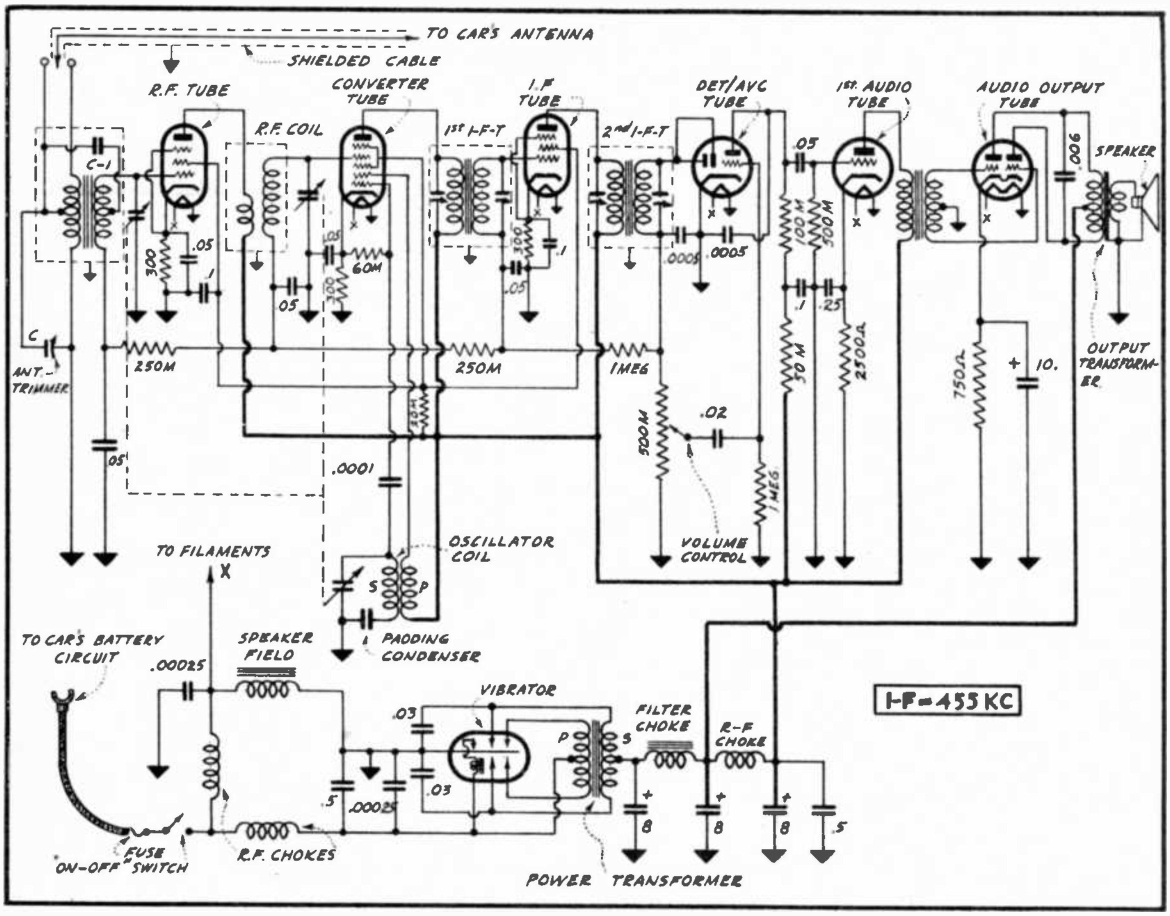

FIG. 13
SIX-TUBE AUTOMOBILE RECEIVER WITH SYNCHRONOUS VIBRATOR

While studying these complete circuit diagrams, it is well to familiarize yourself with the different methods used by various manufacturers to illustrate vibrator connections. Regardless of the circuit arrangement used, or the manner of illustrating the circuit, the principle of the unit's operation remains the same as explained to you in the previous lesson. Also notice that although the physical placement of the speaker field may vary in the different wiring diagrams, it is connected across the car's battery circuit in all cases.

You will also observe in all of our diagrams that the "on-off" switch is connected in series with the hot "A" lead so that opening this switch will make all sections of the receiver inoperative. It is common practice to connect a fuse in series with hot "A" leads to protect the circuit in case of an abnormal overload or short circuit in the receiver.

FIVE-TUBE, PERMEABILITY-TUNED SUPERHETERODYNE RECEIVER

In a previous lesson dealing with superheterodyne receivers, you were shown how it was possible to eliminate the usual variable condenser from the tuning circuits, and that a ganged group of continuously-variable iron-core tuning coils could be used in its place. You also learned that such a continuous permeability-tuning system will cover the entire broadcast band satisfactorily.

Due to the success of this method of tuning superheterodyne receivers, it has become used quite extensively -- in fact, more so in automobile receivers than in home radios. The reason for this is that automobile receivers are required to cover the standard broadcast band only, for which this type of tuning is best suited. Also, the elimination of the variable condenser makes possible the construction of a more compact receiver.

In Fig. 14 is shown the circuit diagram of a typical automobile receiver that employs "continuous" permeability-tuning. No effort will be made at this time to discuss the operating principles of this type of tuning, as it was covered thoroughly in a previous lesson. However, we do wish to direct your attention to the antenna input circuit. As you will observe, the antenna is coupled to the control-grid circuit of the converter tube through the antenna trimmer condenser, which is adjusted for maximum signal-transfer and proper impedance matching between the two circuits. The .00003-mf condenser, which is shunted across the antenna input circuit, helps to bypass some of the high-frequency motor-noise, while the r-f choke in the grid circuit prevents such interference from reaching the control grid of the converter tube.

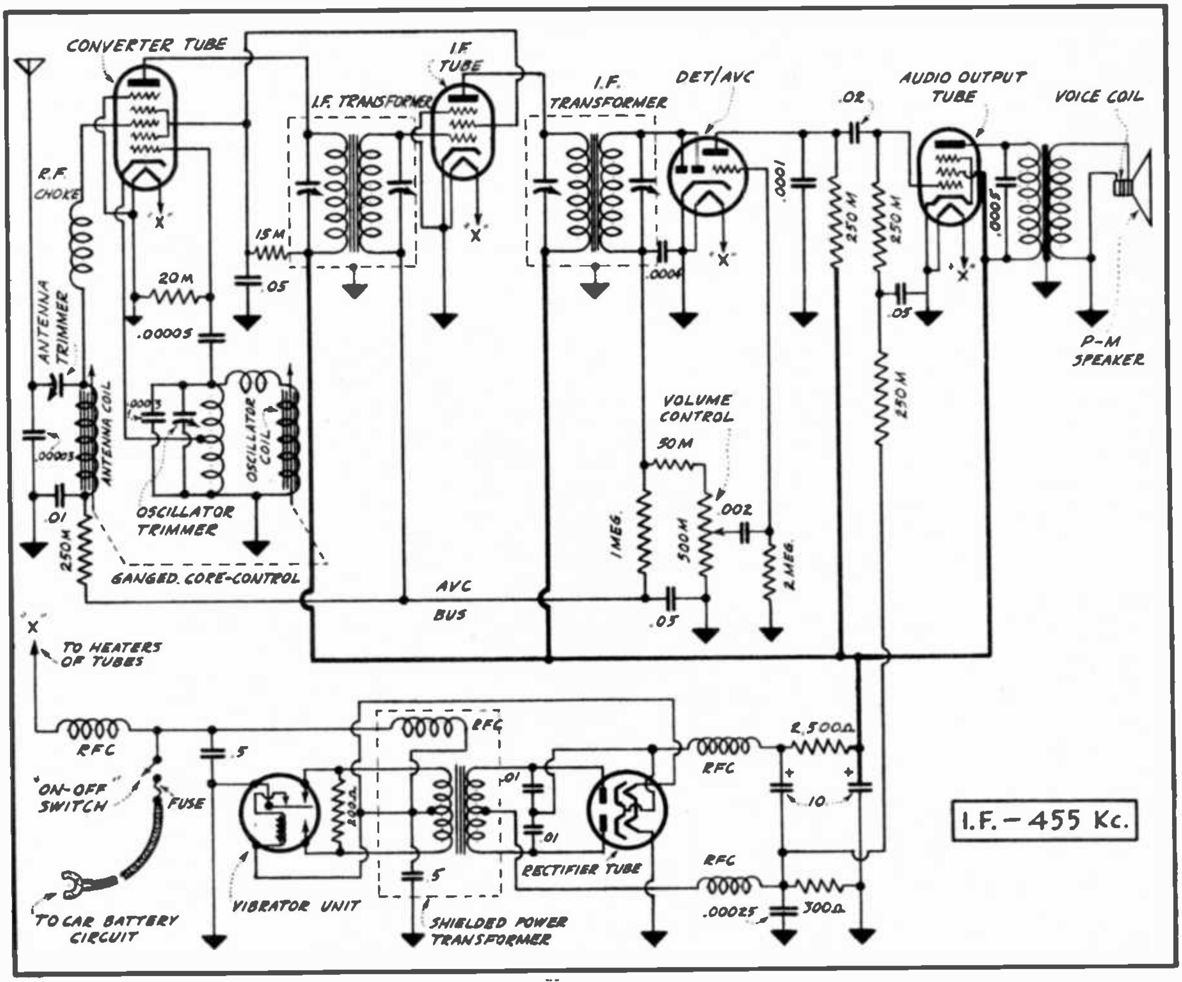

Fig. 14
Five-tube Permeability-tuned Automobile Receiver

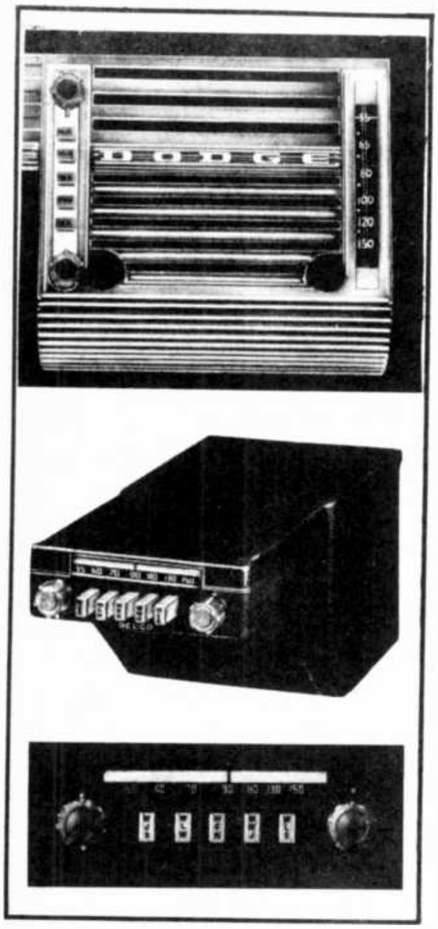

FIG. 15
AUTOMATIC TUNING (PUSH BUTTON) DIAL ASSEMBLIES

The B-power supply unit contains a non-synchronous vibrator that operates in conjunction with a full-wave, cathode-type tube rectifier. Also notice that r-f choke coils are used at both the input and output of the B-power supply circuits. The chokes at the input eliminate r-f motor noise, while the chokes in the output tend to eliminate "B" hash interference. To still further aid in the construction of a compact receiver, a 2500-ohm resistor is used in the B-power supply circuit in place of an iron-core choke. For this same reason, a PM dynamic speaker is used instead of a field-coil dynamic speaker.

AUTOMATICALLY-TUNED AUTOMOBILE RECEIVERS

A great many automobile receivers employ **AUTOMATIC TUNING SYSTEMS**, in addition to the conventional tuning control. Examples of such receivers are shown in Fig.15.

Some of these systems operate on a mechanical principle where movement of the push-button rotates the variable tuning condenser to the desired station position. Others consist of pre-tuned circuits that are cut in and out of service by depressing any one of the various station-selecting buttons.

As these systems are explained thoroughly in a later lesson, which is devoted exclusively to automatic tuning systems, there is no need for discussing the operating principles of such systems at this time. For the present, it is sufficient for you to know that all such systems operate on a basic principle whereby depressing a marked push button or lever automatically tunes-in the desired station.

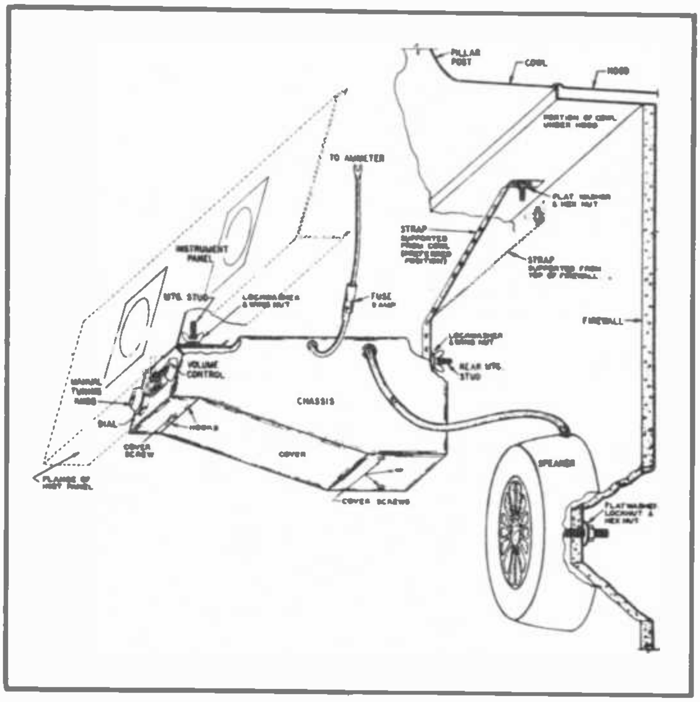

FIG. 16
TYPICAL MOUNTING ARRANGEMENT

INSTALLATION DETAILS

Now, you are ready to learn about receiver installations as a whole. In Fig. 16 you are shown the mounting details for a receiver where the control panel is a part of the set, while the speaker is an independent unit.

Another installation of equal importance is shown in Fig. 17. Here, we have a receiver with a remote control tuning unit. In such cases, the receiver case is generally mounted to the bulkhead of the car's chassis, while the tuning unit is either mounted in a special compartment provided for it on the instrument panel of the car or to the steering column of the car. In either case, the tuning controls must be extended to the receiver cabinet and properly fastened into place.

Both these illustrations are self-explanatory so that further explanation should not be necessary. You should also bear in mind that although the installation methods here shown are typical for the receiver types illustrated, installations as a whole differ in accordance with the make and model of receiver, as well as with the make and model of automobile.

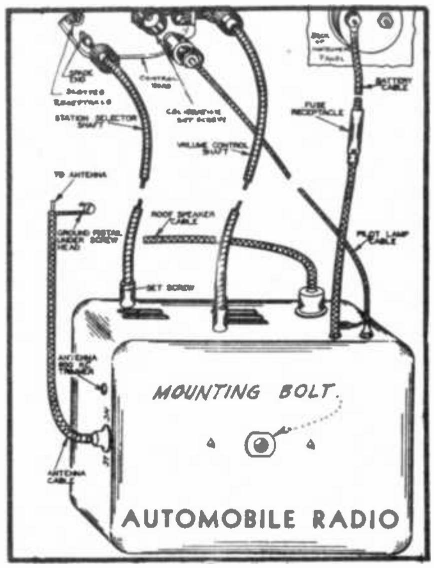

FIG. 17
RECEIVER MOUNTING FOR REMOTE CONTROL

Receiver manufacturers furnish complete instructions with each radio, explaining in detail how that particular set should be installed in the car for which it is intended.

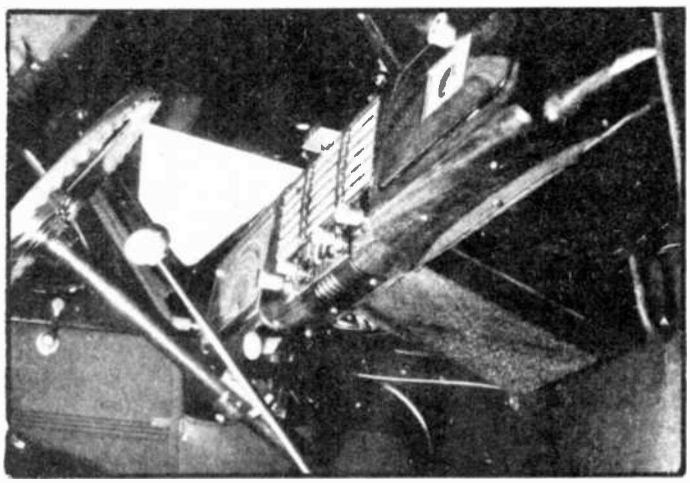

FIG. 18
SINGLE-UNIT RECEIVER FOR DASH-PANEL MOUNTING

Another popular installation is illustrated in Fig. 18. This receiver is known as a "single-unit, dash-panel" receiver. It is designed especially for cars whose instrument panel is provided with a grille, behind which the speaker is to be mounted. In this case, the speaker is raised to a level suitable for good sound distribution. The installation as a whole is attractive, and no remote control apparatus is required. This same installation is also shown in Fig. 1 of this lesson.

In Fig.19 you are shown this receiver preparatory to mounting. Notice how the

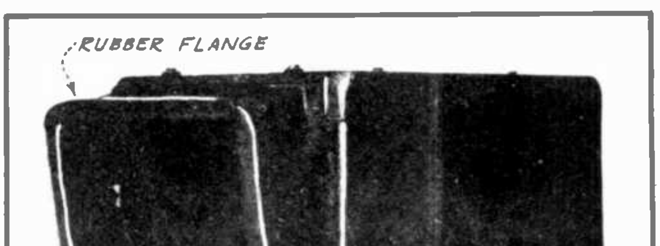

FIG. 19
SINGLE-UNIT RECEIVER

speaker-opening is equipped with a soft rubber flange which fits tightly against the grille of the car's instrument panel. Also notice how the controls are designed to become an integral part of the car's instrument panel.

Aside from the general installation suggestions thus far presented, there are also other important points to be considered, which are frequently overlooked by the technician who is responsible for the installation. For instance, it is necessary to scrape the paint from the bulk-head around the mounting-bolt holes so as to provide a good low-resistance ground connection for the chassis. It is also necessary to repaint this area upon completion of the installation to guard against the ravages of rust.

Most of the new sets are completely enclosed in metal cabinets that have no ventilation louvres. Such construction provides excellent shielding, and the direct radiation of heat through the case itself is regarded as being sufficient for all practical purposes. To assure perfect shielding, the covers are usually grounded, either by a multitude of screws or a series of grounding springs.

Interference Problems in Auto-Radio Installations

Even though the installations described in this lesson are made with the most extreme care, and with all shielding, etc., carefully attended to, the quality of reception might still be impaired by interference noises which have their origin within the engine compartment or in other parts of the automobile. This interference is more closely allied to the HIGH TENSION IGNITION CIRCUIT then to any other source.

Since automobile radio installations are becoming more universal, and interference complaints more often encountered by the service engineer, the balance of this lesson will be devoted to this subject.

The most common sources of interference are:

1. - Radiation from ignition secondary.
2. - Radiation from ignition primary, voltage regulator, gas gauge controls, etc.
3. - Radiation from free metal members.
4. - Wheel and tire static.
5. - Outside sources -- power lines, etc.
6. - Vibration of motor block due to non-rigid suspension.

Fig. 20 illustrates the principal sources of interference on the average automobile.

HOW TO LOCATE THE SOURCE OF INTERFERENCE

Much time will be saved in eliminating interference, if a careful check is first made to make sure that the radio receiver and antenna have been properly installed, and in accordance with good practice. Frequently, the antenna or lead-in will be found to have been installed in a more or less makeshift manner, without proper shielding; or else, the receiver has not been properly grounded to the frame of the car.

To eliminate interference, one must naturally first determine its origin. That is, it must be ascertained if the interference is being picked up by the antenna or if it is being fed into the receiver through the controls, pilot light lead, or power supply leads. This may be determined by disconnecting the antenna from the receiver, turn-

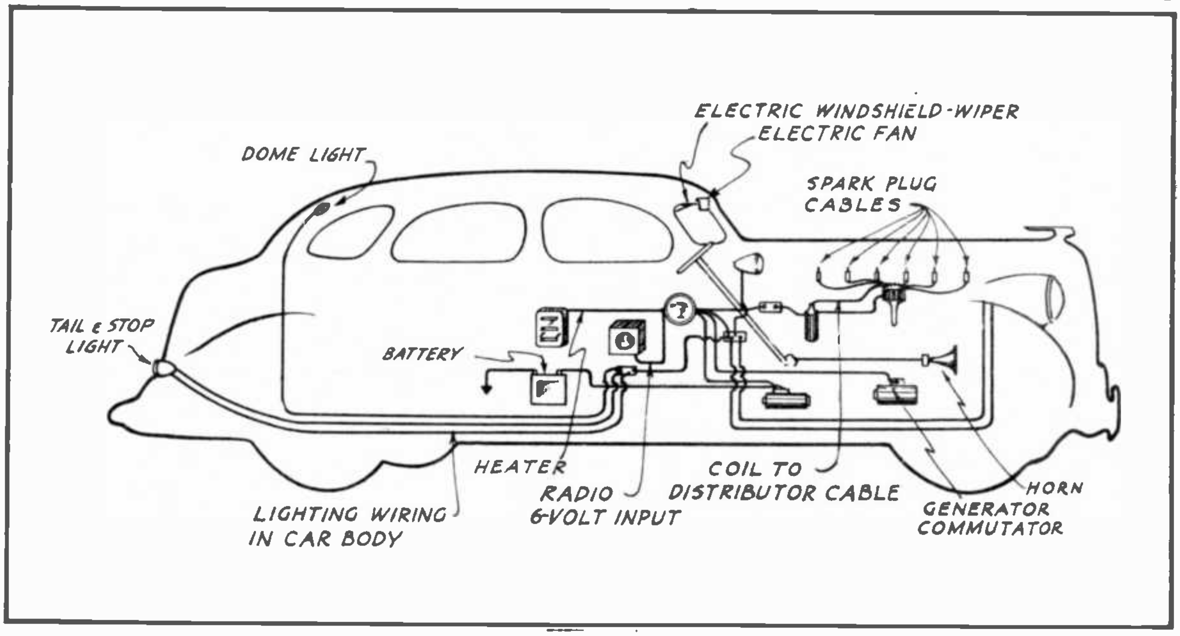

FIG. 20
PRINCIPAL SOURCE OF RADIO INTERFERENCE ON THE AVERAGE CAR

ing the volume control to the "full-on" position and tuning the set through the entire broadcast range, while the engine is in operation. If no ignition interference is heard, it indicates that the interference is being picked up by the antenna and can therefore be eliminated by reconnecting the antenna and following the recommendations contained in this lesson.

If interference persists with the antenna disconnected, it may be caused by the control cables being poorly grounded at the point of entrance to the receiver. In such case, slip back the control cables, scrape the surface of the metal and reinstall the assembly securely by tightening the set screws.

If the noise continues, stop the engine and note the performance of the set. Then, if the noise still persists, it has its origin in the receiver itself.

RADIATION FROM IGNITION SECONDARY

Each time that a spark occurs at the gap of a spark plug, high-frequency oscillations are set up. Each spark plug acts as a small broadcasting station and radiates "signals" to the radio antenna as illustrated in Fig.21.

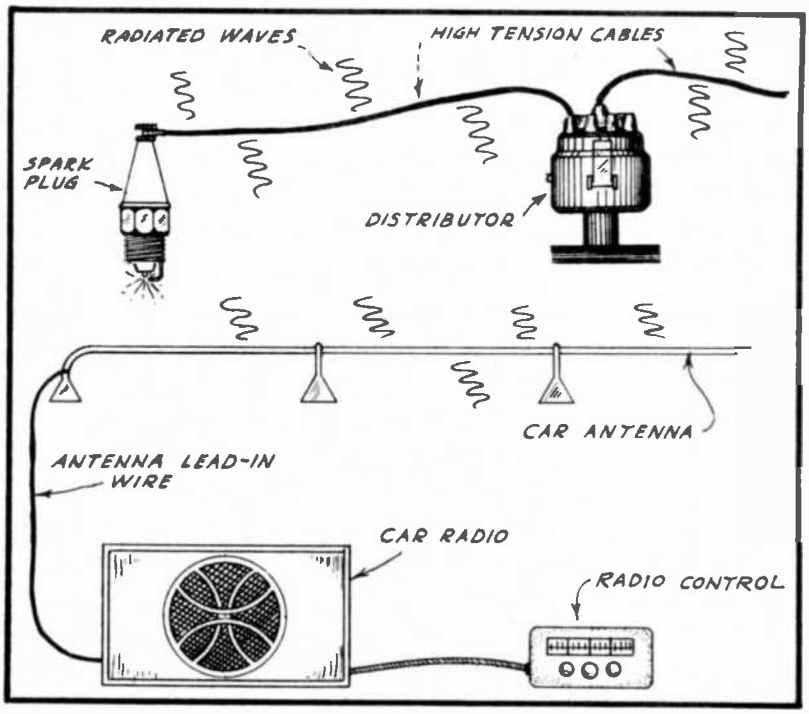

FIG. 21
HIGH-TENSION CABLES ACT AS ANTENNA OF RADIO TRANSMITTER

You will recall that early radio-telegraph sets employed a spark-coil and gap as the means for producing the signal, and that such apparatus is now barred because the signal produced thereby causes interference noises in all nearby receiving sets.

The gap between the rotor blade and the distributor cover segment (see Fig. 22) and all other gaps in the secondary circuit, may cause radio interference.

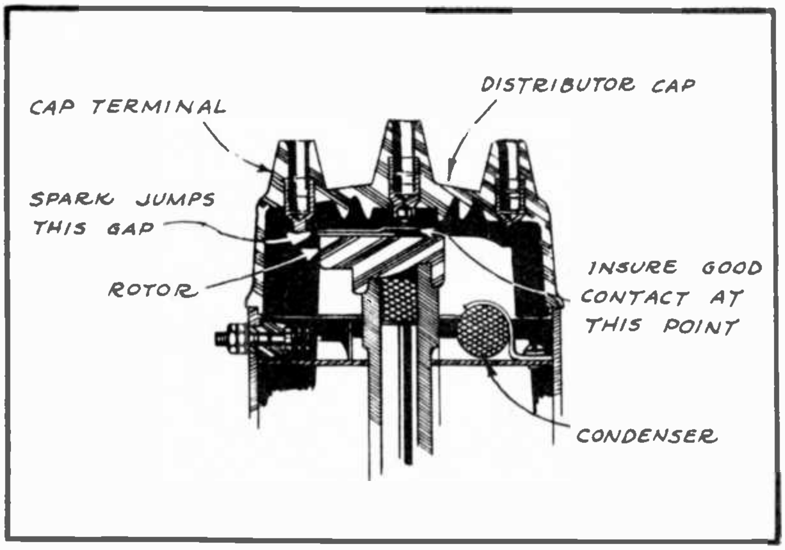

FIG. 22
SECONDARY CURRENT SPARKS ACROSS GAP IN DISTRIBUTOR

Three methods have been used to eliminate spark interference, namely:

1. - The use of carbon or wire-wound suppressors at each spark plug and at the center distributor cover terminal.

2. - Improved shielding of the car's high tension ignition circuits.

3. - Internal filtering within the radio receiver.

SUPPRESSOR TROUBLES

Suppressors are used to quench high-frequency oscillations and thereby prevent the spark from radiating electromagnetic waves. However, carbon suppressors also reduce the heating ability of the spark considerably. Therefore,a more efficient ignition coil is sometimes required to compensate for the engine power that is lost in this way. For the reasons here given, suppressors should be used only as a last resort on the older cars, and should not be necessary on late-model cars.

Carbon suppressors should be tested with an ohmmeter. No matter what the suppressor markings may be, their resistance increases with heat and use. The resistance of each suppressor should be between 8,000 and 10,000 ohms. A few years ago, suppressors with resistance values as high as 20,000 ohms or more were commonly used, but high resistance suppressors will cause the engine to heat abnormally. They are also responsible for hard starting and poor mileage. Open circuited suppressors should be replaced.

Wire-wound suppressors reduce the objectionable high-frequency oscillations through their inductive reactance. Therefore, their d-c resistance rating need not be as great as that of carbon resistors. Such suppressors should be checked for continuity with an ohmmeter or other tester, and if open-circuited, should be replaced. Their usual resistance value ranges from 80 to 200 ohms.

Practically all of the later model receivers have filters incorporated in the antenna circuit of the set. Such filters reduce or eliminate spark interference, as already explained earlier in this lesson. When this device is properly aligned, there is generally no need for spark plug suppressors. If spark interference cannot be eliminated by adjusting the antenna input filter properly, connecting one end of a ground strap to the top of the engine block and the other end to a good ground (preferably the engine dash as shown in Fig. 23) will improve the performance of the receiver materially. The need for suppressors can thus be eliminated in the majority of cases. This ground strap is standard equipment on many of the new cars.

OTHER INTERFERENCE FACTORS TO BE CONSIDERED

Since any "sparks" occurring in the secondary circuit cause interference, it is necessary to eliminate all unnecessary gaps. The high-tension wires should therefore be pushed firmly into the coil and distributor cover terminals; also, the terminal clips should make good contact with the wire. It may even be necessary to solder the clip to the wire to obtain permanent continuity.

Cracked or frayed secondary wires also cause radio interference and loss of engine performance. Therefore, all secondary wiring should be inspected carefully and replaced if necessary.

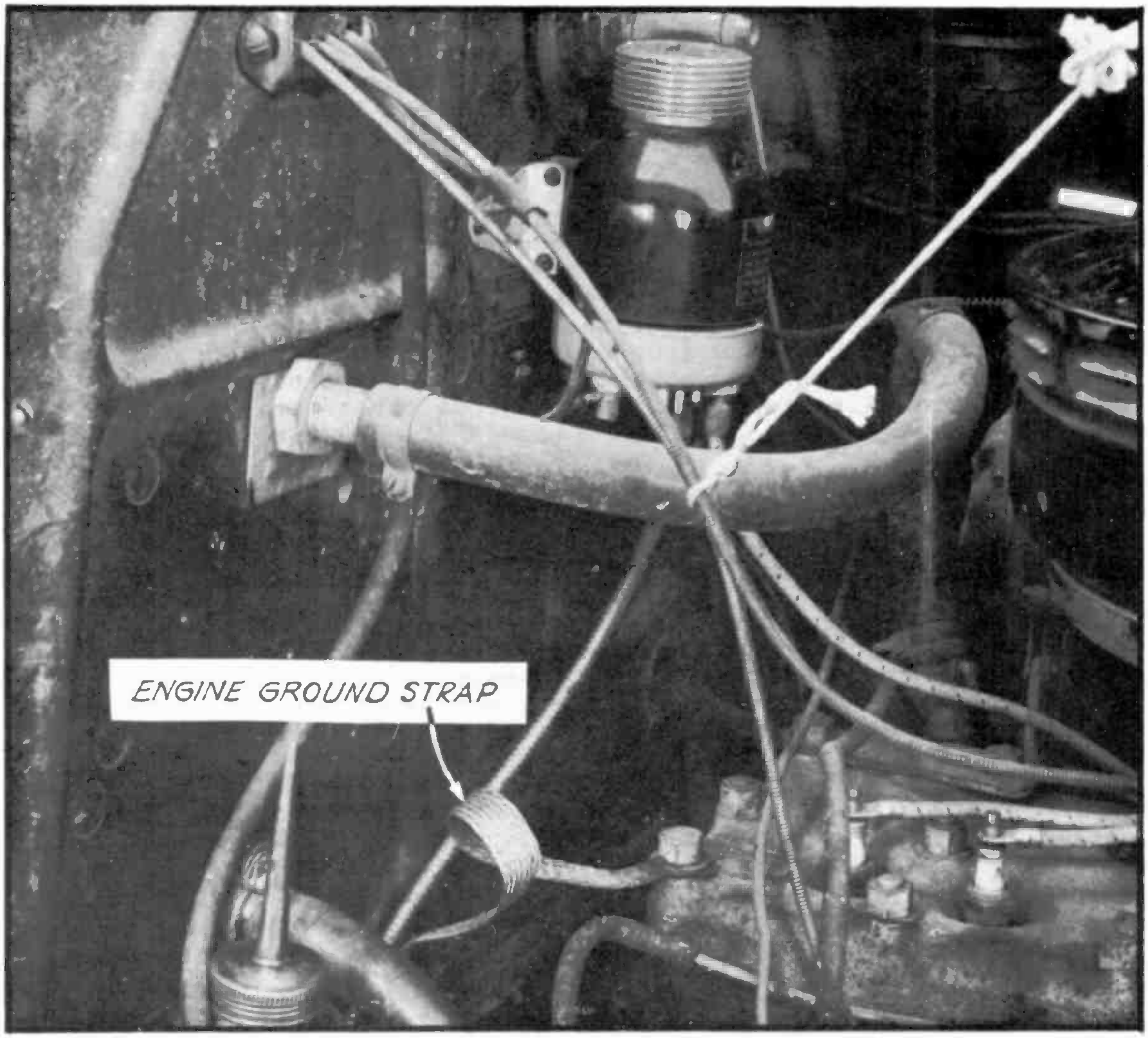

FIG. 23
RADIO INTERFERENCE REDUCED BY LARGE FLEXIBLE GROUND STRAP
CONNECTED BETWEEN ENGINE AND ENGINE DASH

The location of the ignition coil also has some bearing on radio performance. The coil should be mounted on the engine-side of the dash, as far from the receiver as practical. If the receiver is mounted on the left side of the car, for example, the coil should be mounted on the right side. However, the coil should never be mounted near the exhaust pipe or exhaust manifold, otherwise it will be damaged by the excessive heat. (Cooperation between radio manufacturers and car manufacturers has made movement of the coil unnecessary in practically all late-model cars.)

REDUCING RADIO INTERFERENCE ORIGINATING IN THE CAR'S ELECTRICAL SYSTEM

SPARK PLUG CABLES: A high-frequency oscillating current is set up by the discharge across the spark plug points. With sets which do not include internal filter devices, suppressors or shielded high-tension-cables are used to keep such oscillations from reaching the radio.

On installations having a suppressor only in the coil's high-tension lead, improved reception can generally be secured by using shielded high-tension cables or placing a suppressor in each spark plug lead. (Shielded cables are preferred.)

COIL TO DISTRIBUTOR CABLE: A shielded cable or suppressor at this point reduces oscillating current interference that originates from the spark occurring between the distributor cap terminals and the rotor. Peen down the distributor rotor or add solder to reduce this gap to a minimum.

GENERATOR COMMUTATOR: Here, the problem is the introduction of noise producing oscillations within the electrical system, and is caused by sparking at the brushes. To correct this condition,clean the brushes so as to minimize sparking and connect the terminal of a condenser's lead wire to the battery-side of the generator cutout, and ground the condenser case to the generator housing. (A 0.25-mf condenser is generally suitable for this purpose.) If the noise persists when idling the motor, install a second condenser across the generator side of the cutout. Never connect a condenser to the "F"(field) wire of a generator.

HORN: Sparking at the horn armature causes interference that finds its way into the receiver. Connecting a 0.25-mf condenser across the horn terminals will usually eliminate such interference. Some horns that draw a heavy current may require a condenser of larger capacity.

RADIO 6-VOLT INPUT: Interference may be picked up by this lead, even though all electrical units are properly filtered. In this case, the disturbance is frequently caused by loose electrical connections, insecurely grounded electrical accessories, or static discharges caused by friction at some point on the car.

LIGHT-CIRCUIT WIRING IN CAR BODY: Miscellaneous "hash" or noise, finding its way into the electrical system,may be radiated from every wire that is not enclosed in a metal shield. Dome-light, stop-light, tail-light, and other wiring that passes near the radio antenna causes such interference to enter the receiver. By properly filtering these wiring cables with capacity or capacity-inductance units, they may be cleared of radio-frequency radiation.

The offending wires may be located by disconnecting, one at a time, each cable at the point where it connects to the light switch,ammeter,or starter switch. Having found a wire that, upon being disconnected, eliminates the interference, reconnect it and connect a .25-mf condenser between it and ground. In some cases, condensers of various values should be tried to determine which value gives best results.

ELECTRIC WINDSHIELD WIPER, ELECTRIC FAN, or HEATER: Sparking at the commutator and switch points of such accessories causes interference that may be eliminated by connecting a condenser between the hot terminal of the appliance and ground. The condenser should be installed as close to the device as possible. The larger the capacity of the condenser used, the more effective will be the elimination of noise.

Most radio engineers agree that the radio input wire which is usually attached to the ammeter, will, if run directly to the battery, reduce tube interference and "cross talk." The reason for this is that the wire extending from the ammeter to the battery offers too much resistance as a battery common, no matter how small this resistance may be apparently.

RADIATION FROM IGNITION PRIMARY

At the instant the breaker points in the distributor assembly open, oscillations are set up in the primary circuit. Filters are commonly used to eliminate this interference. In this case, a bypass condenser should be connected between the car ammeter and ground, and a similar condenser between the dome-light circuit and ground, if a roof antenna is employed. It may also be necessary to use a bypass condenser from the ammeter side of the coil to ground. However, do not connect a bypass condenser to the coil terminal that is connected to the breaker points, as poor engine performance will result from such a connection.

If the distributor housing is not grounded effectively, intermittent interference will be heard. The distributor housing may be grounded by soldering one end of a wire to the metal of the distributor housing, and connecting the other end of the wire to the frame of the car. Be sure to scrape the metal clean at the point where the connection is being made. If the distributor is equipped with a vacuum control, it is important that the flexible primary lead wires are in good condition. The movement of the breaker plate causes these wires to flex continually, which may break them or rub off the insulation.

Some cars are equipped with a rheostat-type gasoline level indicator. The movement of fuel in the tank causes the rheostat arm to move continually and sets up an irregular scratching or squawking interference. This type of interference can be eliminated by connecting a 0.5-mf condenser between the gasoline tank terminal and the car-frame.

In Fig. 24 is shown the general

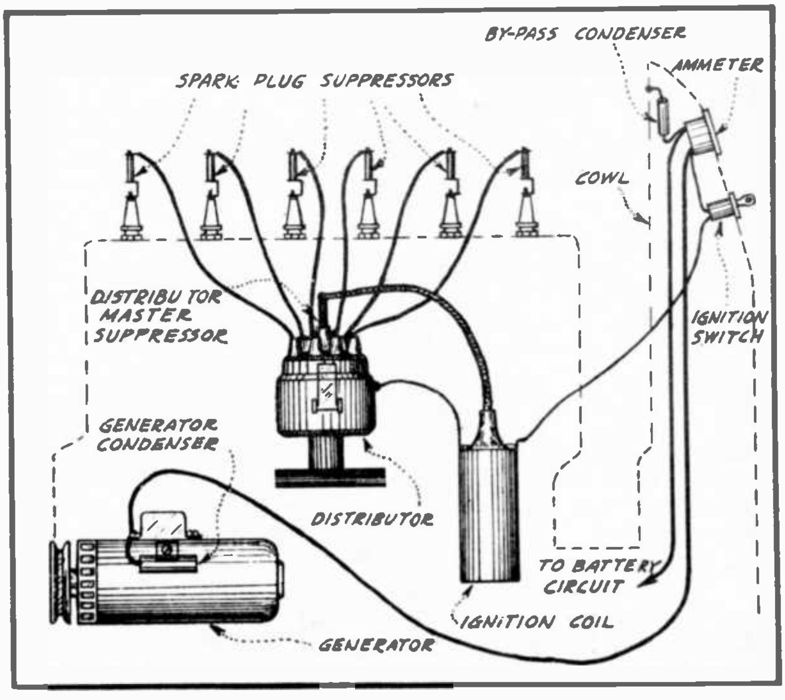

FIG. 24
FILTERING THE IGNITION SYSTEM

layout of a typical auto ignition generator circuit, illustrating the placement of suppressors and bypass condensers that are most generally necessary to reduce engine interference noises to a minimum.

RADIATION FROM FREE METAL MEMBERS

One terminal of the car's storage battery is usually connected to the frame of the car. In this case, the entire metallic mass of the car becomes the ground or return-circuit.

If any part of the car, such as the hood or the dash, is not grounded, a static charge will develop on this part and cause radio interference. To eliminate such interference, ground all metallic parts to the engine or car frame. The engine should be grounded to the frame with a flexible metal strap as already explained and illustrated in Fig. 23. If the car is already equipped with this grounding strap, be sure that it is not broken and that its connections are tight and free from rust.

THE RECEIVER ITSELF MUST BE WELL GROUNDED: This is extremely important. The receiver should be grounded directly to the frame of the car, or to the cowl. The cowl in turn should be well grounded at several points to the frame of the car. Ground connections should be soldered. A rusty bolt or screw does not make a good electrical connection.

Considerable radio interference can be eliminated by improving the ground connections at the following points:

1. - Set mounting bolts.
2. - Antenna lead-in shield. (Ground the shield to the cowl or frame of the car -- not to the instrument panel or running board.)
3. - Steering column -- especially,if the distributor suppressor is omitted.
4. - Rear edges of hood. (This is especially important if a roof-type or ornamental antenna is used.)

   This ground connection may be made by lifting the fabric hood beading and wrapping flexible bonding material around the beading for a distance of about 3 inches, and then soldering both ends to the cowl. Paint should be scraped from the inner side of the hood where the hood rests on the bonding material.

A sharp screwdriver offers a convenient means for testing the effectiveness of a ground connection. The screwdriver should be wedged between loose members so as to ground them, at which time any decrease in radio interference should be noted. For example, if a decrease in interference is noted when the screwdriver is wedged between the steering column and the steering column supporting bracket, then the steering column should be grounded at that point with a flexible bonding conductor. The connections should be soldered.

WHEEL AND TIRE STATIC

Wheel and tire static produces an intermittent rasping or clicking noise in the radio. At some driving speeds it may even become a steady hiss. This form of interference is most pronounced when the car is driven over an asphalt or concrete pavement, but may also occur when the car is driven over dry gravel or bricks. The noise will often stop during periods of high humidity, or when the road and wheels are wet. When the brakes are applied, noise is usually eliminated.

Wheel static is generally eliminated by grounding the wheels. This may be done at the rear wheels by removing the wheels and placing around the axle two turns of heavy spring brass wire so as to provide an electrical contact between the stationary brake housing and the wheel.

Wheel static may be eliminated at the front wheels by removing the large hub-cap and the grease cap, inserting into the grease cap a circular cone brass spring, with the large turns placed in the cap, as shown in Fig. 25. When the grease cap is pressed in position, the point of the spring will bear against the end of the axle, thus grounding the wheel to the axle. This should be done at both front wheels. (Such springs can be purchased from most automobile accessory houses.)

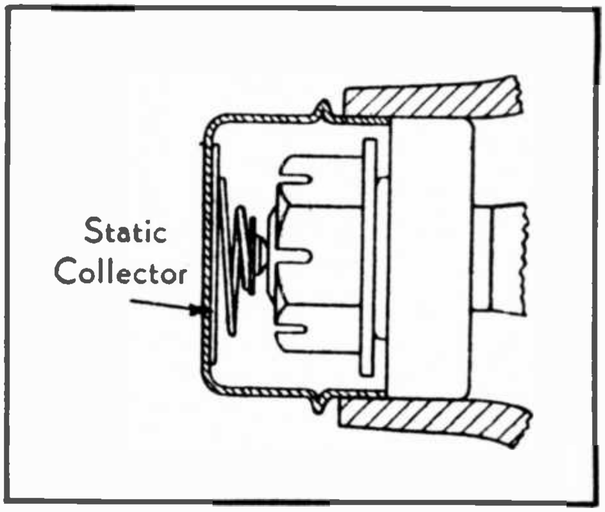

FIG. 25
FRONT WHEEL STATIC COLLECTOR

Wheel static may also be caused by loose brake lining rivets contacting the brake drum, by metal particles lodged in the brake lining, by patches that have been vulcanized on the tube or casing with metal-base glue, by accumulations of rust on removable rims (insulating the rim from the wheel), and by use of metallic balances in the bottom of the tire casing to serve as a valve-stem balance.

SUMMARY

Upon summarizing our discussion relative to radio interference, we come to the following conclusions:

1. - Make sure that the receiver, antenna, and lead-in have been properly installed.
2. - If suppressors are used, check each suppressor with an ohmmeter. The resistance of carbon suppressors should be uniform, and between 8,000 and 10,000 ohms. The resistance of wire-wound suppressors should not be over 200 ohms. Push all high-tension cables firmly into the distributor cover towers and check continuity with an ohmmeter.
3. - Check all bypass condensers. Make sure that a bypass condenser is installed between the ammeter and ground. (Bypass condensers should have a capacitance of 0.25 mf or greater.)
4. - Improve grounds, particularly at set-mounting bolts, steering column, filter condensers, rear edges of hood, and at other free members.

WHEN SUPPRESSORS ARE NOT REQUIRED

Another point which should be considered at this time is that suppressors are used on many cars where they are not actually necessary. In such cases, they have generally been installed through ignorance by some technician or garageman.

The later model radios are so designed that radio suppressors are not generally necessary. This is not usually known -- and, believing that every radio-equipped car should have suppressors, uninformed mechanics frequently install them when they are not really needed. Consequently, the mere fact that you find suppressors on a car does not necessarily mean that they should be used. When in doubt about this matter, check the make and model of radio, and if it is so designed as to eliminate interference, removal of the suppressors will improve engine performance.

ANTENNA RESONATOR OR "BOOSTER" DEVICES

In a previous lesson on automobile receivers, you were shown various forms of early antennas, such as the roof, built-in, and running-board types -- all of which were of the high-capacity type, but of widely differing characteristics. In order for the receiver to perform at its best in such cases, it was necessary to match the receiver to the particular antenna being used.

Many receiver manufacturers made some provision in their sets for this matching purpose; however, a great many did not. In the latter case, it was usually necessary for the set-owner or installation technician to provide a matching means. Usually, this was accomplished by using a device known as an "antenna resonator" or "antenna booster," which was connected in series with the antenna lead-in, as shown in Fig.26. Here, you are shown two typical antenna resonator circuits.

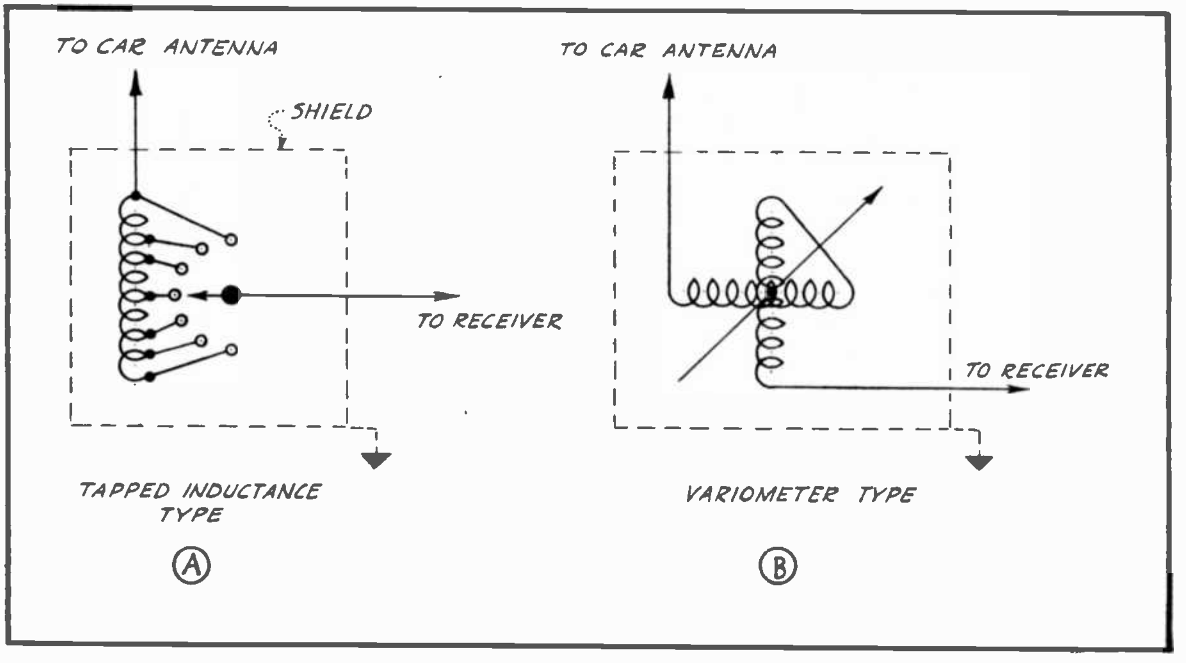

FIG. 26
CIRCUIT OF AUTO ANTENNA RESONATOR OR "BOOSTER"

The unit illustrated at (A) consists merely of a tapped inductance, providing a choice of seven inductance values. The device illustrated at (B) is nothing more than a simple variometer-coupler. Each of these coupling devices is housed in a metal shield-can that is grounded to the car. Fig. 27 will familiarize you with the actual appearance of the device.

With one of these units inserted in series with the antenna, it was possible to realize a "boost" or gain in signal strength of from 50 to 500 per cent over a fairly wide band of frequencies. It was for this reason that these devices were commonly referred to as "antenna boosters." However, all that they actually accomplished was to more accurately match or resonate the antenna to the set, and thereby allowed a maximum transfer of signal energy from the antenna to the receiver. This resulted in "boosting" the antenna-signal so far as the set-owner was concerned. In fact, in some cases, an r-f stage of amplification was incorporated in the booster to provide an additional increase in signal strength.

Such devices were generally installed as a separate unit within the car's driving compartment, where they would be easily accessible to the operator for adjustment to insure best possible all-around performance.

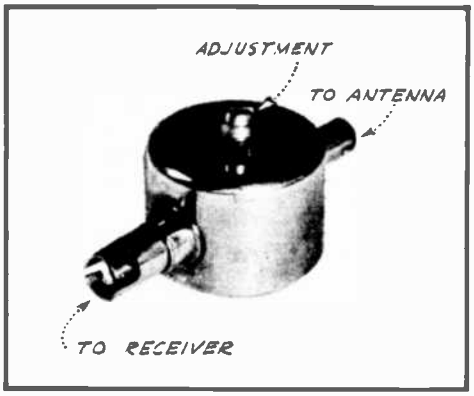

FIG. 27
AUTO ANTENNA RESONATOR

Vertical or fish-pole antennas have become standard equipment in practically all of the later type of receiver installations. This practice of standardizing the type of antenna being used created certain well defined requirements for receiver manufacturers to meet, and has made it possible for them to incorporate antenna-matching characteristics directly into the antenna-input filter system as described earlier in this lesson. Thus, the need for an accessory antenna booster unit has been eliminated in nearly all cases.

Although the antenna booster or resonator has no application when late-model receivers with a good antenna filter-input are used in conjunction with a fish-pole antenna, you should, nevertheless, be acquainted with them. You may at some time have occasion to work on an older model auto-radio with which such a device is being used, or you may be able to improve reception with an old set by installing such a device.

The instruction given you in these two lessons treating with automobile receivers has served to acquaint you with the constructional features, operating principles, and installation problems of automobile receivers and their related equipment. You will find this knowledge to help you greatly to cash-in on this profitable branch of the radio business.

****

EXAMINATION QUESTIONS

LESSON NO. 27

1. - Why are the field coils of dynamic speakers, as used with automobile receivers, of lower resistance values than those used in a-c receivers?

2. - What is "vibrator-hash," and how may it be prevented from causing disturbances in the receiver?

3. - (a) Of all the antenna-input filters described in this lesson, which would you say is the most efficient?
   (b) State the reason for your answer to part (a) of this question.

4. - What is the chief reason why antenna-input filters are able to "separate" the desired radio signals from interference noises originating in the car?

5. - Why are "antenna boosters" used in some auto receiver installations?

6. - What three methods have been used to eliminate spark interference that has its origin in the car's high-tension ignition circuit?

7. - How may wheel static be eliminated?

8. - How may interference noises, as produced by the car's generator, usually be eliminated?

9. - If interference noises are being reproduced by the speaker of an automobile receiver, how would you determine if such noises originate within the receiver itself or are being picked up by the antenna?

10. - What precautions should be taken in the use of carbon suppressors?

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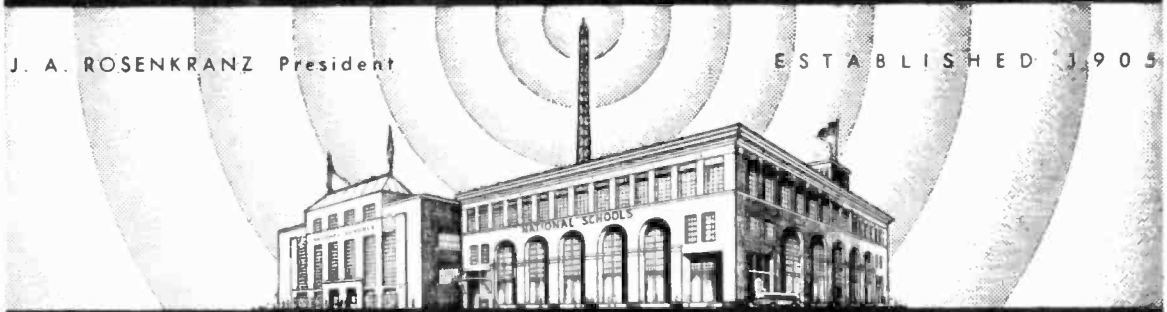

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LESSON NO. 28

SHORTWAVE RECEIVERS AND CONVERTERS

Standard shortwave receivers are designed to tune from 1600 kc to approximately 30,000 kc, or from 187.5 meters to about 10 meters. Wavelengths below 10 meters, in what is known as the ultra-shortwave or ultra high-frequency band, are also being utilized; but we are not concerned with them in this lesson.

In Fig. 2 is shown a graphical comparison between the standard shortwave band and the standard broadcast band. You will no doubt be impressed by the small portion of the spectrum occupied by the broadcast band as compared to the shortwave band. Notice in this illustration how the frequency increases rapidly as we approach the lower wavelengths. That is, the shorter the wavelength, the greater will be the frequency. This is an important fact to remember.

Fig. 2 also shows that the frequencies included in this shortwave band extend from 1600 to 30,000 kc -- these higher frequencies are responsible for the remarkable results that can be obtained on long-distance reception. You have probably already heard of

FIG. 1
HIGH-QUALITY SHORTWAVE RECEIVER

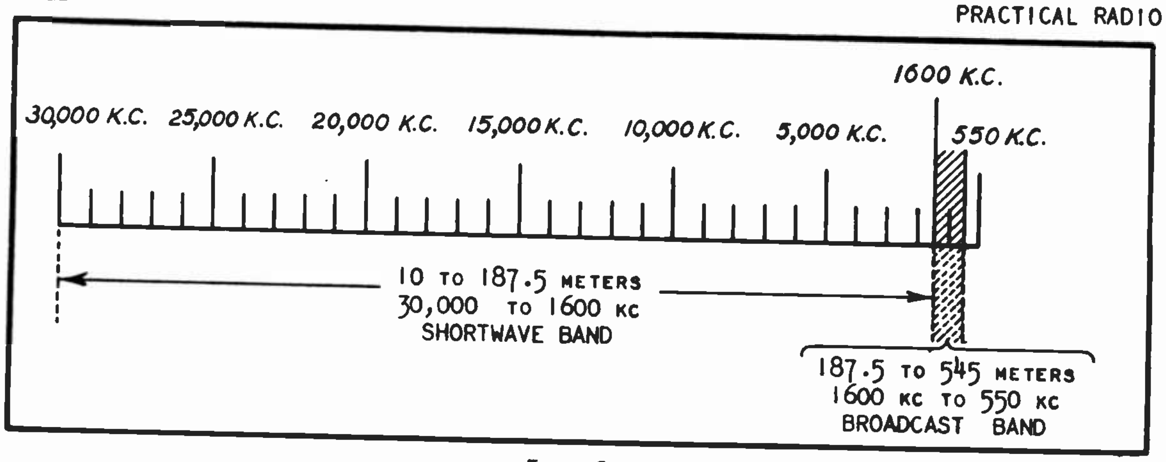


FIG. 2
COMPARISON OF BROADCAST AND SHORTWAVE BANDS

many instances where a small one or two-tube shortwave receiver has "picked up" stations in all parts of the world, which is unheard of in the case of standard broadcast reception.

Let us now investigate the nature of short waves more thoroughly and thus see why they are particularly suitable for long-distance communication.

WAVE REFLECTION AT HIGH FREQUENCIES

Two receiving stations are shown in Fig. 3 -- each receiving signals from the same transmitter. As you already learned, the transmitter radiates waves in all directions. Some of these waves spread outward, close to the earth's surface -- these are known as GROUND WAVES. All obstacles as trees, buildings, mountains, etc., absorb a certain amount of this signal-energy; therefore, the ground-wave signal becomes weaker as it travels farther from the transmitter. Finally, it dies out altogether.

The higher the frequency of transmission, the greater will be the effect of absorption upon the ground-wave. For this reason, short wave reception was at one time regarded as being impractical for long-distance communication. For this same reason, all amateur transmitters

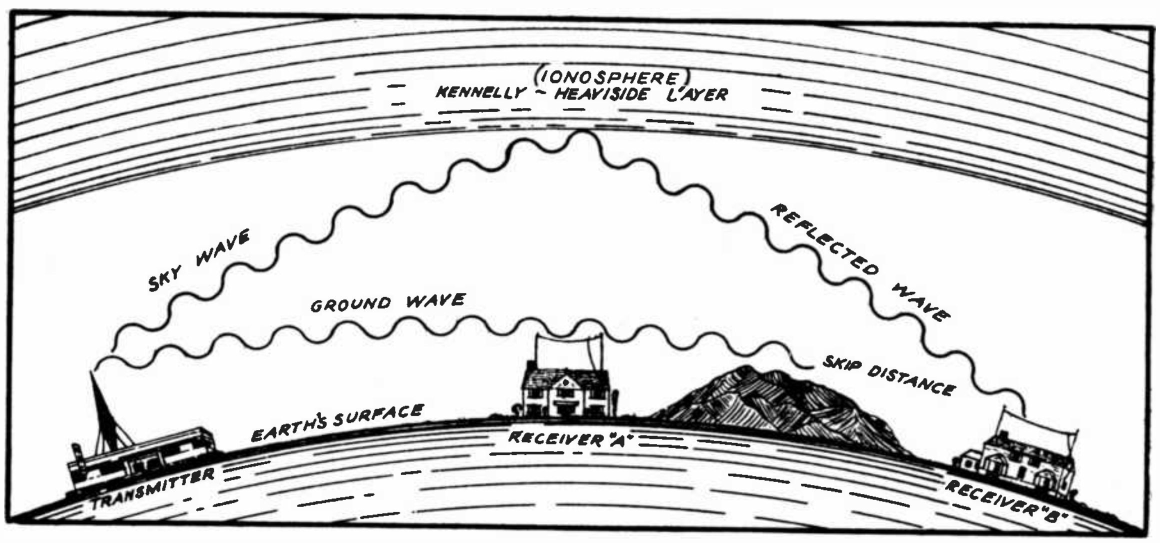


FIG. 3
EFFECT OF KENNELLY-HEAVISIDE LAYER ON RADIO WAVES

were assigned to the higher frequencies or shorter wavelengths, while the longer wavelengths were reserved for commercial use. However, amateur radio enthusiasts soon discovered that they could cover a greater distance with less power on the shorter wavelengths than was heretofore possible on the longer broadcast wavelengths.

Early experiments by amateur radio operators also proved that the theories of wave propagation had not yet all been fully solved. This led to additional research by prominent scientists and radio engineers, from which were developed our present theories of wave propagation and reflection.

By again referring to Fig. 3, you will observe that part of the transmitter's radiated energy "shoots" upward into space at a rather steep angle -- we call this the SKY WAVE. The sky wave does not continue its skyward travel indefinitely, but is reflected back toward the earth by the Kennelly-Heaviside layer in much the same manner as light is reflected by a mirror. The Kennelly-Heaviside layer (named after the two scientists who discovered its existence) is a blanket of ionized (decomposed) gas comprising our atmosphere, and completely encircles the earth at an estimated height of approximately 150 miles.

Notice in Fig. 3 that receiving station "B" is not influenced by the ground wave, but receives its signal energy directly from the sky wave which is reflected back to earth by the Kennelly-Heaviside layer. The latter portion of the sky wave is called the REFLECTED WAVE.

For reception at great distances,shortwave receivers depend upon the reflected wave rather than on the rapidly dissipated ground wave. Standard broadcast reception,on the other hand, is primarily dependent on the ground wave. This explains why the phenomena of wave reflection is of such great importance in shortwave work.

SKIP-DISTANCE

Another important point to observe in Fig. 3 is that along the earth's surface, between the ending of the ground wave and the point where the reflected wave again reaches the earth, we have a space in which no waves are close enough to the ground so as to act upon a receiving antenna. This is a so-called "dead spot" for radio reception, and we refer to this interval as the SKIP-DISTANCE.

Under average conditions, no signal will be picked up by a receiver that is located within this skip-distance area. However, it will reappear at a point beyond that where the wave first strikes the earth, because the wave is reflected back and forth repeatedly between the ground and the Kennelly-Heaviside layer (or ionosphere) as it travels farther from the transmitter.

Fig. 4 illustrates more clearly how the skip-distance occurs periodically during the wave's progress through space. Notice in this illustration that the 40-meter wave is shown as striking the earth at intervals of 400 miles, and that a skip-distance occurs periodically between these points. It is to be noted that the distances specified in Fig. 4 are only arbitrary values, as they vary considerably with shifting of the Kennelly-Heaviside layer, the type of antenna used at the transmitter, atmospheric conditions, geographic conditions, etc.

Another important point to be learned from Fig. 4 is that the skip-distance varies at different frequencies, and that it is greater for the shorter wavelengths (higher frequencies). A comparison between the propagation of the 20, 40 and 200 meter waves in Fig. 4 will illustrate this.

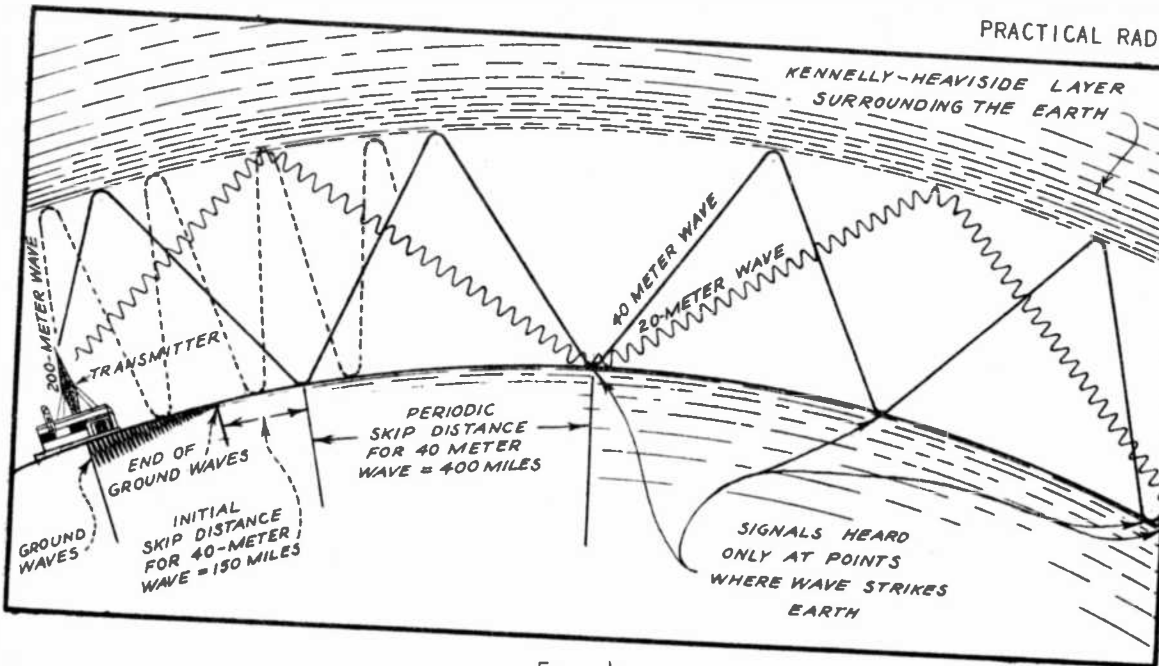


FIG. 4
SKIP-DISTANCE VARIES AT DIFFERENT FREQUENCIES

THE EFFECT OF THE SUN'S RAYS UPON RADIO WAVES

From your studies of radio tubes, you will remember that heat causes electrons to be emitted from the filament. A similar condition occurs at the Kennelly-Heaviside layer, where the heat of the sun's rays break up the molecules of the atmosphere, freeing a tremendous number of electrons. This condition causes much of the signal-energy to be attenuated (reduced in strength) by the resulting layer of ionized air; therefore, only a small percentage of the sky wave is reflected. The latter causes a decrease in reception at distant points.

At night, the heating effect upon the layer of ionized air is less. Therefore, less attenuation and more reflection occurs at the Kennelly-Heaviside layer during darkness, and thus increases the reception at distant points.

Another interesting fact concerning the Kennelly-Heaviside layer is that it is closer to the earth during the daytime or warmer weather than during cooler temperatures. For this reason, the skip-distance for a given wavelength is not as great during warmer temperatures as when the weather is cooler.

This knowledge is of value to you, as it will help you materially to analyze the reasons for the many different peculiar effects which are always encountered in shortwave communication. Having investigated the nature of the shorter wavelengths, let us now proceed with a discussion of shortwave receivers.

SHORTWAVE RECEIVERS

In Fig. 5 you are shown the circuit diagram of a simple two-tube regenerative t-r-f type, shortwave receiver, designed for the use of headphones. Upon studying this circuit, you will observe that it is essentially the same as that of an ordinary two-tube broadcast receiver, and that it consists of a detector and audio stage.

Even though shortwave receivers are regarded by the general public as being rather mysterious in their construction and operation, when compared to the average broadcast receiver, the same principles are nevertheless employed in both of these receivers. This means that all of the radio principles which you have learned about broadcast receivers can be applied equally well to shortwave receivers.

The essential difference in the operation of shortwave receivers, as compared to standard broadcast receivers, is that the r-f signals handled by shortwave receivers are of a much higher frequency order than are those handled by broadcast receivers. Therefore, even though the parts of these two receivers are fundamentally the same as to operation, the construction of the shortwave parts must nevertheless be such as to enable them to operate effectively at higher frequencies. Since the radio frequency energy is not used in the audio stages of a receiver, it is obvious that the audio section of shortwave receivers can be basically the same as in conventional broadcast receivers. Thus, it is apparent that the chief difference between t-r-f type shortwave and standard broadcast receivers exists only in the tuned r-f input and detector circuits.

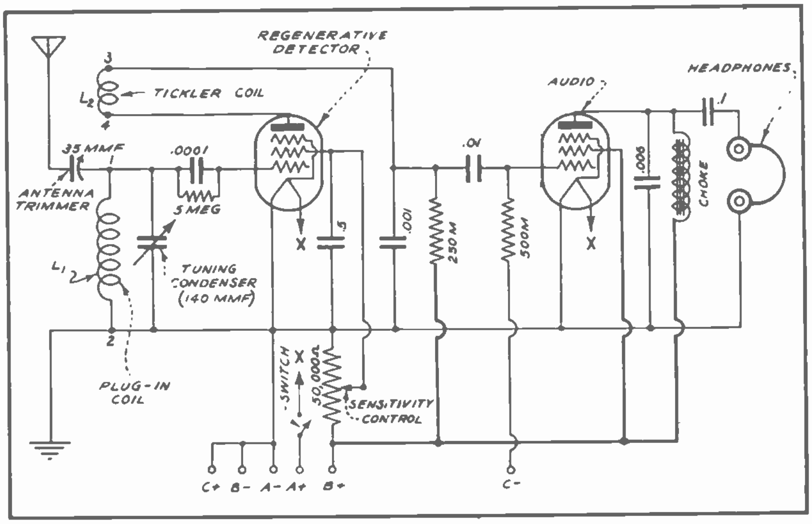


FIG. 5
TWO-TUBE BATTERY-OPERATED SHORTWAVE RECEIVER

Before discussing in detail the circuit illustrated in Fig. 5, it is well that you first become familiar with the parts in general, as used in such circuits. We will begin this description of parts with the tuning condenser.

SHORTWAVE TUNING CONDENSERS

During your studies of tuned-radio-frequency circuits, you learned that the frequency to which the tuned circuit responds is dependent upon the capacity of the tuning condenser and the inductance of the coil which is used with the given condenser. You also learned that the tuned circuit will respond to higher frequencies if the capacity of the tuning condenser is reduced, or else the inductance of the coil reduced. If this condition is carried still farther, so that the capacity of the tuning condenser and the inductance of the coil are both decreased, the tuned circuit will respond to still higher frequencies. This is exactly what is done in shortwave receivers.

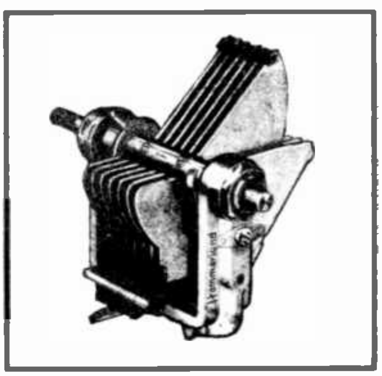


FIG. 6
SHORTWAVE TUNING CONDENSER

For example, in Fig. 6 you are shown a typical tuning condenser as used in shortwave receivers. Notice that it consists of fewer plates than found in the conventional tuning condenser for broadcast purposes, and that these plates are made of heavy stock, with considerable separation between them. This means that the shortwave tuning condenser has less maximum capacity than the standard broadcast type tuning condenser.

Due to high frequencies handled by shortwave receivers, we are continually faced with the problem of preventing these flighty currents from leaving their intended circuit or path, and darting in all directions toward adjacent parts. High-grade insulation is used on the better quality shortwave type tuning condensers to reduce the probability for any such undesirable losses. This also holds true of other parts that handle r-f energy.

SHORTWAVE TUNING COILS

The study of shortwave coils is most fascinating, as many interesting problems arise in connection with them. For instance, tuners for standard broadcast work are only required to cover the band of frequencies extending between 550 and 1600 kc. This is equivalent to a frequency range of but 1050 kilocycles that the tuner must cover in order to pick up every station within the broadcast band.

The shortwave band, on the other hand, includes all frequencies between 1600 kc and 30,000 kc -- a frequency-range of 28,400 kilocycles. Therefore, if full coverage is to be obtained, shortwave receivers must tune over a band that is approximately twenty-seven times as great as that covered by standard broadcast receivers.

When constructing broadcast receivers, it is a simple matter to design a coil that will cover the broadcast range of 1050 kilocycles when tuned by a standard tuning condenser, but to cover the entire shortwave band (a range of 28,400 kc) with a single coil-condenser combination is not such a simple problem. This is why shortwave receivers generally employ a combination of several sets of r-f coils to cover the complete wave-band.

PLUG-IN TYPE SHORTWAVE TUNING COILS AND THEIR APPLICATION

A typical plug-in type shortwave coil is shown in Fig. 7. Notice that this coil is wound on bakelite tubing, having longitudinal ribs that are also made of bakelite. The winding is wound around this coil form in such manner that the ribs hold the winding away from the main body of the coil-form.

FIG. 7
PLUG-IN SHORTWAVE COIL

This method of construction limits the area of coil-form surface that actually contacts the winding and thus reduces the dielectric losses of the coil that would otherwise be quite noticeable at the higher frequencies. Also notice in Fig. 7 that a slight air-space is allowed between adjacent turns of the winding. Such a coil is said to be space-wound. Space-winding reduces the distributed capacity of a coil and facilitates tuning the circuit to the higher frequencies.

Another interesting fact concerning the construction of shortwave coils is that bare copper wire and plain enameled copper wire are preferable to copper wire having a cloth insulation (silk or cotton). Enamel-coated copper wire is most generally used for shortwave receiver coils. The enamel coating and spacing, together, offer adequate insulation between adjacent turns of the winding.

Wire of rather large size is generally used for coils that are included in the tuned circuits. This is done to keep the resistance of the tuned circuit to as low a value as possible, thereby reducing extraneous losses to a minimum and thus increasing the receiver's efficiency.

Also notice in Fig. 7 that the coil-form is fitted with a standard four-prong tube base. The ends of each of the windings are connected to the prongs within the form, so that the coil can be installed in the tuning circuit by plugging it into a standard four-prong socket. In this way, various coils can be interchanged conveniently to tune over the entire shortwave band.

In Fig. 8 is shown a set of four plug-in coils, as frequently used to cover the shortwave bands. When using a .00014 mf tuning condenser, coil #1 of Fig. 8 will tune through that portion of the shortwave band between 17 and 41 meters, coil #2 will cover from 33 to 75 meters, coil #3 from 66 to 150 meters and coil #4 from 135 to 270 meters. Notice how the ranges of the various coils overlap so as to insure complete coverage of the entire shortwave band.

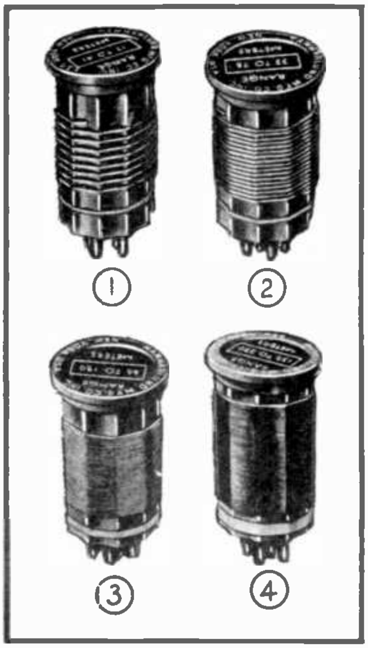


FIG. 8
SET OF PLUG-IN COILS

Cheaper shortwave coils are sometimes wound on forms made of special fiber, whereas forms made of isolantite are frequently used for the more expensive shortwave coils. Isolantite is similar in appearance to porcelain, and possesses excellent dielectric properties.

CIRCUIT DETAILS: Upon again referring to Fig.5 you will observe that grid condenser and leak detection is used in combination with regeneration. This is the common practice in many t-r-f shortwave receivers because this arrangement provides good sensitivity with a minimum number of tubes. This feature also makes possible a sensitive receiver at low cost.

A single 140 mmf (.00014 mf) variable tuning condenser is used in the circuit diagrammed in Fig.5. This condenser is connected across winding L-1, thereby serving as the only tuning control. A 50,000 ohm potentiometer is connected in the B+ lead of the detector tube's screen-grid circuit; by thus varying the screen-grid voltage of this tube, it serves simultaneously as a regeneration and volume control. (Increasing the screen-grid voltage will increase regeneration and consequently the volume.) This type of regeneration control operates quite smoothly and is therefore used extensively on receivers of this type.

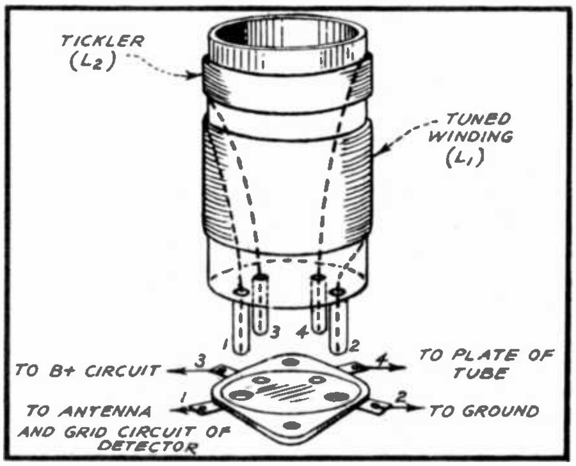


FIG. 9
PLUG-IN COIL BASE AND SOCKET CONNECTIONS

The 35 mmf condenser, which is connected between the antenna terminal and coil L-1, is of the semi-variable trimmer type. That is,its capacity can be varied within certain limits by means of a bakelite screwdriver. Its purpose is to more nearly resonate the antenna to the signal-frequencies being received. This feature serves to somewhat increase the volume of signal reproduction.

The numbers 1, 2, 3 and 4 in Fig. 5 indicate the corresponding prongs and socket terminals for the plug-in coil illustrated in Fig.9.

When constructing shortwave receivers, still more care is exercised in placing the parts than is the case when constructing standard broadcast receivers. The chief reason for this is that the higher frequencies are more difficult to handle, having a natural tendency to enter ground or grounded structures whenever possible. Extraneous coupling between parts also occurs more readily when the circuits operate at higher frequencies. Because of these factors, considerable space is allowed between coils,condensers,etc.,on shortwave receivers.

A ONE-TUBE, SHORTWAVE, REGENERATIVE RECEIVER

In Fig.10 is shown the circuit diagram of a simple but efficient one-tube regenerative shortwave receiver which is also designed for headphone reception. Regeneration and volume are in this instance also controlled by varying the screen-grid voltage of the tube. The values of all the parts are indicated directly on the diagram so as to better acquaint you with the constants typical of such circuits.

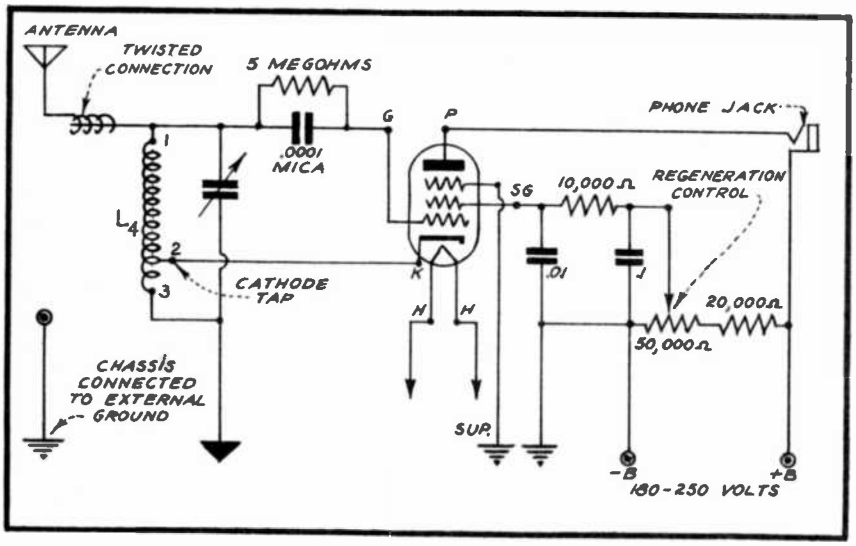


FIG. 10
ONE-TUBE REGENERATIVE SHORTWAVE RECEIVER

No primary winding is used for the antenna input in this receiver,the signal being fed from the antenna thru a lead that is twisted a few times around a piece of wire which in turn is connected to the grid end of tuned winding L-4. The latter forms part of the detector circuit. The complete winding of L-4 (terminals 1 to 3) corresponds to the tuned secondary winding of a conventional shortwave r-f transformer, and it is tapped at point 2 so that the section between 2 and 3 serves as a tickler or regeneration coil. A set of forms with four-prong bases can be used to affect the plug-in feature. The coil connections on each form will then appear as detailed in Fig. 11.

In the regenerative detector circuit shown in Fig. 10, no separate feedback coil is employed. Instead, the feedback coil is that portion of the tuned winding which is included between the tap and the bottom end of the coil. In this type of circuit, the screen element of the tube acts as a plate, and together with the control grid and cathode, forms a triode oscillator.

Considering the operation of this portion of the circuit first, we find that any signal variations flowing in the tuned coil will induce corresponding voltage variations in the cathode circuit of the tube. Now, as the plate circuit of the tube is completed through the cathode circuit, and as the cathode circuit is also part of the grid circuit, feedback will occur and promote a condition of self sustained oscillation, the same as though the plate circuit were coupled to the grid circuit of the tube through a tickler coil. The intensity of this feedback voltage will depend upon the potential applied to the screen grid which now serves as the plate of the oscillator section. As only regeneration is desirable, this voltage is kept just below the point where it produces oscillation.

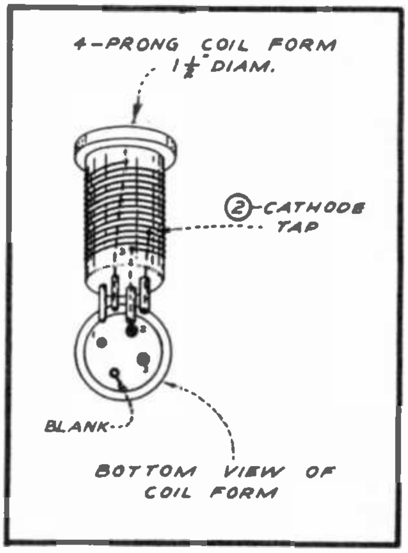


FIG. 11
COIL CONNECTIONS

Many of the electrons which are attracted toward the screen grid will pass right on through this electrode because of its mesh construction, finally reaching the more highly charged true plate. Thus, the true plate is coupled to the oscillator section of the tube through the electron stream within the tube. For this reason, this type of circuit is known as an ELECTRON COUPLED oscillator.

For the circuit diagrammed in Fig.10, the filament supply can be furnished by either a 6-volt storage battery or a filament transformer connected to the 110-volt a-c circuit. Batteries or a B-power unit can be used to supply the B-voltage.

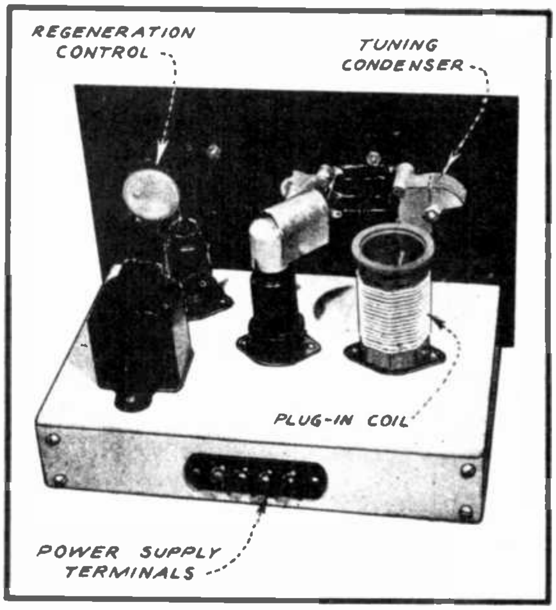


FIG. 12
PARTS ARRANGEMENT OF SHORTWAVE RECEIVER

The arrangement of the parts on the chassis of a simple shortwave receiver is shown in Fig. 12.

SHORTWAVE COIL SPECIFICATIONS

For the convenience of those who may be interested in constructing shortwave coils, we are furnishing in Table I on the following page complete specifications for a set of five coils, from 8 to 215 meters, inclusive. The coil data here given is listed under the headings L_1, L_2, L_3, L_4 and "cathode tap," and corresponds with coils of similar identification used in the circuits diagrammed in Figs.10, 14 and 15 of this lesson.

THREE-TUBE SHORTWAVE RECEIVER

In Fig. 13 is shown a typical example of how the parts should be arranged on the deck of a metal chassis base for a three-tube shortwave t-r-f receiver. In this particular case, three tubes comprise an r-f amplifier, a detector and a power amplifier. The circuit diagram for this same receiver appears

TABLE I

CONTINUOUS COVERAGE T. R. F. RECEIVER COIL TABLE

All Coils Wound on 1½" Diameter Forms.

APPROX. RANGE IN METERS	ANT. COIL L_1	SECONDARY COIL L_2	PRIMARY COIL L_3	SECONDARY COIL L_4	CATHODE TAP ON L_4
8 to 16	3 turns, spaced ⅛-in. from ground end of L_2	3½ turns #20 d.s.c. ¾-in. long	2½ turns #24 d.s.c. interwound with L_4 B+ at bottom	3½ turns #20 d.s.c. ¾-in. long	Tap at 1/3 turn on bottom turn
15½ to 32	5 turns, ⅛-in. from L_2	7 turns #24 d.s.c. 1½-in. long	3 turns #24 d.s.c. interwound with L_4	7 turns #24 d.s.c. 1½-in. long	Tap at ½ turn on bottom turn
29 to 62	8 turns, ⅛-in. from L_2	16 turns #24 d.s.c. 1½-in. long	6 turns #24 d.s.c. interwound with L_4	16 turns #24 d.s.c. 1½-in. long	Tap at ¾ turn on bottom turn
59 to 107	10 turns, ⅛-in. from L_2	31 turns #24 d.s.c. 1½-in. long	8 turns #34 d.s.c. interwound with L_4 at ground end	31 turns #24 d.s.c. 1½-in. long	Tap at 1 turn up from bottom
97 to 215	12 turns, ⅛-in. from L_2	54 turns #24 d.s.c. 1½-in. long	12 turns #34 d.s.c. wound over bottom end of L_4 over celluloid layer of insulation	54 turns #24 d.s.c. 1½-in. long	Tap at 1¼ turns up from bottom

in Fig. 14. This receiver may be operated by batteries or from an A and B power unit that is connected to the a-c lighting circuit.

Two tuning coils are used in this receiver, one for the r-f stage and one for the detector stage. Notice in Fig. 13 the great spacing between the two coils, and also the shield plate that is placed between them. This is done so that practically no inductive coupling can exist between these two coils, and thus makes the high-gain circuits more stable in operation without excessive shield-loss.

You will observe in Fig. 13 that each of these coils is mounted in an isolantite socket which is raised slightly from the chassis deck. Also notice that the coils are not enclosed in shield cans, as eddy currents induced in such metal cans by the coil's field cause losses that materially reduce the efficiency of the coil. This is particularly true at the higher frequencies.

Since windings L-2 and L-4 of the antenna and detector stages (Fig. 14) both require tuning, they can be tuned simultaneously by a main (140 mmf) two-gang condenser, the same as in a standard broadcast receiver. A miniature 25 mmf variable condenser is connected in parallel with each of the main tuning condensers. These small condensers are operated simultaneously by a common shaft, but independently of the main tuning condenser.

This feature is known as BAND-SPREAD, and is covered more fully later in this lesson.

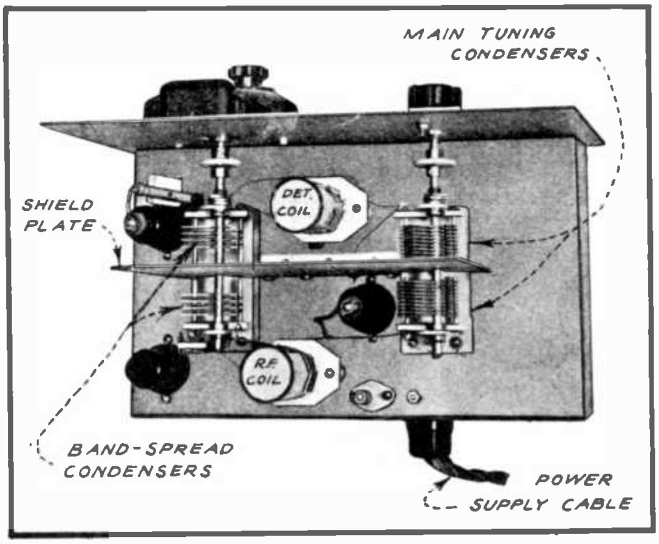


FIG. 13
THREE-TUBE T-R-F SHORTWAVE RECEIVER

Special care should always be exercised in the construction of shortwave receivers so as to make the control grid wires as short as possible, and to keep them separated as much as possible from the metal structure of the receiver, as well as from all other circuit wiring. To assist in this matter, the circuit wiring between terminals is always made short and direct. For best results on short waves, it is advisable to house the entire receiver in a metal cabinet..

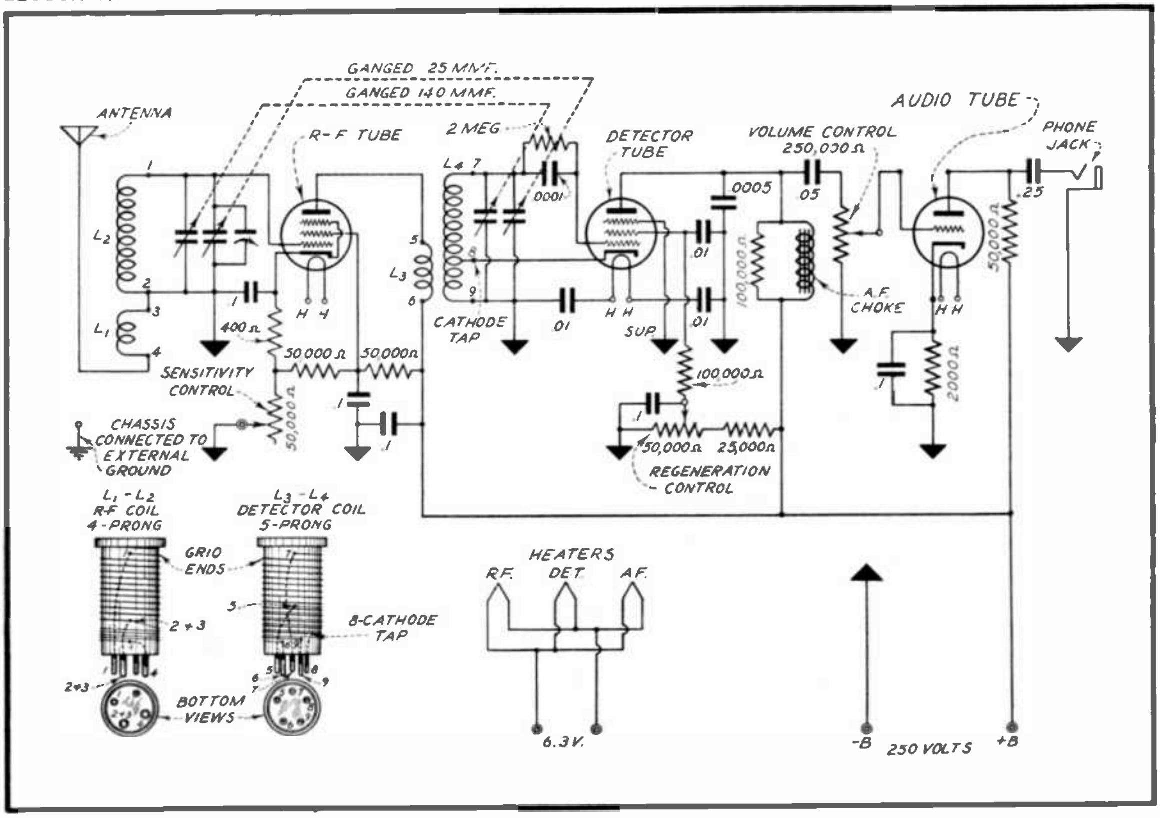


FIG. 14
DIAGRAM OF THREE-TUBE SHORTWAVE RECEIVER

Other than the points just mentioned, the circuit in Fig. 14 does not differ from those with which you are already familiar.

FIVE-TUBE A-C OPERATED SHORTWAVE RECEIVER

Let us now study an arrangement wherein the power supply is an integral part of the set so that it can be operated directly from a 110-volt a-c lighting supply. Such an arrangement is shown in Fig.15, and features an r-f amplifier, a regenerative detector, audio stage and a power output stage. In studying this schematic diagram,you will observe that the tuning circuits are essentially the same as in those circuits already described. However, a power output stage has been included to furnish sufficient signal power to properly excite a loudspeaker. A headphone jack is included in the plate circuit of the first audio stage for reception when it is not desired to use the speaker.

The remainder of the circuit is of conventional design and similar to others that you have already studied in this and earlier lessons.

OPERATING NOTES

When operating a shortwave receiver employing a regenerative detector, it is the common practice to first turn the receiver switch to the "on" position, so as to permit the tubes to heat up to full operating efficiency. The regeneration control is then rotated toward the "on" position until a "hissing" sound is heard in the speaker or headphones. This hissing sound indicates that the receiver is regenerating.

Now, proceed to tune in a station by operating the tuning control very slowly until a station is heard. Set the dial to the point where the station comes in loudest and adjust the regeneration control for the desired volume. If the regeneration control is turned on too far toward the "on" position, the circuit will commence to oscillate; this condition is indicated by a squealing sound being emitted by the headphones or speaker when the station is "tuned in."

For maximum sensitivity, the regeneration control should be turned "on" as far as possible, without causing a squeal.

Shortwave Superheterodyne Receivers

All of the shortwave receivers described thus far in this lesson have been of the t-r-f type. However, this does not mean that receivers of this type exclusively are employed for shortwave reception.

While it is true that remarkable results may be obtained from a regenerative t-r-f receiver, the present trend is nevertheless toward shortwave receivers that employ the superheterodyne principle.

ADVANTAGES AND DISADVANTAGES OF SHORTWAVE SUPERHETERODYNES

The qualities of high sensitivity, selectivity, and more uniform response on all bands possessed by the superheterodyne receiver, in addition to the fact that a-v-c principles may also be incorporated therein, makes this type of receiver highly desirable for shortwave reception. On the other hand, high background noise, as well as tube and circuit noises,is constantly present in these receivers, and therefore at times makes them unsuitable for the reception of extremely weak signals. In other words, the noise-to-signal ratio is considerably higher in superheterodyne receivers than in t-r-f receivers.

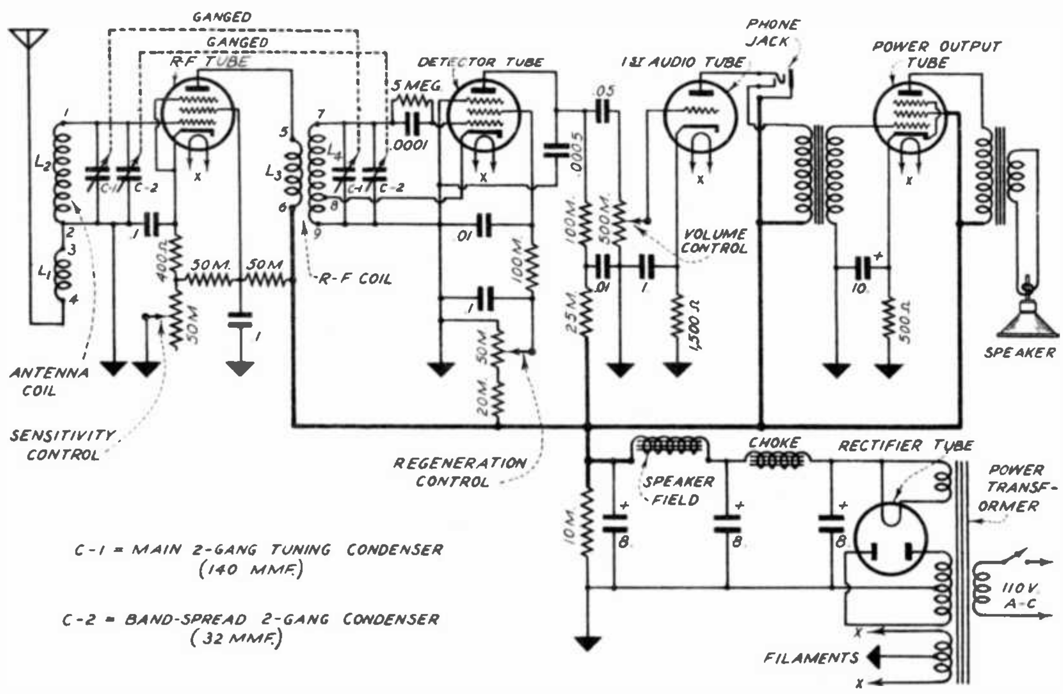


FIG. 15
FIVE-TUBE, A-C, REGENERATIVE SHORTWAVE RECEIVER

Another disadvantage of the superheterodyne principle,as applied to shortwave receivers, is that repeat points or image signals occasionally interfere with normal reception. This condition was fully explained in an earlier lesson treating with superheterodyne principles. A stage of r-f pre-selection ahead of the "mixer" tube will help materially to reduce this tendency, but it will not eliminate it entirely.

SIX-TUBE, A-C OPERATED SHORTWAVE SUPERHETERODYNE

The shortwave superheterodyne receiver to be described at this time employs six tubes and is designed for operation from the a-c lighting circuit. The circuit diagram appears in Fig. 16. Upon studying this diagram,you will observe that a special converter tube (first detector) is used in a semi-regenerative mixer circuit, while a pentode functions as a high-frequency oscillator. Another pentode is used in the i-f amplifier; a diode-triode serves as a combination detector, a-v-c and first audio tube; and a pentode audio output tube operates the loudspeaker.

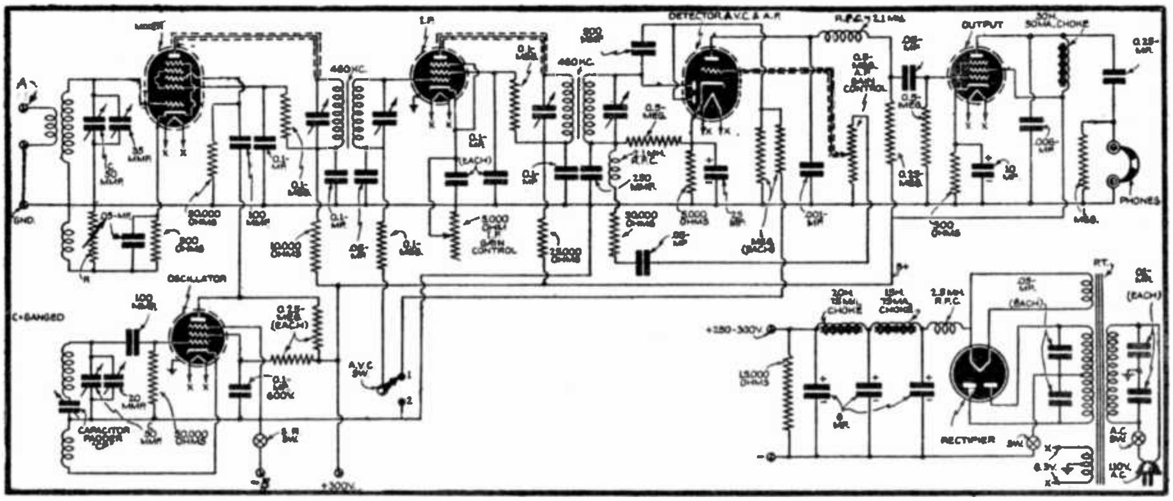


FIG. 16
DIAGRAM OF SIX-TUBE, A-C SHORTWAVE SUPERHETERODYNE RECEIVER

CIRCUIT DETAILS: The mixer circuit in Fig. 16 is made semi-regenerative, so that just enough feedback is available to "boost" the sensitivity and selectivity of the receiver. The variable 5000-ohm resistor "R" is connected across the cathode coil to level out the regenerative effect over the entire tuning range of each coil-set.

While this particular receiver uses a separate oscillator tube, you will often find a conventional converter stage used in shortwave receivers, the same as in standard broadcast sets.

You will further observe that a switch is employed to enable the operator to cut the a-v-c in or out as desired. Without a-v-c,the sensitivity of the receiver as a whole is increased considerably,although the fading of stations will be more pronounced. Under these conditions, it will also at times be difficult to maintain a uniform speaker level without continually manipulating the gain or volume control.

As is the practice in most shortwave receivers, an r-f or i-f gain, or sensitivity control, is included in this circuit. This control is in the form of a 5000-ohm variable resistor connected in the cathode circuit of the pentode i-f tube. Connected in such a manner, it will vary the grid bias applied to that tube and thereby provide a means for controlling this tube's amplification.

Observe the extensive use of bypass condensers in Fig. 16, and also the r-f chokes in the detector and "B" unit of the power supply. These means are employed to provide good r-f filtering in order to stabilize the operation of the receiver and also to reduce background noise.

The arrangement of the parts in a typical shortwave superheterodyne receiver is shown in Fig. 17. In this particular case, the power unit is included as part of the main receiver chassis; however, it is often constructed as a separate unit so that it may be placed at a short distance from the receiver proper. The latter practice is often followed in constructing shortwave receivers, as it reduces the probability of the receiver circuits picking up extraneous power supply noises in the form of hum, etc. The more quiet performance of the receiver allows extremely weak signals to be heard distinctly.

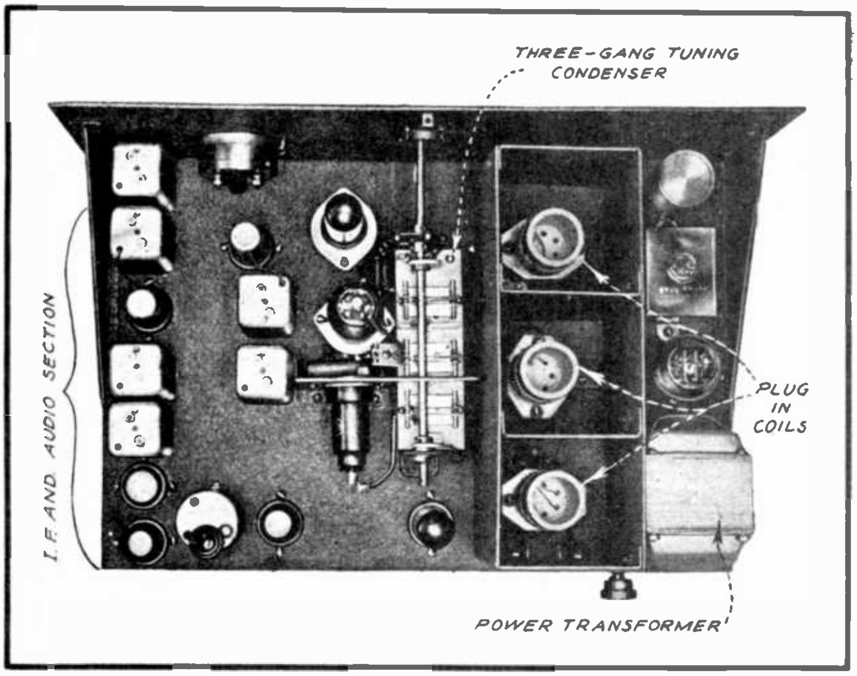


FIG. 17
A-C SHORTWAVE SUPERHETERODYNE RECEIVER

Observe in Figs. 16 and 17 that plug-in type coils are used to cover the 20, 40, 80 and 160 meter wave-bands. Also notice in Fig. 17 that each coil of any one set is enclosed in an individually-shielded compartment which prevents undesired coupling between these high-gain circuits. Sufficient space is allowed between the coils and the shielding metal to prevent excessive eddy current losses. The entire receiver chassis is contained in a metal cabinet, similar to the one shown in Fig. 1.

INTERMEDIATE FREQUENCIES FOR SHORTWAVE SUPERHETERODYNES

In the earlier models of broadcast superheterodynes, an intermediate-frequency of 175 or 262.5 kc was generally used. A frequency of 455 kc has now been accepted as standard for home radios by nearly all receiver manufacturers. However, the trend in shortwave superheterodynes is to use a much higher frequency, although i-f's of 455 kc are used in many such sets. Frequencies as high as 1500 kc have been found to be very satisfactory -- especially in receivers where no preselector stage is used ahead of the mixer stage. The higher intermediate frequencies do not provide as much amplification in the intermediate amplifier stage as do the lower frequencies; however, they do allow the mixer stage to function more efficiently. Thus, more mixer gain is obtained, and image or repeat station-interference is reduced materially. In other words, receivers employing such a high intermediate-frequency will require an additional i-f stage to offset the loss of

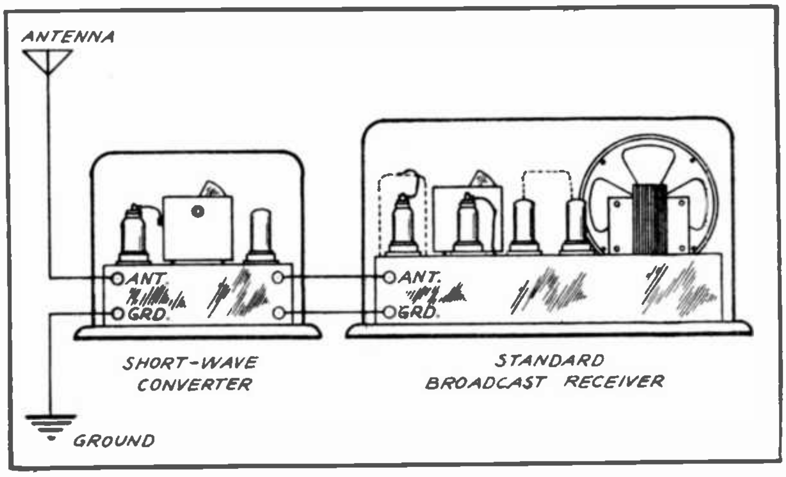


FIG. 18
SHORTWAVE CONVERTER USED WITH STANDARD BROADCAST RECEIVER

i-f amplification, but the mixer stage will perform nearly as efficiently as if a stage of r-f pre-selection and amplification were employed ahead of this tube.

Converters

The shortwave receivers described in this lesson are suitable for shortwave reception only, and not for standard broadcast reception. Some time ago, many owners of good broadcast receivers desired to pick up shortwave programs as well, but did not feel inclined to invest in a special shortwave receiver. To meet this demand, engineers developed the <u>shortwave converter</u> -- also known as the <u>shortwave selector</u>.

The shortwave converter is a shortwave tuner, oscillator and mixer stage, contained in a separate cabinet. Its circuits are so arranged that it can be easily connected ahead of a regular broadcast receiver, and thus make shortwave reception possible.

The principle is illustrated in Fig. 18 where you are shown how the shortwave converter is connected to the broadcast receiver. A typical circuit is diagrammed in Fig. 19. You will observe in Fig.19 that this shortwave converter consists of a mixer circuit, similar to that used in a conventional superheterodyne receiver.

A two-gang switch with two positions is used in the circuit shown in Fig. 19. If this switch is closed to the "BC" position it will connect the antenna directly to

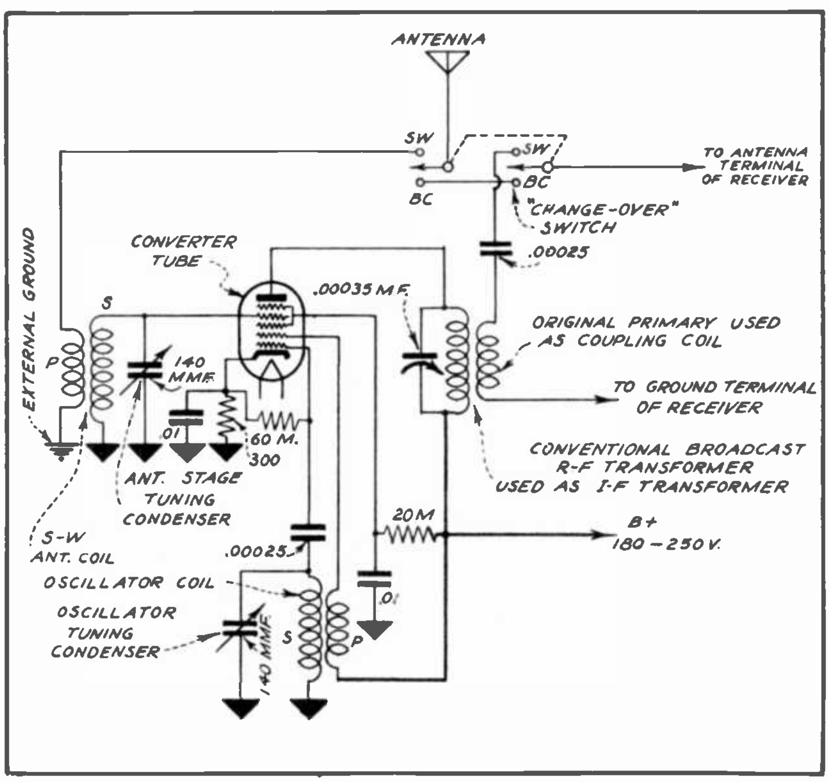


FIG. 19
ONE-TUBE SHORTWAVE CONVERTER

the antenna terminal of the broadcast receiver. The shortwave converter will then be inoperative.

To receive shortwave signals, the change-over switch is closed to the "SW" position, thus connecting the antenna to the primary winding of the shortwave converter's input transformer, and at the same time connecting the converter's output coupling coil to the antenna input circuit of the broadcast receiver. The coil and tuning condenser values are such that the circuits tune over a shortwave band -- plug-in coils can be used to cover the different wave-bands, the same as in shortwave receivers. The arrangement then operates as follows:

After being picked up by the antenna, the shortwave signals are transferred to the control grid circuit of the converter's first detector section which is tuned to the frequency being received. At the same time, the converter's oscillator section is generating a different frequency which is combined with the signal-frequency to produce a third, or beat-frequency. The latter frequency appears in the tuned winding of the r-f transformer which is connected in the plate circuit of the converter tube.

This beat or intermediate-frequency is then fed through the coupling coil into the first r-f stage of the broadcast receiver, which is tuned exactly to resonate with this beat-frequency. Thus, the r-f amplifier of the broadcast receiver now becomes the i-f amplifier of a superheterodyne type shortwave receiver. To make this possible, it is of course necessary that the beat frequency be within the tuning range of the broadcast receiver's r-f amplifier.

After being amplified by the broadcast receiver's r-f amplifier, the beat frequency is handled by the remaining circuits of the broadcast receiver exactly as though it were a standard broadcast signal coming into this set directly from the antenna.

To obtain satisfactory performance when using a shortwave converter in combination with a t-r-f broadcast receiver, the broadcast receiver should have at least three stages of r-f amplification, employing pentode tubes. Still better results will be obtained by operating the shortwave converter with a superheterodyne-type broadcast receiver.

From the description given, you will realize that if the broadcast receiver is of the superheterodyne type, the combined arrangement will function as a "double superheterodyne," the first intermediate-frequency being in the broadcast channel, and amplified by the r-f stages of the broadcast receiver, while the second intermediate-frequency is the regular intermediate-frequency of the broadcast receiver.

Since the particular converter diagrammed in Fig. 19 does not have its own power pack, it will have to obtain its operating voltages from the broadcast receiver. In other words, the heater terminals of the converter's tube must be wired to the heater circuit of corresponding voltage in the broadcast receiver; the B+ terminal of the converter is to be connected to the high B+ line of the broadcast receiver, and the B- terminal of the converter to the ground terminal (B-) of the broadcast receiver.

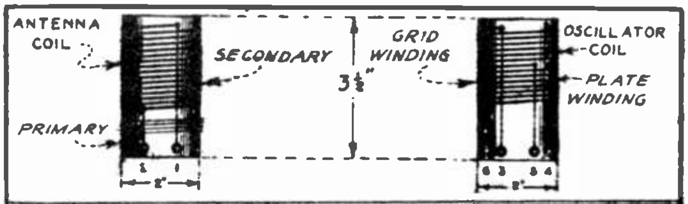
Four oscillator and four antenna coils are required to cover a band from 15 to 115 meters. Fig. 20 shows you the constructional details for both the antenna and oscillator coils, as well as giving you the specifications for their windings. All of these coils, except the antenna coil's primary, are wound with #16 B & S enamel-covered wire.

OPERATING THE SHORTWAVE CONVERTER

To use the converter, the broadcast receiver and converter are connected together as shown in Fig. 18. The volume control of the broadcast receiver is then turned all the way on and its tuning control turned to the lowest frequency setting (end of tuning dial scale) where no standard broadcast signals are heard.

This will now be the intermediate-frequency setting and should not be altered. Next, the shortwave converter is tuned by slowly turning the mixer and oscillator tuning controls simultaneously until the desired shortwave signal is heard. Experiment will usually show which intermediate-frequency setting of the broadcast tuner is most satisfactory.

The shortwave tuning controls are then set to the position offering maximum volume, and the volume control of the broadcast receiver is adjusted so as to provide the desired speaker volume.



COIL No.	ANTENNA COIL (SECONDARY)	OSCILLATOR COIL GRID	OSCILLATOR COIL PLATE	BAND COVERED
#1	5 TURNS	3 TURNS	2 TURNS	15 TO 25 METER
#2	7 TURNS	4 TURNS	3 TURNS	24 TO 40 METER
#3	13 TURNS	7 TURNS	6 TURNS	37 TO 65 METER
#4	25 TURNS	13 TURNS	12 TURNS	64 TO 115 METER

PRIMARY OF ANTENNA COIL = APPROXIMATELY 5 TURNS #30 B & S CLOSEWOUND FOR ALL BANDS.

FIG. 20
COIL SPECIFICATIONS

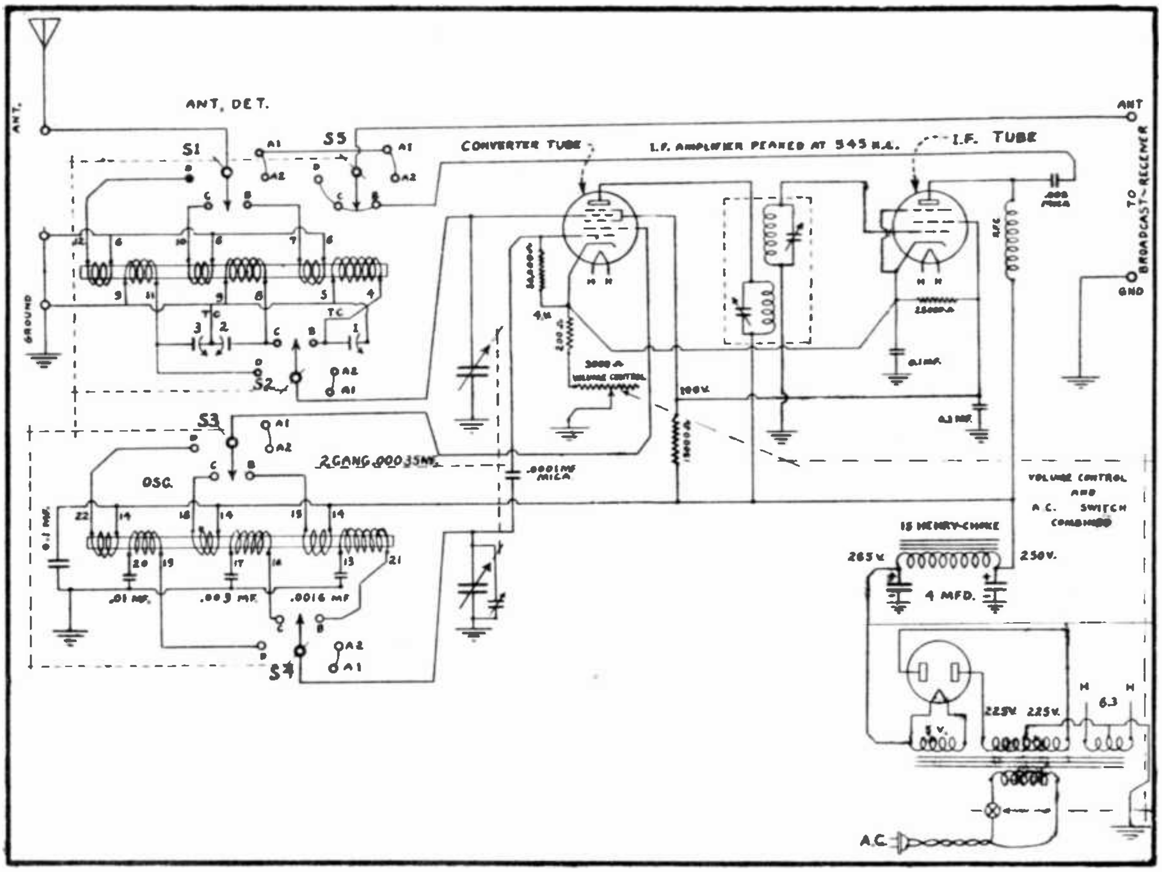


FIG. 21
SHORTWAVE CONVERTER WITH POWER UNIT

THREE-TUBE, A-C SHORTWAVE CONVERTER

In Fig. 21 you are shown the circuit diagram of an a-c operated shortwave converter, having its own power pack.

This particular converter features a converter-type mixer circuit, followed by a pentode i-f stage. An 80 rectifier is used in the power unit. Instead of using plug-in coils to cover the various short wave bands, special fixed coils are used in combination with a switching arrangement for selecting the band desired. In this way, it is only necessary to set the three switches shown on this diagram to whichever of the three positions is required to include in the tuned circuit the winding of the necessary number of turns.

As will be noted in Fig. 21, the input r-f transformers for all three of the wave-bands covered are wound side by side on the same winding form. The three oscillator coil groups are also wound side by side on one winding form.

We will not discuss the coil-switching arrangement in detail at this time, as it is treated thoroughly in the next lesson.

THE CHASSIS-PARTS ARRANGEMENT

In Fig. 22 are shown illustrative views of this self-contained converter, clearly showing the placement of the various parts and also the arrangement of the wiring.

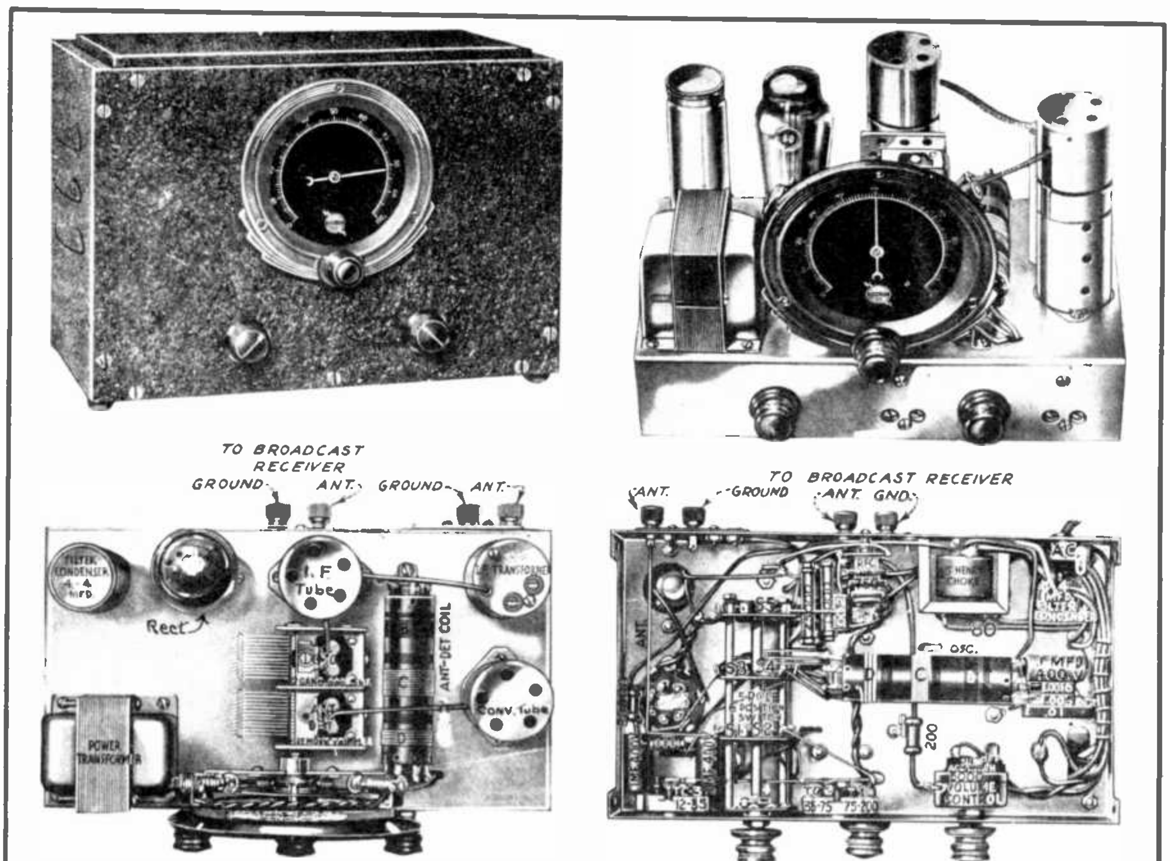


FIG. 22
CHASSIS ARRANGEMENT OF THREE-TUBE A-C SHORTWAVE CONVERTER

To operate this converter, it is only necessary to connect the antenna lead-in wire to the terminal marked "antenna" at the input of the converter. The ground terminal at the input end of the converter should be connected to the external ground connection, the ground terminal at the output of the converter should be connected to the ground terminal of the broadcast receiver, and the antenna output terminal of the converter should be connected to the antenna terminal of the broadcast receiver.

This done, adjust the broadcast receiver to some suitable broadcast frequency which is free from interference, and tune-in the shortwave programs by operating the converter's tuning condenser in the usual manner.

Band - Spread Features

The 20, 40 and 80-meter amateur bands are so congested that only a few degrees movement of the tuning dial will cause many different stations to be tuned in and out. Since the condenser-setting for bringing in any one particular signal is very critical, accurate tuning is somewhat difficult. For this reason, the dial drive on shortwave receivers and converters is so arranged that considerable movement of the dial knob produces very little movement of the dial needle and tuning condenser plates.

Band-spread systems are now being used extensively to enable the operator to tune accurately with greater ease. This is done by separating the stations more on the tuning dial.

The simplest method of accomplishing the band-spread feature is illustrated in Fig.23. In this case, an additional variable condenser is shunted across or connected in parallel with the main condenser. This additional condenser is of smaller capacity rating than the main condenser and now becomes the tuning control or "spread capacity" while the larger condenser becomes the "tank capacity."

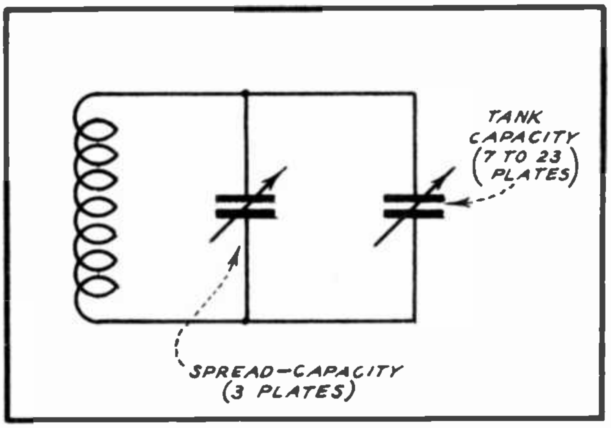


FIG. 23
BAND-SPREAD WITH TWO CONDENSERS

To cover the 25-meter shortwave broadcast band with this arrangement,we would first tune the receiver to approximately 24 meters,using the main variable condenser of larger capacity. This done, we proceed to tune the smaller band-spread condenser through the 25-meter band (from 24 to 25 meters). The dial of the small condenser can thus be rotated through practically its entire limit of travel while tuning the circuit through this range and "spotting" the various stations desired.

By applying this principle,we have spread the 25-meter band over about 180 degrees of the small condenser's tuning dial. Therefore, the stations in this band are apparently spaced farther apart on the dial that is being used for precise tuning. On the other hand, all of these stations would have been tuned-in and out with only about three degrees movement of the large condenser. The latter condition would make tuning very difficult, whereas spreading the stations over the small condenser's dial simplifies tuning considerably.

ADDITIONAL SHORTWAVE INSTRUCTION TO FOLLOW

Having completed this lesson, you should now be familiar with the basic principles of shortwave reception, as well as with the constructional features of receivers and converters used for this purpose. Bear in mind, however, that you will receive still more advanced instruction on shortwave work later in the course. At that time, we will discuss shortwave communication-type receivers thoroughly, covering crystal filters, beat-frequency oscillators and other special features incorporated in such receivers. More advanced instruction on the propagation of short waves will also be given you at that time.

Another important point to bear in mind is that even though the modern all-wave receiver has in a large measure replaced the shortwave converter and standard broadcast receiver combination, the converter, nevertheless, still serves a definite purpose, and the knowledge acquired from the study of it will help you to understand the principles of all-wave receivers more easily.

EXAMINATION QUESTIONS

LESSON NO. 28

1. - How do shortwave coils or r-f transformers differ from the conventional coils or r-f transformers as used in broadcast receivers?

2. - What is meant by the term "skip-distance"?

3. - Why is it more difficult to tune-in shortwave signals than standard broadcast signals?

4. - What are some of the more important points to consider regarding the placement of parts on the chassis of a shortwave receiver?

5. - What is one of the reasons for shortwave signals being received at greater distances than standard broadcast signals?

6. - How do shortwave tuning condensers compare with the ordinary type of tuning condensers as used in broadcast receivers?

7. - What is a shortwave converter or selector?

8. - Is the trend toward using a higher or lower i-f frequency in shortwave superheterodynes?

9. - What is the purpose of a band-spread tuning system?

10. - Is the skip-distance the same at all frequencies or does it vary at different frequencies?

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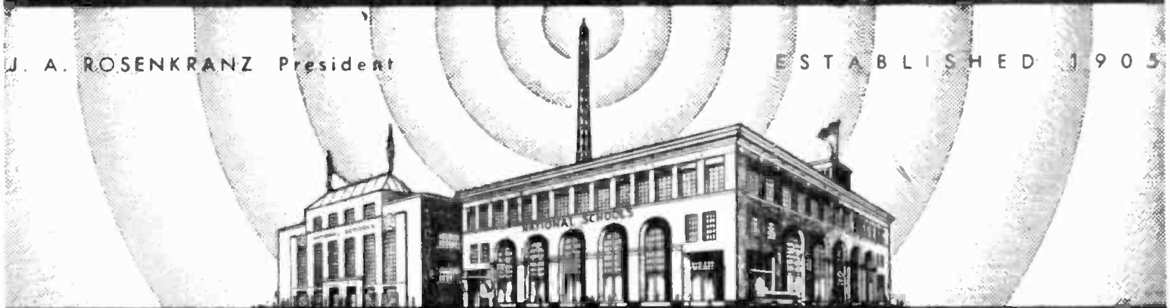

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LESSON NO. 29

ALL-WAVE RECEIVERS

The shortwave converter answers the purpose so far as making all wave reception possible with a standard broadcast receiver. However, this arrangement is somewhat inconvenient to the average broadcast listener, as it makes two distinct radio units necessary. The desire to incorporate the shortwave and standard broadcast tuner into a single unit led to the development of the present-day all-wave receiver.

FIG. 1
THE ALL-WAVE RECEIVER BRINGS THE ENTIRE WORLD OF ENTERTAINMENT INTO THE LIVING ROOM

All-wave receivers operate on the superheterodyne principle and differ from standard broadcast receivers only so far as the tuning circuits are concerned. I-F amplifier, detector, audio channel, and power supply systems of all-wave sets are identical to those of standard broadcast receivers. Therefore, the ALL - WAVE TUNER is our primary concern.

N

ALL-WAVE COIL AND SWITCH ARRANGEMENTS

Plug-in coils,as described in the previous lesson, are efficient and inexpensive. However, they are somewhat inconvenient when it becomes necessary to change from one wave-band to the other,particularly when the receiver is housed in a cabinet. Therefore, it has become standard practice among manufacturers of all-wave receivers to mount the various coils in the receiver permanently, and to use a switching device whereby the proper coil combinations can be cut in and out of the tuning circuits conveniently.

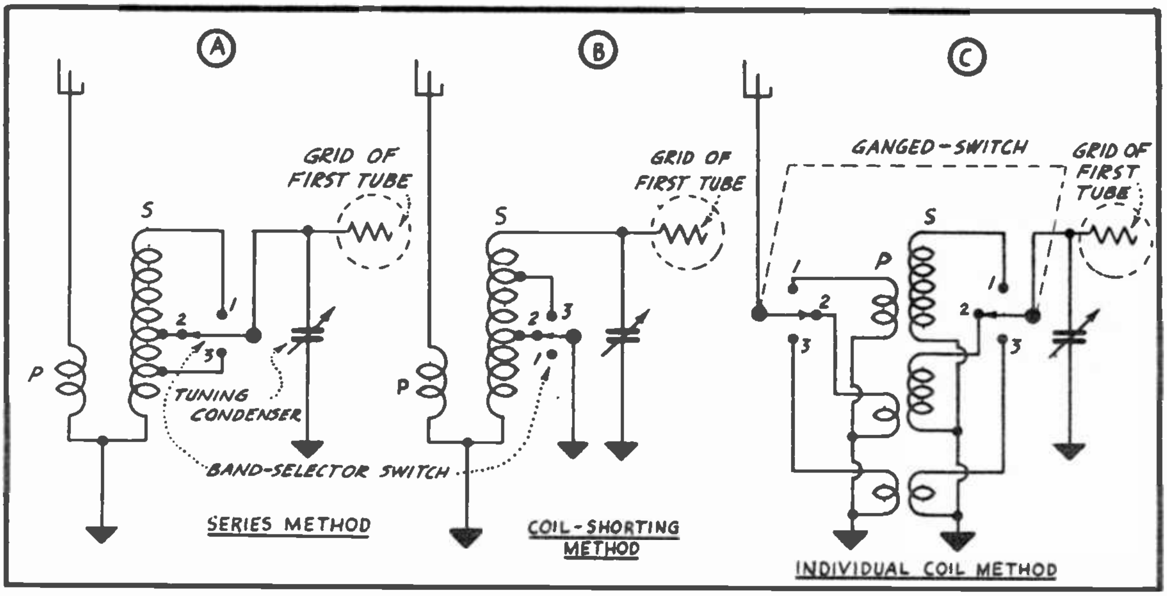


FIG. 2
THE PRINCIPLE OF COIL-SWITCHING CIRCUITS AS USED IN ALL-WAVE RECEIVERS

The first all-wave tuning coils were constructed along the principle illustrated at (A) of Fig. 2. Here, a primary and a secondary winding are placed on a coil-form in the usual manner. The secondary winding is tapped and connected to switch terminals so that operation of the switch will vary the inductance of the secondary winding and thus make tuning over several bands possible. This arrangement operates as follows:

When the switch is in position #1, the entire secondary winding is connected across the tuning circuit. Placing the band-selector switch in position #2, includes only half of the coil's inductance in this tuning circuit, while closing the switch in position #3 permits only a small portion of the coil's inductance to remain connected in the tuning circuit. Thus, by means of the band-selector switch, wavebands from 545 meters to 10 meters (550 kc to 30,000 kc) can be selected in three steps by merely turning the knob of the band-selector switch to the required position. Since the various sections of the secondary winding are connected in series as the coil's inductance is increased,this system of coil-switching is known as the SERIES METHOD. The variable (tuning) condenser is then used to select the desired station in any one of the particular wave-bands covered.

While this method is very simple, inexpensive, and to a certain extent satisfactory, it is nevertheless subjected to the so-called "dead-end" effect of the unused turns. These unused turns cause heavy losses due to their tendency to "absorb"signal energy present in that section of the coil which is being used.

To help overcome this undesirable condition, the modified connection shown at (B) of Fig. 2 was next employed. Here you will observe that instead of leaving certain portions of the coil "hanging free" (unused) as at (A), the unused turns are shorted to ground. Thus, if the band-selector switch is placed in position #3, only a small portion of the coil's inductance is actually used, while the remaining unused turns are shorted directly to ground. Closing the switch in position #2 places more inductance in the tuning circuit, while closing the switch in position #1, places all of the coil's inductance in the tuning circuit and permits tuning-in stations that operate at the lower frequencies. This is known as the COIL-SHORTING METHOD.

While this arrangement proved more satisfactory by eliminating the dead-end effect of the unused turns, its performance was, nevertheless, still inferior to that of the plug-in type coils. So, the next step was to use separate coils for each band, similar to the practice employed with plug-in coils, only that the coils were now permanently mounted within the receiver. A switching arrangement was provided so that the proper coil combination could be connected into the circuit conveniently. This arrangement is shown at (C) of Fig. 2, where you will observe that separate coils are employed for each individual band. Also, notice that separate primary windings are used for each of the secondary windings, thus affording a perfect antenna coupling-match for each of the wave-bands covered. The operation of such coil-switching systems is explained fully in later paragraphs of this lesson.

Now that you have a general understanding of the basic coil-switching principles as employed in all-wave receivers, let us proceed with a more detailed discussion of the coils and switches as used in such receivers.

ALL-WAVE TUNING COILS

There are many styles, shapes and types of all-wave tuning coils, but a typical three-band antenna-stage coil is shown in Fig. 3. This coil corresponds with the wiring diagram appearing at (C) of Fig. 2, in that it has three individual sets of primary and secondary windings, each set handling one of the three bands covered by the assembly.

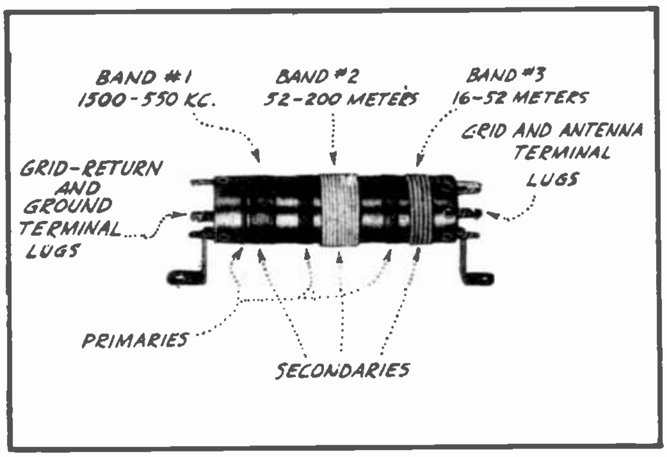


FIG. 3
TYPICAL THREE-BAND TUNING COIL

In Fig. 3 all three coil-sets are placed on a single form, which practice has become widely used. In many instances, separate coil-forms are employed for each of the wave-bands covered, while in other cases all of the shortwave windings are placed on one form and the standard broadcast windings on separate forms.

Notice also in Fig. 3 that each primary winding is placed adjacent to its respective secondary, and that all of the grid and antenna terminal lugs are fastened to one end of the coil-form. The grid-return or ground-lead lugs are fastened to the opposite end of the coil-form. This is done so that the leads between the band-selector switch and the coil terminals may be as short as possible. Therefore, the switch would be placed directly to the right of the coil, near the grid and antenna terminal lugs.

By observing closely the two shortwave secondary windings (bands #2 and #3), you will notice that these windings employ a larger size of wire and are space-wound. This is the usual practice and is important for two reasons: first, the large size of wire is used to reduce the resistance of the coil, which, if of a high value, would cause high-frequency losses when handling shortwave signals; and second, space-winding provides a lower minimum capacity between adjacent turns, thereby resulting in a greater frequency-range, as well as permitting a higher frequency to be handled by the coil. These factors apply to the secondary windings only. The primaries are conventional close-wound coils.

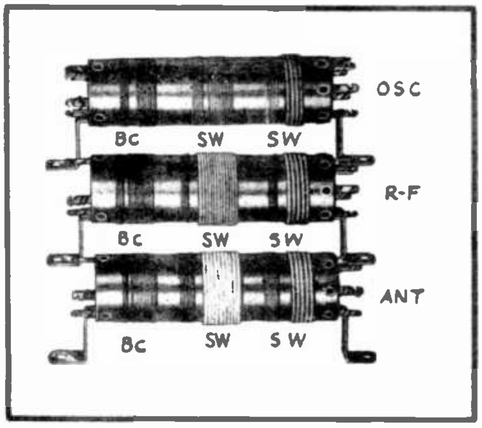


FIG. 4
SET OF ALL-WAVE COILS

The all-wave coil shown in Fig. 3 is intended for a single stage, such as the antenna or r-f stage. If two or more stages are to be employed, additional coils must be used. In Fig. 4 is shown a complete set of all-wave tuning coils for a superheterodyne receiver comprising an antenna, r-f, and oscillator circuit. Upon inspecting this set of coils, you will observe that the oscillator windings for all bands are on one form, while the r-f and antenna stage windings are on individual forms. This constitutes good engineering practice, for if all of the coils for each band are placed on a single form, coupling between the different circuits of the band may occur. This would, of course, be very undesirable.

SHIELDED ALL-WAVE TUNING COILS

In a great many of the more expensive all-wave receivers, the tuning coils are placed within shielding containers. This practice provides greater selectivity, permits the use of high-gain coils, and prevents undesirable coupling between the different tuning circuits.

In Fig. 5 is shown a set of shielded all-wave coils, intended for use in the antenna, r-f and oscillator circuits. Also, notice in this illustration how "trimmer" condensers are mounted on the side of each shield can. These condensers are connected across the secondary windings of each coil, thus permitting the coil-groups for each band to be aligned accurately.

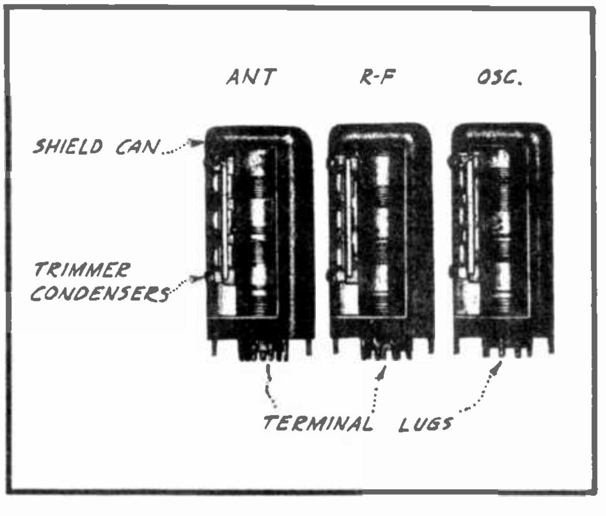


FIG. 5
SET OF SHIELDED ALL-WAVE COILS

BAND-SELECTOR SWITCHES

Nearly all band-selector switches employ a rotary contact action and are assembled in sections according to the number of tuning circuits that they control. Two such band-selector switches are shown in Fig. 6.

The switch shown at (A) is of better construction and typical of the more efficient type, while the type shown at (B) is generally used in the less expensive and more compact receivers that employ either the series or coil-shorting method illustrated at (A) and (B) in Fig.2. Switch (A) in Fig. 6 contains individual sections that are ganged together, and is therefore employed whenever separate or individual coils are used. Switch (A) is available in types having one or more sections, while switch (B) is not designed to accommodate additional sections. Details of one section of switch (A) appear in Fig. 7.

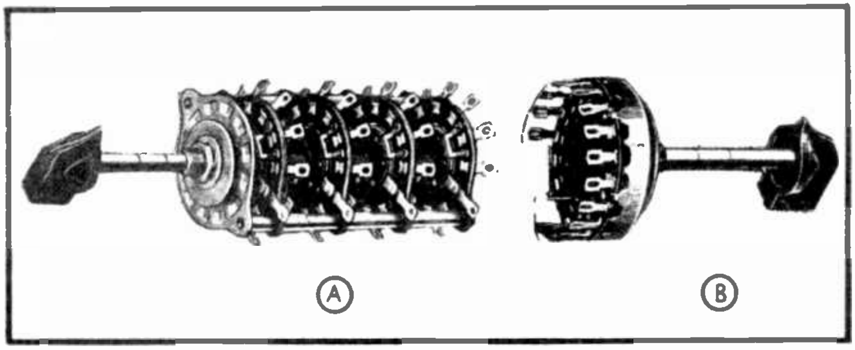


FIG. 6
TYPICAL BAND-SELECTOR SWITCHES

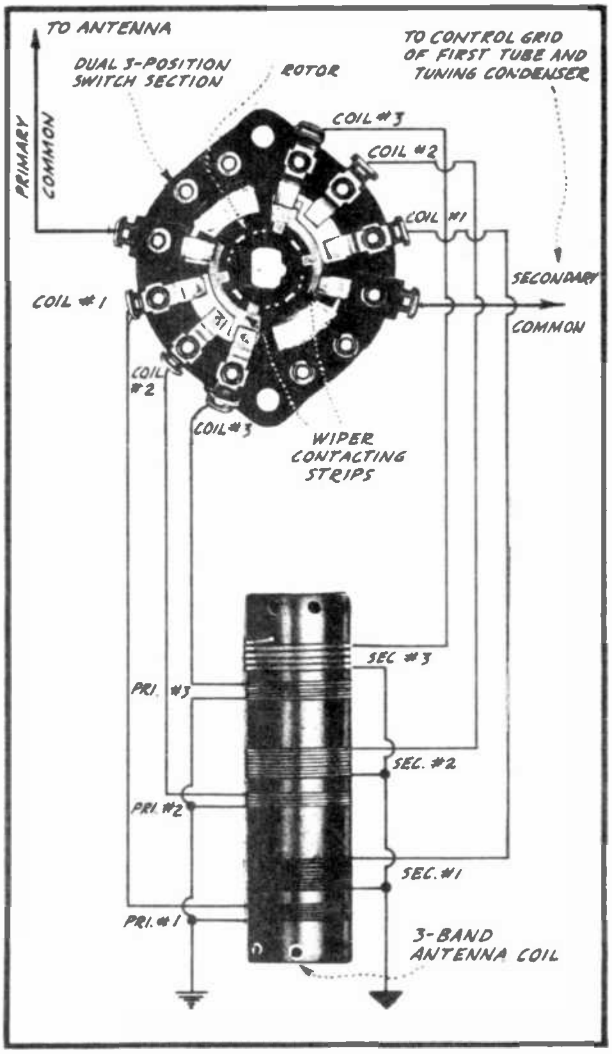


FIG. 7
SELECTOR-SWITCH CIRCUIT FOR THREE-BAND ANTENNA-STAGE COIL

The rotor-section of the switch in Fig. 7 is made of an insulative material, having two "wiper" contacting strips located opposite each other. The "common" terminal of each half of each switch section protrudes farther into the switch mechanism than do any of the other terminals; therefore, it will at all times contact the wiper strip, regardless of the latter's position. One end of each wiper strip is enlarged so that it will contact the shorter coil terminals, one at a time, as the rotor is rotated through the various switch positions.

The switch position illustrated in Fig. 7 is such that the wiper contact of the left rotor-section is shorting together coil terminal #3 and the common terminal that is connected to the antenna lead-in. Thus, the primary winding of coil #3 is connected in circuit. At the same time, the wiper contact of the right rotor-section is shorting together coil terminal #3 and the common terminal that is connected to the control grid of the first tube. Therefore, the secondary winding of coil #3 is connected in its circuit at the same time that the corresponding primary winding is being used.

By turning the rotor clockwise to its next position, the projection of the wiper strips will break contact with coil terminals #3 of both the primary and secondary switch sections simultaneously, but will contact coil terminals #2 so as to complete the circuits for the primary and secondary windings of this wave-band.

Although the mechanical details of the mechanism may vary in switches of different design, the typical example here shown illustrates the general principles involved.

ALL-WAVE COIL ASSEMBLIES

Our next step is to study the placement of the band-selector switch and coil assembly in typical all-wave receivers. While this arrangement varies according to the type and model of receiver, there are, nevertheless, certain standard practices that are usually followed by the majority of manufacturers. Therefore, our study will be directed toward these more typical assemblies.

In Fig. 8 is shown the placement of the coils and the switching arrangement in a superheterodyne receiver having no pre-selector r-f stage, and using coils of the type illustrated in Fig. 3. Notice that one section of the switch controls the connections of the antenna-stage windings, while the other section controls the connection of the various windings of the oscillator coil. Individual trimmer condensers are connected across the shortwave secondaries of the two coil assemblies so that they may be aligned properly. The trimmers for the broadcast band are placed elsewhere on the chassis and are not shown in Fig. 8.

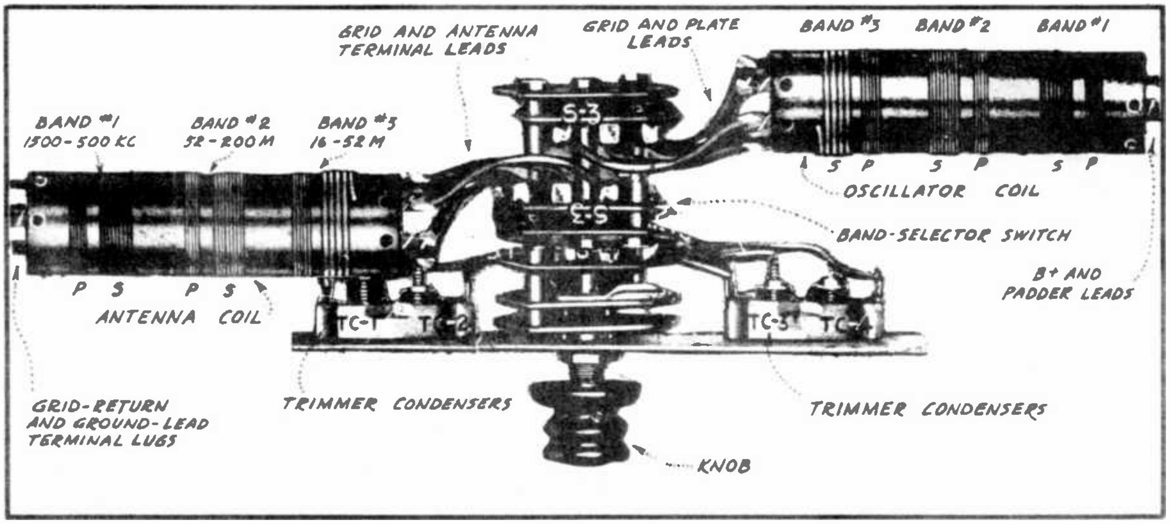


FIG. 8
ALL-WAVE COIL AND SELECTOR-SWITCH ASSEMBLY

Placing one coil on one side of the switch and the other coil on the other side, provides adequate separation between the two coils so as to prevent undue coupling between them. Such coupling may cause undesirable feed-back between the circuits, especially during the reception of shortwave programs. Some manufacturers even go so far as to place a shield between the two sections of the switch and their connecting leads, as a further precaution.

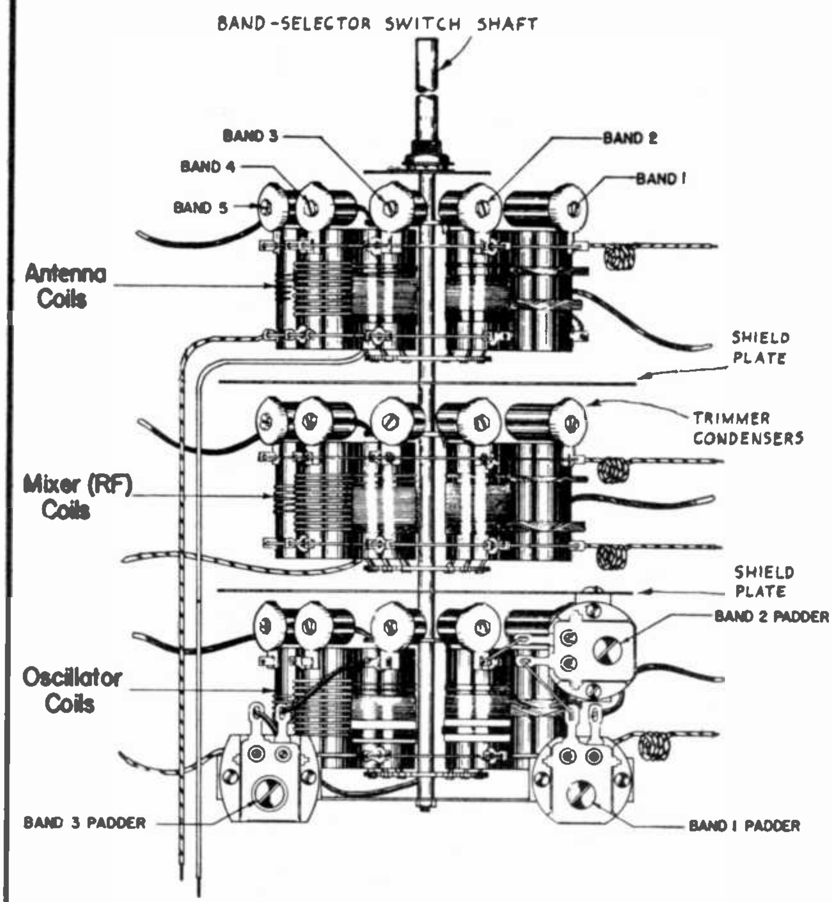
APPLICATION OF INDIVIDUAL COILS

As we have mentioned previously, many of the more elaborate all-wave receivers employ separate coils for each of the different tuning bands instead of placing the windings of two or more wave-bands on a single coil-form. While the latter arrangement is by far the most simple and economical (with the exception of the shorting or series coil arrangement described in Fig. 2) it does have certain disadvantages. The chief disadvantage of the single-coil idea is that the different windings may react upon each other inductively. This condition causes the unused windings to absorb signal energy and thus produces "dead-spots" at certain points on the tuning band where the frequencies of the different coils may be resonated to each other when tuning.

Another disadvantage of the single-coil is that long leads must necessarily be employed to connect such a coil to the band-selector switch -- for instance,if the coil-form happens to be six inches long, the grid leads to the coil farthest from the switch would also need to be at least six inches long. Therefore, the shortwave windings are usually placed nearest the switch, as the shorter the grid leads, the less will be the capacitive effect between these leads and other wiring or the chassis. Extraneous capacity introduced in the circuit in this way makes it difficult for the coil to operate satisfactorily at the high-frequency end of the band.

To overcome these disadvantages, the coils shown in Fig. 9 are all wound on separate forms, and mounted directly to the lugs of the switch. Notice,too, that a trimmer condenser is placed at the grid-end of each coil's secondary. This feature makes it possible to obtain perfect alignment between the various coils that operate together on each band.

Three sets of coils are used in Fig. 9 -- one set for the antenna or pre-selector r-f stage, another set for the first detector(mixer)stage, and a third set



BAND	FREQ. RANGE	METERS
1	535 to 1580 KC	560 TO 190
2	1.56 to 4.4 MC	200 TO 60
3	4.2 to 12.6 MC	74 TO 24
4	7.4 to 18.8 MC	42 TO 16
5	11.2 to 32 MC	26 TO 9

FIG. 9
FIVE-BAND COIL ASSEMBLY

for the oscillator section. Five individual coils are included in each set, each coil covering one of five selected bands in accordance with the table appearing at the bottom of Fig. 9.

Another point to be observed in Fig. 9 is that metal plates are installed between the three coil-groups to provide the advantages of shielding.

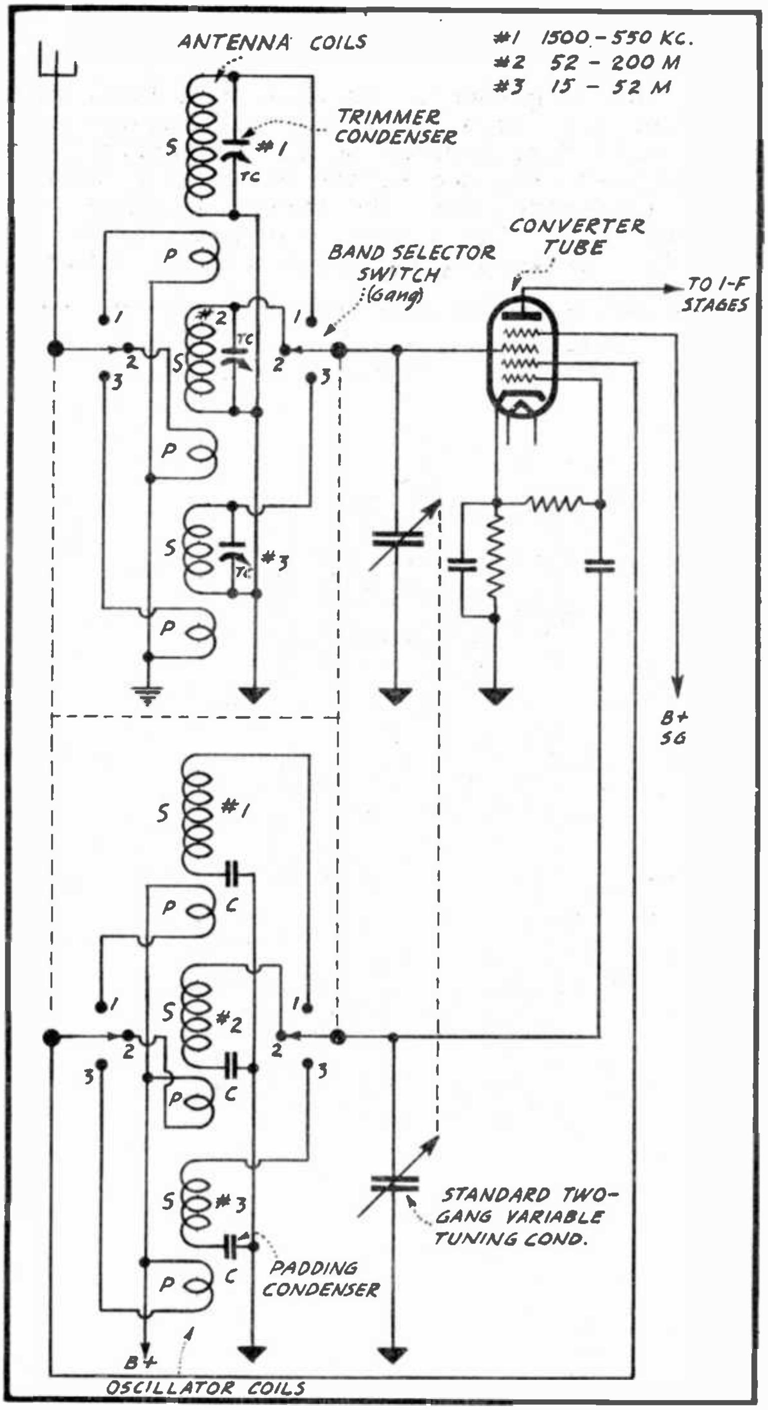


FIG. 10
CIRCUIT DIAGRAM OF THREE-BAND TUNER

THREE-BAND TUNER

The circuit wiring is necessarily much more complicated in all-wave receivers than in receivers designed for standard broadcast reception only. This is of course due to the additional coils, the associated selector-switch and the trimmer condensers. However, in all-wave tuning circuits employing only a mixer stage, the assembly and circuit connections are quite simple and not really as complex as they might appear at first glance.

In Fig. 10 is shown the circuit diagram for the all-wave tuning coil and switch assembly appearing in Fig. 8. From a close inspection of this circuit, you will observe that it is a conventional superheterodyne mixer, similar to that employed in many of the standard broadcast superheterodynes described in previous lessons. Fig. 10 differs from these other circuits only in that in addition to the standard broadcast coils, two shortwave coils are employed in conjunction with a selector switch for cutting the various windings in or out of circuit.

Upon analyzing this circuit, you will

observe that the four switch-sections are ganged together, thus affording simultaneous action whenever the selector switch arm is rotated. For instance,when the switch arm is placed in position #1, windings #1 of the antenna and oscillator coils are connected across the tuning circuit and thus make standard broadcast reception possible. Closing the switch to position #2 places windings #2 of the antenna and oscillator coils in the tuning circuits and enables the receiver to be tuned through the 52-200 meter band. Similarly, closing the switch to position #3 permits the 15-52 meter band to be covered.

Notice that the padding condensers (C) are included in the grid-return circuit of each of the oscillator's secondary coils, thus allowing perfect tracking between the oscillator and detector tuning circuits. Also, observe that the primaries are cut in and out of circuit with their respective secondaries.

The wave-bands covered by these coils are as follows: Coil #1, 1500 to 550 kc; coil #2, from 52 to 200 meters; and coil #3, from 15 to 52 meters.

FIVE-BAND TUNER

The circuit just described was for a three-band superheterodyne tuner, consisting of a mixer stage employing only two tuning circuits. The tuner to be described at this time is of a more elaborate and efficient design, covering five wave-bands.

The wiring diagram of this tuner is shown in Fig. 11. This tuner comprises an r-f pre-selector, first detector and oscillator stages. The arrangement of the coils and switch, as here used, is the same as that shown in Fig. 9. You will recall this assembly as having separate coils for each of the wave-bands.

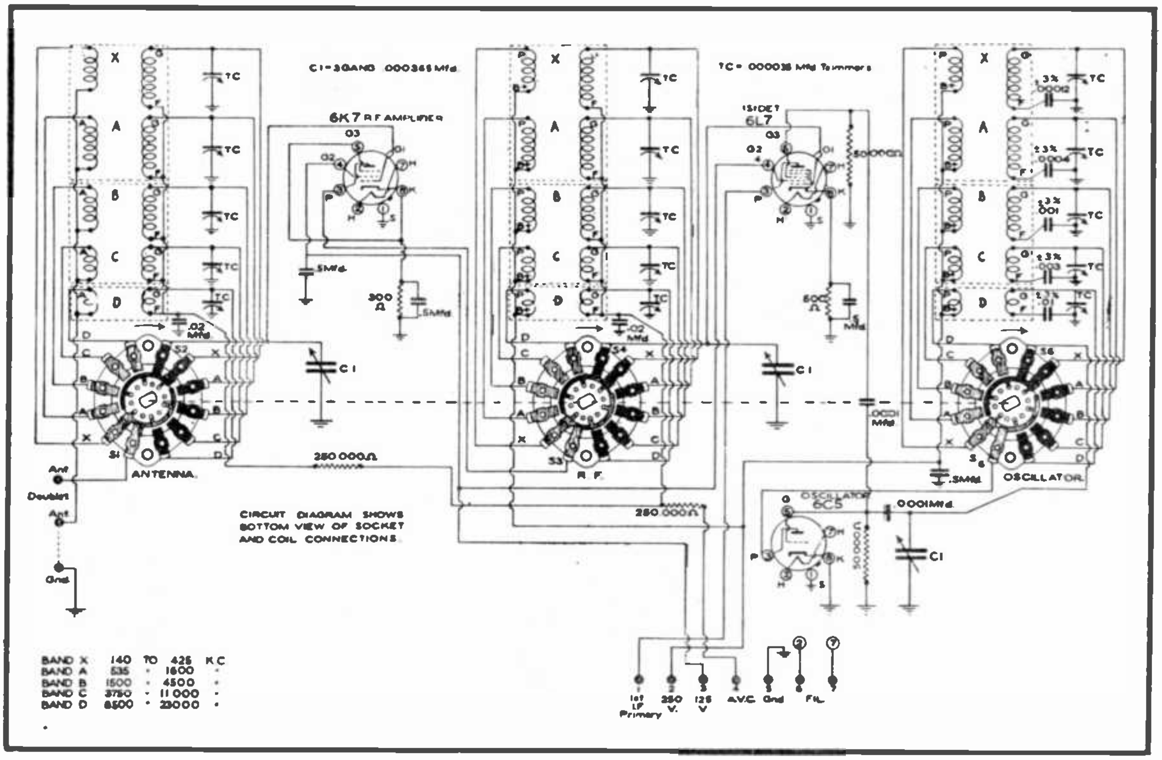


FIG. 11
COMPLETE SCHEMATIC DIAGRAM OF ALL-WAVE TUNER

Fig. 11 also shows that this tuner employs a separate oscillator and first detector tube instead of a converter tube. However, the latter type tube could be used with equivalent results.

Upon studying the band-selector switch in Fig. 11, you will observe that the primary coils are all connected to the lightly shaded contact terminals of the various switch sections,while the secondaries are connected to the dark portions. Observe closely that the "common" control terminal lugs of the antenna section are marked "S1" for the primary windings and "S2" for the secondary windings. You will further observe that the switch is illustrated in the position where the X-band coil is connected in the tuning circuit, because the lightly shaded switch-blade is shorting together switch terminals X and S1, so as to complete the primary circuit of the X-coil. The dark switch-blade is at this same time shorting together switch terminals X and S2 so as to complete the secondary circuit of this X-coil. The other two switch-sections are also completing the circuits of their respective X-coils.

CONTROL PANELS OF ALL-WAVE RECEIVERS

In Fig. 12 is shown the front panel layout of a typical all-wave receiver, showing the dial, tuning and volume control knobs, and a

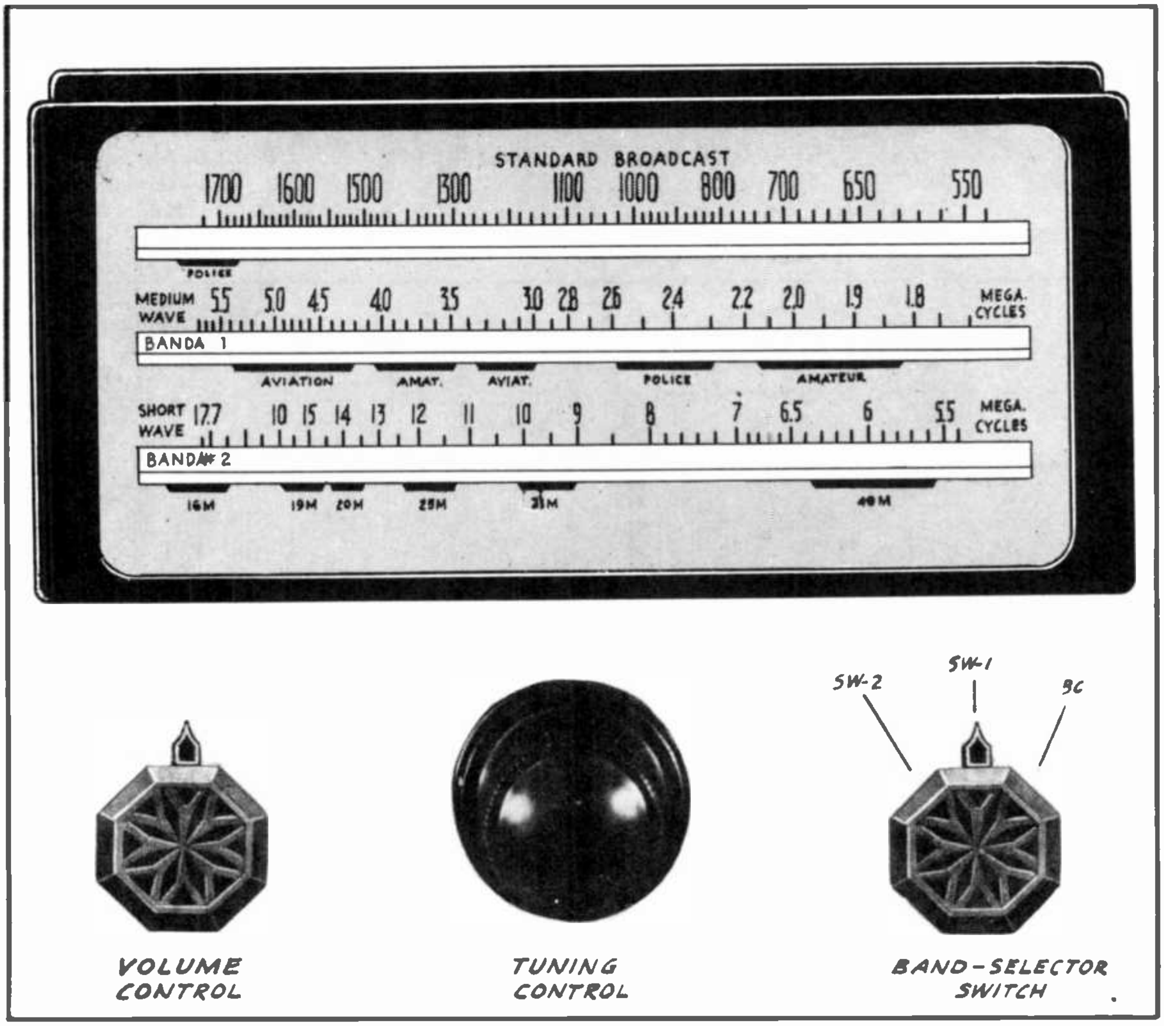


FIG. 12
TYPICAL CONTROL PANEL OF ALL-WAVE RECEIVER

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three-band selector-switch. The dial is calibrated for the standard broadcast and two shortwave bands; the band-selector switch is therefore provided with three positions. When the band-selector switch is placed in "BC" position, the broadcast tuning coils will be connected in their respective tuning circuits, and the standard broadcast scale of the dial is then used for tuning. This scale is calibrated in kilo cycles. A police-band is also indicated on the lower edge of the high frequency end of the dial for the convenience of the operator.

To tune in shortwave band #1 on this receiver, the band-selector is placed in the "SW-1" position, and the station is selected according to the center scale of the dial which is calibrated in megacycles. Here too, various interesting portions of the band are designated as "aviation," "police," and "amateur" so as to aid the listener in obtaining the type of reception desired.

Shortwave band #2 is covered by turning the band-selector switch to the "SW-2" position, and selecting the station on the lower dial scale which is calibrated in megacycles. Various sections of this band are also designated on this dial scale in meters as 16M, 19M, 20M, 25M, 31M and 49M.

Numerous dial scale arrangements are used by the many manufacturers of all-wave receivers -- the one illustrated in Fig. 12 is therefore only one typical example.

ALL-WAVE RECEIVER CIRCUITS

Now that we have covered shortwave tuners, let us next analyze in their entirety several typical all-wave receivers. Bear in mind that there are many variations in the arrangement of parts and circuits in these receivers, depending upon the type and model of set. Only the more typical circuits will be discussed at this time.

In Fig. 13 is shown the circuit of a four-band, five-tube all-wave, a-c superheterodyne. The tuner in this receiver differs from

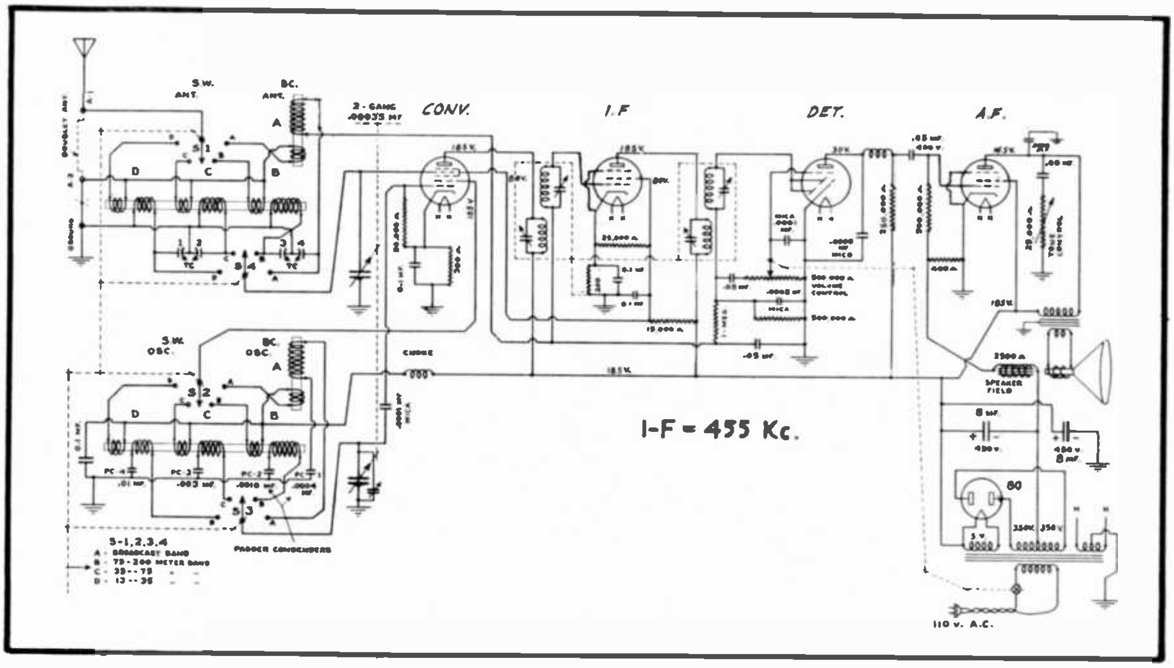

FIG. 13
FOUR-BAND, FIVE-TUBE, A-C SUPERHETERODYNE RECEIVER

that illustrated in Fig. 8 only in the fact that the broadcast coils in Fig. 13 are wound on separate forms instead of being placed on the same form with the shortwave coils. This is done for two important reasons: first, if all four bands are wound on one coil-form, the grid and plate leads for the coil winding on the end of the form farthest from the band-selector switch would have to be several inches long in order to reach the switch terminal lugs; the second reason is that by placing all windings close together, there is a possibility for inductive coupling between the different coils. Such coupling would cause the unused coils to absorb signal energy at their resonant frequency, resulting in "dead spots" at various points on the dial.

Placing the broadcast coils on separate forms allows for greater spacing between the shortwave windings on a coil-form of convenient length, and at the same time eliminates any probability for coupling between the broadcast coils.

In Figs. 14 and 15 are shown top and bottom views of the same receiver, illustrating how the parts are arranged on the chassis. Notice, especially, in Fig. 14 how the broadcast and shortwave coils of

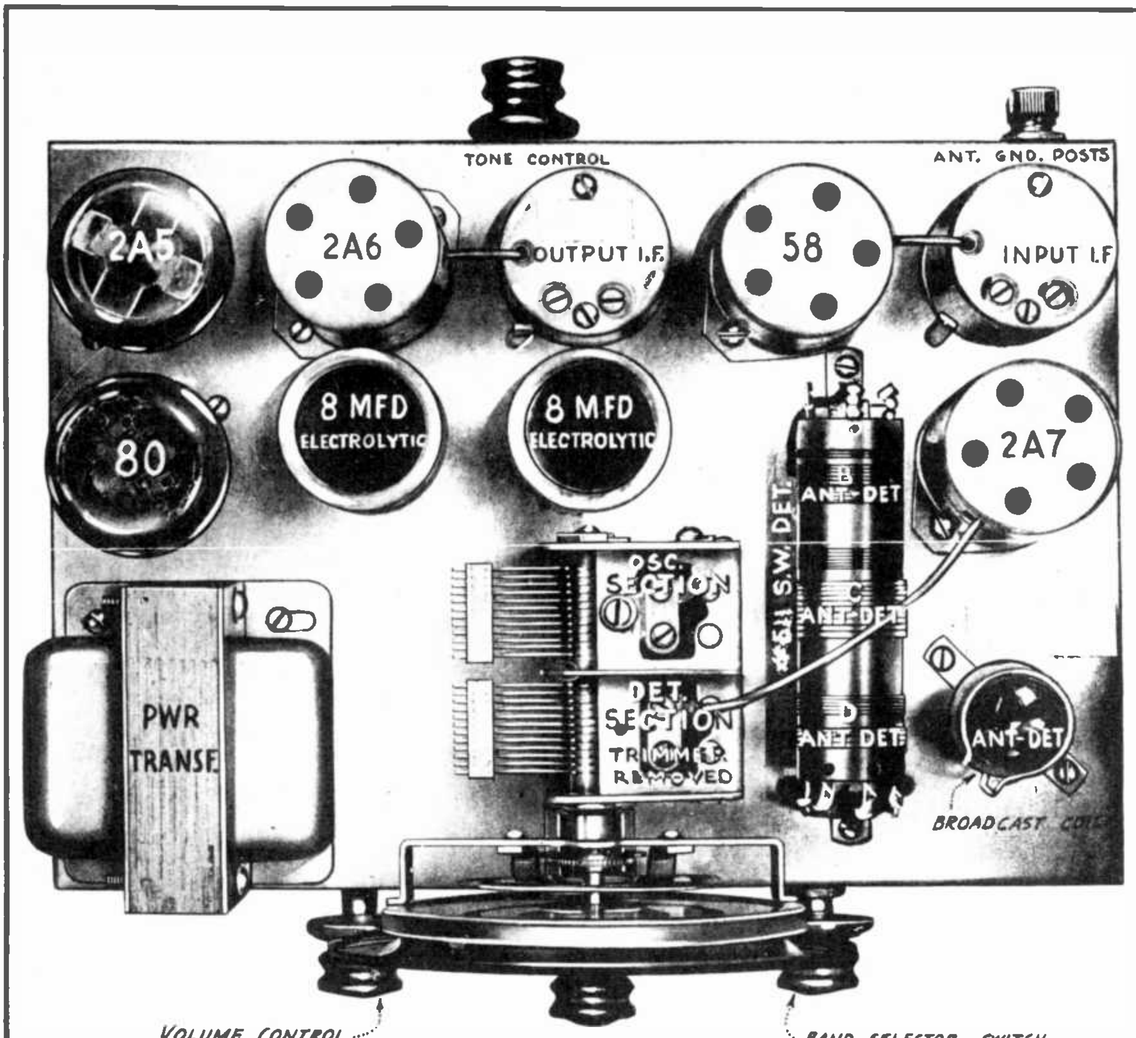

FIG. 14
TOP VIEW OF FOUR-BAND, FIVE-TUBE SUPERHETERODYNE

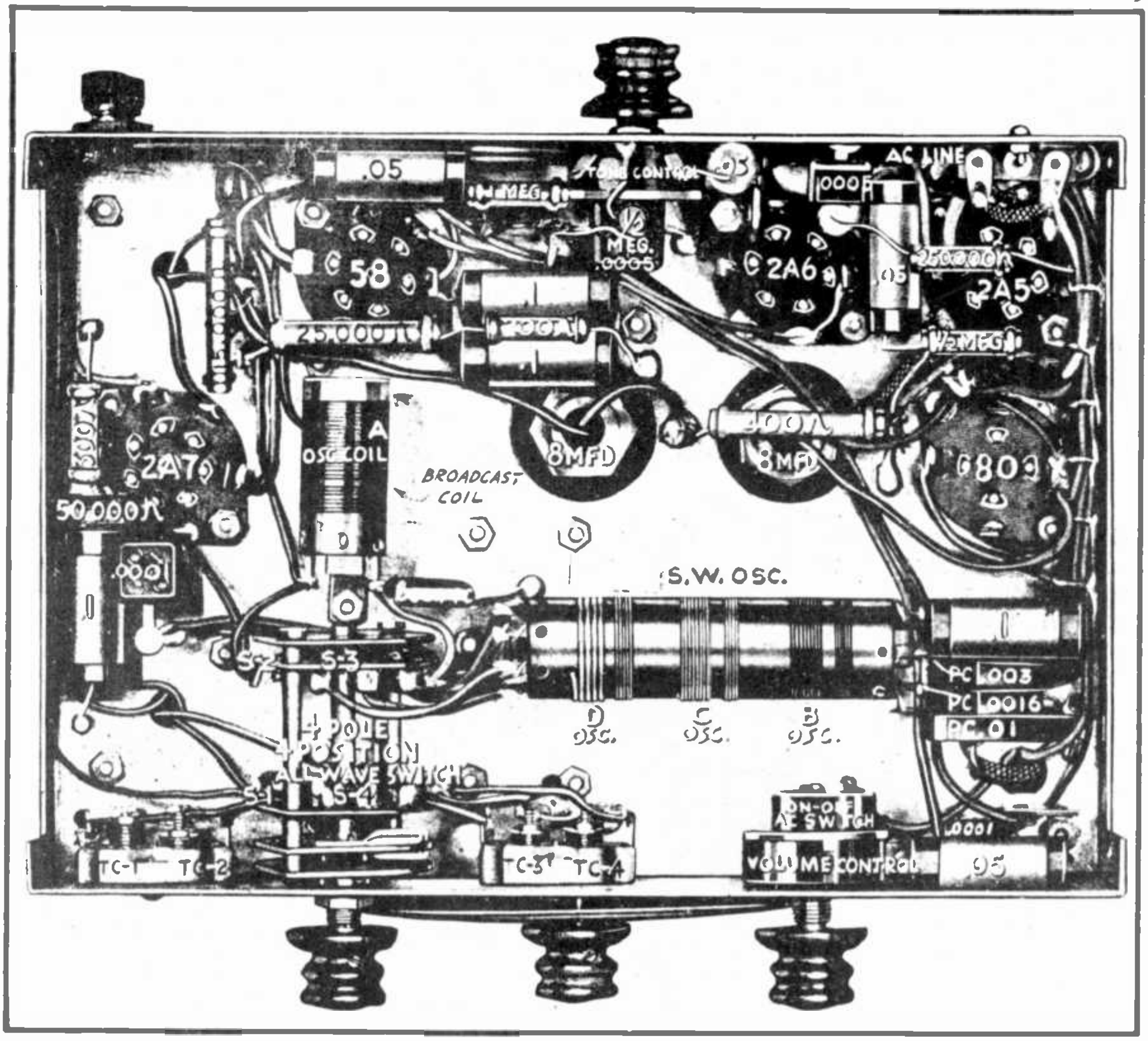

Fig. 15
Bottom View of Four-band, Five-tube Superheterodyne

the antenna-detector section are placed on top of the chassis,and that their relative positions are such that coupling between these two coil assemblies will be at a minimum.

The broadcast and shortwave coil-forms for the oscillator section are placed below the chassis deck as shown in Fig. 15. These two coil-forms are placed at right angles to each other to reduce coupling, and their placement is also such that the "switch ends" of the coils are nearest the band-selector switch so that the leads will be as short as possible. This type of construction is used extensively in all-wave receivers of the lower price class.

A two-gang tuning condenser is adequate, as no r-f pre-selector stage is used in this receiver. By placing one coil-set above the chassis deck and the other below,the chassis serves as an excellent shield between them. Aside from the tuner, the remainder of this circuit is identical to that of conventional superheterodynes that use a corresponding tube set-up. An intermediate frequency of 455 kc has been adopted by the industry as standard for all-wave receivers, for the same reasons as given in a previous lesson relative to standard broadcast superheterodynes.

The antenna input of the circuit appearing in Fig. 13 is so arranged that either a conventional L-type or doublet antenna may be used. When employing an L-type antenna, the antenna lead-in wire is connected to terminal A-1. Terminal A-2 is then connected to the ground terminal with a jumper (short piece of wire or metal band) and the ground terminal is in turn connected to the external grounding system.

Doublet antennas, as described in another lesson, have a twisted pair lead-in. One of the antenna leads is then connected to terminal A-1 and the other to terminal A-2, as indicated by the dotted lines in Fig. 13. The connection between terminal A-2 and the set's ground terminal is then broken, but the ground terminal is still left connected to the external grounding system.

ALL-WAVE CHASSIS WITH SHIELDED COIL-GROUPS

The coil and band-switching arrangement of a more elaborate receiver is shown in Fig. 16. This receiver has an r-f pre-selector stage in addition to the converter stage, and uses an individual coil for each of the six bands covered. The six coils of each stage are shielded as a group from those of the other stages. The trimmer condensers are mounted directly above the grid ends of the various coils so as to require the shortest leads possible.

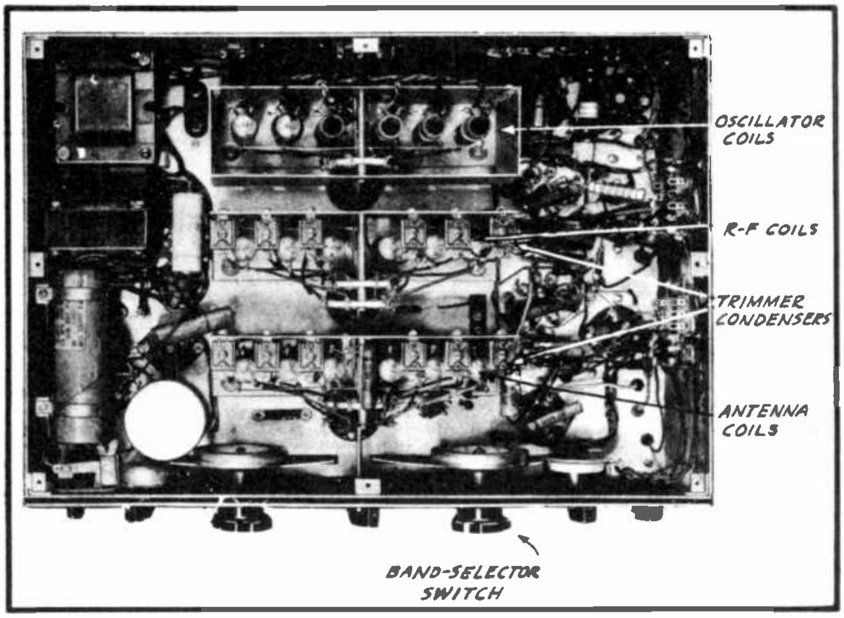

FIG. 16
BOTTOM VIEW OF SIX-BAND RECEIVER, SHOWING SHIELDED COIL-GROUPS

Individual band — selector switch — sections are placed at the center of each coil-group to further aid in obtaining the shortest leads possible between the coil and switch terminals. A long shaft extends through the center of the chassis, connecting together the various switch sections so that they can all be operated simultaneously by a single knob that is located on the front panel of the receiver.

TWO-BAND RECEIVERS

Not all of the combination broadcast-shortwave receivers employ all-wave features. That is, they do not all provide continuous band coverage from the high-frequency end of the shortwave spectrum to the low-frequency end of the broadcast band. Instead, they often "skip" a band or two between these limits and are therefore called "skip-band" receivers.

The operating and constructional details of skip-band receivers are identical to those of all-wave receivers, with the exception that they do not have as many tuning coils and switch contacts. Thus, skip band receivers are of simpler design and less expensive construction.

Two-band receivers of better quality employ individual coils for the different bands, but many such receivers use the "shorting" type of coil shown at (B) of Fig. 2, in conjunction with a band-selector switch of the type shown at (B) of Fig. 6.

Since the switching arrangement for individual coils is the same in skip-band receivers as in all-wave receivers, we will not repeat this explanation. However, we will treat the "shorting method" in greater detail at this time.

TWO-BAND, COIL-SHORTING TUNER

A typical two-band tuner is illustrated in Fig. 17. Upon closely inspecting this wiring diagram, you will observe that the antenna coil consists of two secondary windings wound on a single form and connected in series. A primary winding is placed at the lower end of this same coil-form so as to be inductively coupled to both secondaries.

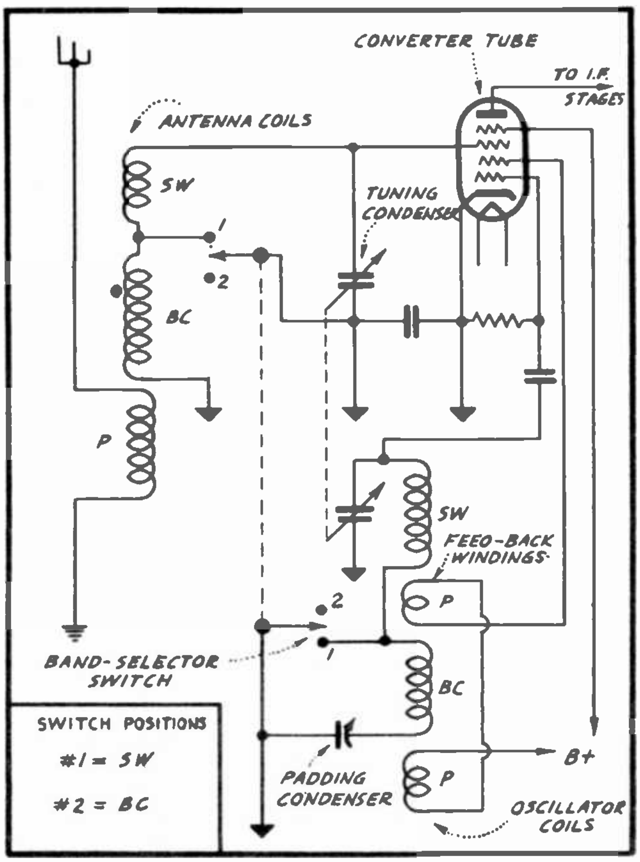

FIG. 17
TWO-BAND TUNER CIRCUIT

The antenna coil circuit operates as follows: When the band-selector switch is placed in position #1, that portion of the coil marked "BC"(broadcast) will be shorted out to ground, leaving only the "SW" (shortwave) winding of the coil operative. In position #2 both windings are in series for broadcast reception.

The oscillator coil connections are similar,with the exception that the feed-back winding is split into two sections. One section is wound near the "SW" secondary and the other near the "BC"secondary. Thus, a feed-back winding will be in the proper inductive relation to whichever secondary winding is being used at the time. This same principle is also employed on some antenna coils when it is necessary to increase the coupling between the "SW" secondary and the primary winding.

Since the secondary winding arrangement on any one coil-form consists merely of a tapped inductance, the band-selector switch need be only a simple double-pole, single-throw (DPST) type, instead of an elaborate rotary type with separate sections for each tuning circuit. However, the latter type of switch, while being considerably more expensive, is nevertheless much more efficient and is therefore nearly always employed in the better-class, all-wave or two-band receivers.

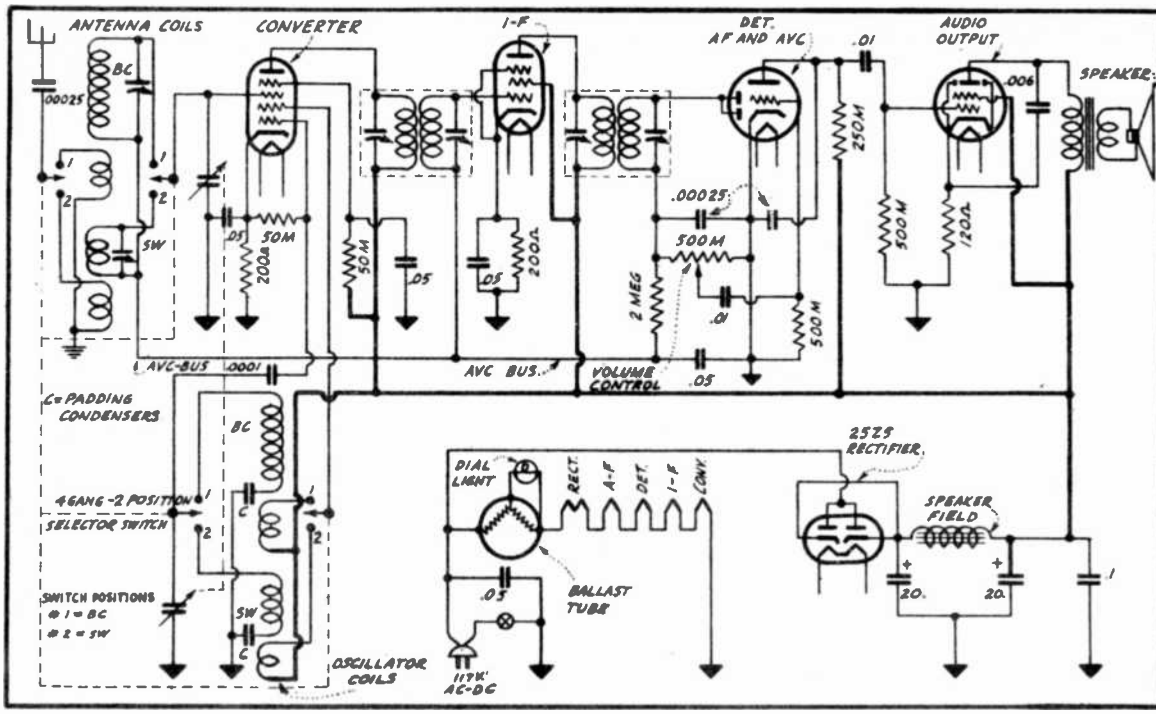

Fig. 18
Five-tube, Two-band, AC-DC Superheterodyne

FIVE-TUBE, TWO-BAND, AC-DC SUPERHETERODYNE

In Fig. 18 is shown the complete circuit diagram of a modern two band, ac-dc receiver, employing five tubes and a separate primary winding for each band. In this particular case, a converter tube is employed in the mixer stage, followed by a pentode i-f tube; a duplex diode-triode functions as a detector,a-v-c and first audio tube; while a beam-power tube is used in the audio output. The rectifier tube is the well-known 25Z5 type, operating in conjunction with a conventional ac-dc power supply.

In Fig. 19 is shown the two-band tuning coil assembly as employed in this receiver. Notice that the two antenna-stage secondaries are placed on one form, together with their individual primaries, while the oscillator secondaries and their individual feed-back windings are placed on the other form. The standard broadcast windings are placed on one end and the shortwave windings on the other end of the coil-forms. This is considered good engineering practice.

In many cases,these two coil-forms are placed in individual shielding containers, similar to the three-band coils shown in Fig. 5. However, the general practice among manufacturers has been to employ individual coil shields only when a stage of r-f amplification precedes the mixer stage. This is done to prevent r-f coupling between the various high-gain tuned stages, which would result in instability and oscillation in these circuits.

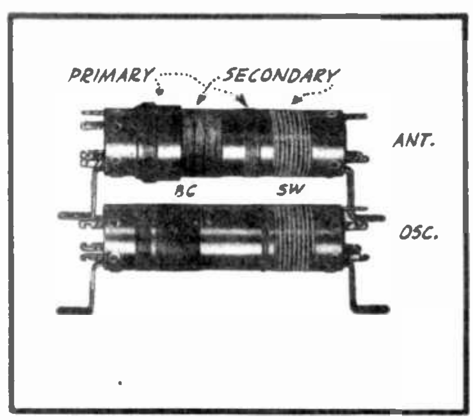

Fig. 19
Typical Two-band Coils

While the coils shown in Fig.19 have both the standard broadcast and shortwave windings on one coil-form for convenience and economical reasons, it is to be remembered that separate coil-forms are often employed for each band. In other words, the broadcast and shortwave windings are then placed on individual coil-forms and shielded individually.

When the band-selector switch in Fig. 18 is placed in position #1 of all sections, the standard broadcast windings will be connected into the tuning circuit. Closing all switch sections to position #2 disconnects the broadcast coils from the tuning circuit and connects the two shortwave coil-groups in their place. Since the different sections of the band-selector switch are ganged together, the switching operations at all switch-sections occur simultaneously as the position of the band-selector knob is changed.

PUSH-BUTTON TUNING AS APPLIED TO ALL-WAVE RECEIVERS

A great many all-wave and two-band receivers employ push-button tuning features. Therefore, your study of combination shortwave and standard broadcast receivers would not be complete unless the description of a receiver of this type were included herein.

No effort will be made in this lesson to cover in detail all of the many principles used in automatic (push-button) tuning systems, as this subject is covered thoroughly in the next lesson. However, we will discuss at this time the change-over switching method as usually employed on push-button type all-wave receivers.

In beginning our study of these receivers, let it be understood definitely that automatic tuning is NOT employed on the shortwave bands, but is used only for the reception of certain pre-selected stations that operate on the standard broadcast band. The reason for this will become apparent as you continue your study of these circuits.

WHAT AUTOMATIC TUNING IS

All of the receivers about which you have studied thus far, are of the manually-tuned types. That is, the various stations were tuned in by operating the tuning dial mechanism by hand, which in turn rotated the variable tuning condenser to the position required to tune-in the station desired. In receivers employing automatic tuning (push button tuning), the desired station is tuned-in automatically by either pushing a button or depressing a lever, which action in some cases rotates the variable gang condenser to the desired station position. In other cases, the variable condenser is disconnected entirely from the circuit, and a group of small semi-variable condensers substituted in its place. At this time, only the latter system will be described insofar as it pertains to all-wave and skip-band receivers. The other systems bear no direct relation to all-wave sets and will therefore be discussed later.

CIRCUIT DETAILS

The principle of this tuned-circuit substitution system is to substitute pre-set tuned circuits for the usual tuning circuit with which the variable condenser is used. For automatic tuning, control is shifted from the gang condenser to the pre-set trimmer condensers that are mounted adjacent to the switch terminals of a push-button, station selector switch assembly. This transfer of control is usually accomplished by means of a change-over switch that is incorporated in the band-selector switch as shown in Fig. 20. The control panel layout for such an arrangement is illustrated in Fig. 21.

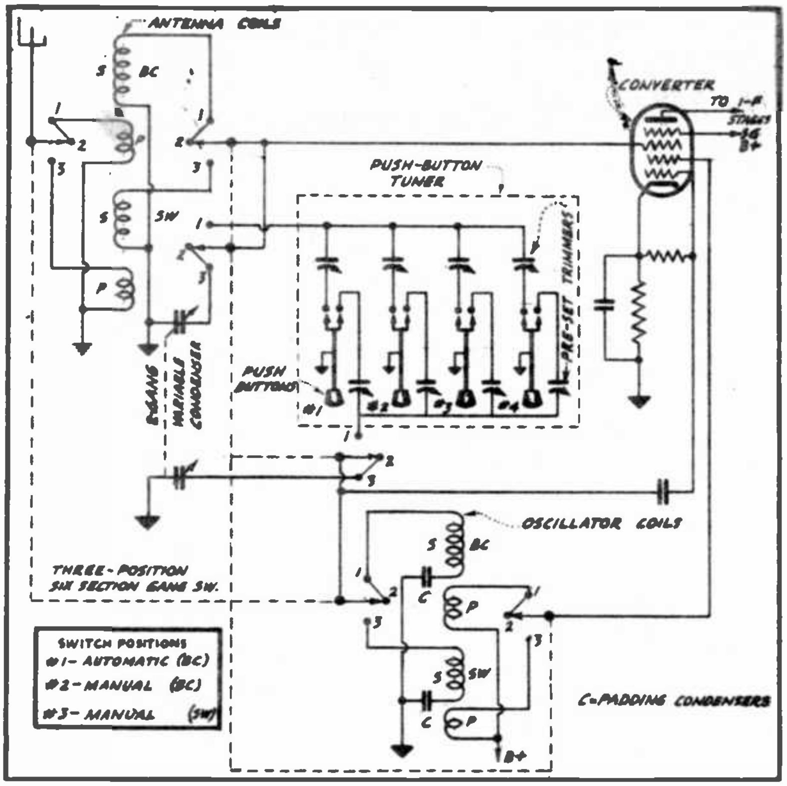

FIG. 20
SWITCH CONNECTIONS FOR ALL-WAVE RECEIVER EMPLOYING PUSH-BUTTON TUNING

CIRCUIT OPERATION

When the band-selector switch in Figs. 20 and 21 is placed in position #1, the two sections of the variable tuning condenser are disconnected entirely from the tuning circuits, and in their place will be connected the antenna and oscillator sections of the push-button tuner.

Upon now depressing any one of the station — selecting push-buttons, we will automatically tune-in the broadcast station for which this push-button circuit has been pre-tuned. This feature is explained in detail in the next lesson, so there is no need for devoting too much time to it now.

When the band-selector switch is closed to position #2(see Figs. 20 and 21), the two sections of the variable tuning condenser are connected across their respective broadcast secondary winding and tuning is then accomplished by operating the tuning knob in the conventional manner. The push-button tuner is disconnected from the system at this time.

Closing the band-selector switch to position #3 connects the shortwave secondaries across the variable tuning condenser, and disconnects the push-button tuner so that shortwave tuning is accomplished manually in the usual way.

ANTENNAS FOR ALL-WAVE RECEIVERS

In districts that are relatively free of noise, a well-installed inverted L-type antenna will furnish satisfactory all-wave performance. However, the antenna should not be too long if the best possible performance is to be expected on the shorter wavelengths. A doublet or other special type of "all-wave" antenna will generally produce better results in dis-

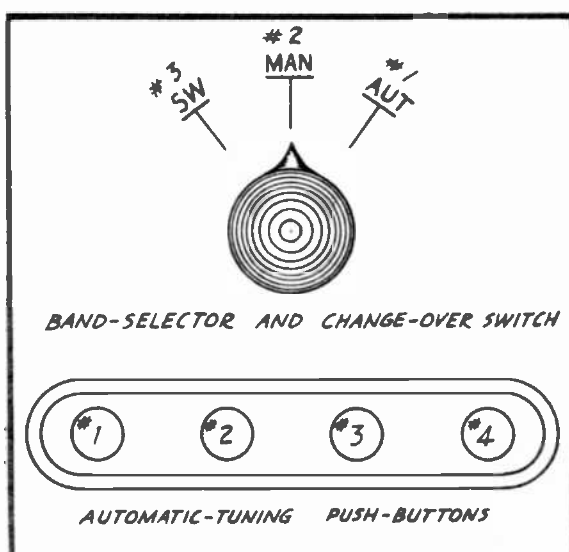

FIG. 21
TYPICAL PANEL ARRANGEMENT FOR PUSH BUTTON AND CHANGE-OVER SWITCH

tricts that are subjected to considerable man-made interference disturbances.

The so-called "all-wave" antenna systems of various designs are manufactured in kit-form by several concerns. Such antenna systems are generally assembled by the manufacturer, ready for erection, and are accompanied by detailed instructions to assure the best possible performance from the particular antenna system in question.

In this lesson we are not particularly concerned with outdoor antennas, as they are not a part of the receiver -- furthermore, they are all described fully elsewhere in the course.

ALL-WAVE RECEIVER LOOP ANTENNAS

In adapting self-contained loop antennas to all wave receivers, the usual practice is to employ two loops, one for standard broadcast reception and the other for shortwave reception. In Fig. 22 is shown a phantom view of an all-wave receiver, showing the position of two such loops in a console cabinet. The shortwave loop consists of only two turns, and is fastened in a horizontal position to the top of the cabinet. Placing the loop in this position gives it non-directional properties and therefore permits reception of stations equally well in all directions, and without the operator having to point it in the direction of the desired station.

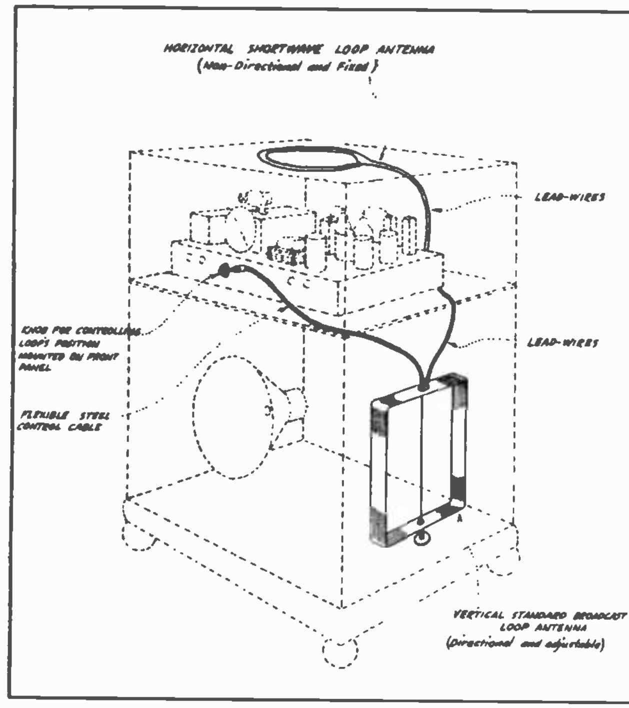

FIG. 22
PLACEMENT OF STANDARD BROADCAST AND SHORTWAVE LOOP ANTENNAS IN A CONSOLE CABINET

The standard broadcast loop antenna, on the other hand, has directional properties and therefore is placed in a vertical position in the lower compartment of the cabinet. It is so mounted that it can be rotated and pointed in the direction necessary for maximum signal pick-up from the station desired. On some receivers, the loop is rotated by hand simply by reaching into the back of the cabinet, while in more elaborate designs the loop's position is controlled by a knob or lever that is

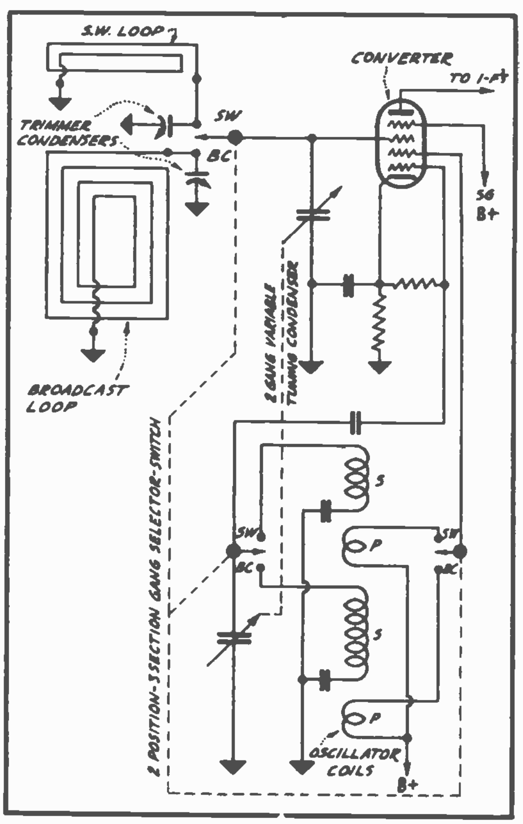

FIG. 23
SWITCH CONNECTIONS FOR LOOP ANTENNAS

located on the control panel of the receiver. Fig. 22 illustrates the latter arrangement, where the control knob is connected to the broadcast loop antenna through a flexible steel cable similar to that employed with remote control units of automobile receivers.

Fig. 23 illustrates the method used for changing from one loop antenna to the other. Here, you will observe that the change-over switch is a part of the band-selector switch. Placing the band-selector switch in the shortwave (SW) position, connects the shortwave loop antenna to the tuning circuit of the mixer stage, connects the shortwave oscillator coil in its circuit and disconnects the broadcast loop from the system. On the other hand, placing the band-selector switch in the standard broadcast (BC) position, disconnects the shortwave loop antenna from the mixer-stage tuning circuit, and in its place connects the broadcast loop. At the same time, the broadcast oscillator coil is connected in its circuit.

Note in Fig. 23 that the loop takes the place of the regular antenna transformer in both instances. Therefore, the loop must have the proper inductance value to track correctly with the inductance of the oscillator coil. Trimmer condensers are connected across each loop to align it properly with the oscillator tuning circuit.

EXAMINATION QUESTIONS

LESSON NO. 29

1. - What precautions should be exercised in the construction of an all-wave receiver with respect to the relation between the placement of the tuning coils and the band-selector switch?
2. - What provisions are generally made for aligning each band individually?
3. - Name three methods used for selecting any one of several tuning bands by manipulating a band-selector switch?
4. - What is the chief disadvantage of the series method of coil-switching?
5. - Why is the practice of using an individual coil-form for each tuning circuit considered preferable to placing several windings on a single form?
6. - A certain all-wave superheterodyne receiver has a preselector r-f stage, a first detector stage and an oscillator stage, and covers five bands. If individual tuning-coil forms are used for each band, what is the total number of such coils in this receiver?
7. - What is meant by a "skip-band" receiver?
8. - Describe briefly a typical loop antenna system as used with some all-wave receivers.
9. - Mention the various switches which are used in a typical all-wave receiver that is also equipped with a push button tuning system.
10. - By examining an all-wave band-selector switch, how can you determine which is the <u>common</u> terminal of each switch-section?

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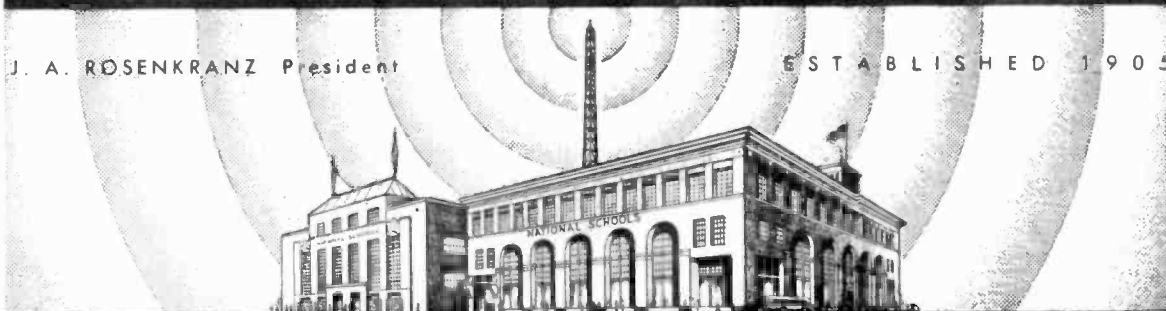

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LESSON NO. 30

AUTOMATIC TUNING SYSTEMS

Up to the present time, your receiver studies have been confined strictly to sets employing MANUALLY operated tuning systems. Receivers of such design are tuned by means of rotating a knob, which in turn swings the dial needle across the scale and rotates the condenser plates to the proper position to bring in the desired station. In this lesson you are going to continue your study of receivers by learning about the theory, operation and maintenance requirements of AUTOMATIC tuning systems, as used on receivers featuring "push-button" tuning, "touch" tuning, and other similar methods.

FIG. 1
MODERN RECEIVER, FEATURING AUTOMATIC TUNING

With the widespread adoption of automatic tuning by every radio manufacturer, and the appeal of this feature to the public as a necessary adjunct to the modern radio receiver, it is important that the trained radio technician be thoroughly familiar with such tuning systems. Therefore, this lesson has been prepared to aid you in applying your present knowledge of radio to the maintenance work as applied to these more modern types of receivers.

An important fact to be considered relative to automatic tuning systems is that they present to the radio service engineer a unique opportunity for the establishment of closer customer-contact,since in many instances the original set-up of selected stations,as well as the maintenance of continued satisfactory automatic operation, is a function which he alone is technically capable of rendering. This naturally means more work for the serviceman.

CLASSIFICATION OF AUTOMATIC TUNING SYSTEMS

In this lesson you are given a complete descriptive review of the various methods used to accomplish automatic tuning. Some of these methods may at first glance appear to be a bewildering complex arrangement of parts, but upon closer study of the subject you will find that the various systems are related, and that it is therefore possible to classify them, as explained in the following paragraphs.

In general, automatic tuning systems may be divided into the following three main groups:

1. - Mechanically-operated manual types.
2. - Motor-operated types.
3. - Tuned-circuit substitution types.

The first and third main classifications may be subdivided still further into the following individual variations: Group 1, consisting of the rotary (telephone dial),cash register, and push-button types; and Group 3, consisting of the trimmer condenser and the iron-core coil types. Fig. 2 will further assist you in acquiring a clearer conception of the chief classifications of automatic tuning systems.

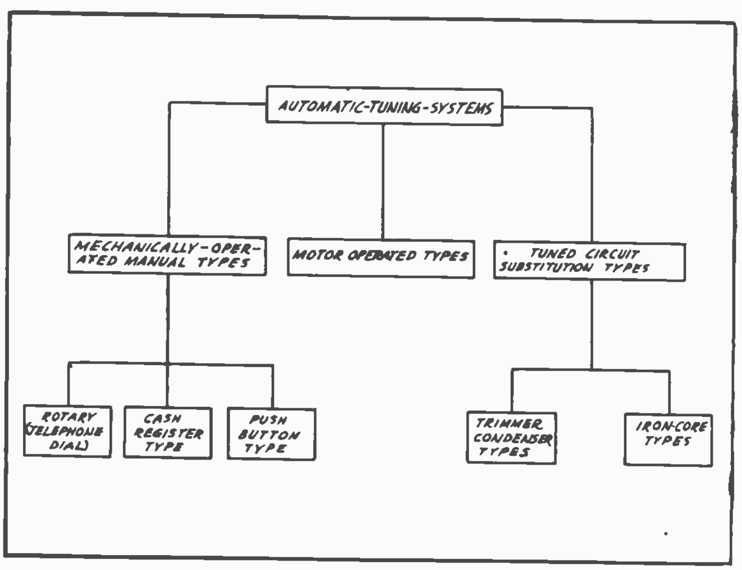

FIG. 2
CLASSIFICATION OF AUTOMATIC TUNING SYSTEMS

So far, we have given you a bird's-eye-view of automatic tuning systems, so that you will have somewhat of an idea of the various types before we go into a detailed study of the different mechanisms and arrangements. With this complete picture in mind, we will now start at the very beginning and progress through this lesson step by step, covering the subject of automatic tuning in detail.

Mechanically Operated Manual Types

As briefly covered in the classification outline, this method of automatic tuning includes all of the devices which permit the variable gang-tuning condenser to be adjusted directly by mechanical effort of the person tuning the receiver so as to"bring in" the desired station.

ROTARY OR TELEPHONE DIAL SYSTEMS

The design of this system is such that stations are tuned-in by applying a procedure similar to dialing a telephone (see Fig.3). This type of mechanism was the forerunner of mechanical automatic tuning, and has found widespread use. In most models of the telephone-dial system, a pin or lever is attached to the inner end of each of the station push-button plungers. The series of button-plungers are usually attached to a dial plate which in turn drives the gang condenser thru a gear-train so proportioned as to allow almost 360 degrees of dial plate rotation.

As the plunger corresponding to the desired station is depressed against spring tension, and the dial plate rotated at the same time, the indexing pin rotates with the dial plate and is arrested in its rotary motion by some form of stop or lock-in device. At the instant that the stop becomes effective the tuning condenser plates will have rotated to the position required to tune-in the station, and designated by the marking on the push-button in use. The precise position at which condenser rotation stops is adjustable by one of several methods that allow for setting-up the receiver to a group of desired stations.

The operating principle of this tuning system will be made more clear after you have studied the constructional details of the system illustrated in Fig. 4, together with the following explanation of this device.

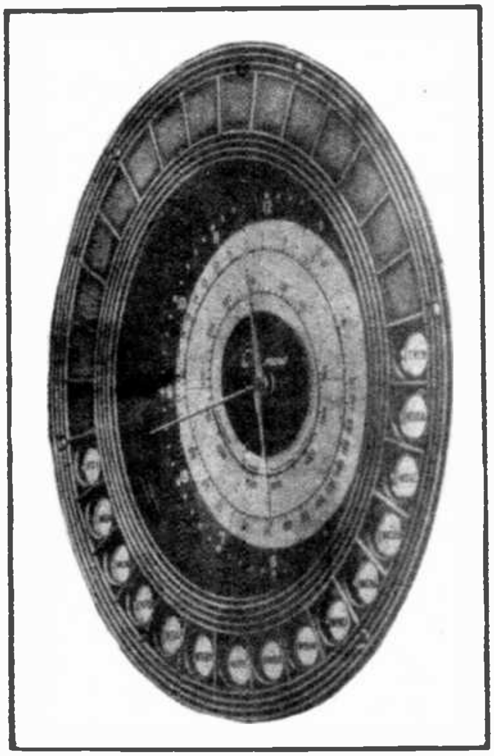

FIG. 3
TELEPHONE TYPE DIAL

TYPICAL TELEPHONE DIAL ASSEMBLY

CONSTRUCTION AND OPERATION: In the assembly shown in Fig. 4, the circular housing, containing the buttons, is directly mounted and fastened to the shaft of the gang tuning condenser. Consequently, when one of the station-selecting button plungers is pushed inward, and the disc-shaped housing rotated, the inserted button crankpin will eventually contact the floating vane, cause a locking action and prevent further rotation of either the mechanism or tuning condenser. The receiver will then be tuned to the station for which the particular button has been pre-adjusted.

INDEXING METHOD: Fig. 4 also illustrates the action of this particular indexing adjustment. In the upper illustration of Fig. 4 the outer ornamental dial plate has been removed for the set-up operations, and has been replaced by a thin metal disc, held in position by the knurled face-nut. This disc is a special service tool that has a single semi-circular notch cut in its periphery so that by rotating the disc to any desired position, and locking it in place, any one button may be moved toward the front while the rest of the buttons are all held in place. Thus the button aligned with the notch of the disc will, under the action of its spring, be moved toward the front sufficiently to allow its serrations (gear-like head) to clear those of the housing. This particular button assembly may then be rotated one way or the other so that the button crankpin will be in the correct position to jam against the locking vane either sooner or later, and when the condenser plates are in the position to tune in the desired station.

THE STATION STOP: As will be seen in the top and center illustrations of Fig. 4, the station-stop arrangement consists of a floating vane, operating between fixed stops. The vane of the stop assembly is so shaped that the center of the button crankpin will be located on a line drawn vertically through the center of the dial mechanism when the crankpin pushes the vane against either stop. In other words, the shape of the vane and its thickness are such that independent of the position of the crankpin, it will be centrally located when approaching the stop from either direction.

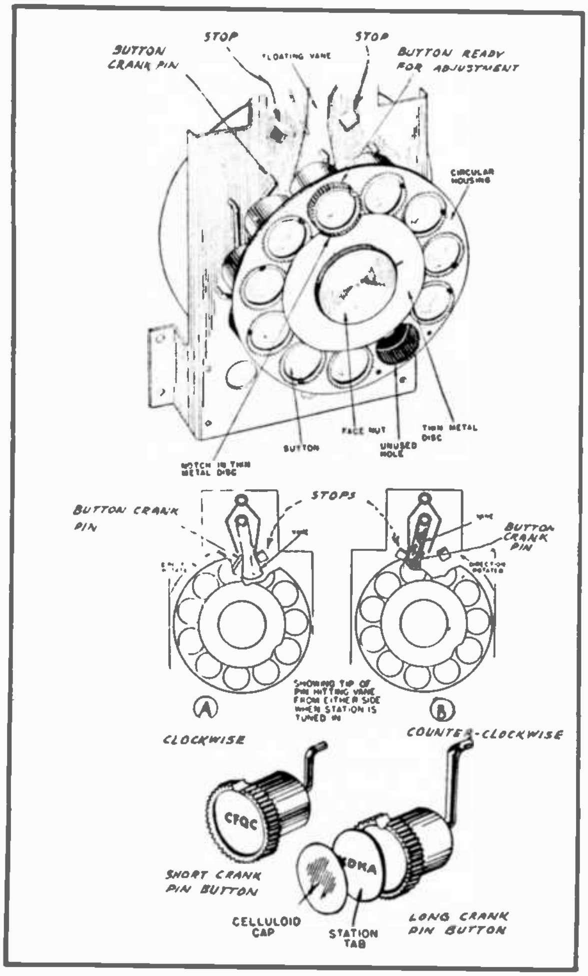

FIG. 4
TYPICAL TELEPHONE DIAL ASSEMBLY

Note also in the top illustration of Fig. 4 that all of the button crankpins, except that of the depressed button, will clear the floating vane by sliding freely over its face, as springs within the button assemblies normally force the button and crankpin outward sufficiently to provide this clearance at all times except when a button is depressed. This feature prevents the crankpins of the unused buttons from dropping into the locking positions.

In this dial assembly, rotation of the mechanism and condenser may be either clockwise or counter-clockwise, as shown in illustrations (A) and (B) of Fig.4. Here it will be observed that (A) illustrates the locking action when tuning the mechanism clockwise, while (B) illustrates the locking action when rotating the mechanism counter-clockwise.

It is of special importance to note in Fig. 4 that each button represents a different station, but that the serrations of each button assembly permit adjustment through a limited range so that an absolute point of resonance can be established for the station selected by each button.

MODIFIED TELEPHONE DIAL ASSEMBLY

CONSTRUCTION AND OPERATION: In the dial assembly illustrated in Fig. 5 the various station selecting buttons are locked in slots cut in the dial disc. This dial disc is locked to the tuning condenser shaft and is free to rotate as a body with the rotor plates of the condenser.

To tune-in a station, the proper button is pushed inward, and the entire dial disc is rotated until the stop pin on the inner end of the depressed button strikes the edge of the floating vane and prevents further rotation. The rotor plates of the tuning condenser will of course move with the dial disc, and will come to rest at the position required to tune-in the desired station. Springs within each of the button assemblies prevent all stop pins, except the one of the depressed button, from striking against the floating vane. The vane furnishes the locking action for either direction of dial rotation, the same as in the system previously described.

STATION BUTTON ADJUSTMENT: Upon referring to Fig. 5, you will observe that the length of the annular slot occupied by each button is such that considerable leeway for adjustment is possible to allow for correct location of the button.

The selection and exact position of the button will depend upon the position of the gang condenser plates at which the desired station is received, and the button position is adjusted in the slot to a corresponding point. In other words, to make an adjustment it is simply necessary to tune the receiver to the desired station by means of the regular tuning knob.

The dial disc will rotate during this procedure because of the cord drive, and will come to rest when the set has been tuned to resonance with the desired station. Having located this point, loosen the locking nut of the station-selecting button which is nearest the vane at this particular instant, and slide this button assembly one way or the other in its slot until its pin jams against the vane. Tighten the locking nut of the button. This button is now so located that it can be used to tune-in the same desired station at any future time.

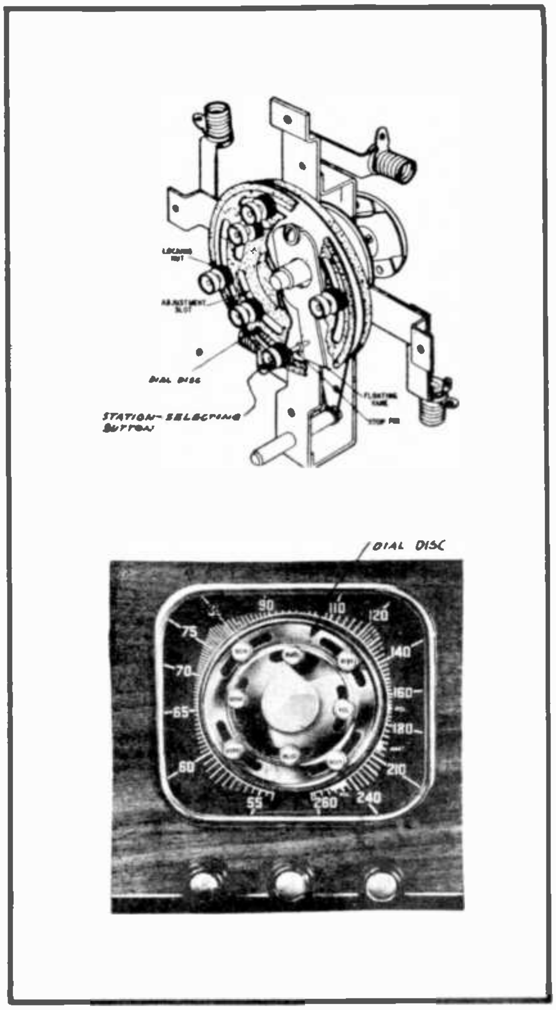

FIG. 5
MODIFIED TELEPHONE DIAL

CASH REGISTER ACTION

In this type of mechanical tuning system, a straight-line downward motion of a key or button, parallel to the tuning panel, rotates the gang tuning condenser by means of cams or levers whose positions are pre-set for the desired station. This action is similar to the manipulation of the keys of a typewriter or cash-register. That is, the action is similar to a keyboard, whereby the motion is made by pressing downward on the station buttons.

This type of tuning system, shown in Fig. 6, consists of a series of "heart-shaped" cams stacked on a shaft attached directly to the gang condenser. These cams are individually adjustable since they can be unlocked from the drive-shaft by a tapered expansion sleeve which is controlled by the locking screw shown in the illustrations.

The tuning levers move through a distance of approximately $1\frac{1}{4}$ inch, and in so doing, turn the cams and the condenser shaft to which they are locked. The stopping point of the lever, cam and condenser is the condenser position at which the desired station will be tuned-in.

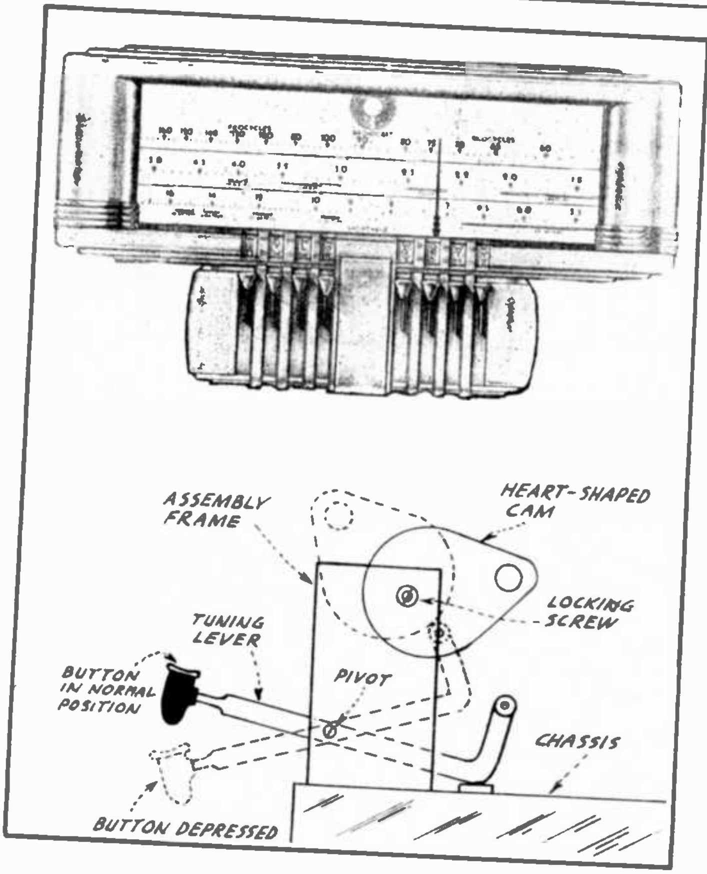

FIG. 6
"CASH REGISTER" TUNING ASSEMBLY

By referring to the diagrammatic illustration in the lower section of Fig. 6, you will observe that when a downward force is exerted upon the button of the tuning lever, the inner (right) end of this lever will move upward, striking against the heart-shaped cam.

If this cam has occupied the position as indicated by the solid line in this drawing, the upward force of the tuning lever will cause it to turn in a counter-clockwise direction until this end of the lever reaches its limit of travel, at which time it will be contacting the "low side" of the cam. The condenser shaft and plates will rotate with the cam.

Each lever actuates an individual cam and thereby controls the setting for one station. Spring action returns the lever to its normal position as soon as the button is released.

As the slope of the cam's contour varies, the position of the cam on the condenser shaft determines how far the condenser shaft will be rotated when the corresponding station-selecting button is depressed.

STATION SET UP: To set up this arrangement for certain stations, the locking screw at the end of the shaft is loosened, and the station-selecting button depressed to the end of its travel, and while holding it down, the station is tuned-in accurately by hand.

This operation is repeated for each of the desired stations by using the separate levers. The locking screw is tightened after this operation.

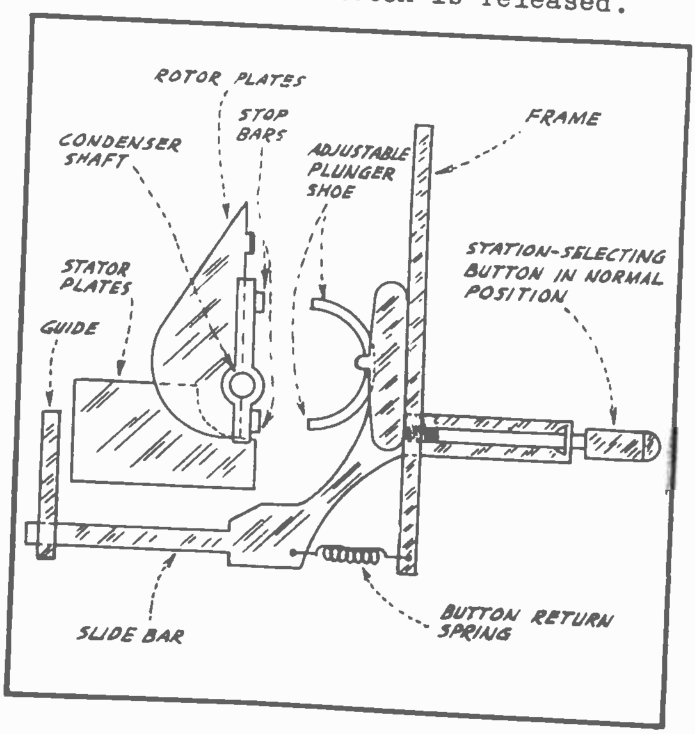

FIG. 7
MECHANICAL PUSH-BUTTON DIAL ASSEMBLY

PUSH-BUTTON ACTION

An end view of a typical mechanically-operated push-button tuning assembly is shown in Fig. 7. In this system the gang condenser and the push-button plunger mechanisms are assembled as one unit. Consequently, when the station button in Fig. 7 is depressed, and its plunger shoe comes in contact with the stop bar that is fastened to the drive-shaft of the rotor plates, the gang condenser will be rotated accordingly, until the button has completed its inward travel, at which time rotation will stop, and the desired station will be tuned-in.

STATION STOP: The station stop consists of two bars running parallel to and also fastened to the shaft of the gang condenser. One of the bars is placed on each side of the rotor shaft. Thus when the station button in Fig. 7 is depressed and its plunger shoe comes in contact with one of these bars, the gang condenser will be rotated, until each of the stop bars strikes an extremity of the plunger shoe. Rotation will then stop and the station will be tuned-in.

The reason for two stop bars is to enable the condenser to be rotated to the desired station position regardless of the rotor-plate position before the desired button plunger is depressed. This is more fully illustrated in the three views appearing in Fig. 8.

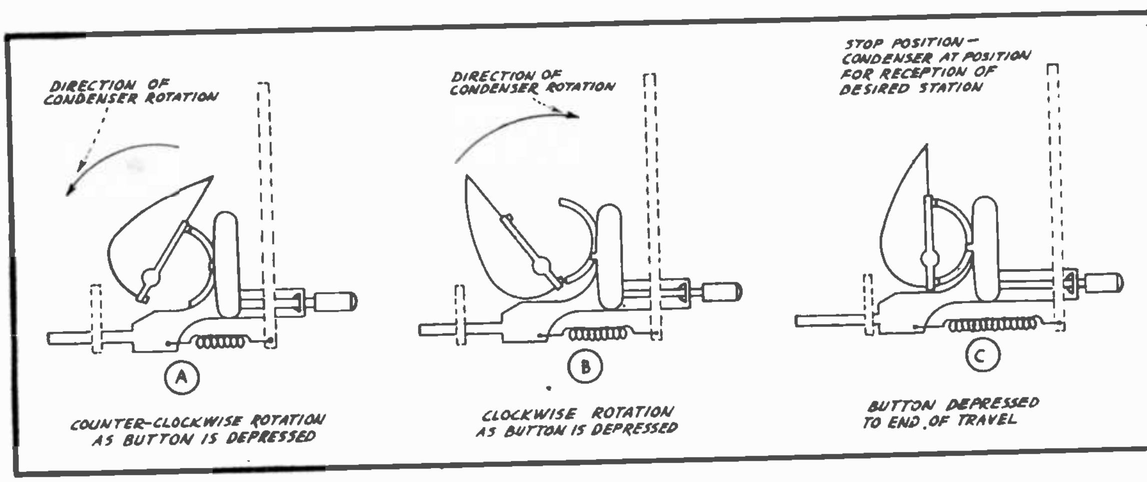

FIG. 8
POSITION OF BUTTON PLUNGERS FOR EITHER DIRECTION OF ROTATION

Upon close inspection of the various views presented in Figs. 7 and 8, you will observe that Fig. 7 shows a station-selecting button in its normal position, while (A) of Fig. 8 shows a button that has been depressed to a point before reaching its end of travel. You will further observe at (A) of Fig. 8, that as the button is depressed, its plunger shoe will first come in contact with the upper condenser stop, rotating the condenser in a counter-clockwise direction until both plunger shoe tips are flush against both condenser stops, as shown at (C) of Fig. 8.

Drawings (B) and (C) of Fig. 8 show the mechanical action when the rotor plates must be turned in a clockwise direction to reach the position for the desired station. You will note at (B) that when such is the case, the lower plunger shoe tip will first strike the lower stop bar and force the condenser plates to turn in a clockwise direction until the stop position (C) is reached.

STATION SET-UP: To set up this arrangement for automatic tuning, the station is accurately tuned-in manually, in the conventional manner. Then a station-selecting button now is loosened by unscrewing it a few turns. The button is then pushed inward to the end of its travel, and the button knob retightened. Depressing this button hereafter will always bring in the same station.

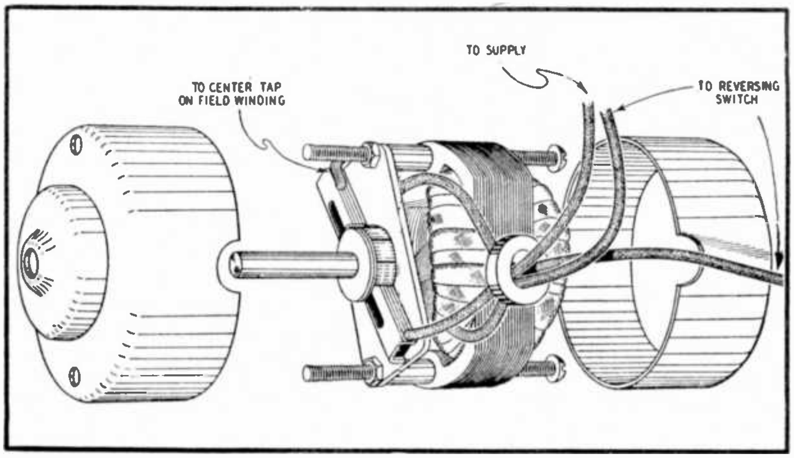

FIG. 9
TYPICAL MOTOR ASSEMBLY

As a precaution to prevent the gang condenser from moving slightly during this operation, one hand should be held on the manual station control knob. Otherwise, when the button shoe comes in contact with the condenser stop bar, the force of the contact might slightly rotate the gang condenser off the position of the pre-tuned station. This operation is repeated at each of the station-selecting buttons for each of the desired stations.

Altogether, there are four or more buttons, which allows a corresponding number of stations to be tuned-in by this method.

The Motor-operated System

In this system of automatic tuning, the variable gang tuning condenser is rotated to a position corresponding to a desired station tuning point by means of a small electric motor. This tuning system, which was the first to be introduced, usually includes an electric motor, a station selector switch or group of selector buttons, and a selecting commutator or other device for stopping the motor at the desired point. Figs. 9 and 10 show cutaway views of typical motor assemblies.

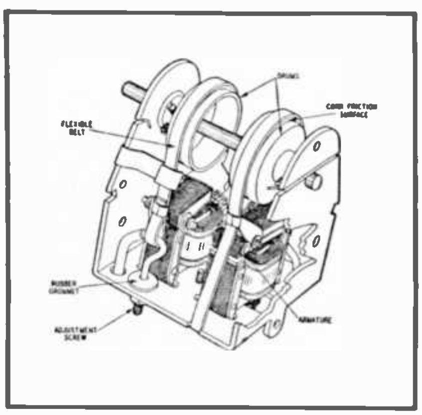

FIG. 10
THE ASSEMBLED MOTOR

A typical four-station motor-tuned system is illustrated pictorially in Fig.11, and its corresponding schematic wiring diagram is shown in Fig. 12. The following description of this system, together with a careful study of Figs.11 and 12, will serve to familiarize you with motor-tuned operation.

The induction type tuning-motor drives the variable gang condenser through a train of gears to which the motor is mechanically coupled by a quick-acting clutch. When the motor is not energized the armature is positioned slightly out-of-center of the motor's magnetic field. It is held in this position by a flat phosphor-bronze spring which also acts as a part of a jack spring switch assembly. When the windings of the motor are energized, magnetic action draws the rotor into the center of the motor's magnetic field, closing the separated parts of the clutch and actuating the jack spring switch.

The clutch performs a dual function in that it relieves the condenser driving system of the load of the motor during manual tuning and also allows the motor to coast to a stop, thereby permitting instant stopping of the gang condenser when the selecting commutator opens the motor circuit.

The selecting commutator is directly coupled to an extension of the variable condenser shaft by means of a universal coupling. In the case illustrated it consists of a series of metal discs, electrically connected to the shaft and driven by means of cupped friction washers.

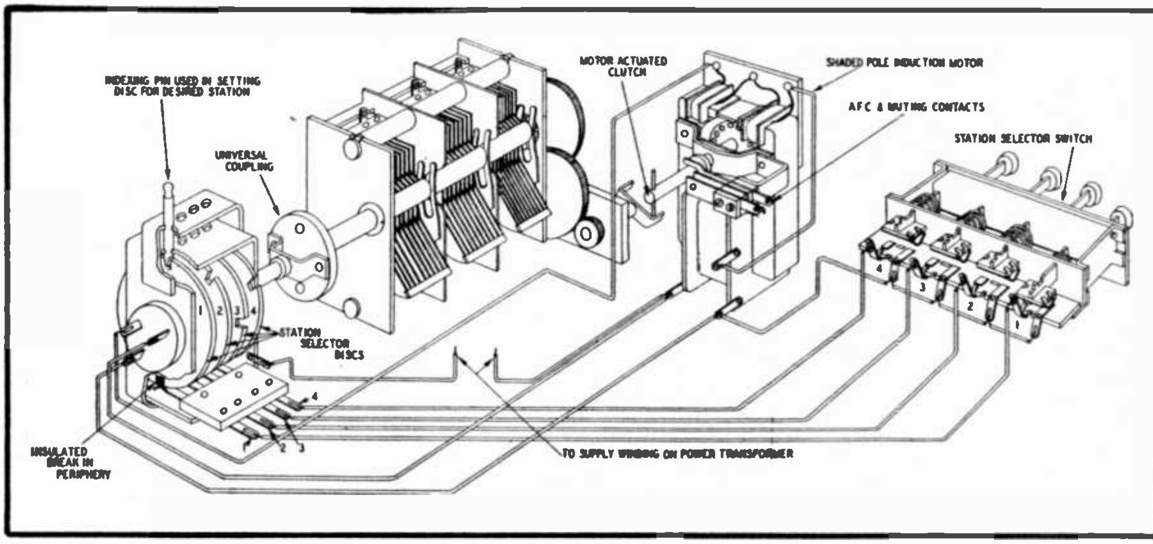

FIG. 11
MOTOR-DRIVEN STATION-SELECTING SYSTEM

A short insulated section or insert is placed in the periphery of each disc and serves to open the circuit when the disc has rotated to such a point where a contacting finger rests upon the insulation. These individual discs may be rotated with respect to their common drive-shaft so as to allow them to be set to positions corresponding to the desired station tuning points, as explained later.

SELECTING THE DESIRED STATION

Selection of the desired station is accomplished by depressing one of the station-selector buttons. A single-circuit switch is actuated by each button, and each of these switches is wired in series with one of the contactor fingers which bear upon one of the station selecting commutator discs. Since the push-button plungers engage a common latch bar, one circuit will be held closed until released by depressing another button.

As will be observed in Fig. 12, the control circuit for any one station is completed through one of the commutator discs and its respective push-button switch, the motor, reversing switch and the motor supply winding on the power transformer -- a ground return wiring system is used. Thus when a station-selector button is pressed, the motor will continue to operate until the insulation insert of the working station-selecting disc comes under the contactor-finger and thereby opens the circuit at the correct station tuning point. In the particular system shown in the illustration, a jack spring switch on

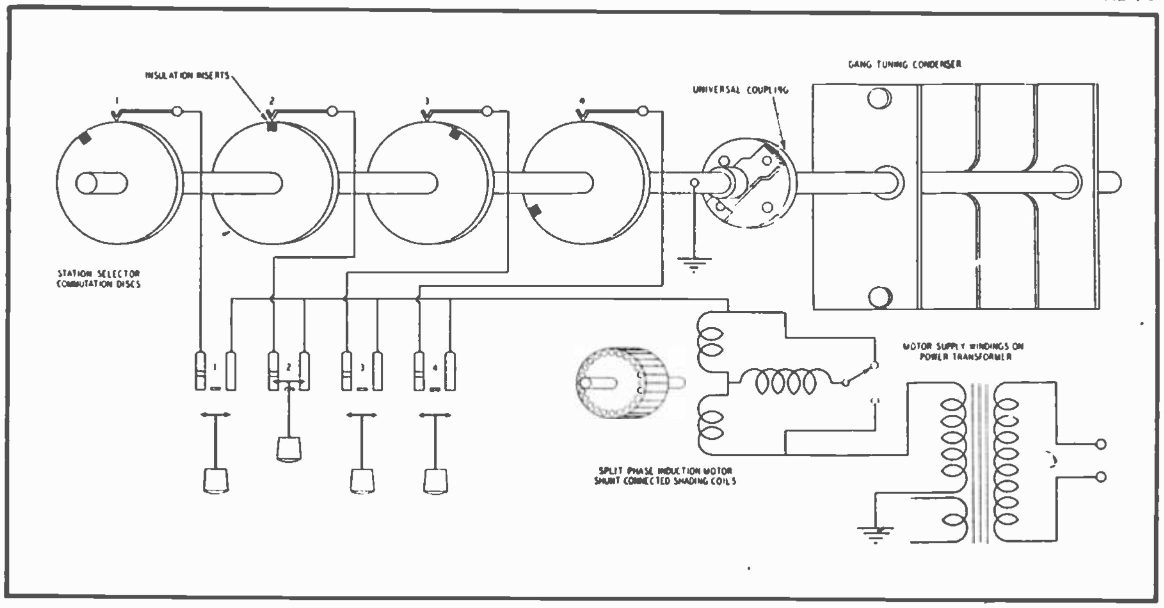

FIG. 12
SCHEMATIC DIAGRAM OF MOTOR-TUNED SYSTEM

the motor clutch silences the audio system of the receiver during the tuning process.

REVERSING THE MOTOR

Since the single-circuit discs cannot select the direction of motor rotation, a motor-reversing switch is attached to the commutator shaft. This switch serves to reverse the motor in the event that the desired station tuning point has not been attained before the gang condenser has reached its limit of travel in any one direction.

STATION ADJUSTMENT

In all motor-driven automatic tuning systems, each push-button is respectively wired to an adjustable station-selector disc, directly coupled to the variable condenser tuning gang. Pressing any of the buttons starts the motor, which in turn engages the tuning drive gear, and slowly rotates the gang condenser. The motor will continue to operate until the insulated segment of the station-selector disc interrupts the motor circuit.

When adjusting the system, any four stations may be chosen. To make an adjustment for one button -- for example, in Fig. 12 -- insert the indexing pin (a service tool) in the bracket hole above station-selector disc #1 as shown in Fig. 11, and push it all the way down to contact the edge of the disc. Tune the receiver very carefully by means of the regular manual (hand-operated) tuning control until you feel the pin drop into the notch of disc #1, and continue turning the hand-operated tuning knob until the dial station-pointer indicates the desired station. Remove the indexing pin -- push-button #1 is now set for electric tuning. The remaining three buttons are set in an identical fashion.

It is important to note that the frictional contact between the station-selector discs and the shaft permits the necessary "slippage" for setting the discs for the various stations in the manner just described. However, the frictional contact offers sufficient "grip" to prevent slippage of the discs on this shaft while tuning normally.

AUDIO SILENCING DURING THE AUTOMATIC TUNING CYCLE

While several variations of this basic system exist, provision is made in practically all of the motor-tuned systems for silencing or muting the audio system of the receiver during the time-interval required by the tuning mechanism to move the gang condenser from one station selection to another. This is necessary to prevent a bedlam of annoying sounds being emitted by the loudspeaker while tuning through the various broadcast channels until the desired station is obtained. The following methods are used to accomplish audio silencing during the automatic tuning cycle.

1. - Short-circuiting the moving coil of the dynamic speaker or the output transformer primary.

2. - Short-circuiting to ground the output of the audio section of the diode detector.

3. - Grounding to the chassis frame an audio grid.

4. - Biasing an audio tube to the cut-off point by applying an excessive negative bias.

5. - Applying a high negative bias to the r-f, converter,or i-f amplifier tubes so as to reduce the receiver sensitivity.

Tuned-Circuit Substitution Systems

The principle of these systems is to substitute pre-set tuned circuits for the usual tuning circuits with which the ganged variable condenser is used. For automatic tuning, control is shifted from the gang condenser to pre-set trimmer condensers (or iron-core tuned coils), mounted adjacent to the switch terminals of a push-button selector switch. The transfer may be accomplished in a variety of ways, either automatically by the selector switch or by a separate change-over switch. In Fig. 13 are shown front panel views of the more common change-over methods.

At (A) of Fig. 13 you are shown a method where the change-over from manual to automatic tuning or vice-versa is accomplished by turning a knob to the required position. Some receivers use an arrangement similar to that shown at (B) of Fig.13, where a single switch may be turned to any one of three positions, offering shortwave reception and broadcast reception by means of manual tuning, and also broadcast reception by means of automatic tuning. A still different method appears at (C) of Fig.13, where the change-over switch is shown in the form of a push-button, and is incorporated

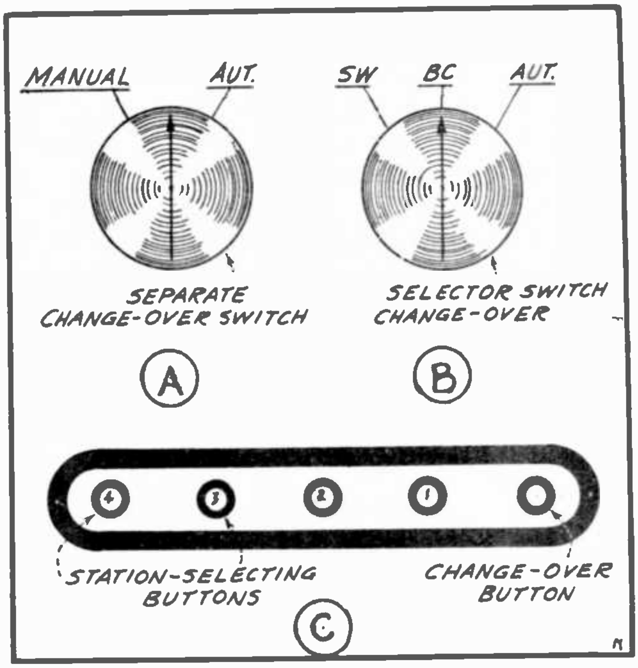

FIG. 13
TYPICAL CHANGE-OVER METHODS

in the same escutcheon (decorative plate) as the station-selecting buttons that are used for automatic tuning.

One outstanding advantage of this type of automatic tuning system is its instantaneous action. That is, response to a desired station occurs immediately upon depressing the station button, and hardly any physical effort is required on the part of the owner when depressing the various buttons.

CONDENSER-TUNED SYSTEM

A typical condenser-substitution system is illustrated pictorially in Fig. 14, while a basic schematic wiring diagram of such a system is shown in Fig. 15. A sectional view of a typical station-selector switch, as used in this system, is shown in Fig. 16.

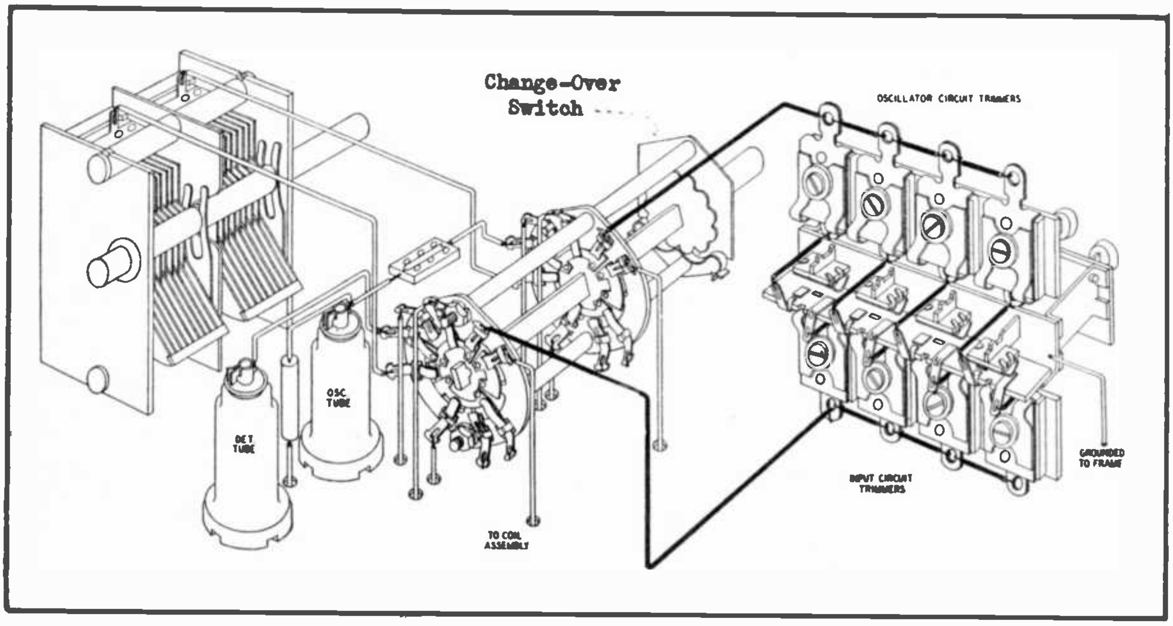

FIG. 14
TYPICAL CONDENSER-SUBSTITUTION TUNING SYSTEM

CIRCUIT DETAILS: The circuit illustrated in Fig. 15 is designed for use in a straight broadcast receiver, and the change-over from manual to automatic tuning is accomplished by special switch contacts built into and as a part of the main push-button selector switch. Such an arrangement corresponds to the escutcheon lay-out shown at (C) of Fig. 13. However, in some receivers the change-over is handled by a separate switch, as shown in Fig. 14 and illustrations (A) and (B) of Fig. 13.

By further referring to Fig. 14, you will observe that the upper bank of trimmer condensers serves to tune the oscillator grid circuits while the lower bank of condensers is used to tune the first detector circuit of a superheterodyne receiver. This particular circuit illustrates ground-side switching, with the high potential side of the trimmer condensers wired in parallel.

OPERATION OF TUNED-CIRCUIT SUBSTITUTION SYSTEMS: By referring to the circuit diagram of Fig. 15, you will observe that when the change-over switch is closed in position #2, in both the detector-grid and oscillator-grid circuits, the two sections of the gang variable tuning condenser are shunted across their respective coils, and when such a connection exists, they will operate in a conventional manner. But when the change-over switch is closed in position #1 in both circuits, the two sections of the gang condenser are disconnected from the tuning circuits, and in their place will be connected two of the small trimmer condensers, depending upon which station-selecting button is depressed.

When such a connection has been established, reception will be limited to the one station for which these condensers have been pre-adjusted. To receive a different station, a different station-selecting button must be depressed.

Due to the dual gang connection of the station-selector switch circuits, simultaneous connection is made for both the first detector and oscillator tuning circuits when only one selecting button is depressed. Although not shown in the diagram of Fig. 15, for the sake of simplicity, provisions are made whereby when transferring from one button selecting circuit to another, the preceding set of dual switch points are automatically opened by action of the selector button switch which is depressed last.

The adjustment and alignment of the trimmer condensers for automatic station selection, will be restricted to stations whose frequencies are within the tuning range of the particular set of trimmer condensers. For instance, if in Fig. 15 button #1 is depressed, only stations operating at some frequency between 1500 and 860 kc can be tuned in by adjustment of these trimmers. Similarly, when button #2 is depressed, the frequency of the desired station must be within the frequency range of that set of trimmer condensers, namely, between 1430 and 800 kc. This is because of the limited capacity coverage of com-

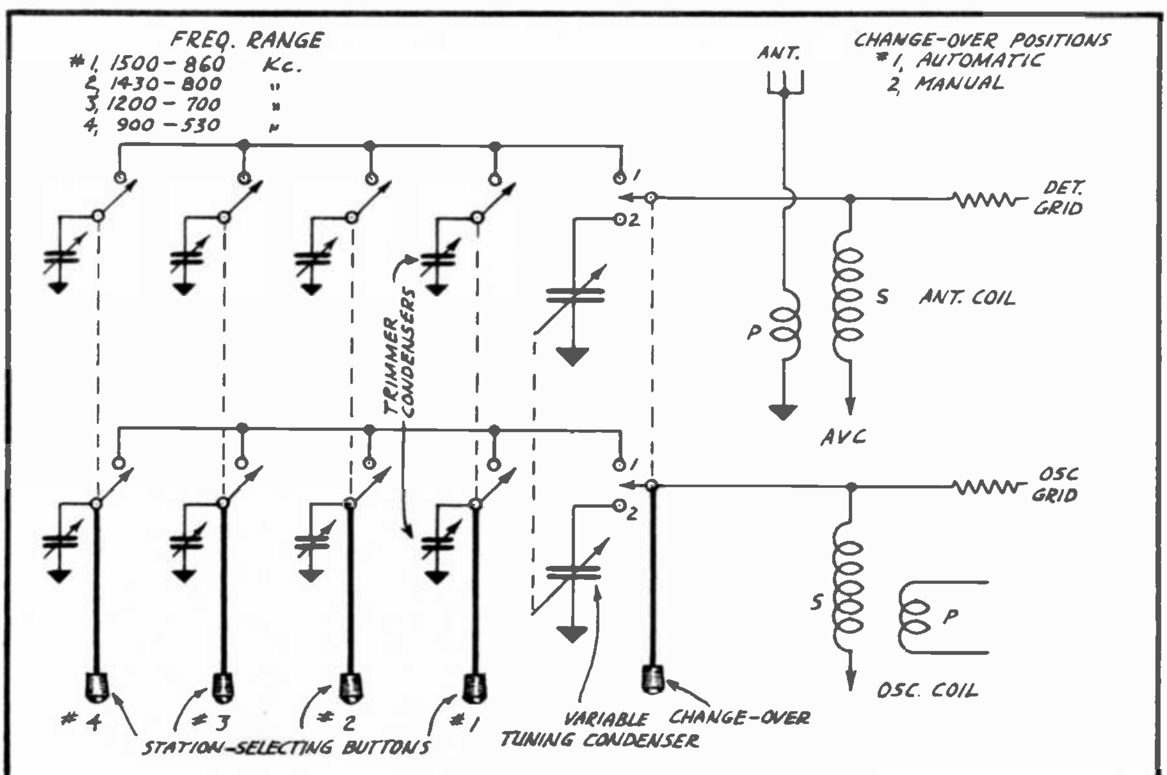

FIG. 15
CIRCUIT DIAGRAM OF TYPICAL CONDENSER-SUBSTITUTION SYSTEM

pression-type trimmer condensers, as explained in the following paragraphs and illustrated in Figs. 17 and 18.

TRIMMER CONDENSER FACTORS: By referring to the frequency ranges designated in Fig. 15 you will observe that the different trimmer condenser sets do not have the same frequency coverage. For instance, trimmer condenser section #1 will tune from 1500 to 860 kc, and section #2 from 1430 to 800 kc, etc.

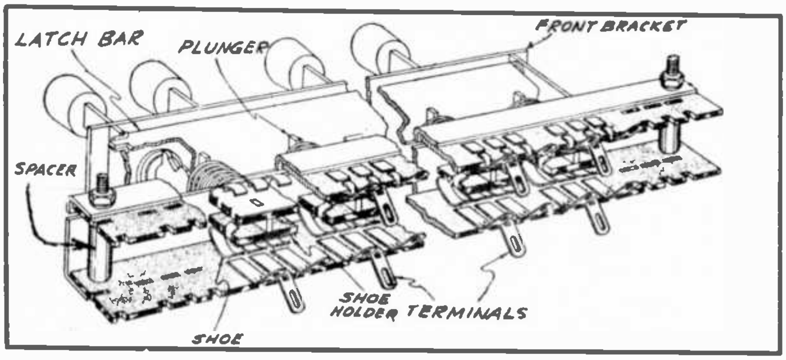

FIG. 16
SECTIONAL VIEW OF TYPICAL PUSH-BUTTON SWITCH ASSEMBLY

The reason for this is that the capacity rating of these condensers is different. Due to the method of constructing compression-type condensers, shown pictorially in Fig. 17, their capacity and consequently their frequency coverage, could never be as great, from minimum to maximum, as that of a variable condenser. So in order to properly cover the broadcast band, some of the trimmer condensers are supplied with three plates and others with as many as seven plates.

It is obvious that a condenser containing seven plates, while being capable of equaling the maximum capacity requirements of the gang variable tuning condenser, would not be able to have a similar minimum capacity value. This is because the small compression-type condenser plates cannot, from a practical standpoint, be opened sufficiently to secure such an effect. In other words, a three-plate trimmer condenser's minimum capacity might be approximately 15 mmf while its maximum capacity might be approximately 90 mmf. On the other hand, a five-plate trimmer condenser might have a capacity range from approximately 50 to 225 mmf,and a seven-plate condenser from 210 to 400 mmf.

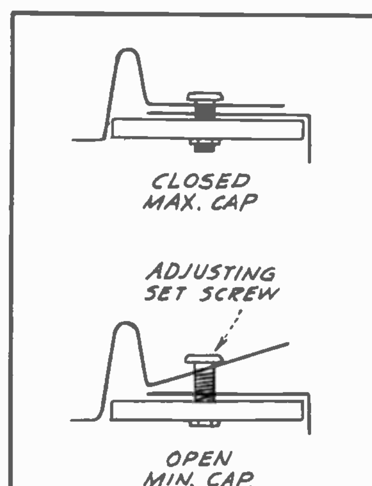

FIG. 17
TRIMMER CONDENSER SETTINGS

By referring to the capacity and frequency chart shown in Fig. 18, you will clearly understand the relation between these frequency coverages and the different sizes of compression-type trimmer condensers, where the number of plates governs the condenser's minimum capacity.

STATION ADJUSTMENT: As is true in all receivers of the superheterodyne type, the adjustment and alignment of the oscillator tuning circuit must be made first, followed by bringing the first detector coil circuit into the proper resonance relation. Similarly, in adjusting all such receivers having automatic tuning features, employing tuned circuit substitution methods, the oscillator adjustment must be made first, followed by adjustment of the first detector circuit.

With these facts in mind the procedure for pre-selecting a given station is as follows:

Place the change-over switch to the position for automatic tuning and press the station-selector button which controls the particular trimmer condenser group that covers the frequency-range in which the desired station-frequency lies. This done, slowly adjust the corresponding oscillator trimmer condenser until the desired station is obtained; follow this by adjusting the trimmer condenser of the first detector circuit until the station "comes through" clearly.

Instead of using the station signal for this purpose, it is also permissible to tune-in the signal of a test oscillator, adjusted to generate a frequency identical to that of the desired station.

DISADVANTAGES OF TRIMMER CONDENSERS

While the trimmer type condenser is the simplest and least expensive for this purpose, it also has its disadvantages, in that all compression-type condensers are far from being "drift proof." Although condensers of this type are "heat cycled" to prevent extensive expansion of the condenser plates, difficulty is still encountered with oscillator circuit "drift."

NUMBER OF PLATES	AVERAGE CAPACITY RANGE	APPROX. FREQUENCY COVERAGE
2	4 TO 50 MMF	1700 TO 1200 KC
3	15 TO 90 MMF	1500 TO 860 KC
5	50 TO 225 MMF	1200 TO 800 KC
7	210 TO 400 MMF	900 TO 530 KC

FIG. 18
CAPACITY AND FREQUENCY RANGES OF AVERAGE TRIMMER CONDENSERS

The term "heat cycled" means that the condenser plates have been subjected to an intense heat, generally in a hot oven, which treatment helps to prevent future expansion of the plates.

By "frequency drift," or simply "drift," is meant that the frequency to which the circuit has been adjusted varies or changes of its own accord and in this way wavers toward either side of absolute resonance. This condition naturally upsets tuning and causes the sounds as reproduced by the speaker to be somewhat fuzzy or harsh in nature.

This difficulty is not so bothersome in the antenna or detector circuits, but it is quite troublesome in the oscillator circuit. Therefore, to overcome this condition that was encountered in the earlier sets of this type -- and even today in some of the less expensive receivers -- an oscillator coil with an iron core was developed for tuning. This arrangement is explained in the following paragraphs.

PERMEABILITY-TUNED OSCILLATOR CIRCUITS

In Fig. 19 is shown a circuit diagram of a typical receiver using compression-type trimmer condensers to automatically tune the antenna or first detector coil circuit, while the oscillator section is individually tuned to a corresponding relation by means of permeability-trimmed oscillator coils. A separate coil is used for each station selected.

<u>CIRCUIT DETAILS</u>: Upon close examination of the circuit diagram in Fig. 19, you will observe that in this arrangement the receiver's regular antenna coil remains in the circuit at all times. When automatic tuning is employed, one of the trimmer condensers is connected across this coil's secondary; the main variable tuning condenser being disconnected from the coil circuit by the change-over switch.

You will further observe in this diagram that when automatic tuning is employed, the regular oscillator coil is entirely disconnected from the circuit, and one of the individually tuned iron-core coils is substituted for it, depending upon which station-selecting button is depressed at the time. The gang variable condenser is also disconnected from the main circuit during this time.

Also notice in Fig. 19 that there is a separate oscillator coil for each station selecting button. These coils are trimmed by permeability action, accomplished in the following manner.

Inserted inside of each coil is a movable portion of Polyiron, a change in the position of which will vary the inductance of the coil, and consequently the frequency characteristic of the coil.

OSCILLATOR COIL ALIGNMENT FACTORS: The stability afforded by the Polyiron (iron-core) method of alignment of the oscillator section, as compared with the usual compression-type of trimmer condenser, makes this system invaluable where oscillator frequency drift is a critical factor.

As in the compression-type trimmer condenser, the frequency range of iron-core oscillator coils is limited. For this reason, it is important that the coil with the right inductance be selected, when adjusting these coils for any particular pre-selected stations. Generally, this can be ascertained by observing the number of turns wound on the different coils. It will be found that some of the coils contained in the assembly will have more turns than others. Naturally, the more

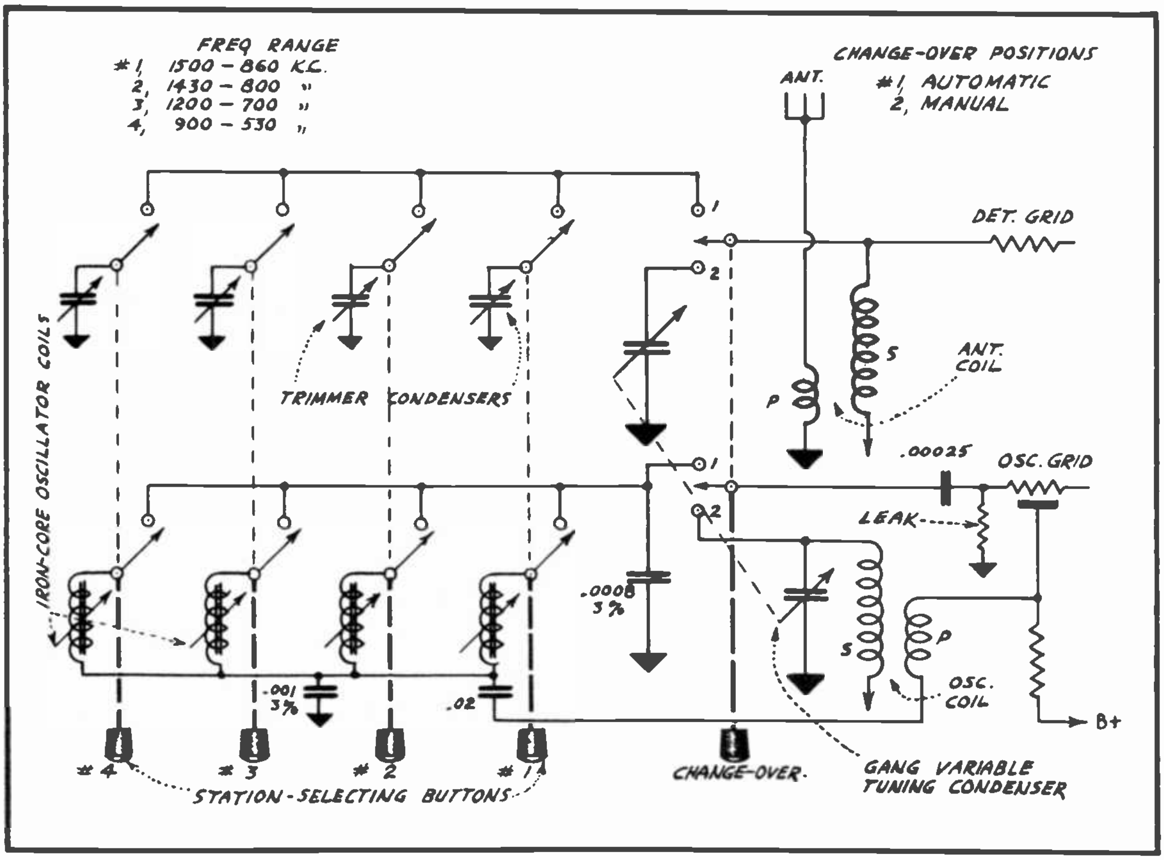

FIG. 19
APPLICATION OF IRON-CORE OSCILLATOR COILS

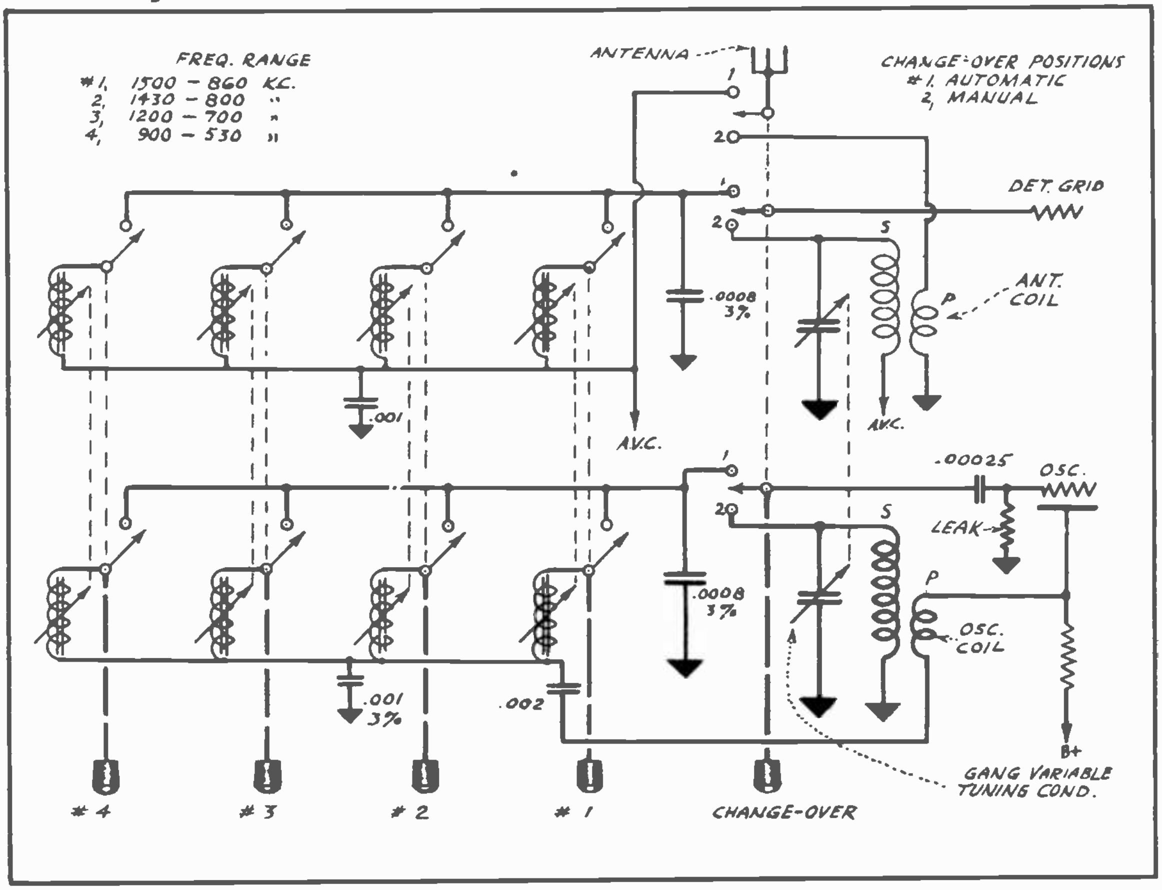

FIG. 20
AUTOMATIC TUNING SYSTEM WITH IRON-CORE COILS THROUGHOUT

turns of wire on the coil form, the lower will be the maximum frequency setting, while at the same time such a coil will not have the necessary minimum value for stations operating in the higher frequency range. These coils are therefcre generally assembled according to their proportionate range.

The proper procedure by which to align this system is to first place the change-over switch in the automatic tuning position, and then to adjust the iron-core of the oscillator coil by means of the screw provided,until the desired station is tuned in. This done,bring the antenna or first detector coil circuit into its proper resonance relation by adjusting the set screw of the corresponding trimmer condenser circuit.

GANGED IRON-CORE COIL SYSTEM

Recent developments with permeability trimmed (iron-core) coils in place of trimmer condensers, have resulted in such a coil for the antenna or first detector circuit, as well as for the oscillator section. In Fig. 20 is shown such a circuit arrangement, and in Fig. 21 a two-gang coil and push-button switch assembly.

The particular switch assembly shown in Fig. 21 provides for automatic selection of four broadcast stations, change-over from broadcast reception to shortwave reception, two positions for tone control, and an a-c line switch for turning the receiver on and off. However, in this lesson we are not concerned with automatic tuning features as applied to all-wave receivers, nor with tone controls as designated in

Fig. 21. Both of these items are thoroughly explained in later lessons devoted to these subjects.

CIRCUIT AND ALIGNMENT DETAILS: Unlike the condenser and combination condenser-oscillator coil arrangement, where separate adjustment of the antenna and the oscillator circuits is necessary, here only one adjustment is required for each station selected.

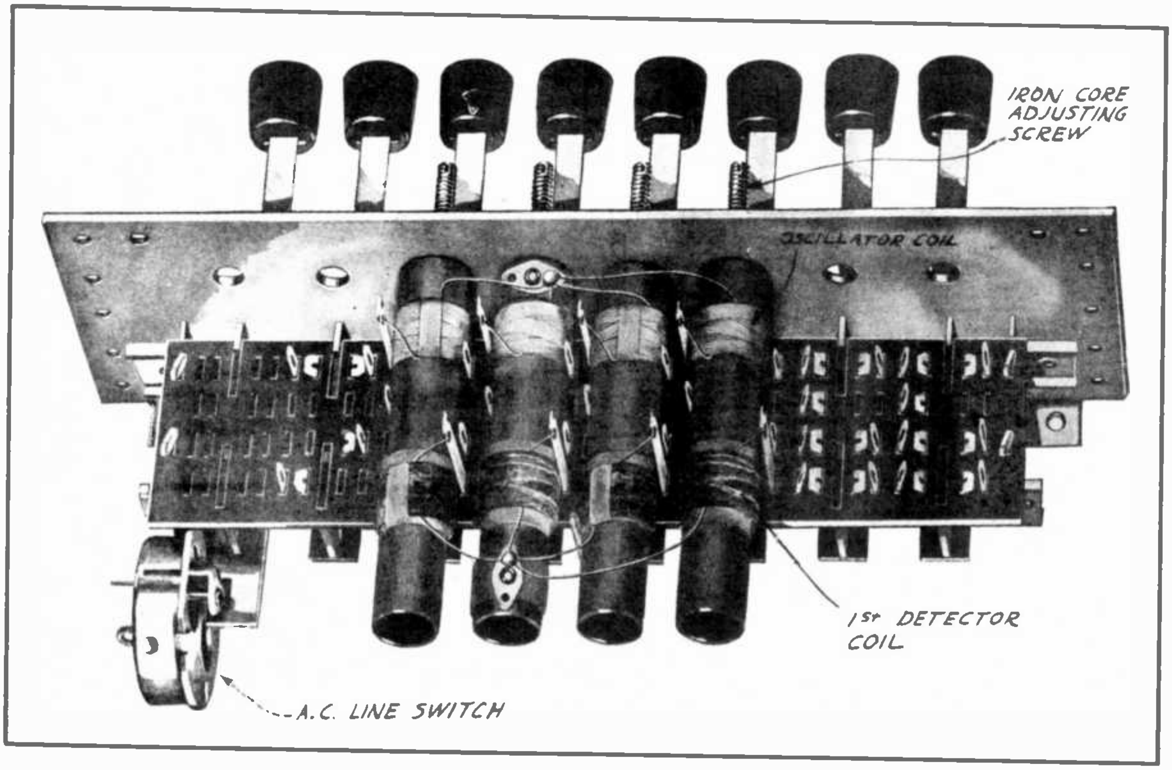

FIG. 21
TWO-GANG COIL AND PUSH-BUTTON SWITCH ASSEMBLY

Upon close examination of Fig. 21, you will observe that the first detector and oscillator windings are both wound on the same coil form. The oscillator winding is placed on the end of the form nearest the front of the assembly, and the first detector winding on the opposite end. Adjustment of both coils for any one station is made simultaneously by varying the position of the iron-core which is inserted inside the coil form. To make this possible, the design of the coils must of course be such that the correct frequency-difference be supplied by the various coil combinations to produce the required intermediate frequency.

To allow for any discrepancies that might result in these dual coil sections, and to secure perfect "tracking" or alignment of the detector and oscillator coil circuits, as well as to increase the tuning ratio, fixed mica condensers of .0008 mf capacity are shunted across each coil. In some receivers one or both of these condensers are adjustable. In either case, the tolerance must be within 3% minus or plus, or less.

TUNED-CIRCUIT METHOD FOR RECEIVERS EMPLOYING 3-GANG VARIABLE TUNING CONDENSERS

All of our explanations which have thus far been presented, relative to the tuned-circuit substitution methods for automatic tuning, have applied only to those superheterodyne receivers which use a two-gang variable tuning condenser, which is more generally the case where this method is employed. Your next step is to learn how this principle is applied to the larger receivers in which a three-gang tuning condenser is employed.

In receivers employing a 3-gang variable tuning condenser, and consisting of an r-f stage ahead of the first detector, the usual practice is to bypass the first r-f stage and to connect the antenna and the automatic tuning circuit directly to the first detector and oscillator stage. In this way the r-f stage is eliminated while the automatic push-button tuning system is in operation, although being 100% effective for manual tuning. The chief reason for resorting to this practice is that automatic tuning features in all three tuned stages would be expensive and would also necessitate considerable work and skill in aligning and balancing in order to get so many substitution tuned circuits to work together correctly.

In Fig. 22 is shown a typical trimmed condenser circuit diagram for sets employing an r-f pre-selector stage and a 3-gang variable tuning condenser. Here you will observe that when the change-over switch is in position #1, the antenna is connected to the primary of the first detector stage coil through the .0005 mf coupling condenser. In this way the r-f stage is not used when automatic tuning is employed, thus simplifying the procedure.

When manual tuning is employed, the change-over switch in Fig. 22 is closed to position #2, which disconnects the automatic tuning system from the circuit, connects the oscillator and first detector sections of the variable gang condenser into circuit, and also connects the antenna directly to the primary winding of the antenna stage coil.

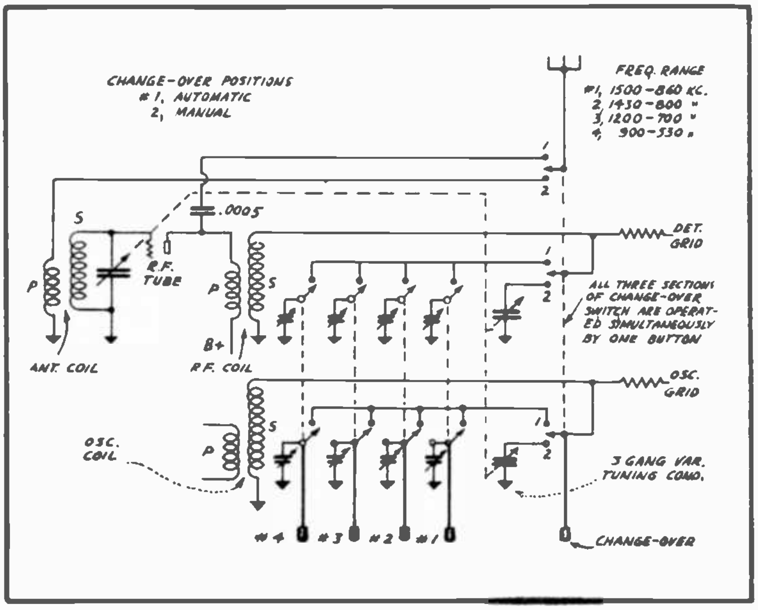

Fig. 22
Circuit Diagram of Typical 3-gang Automatic Tuning System

PERMEABILITY TUNING

Due to the success of iron-core tuned coils in automatic tuning circuits of the type just described, considerable effort has been expended by receiver engineers to adapt these coils to circuits whereby the tuning could be varied from one end of the broadcast band to the other, the same as accomplished by the variable condenser. The idea was to eliminate the variable tuning condenser from the circuit entirely, and to use in its place a ganged group of variable iron-core tuning coils whose tuning range extends throughout the broadcast band. This is known as continuous permeability tuning, and a circuit illustrating this feature is presented in Fig. 23.

Upon inspection of the circuit diagram in Fig. 23 you will observe that two such coils are used, one for the antenna-detector circuit and one for the oscillator circuit. You will further notice that no main variable tuning condenser gang is employed. However, a trimmer condenser is connected across each coil to properly align it. Fixed condensers of .00003 mf value are also shunted across each of these coils to increase the tuning ratio.

Continuous variable tuning of these coils through the standard broadcast band is accomplished by moving the iron-core material in or out of the coil forms. In this particular circuit, an electron-coupled oscillator is employed; this is shown in the diagram by use of the shunt coil. When the iron-core material is moved in or out of the oscillator tuning coil form the inductance, and consequently the frequency coverage of this coil, will change accordingly. Since this coil is connected in parallel with the shunt coil, through the coupling coil, the frequency characteristic of the shunt coil is altered. By properly designing these coils, they were made to tune through the wave band correspondingly, the same as a conventional coil and variable condenser.

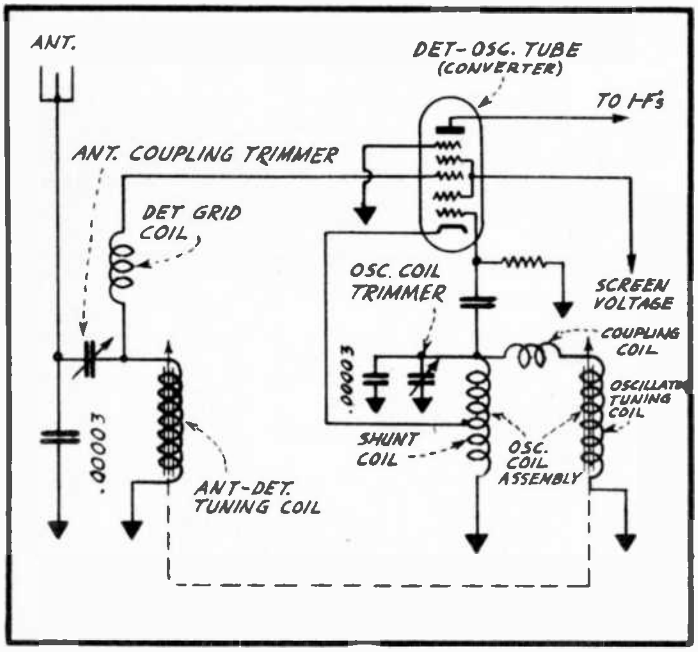

FIG. 23
CONTINUOUSLY-VARIABLE PERMEABILITY-TUNING CIRCUIT

In the detector section, the oscillatory circuit consists of the detector grid coil and the antenna coupling trimmer, the latter serving as an antenna coupling condenser and a tuning compensating condenser. The iron-core tuning coil in this case is connected in a combination series and parallel arrangement with the detector section input. Therefore, by altering the position of the iron core within this tuning coil, the variation in inductance of this coil will be reflected upon the grid coil circuit and will thereby control the frequency characteristic of this circuit, the same as is the case in the oscillator section.

It was also found that these tuning adjustments could be successfully ganged together the same as in a gang variable tuning condenser. This is shown by the dotted lines in Fig. 23.

AUTOMATIC PERMEABILITY TUNING

In Fig. 24 is shown a bird's-eye-view of this tuning assembly. Here it will be observed that rotation of the manual tuning knob will cause the two iron cores to move, through a train of gears and levers, in and out of their respective coil forms simultaneously. Notice especially that one set of tuning coils is employed for the reception of all stations, and not a separate set of coils for each station as was the case in the previously described push-button tuning systems using iron-core coils.

It is only natural that the next step in the development of circuits employing this system would be to adapt them for automatic push-button tuning. This is accomplished by fastening the iron-core material of each coil to a common plunger bar, which is in turn made adjustable to certain pre-set station positions. The method of accomplishing this is also clearly shown in Fig. 24, and in the end-view in Fig. 25.

As will be observed in Fig. 24, five adjustable cams are assembled on the main control shaft -- one for each of the station selecting push buttons. An arm is fastened to each button lever; the latter will come in contact with the flat side of one of the cam-ends when the button is depressed. The cam will thereby be rotated to a vertical position, and its motion stops when the opposite cam-end falls flush against the corresponding side of the button lever arm as shown by the solid line in Fig. 25.

Since the cam is locked to the shaft, rotation of the cam will simultaneously rotate the gear mounted on the end of the common shaft. This will in turn move either forward or backward, the rack plunger

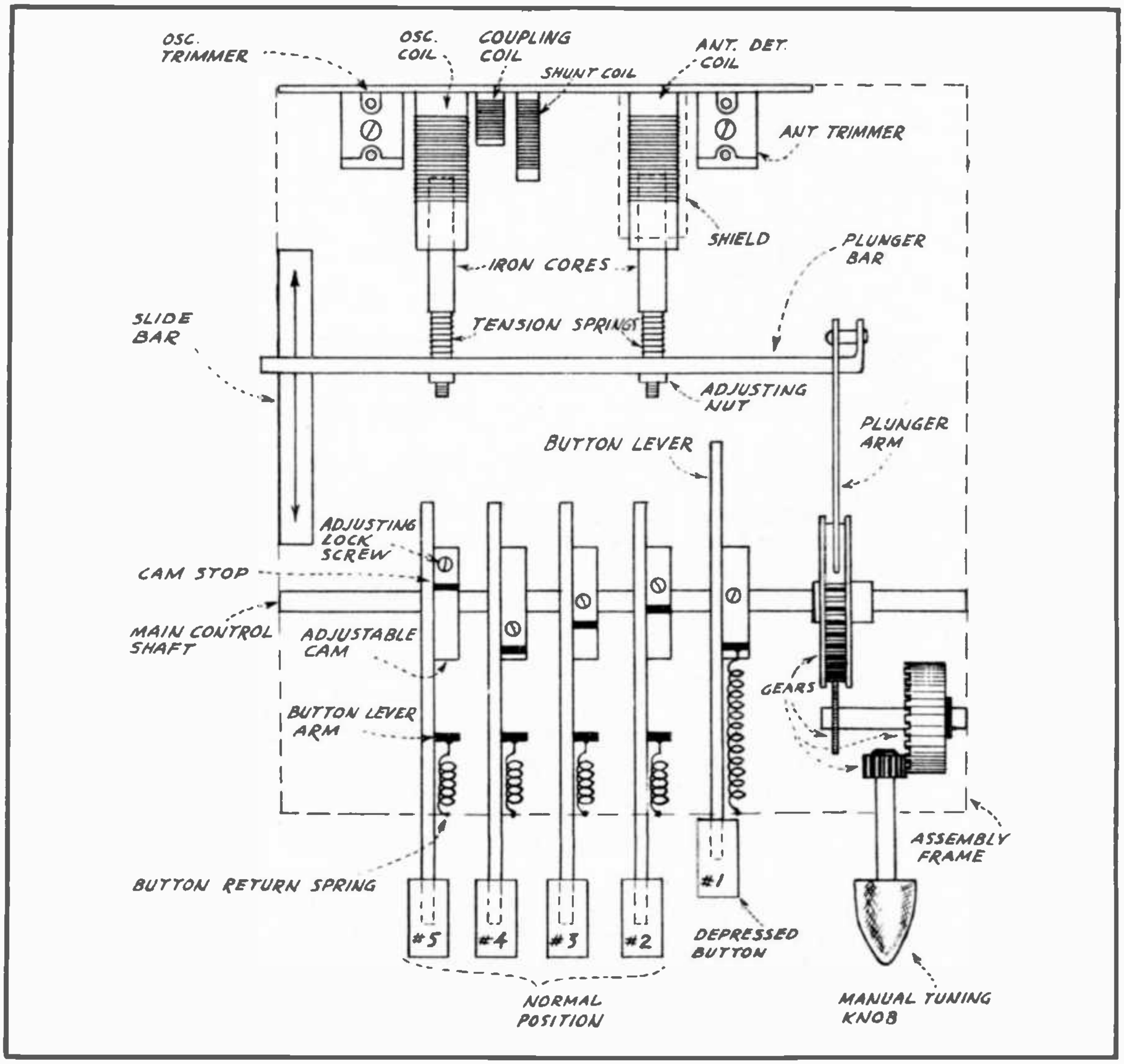

Fig. 24
AUTOMATIC PERMEABILITY-TUNING CIRCUIT

arm that is directly fastened to the plunger bar controlling the movement of the iron-core material. The frequency response of the coils is thereby varied.

STATION BUTTON ADJUSTMENT: To adjust a station-selecting button for a desired station, first tune-in manually the particular station desired. Then loosen the corresponding cam-adjusting lock screw. It is important that the button be held in when loosening or tightening this set screw.

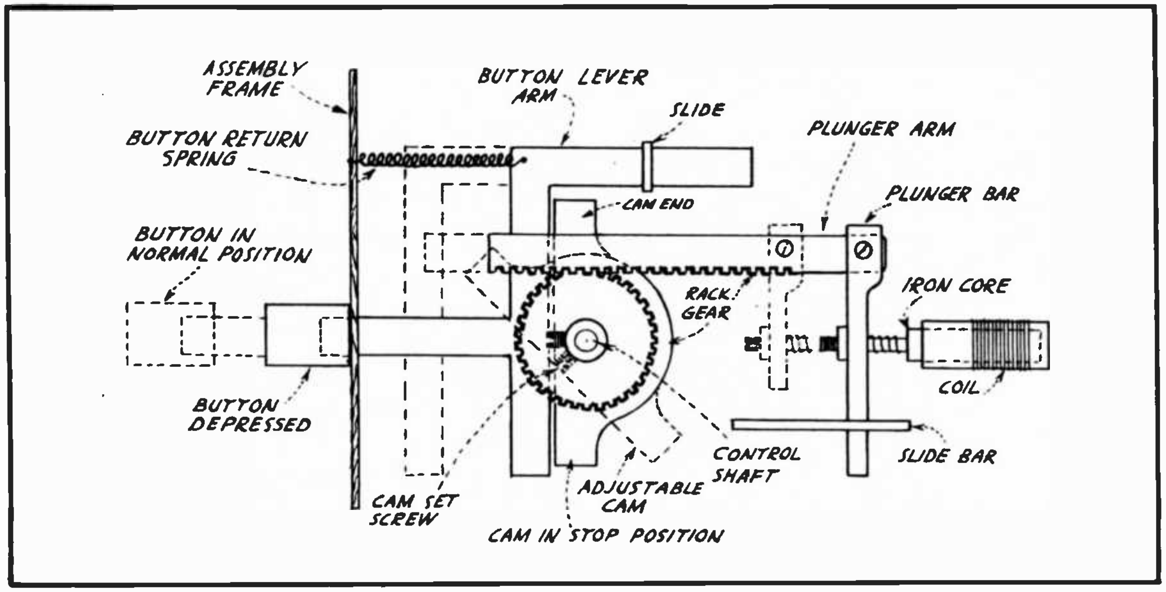

FIG. 25
CUTAWAY END-VIEW OF PERMEABILITY TUNING MECHANISM

In order to secure an accurate set-up, rock the manual tuning knob back and forth slightly until the station is tuned in clearly, and with maximum volume. Do not release the push-button during this time. With the push-button still held down firmly, and the station accurately tuned—in, tighten the lock screw securely and release the button. For other push-button adjustments repeat this same procedure.

SUGGESTIONS FOR SERVICING AUTOMATICALLY TUNED RECEIVERS

The purpose of this lesson, and the presentation of the study of automatic tuning, has been to give you a broad and comprehensive review of the various basic systems now being used. The following general service suggestions as offered are applicable to all makes of receivers featuring automatic tuning and are worthy of consideration.

1. - When setting-up the automatic tuning system for the reception of desired stations, first make certain that the alignment of the i-f and r-f circuits is precise, since the quality of reception and satisfactory signal-to-noise ratio are dependent on precision and resonance.

2. - It is highly desirable to use visual means for alignment of the oscillator and detector circuits when making the adjustment for the desired station to be selected. (The receiver's cathode-ray tuning indicator, an output meter, or other similar device may be used to indicate resonance.)

3. - In making a choice of the stations to be selected, it is important to select only those which are sufficiently above the noise level as to furnish satisfactory entertainment at all times.

An interesting bit of owner-psychology is involved in the consequences of improper choice of stations. The purchaser of a new automatically-tuned receiver is not acquainted with the phenomena of drift of stations due to temperature, mechanical aging of parts, humidity drift, frequency drift due to voltage instability, etc. Nor is he apt to be sympathetic with the vagaries of fading signals and adjacent channel "chatter."

4. - Allow the receiver to operate for at least fifteen minutes before making the station-selector adjustments. This will allow the radio chassis to attain normal operating temperature, with the voltages at their final values. During this period the oscillator frequency gradually drifts as tuned circuit elements and tubes warm up, and their component parts expand.

Certain parts of the receiver cause the oscillator to have a positive frequency drift with increasing temperature; other parts cause the frequency to decrease with increasing temperature. These two effects, unfortunately, are not balanced. Although some receivers provide compensating means for this action, yet in spite of this feature, it is wise to allow a reasonable warm-up time to elapse before making the final adjustments.

5. - Make a check-up after a few days have elapsed, to correct any drift tendencies which may have made themselves evident due to mechanical and aging effects. After this second adjustment, most receivers will have reached a final condition of operation which will continue to give satisfactory performance.

Push-button receivers are becoming increasingly popular, and service problems associated therewith will become even more extensive after these radios have been in use for some time. So that you may adjust these receivers satisfactorily, it is important that you study this lesson with special care.

Furthermore, by having a thorough knowledge of the basic systems described in this lesson, you should experience no difficulty in servicing any such systems as may appear on the market at some future time and which will differ but slightly from those just explained.

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EXAMINATION QUESTIONS

LESSON NO. 30

1. - Name and describe the three principal automatic tuning systems most commonly used at the present time.

2. - (a) What are the two outstanding advantages of the condenser tuned-circuit substitution type of tuning as compared to the other methods?
   (b) What is the main disadvantage of trimmer type condensers as employed in automatic tuning circuits?

3. - What is the procedure for selecting the desired station in tuned-circuit substitution systems?

4. - State briefly the essential difference between the telephone dial type and the cash register type of mechanical tuning.

5. - Describe briefly three change-over methods as used in tuned substitution type circuits, and explain their function.

6. - (a) Why is audio silencing employed in some types of automatic tuning systems?
   (b) Name several methods for accomplishing this.

7. - (a) What is meant by "permeability tuning?"
   (b) What is its chief advantage over other types of tuned circuit substitution systems?

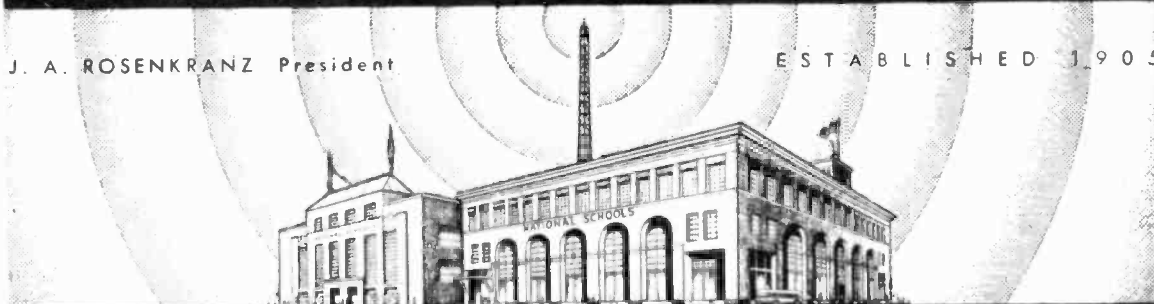
8. - (a) In receivers employing the tuned circuit substitution principle, why are only the mixer circuits generally controlled automatically?
   (b) Draw a circuit diagram showing the usual connections.

9. - In "setting-up" the automatic tuning system for the reception of desired stations, why is it recommended that the receiver first be warmed-up?

10. - What method is usually employed in motor-operated types of automatic tuning systems to adjust the receiver to the desired stations?

Practical Technical Training In
RADIO·TELEVISION
AND ALLIED ELECTRONICS

J. A. ROSENKRANZ President   ESTABLISHED 1905



NATIONAL SCHOOLS ★ LOS ANGELES 37, CALIF.

LESSON NO. 31

VOLUME AND TONE CONTROLS

After the signal from a broadcast station has been handled by the r-f, i-f and detector stages of a superheterodyne receiver, the audio amplifier further intensifies it to a point where the output tubes will supply a considerable amount of audio power to the loudspeaker.

If the receiver has no means by which the amount of power, supplied to the speaker, could be changed at will, we would have a condition where one station might cause enough volume output to shake the house,while another could just barely be heard. However, most modern receivers have automatic volume control systems, which would, of course, prevent these extreme conditions from occurring.

Nevertheless, the manual volume control is a necessary part of the receiver. It acts as a sort of gate by which we can control the signal voltage in the receiver, either in the r-f section, or in the audio amplifier. Just how is the volume control constructed,and how does it operate to control volume? These are two of the questions we will answer in this lesson.

Along with volume controls, you will also learn something about tone controls, because we are not concerned alone with the amount of volume supplied by a receiver. Besides this, we also would like to be able to control the timbre or the quality of the sound produced by the receiver.

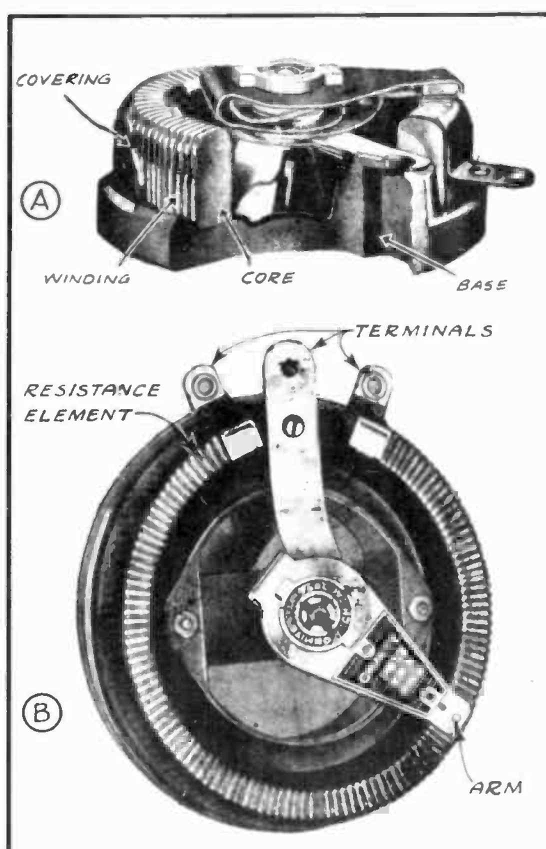


FIG. 1
RHEOSTAT AND POTENTIOMETER

CONSTRUCTION OF VOLUME CONTROLS

There are three basic types of volume controls; however, the construction of all three is similar. We will now explain their construction in the order of their development.

<u>WIRE-WOUND RHEOSTAT</u>: The first type of wire-wound volume control to be developed was the "rheostat." In the earliest types of battery receivers, the rheostat controlled volume by varying the voltage applied across the filaments of the tubes. By varying the voltages of the filament, the heat of the filament was controlled; this variation in heat in turn controlled the amount of electron emission and thereby controlled the amount of amplification. In Fig. 1 you will see two illustrations showing the construction of a rheostat. Notice that the construction consists of three main parts: a base, a resistance element, and a rotating arm.

The base is made of porcelain or bakelite. The resistance element consists of a fine resistance wire wound around a core. This core may be of porcelain, or bakelite, or just a flat piece of fiber. The resistance wire is wound around this core in one continuous piece.

Wire for the resistance winding may be of different sizes, depending on the amount of current that it is required to carry. Only one end of the wire may be connected to a terminal, or both ends of the wire may be connected to terminals. If both ends of the resistance element are used, the term "rheostat" ceases to apply to the control. It then becomes a <u>potentiometer</u>, or voltage divider. (See B of Fig.1.)

The rotating arm is made of spring brass or copper. This arm makes contact with the turns of resistance wire as it is rotated. The contact arm is fastened to one end of a round shaft that extends through the center of the control and projects from it. A knob is usually fastened on the projecting end of the shaft to enable the listener to operate it conveniently.

<u>WIRE-WOUND POTENTIOMETER</u>: The second type of control to be developed was the wire-wound potentiometer mentioned previously. Its construction is practically the same as that of the rheostat; the main differences being that the potentiometer usually has a great many more turns of a finer resistance wire than does the rheostat. Also, both ends of its resistance element are connected to terminals.

<u>CARBON-TYPE VOLUME CONTROLS</u>: The third type of control to be developed was the <u>carbon element</u> type. This type of control is, today, most universally used in all receivers. The construction of this type of control differs from that of the rheostat and wire-wound potentiometer mainly in the type of resistance element used. In Fig. 2 (A) is shown a complete volume control of the carbon-element type. Next to it, at (B), is shown the carbon element.

This resistance element consists of a foundation made of a special fiber, or of bakelite. In most of the newer controls it is made in the flat circular shape shown. The carbon material, which forms the resistance, is sprayed on the fiber base. This carbon spray is then baked in special ovens at accurately controlled temperatures.

After the element is removed from the oven, it is riveted to the bakelite case as shown at (C) of Fig. 2. The contact arm is made of phosphor bronze, and is very light and delicate in structure. It must be made this way so that the pressure and wear of the contact will not break down the thin layer of carbon material, or tear it away from the fiber foundation. Eventually, this does happen in the majority of

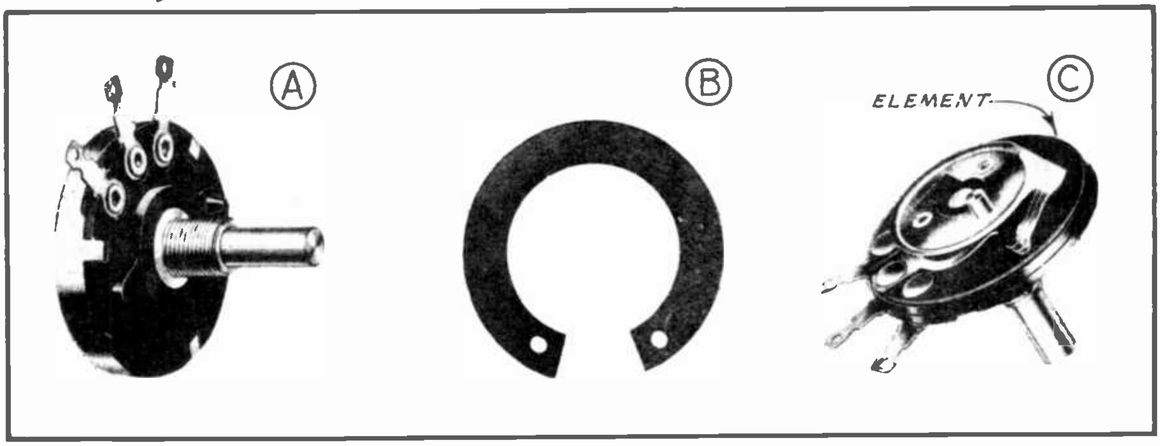


FIG. 2
CONSTRUCTIONAL FEATURES OF THE CARBON-TYPE VOLUME CONTROL

carbon element controls, and is responsible for at least 30% of service work requiring the replacement of noisy or worn volume controls.

There are any number of different designs and combinations of volume controls, but every one is basically constructed as one of the three types we have reviewed. The type of circuit, and the construction of the apparatus in which the volume control is used, determines what volume control is to be employed therein. Sometimes, a circuit may require two resistance elements that must be varied simultaneously. In that case we would use a dual unit similar to that illustrated in Fig. 3.

Before we study applications of volume controls to actual circuits, we must know something about the characteristic of a resistance element known as "taper."

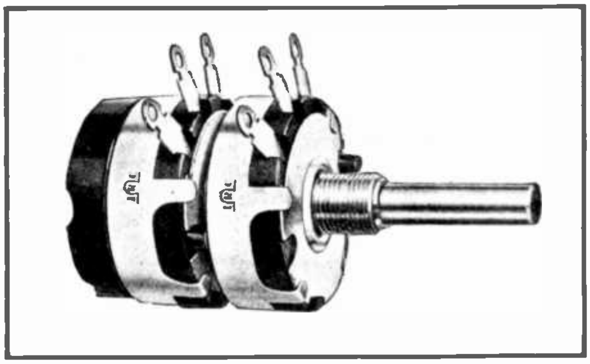


FIG. 3
DUAL UNIT VOLUME CONTROL

TAPERED VOLUME CONTROLS

When you turn the knob of a receiver volume control half way on, you will probably expect to hear half the volume as obtained at the "full on" position. The same is true of any other setting of the control. Of course, you will hear the amount of volume that you expect to hear for different adjustments of the volume control, but the reason that you do hear the amount you expect is because of the fact that the resistance of the volume control is not linear.

If the resistance of the control were made linear -- that is, if equal changes of resistance resulted from equal changes of knob rotation all the way around the control -- we would not obtain half-volume when the control is turned to its mid-position. The reason for this lies in a peculiarity of the human ear, in that equal changes of the volume of a sound do not cause equal response in our hearing. The human ear responds to changes in the volume or intensity of sound according to a law of nature known as the "Logarithmic Law." The meaning of this law is not as complicated as it sounds. Let us take an example to illustrate:

Suppose we are listening to our radio when it is adjusted at a certain volume. This volume corresponds to a certain value of signal applied to the input of the amplifier. Now,let us suppose that the applied signal is reduced to exactly one-half its former value. We naturally would expect the volume of sound coming from the speaker also to be one-half the former value, but are surprised to find the speaker volume to have been reduced by only a small part of its former value.

In order to reduce the volume of sound from the speaker to one half its original value, we find that we have to cut the amount of applied signal down to a very small part of the signal strength we originally had. This value of signal voltage is only about one-tenth of that required for the volume we had at the beginning.

Since the signal input to the audio amplifier is determined by the volume control, we can see that the volume control cannot be constructed with a linear resistance element. To do so would mean that any change of the control setting would supply an equal change of signal voltage. This would mean that practically all of the change in speaker volume would take place at one end of the volume control.

To get away from this condition, the resistance element of the control is tapered. Not all volume controls are tapered, however; the linear type of control has applications,as will be shown a little later in this lesson.

HOW TAPER IS OBTAINED: In the wire-wound type of control, taper is obtained by constructing the resistance element in sections. Each of these sections is wound of a different size of wire, or in some cases, of a different type of resistance wire. The taper is secured by concentrating most of the high resistance sections at one end of the resistance element. There may be several of these sections, depending on the type, or on the amount, of taper desired.

In one method of manufacturing the resistance element for the carbon type of control, taper is obtained by shading (gradually varying) the thickness, or depth, of the carbon material. This causes one end of the element to have a different value of resistance than the other end.

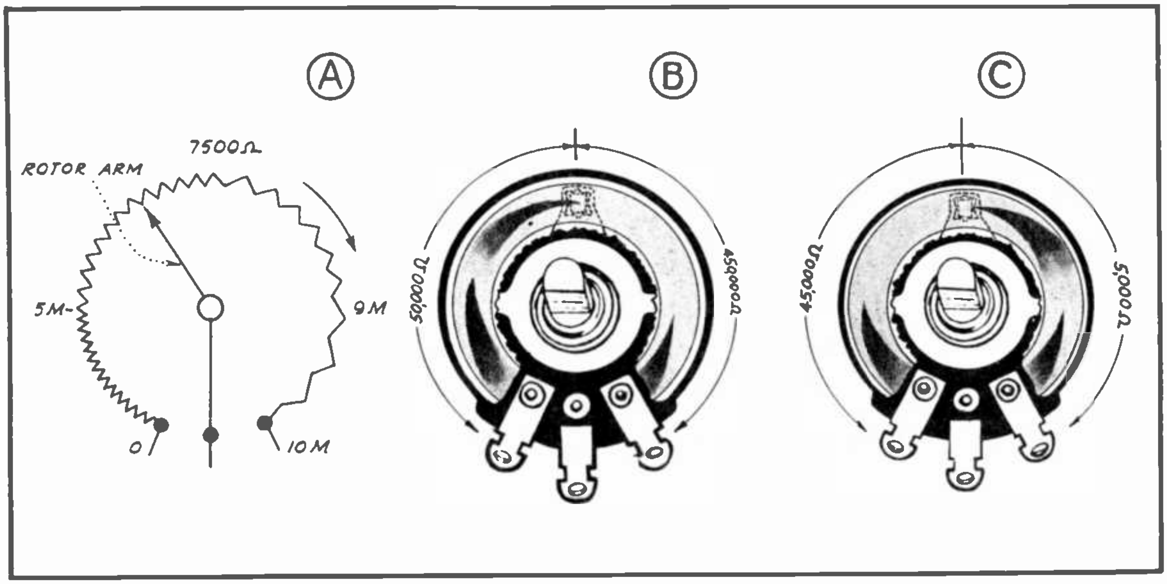


Fig. 4
Potentiometers with Different Tapers

The relative distribution of resistance in all types of controls must not be abrupt or lumped in one spot. Rather, it should be distributed so that control will be smooth and uniform. Figs. 4 and 5 show graphically just how most of the resistance is distributed in a typical control, having what we call "left-hand" taper.

At (A) of Fig. 4, three-fourths or 7500 ohms of the total resistance value is concentrated between the zero position of the rotor and half rotation. The remaining one-fourth, or 2500 ohms, is distributed over the rest of the element. Fig. 4 (B) shows pictorially the same condition, except that in this control the greater part of the resistance is concentrated in the right-hand portion of the element. Fig. 4 (C) shows pictorially still another control in which practically all of the resistance of the element lies in the left-hand portion.

LEFT-HAND TAPER AND RIGHT-HAND TAPER: It is common practice to connect volume controls in the circuit so that rotating the knob all the way toward the left (counter-clockwise) results in minimum volume; while rotating the knob all the way toward the right (clockwise) results in maximum volume. Now, consider the volume-control shaft as being turned exactly to its half-rotation position. If the left-hand half of the control's resistance element has a lower resistance than the right-hand half, as at (B) of Fig. 4, the taper is left-hand. But, if the right-hand half has a lower resistance than the left-hand half, as at (C) of Fig. 4, the taper is right-hand.

This is important to remember in making volume control replacements. Always obtain the correct taper required for the job. You may have considerable trouble in service work when making volume control replacements because of the different types of tapers.

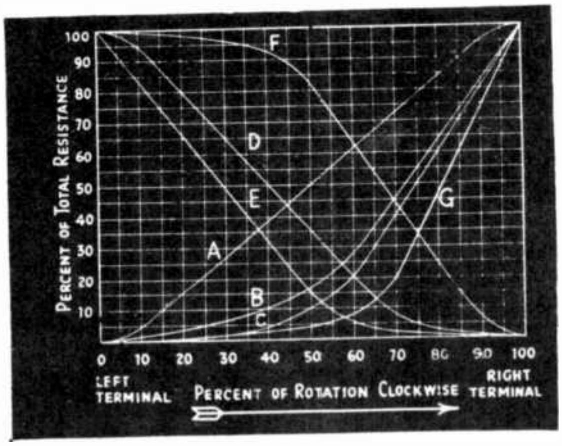


FIG. 5
CURVES OF STANDARD VOLUME CONTROL TAPERS

CHARACTERISTIC CURVES OF VOLUME CONTROLS: In Fig. 5 you will see several curves of common tapers that are used. These curves show the change in resistance as plotted against percentage of control-shaft rotation. Looking at curve A of this illustration, you will notice that this control is practically linear; that is, a 30% rotation causes almost 30% change in resistance. Similarly, a 50% change in rotation causes exactly 50% change in resistance. This relation is maintained fairly well throughout the entire curve.

The three curves B, C, and G represent left-hand tapered controls. By examining these curves closely, you can see that this is true. Notice that the control shaft has to be rotated over 50% before the resistance begins to show a definite increase. That is, from about 60% shaft rotation up to 100%, the slope of the resistance curve turns sharply upward. The average resistance increase for the three curves from this point up to full shaft rotation is from about 20% up to 100%.

Curves D and E illustrate a reverse action. The percentage of resistance for these two curves decreases for clockwise rotation of the volume control shaft. The lesser amount of the total resistance is included between 50% and 100% shaft rotation, so these curves represent right-hand tapers.

Curve F is a special type of taper. Notice that almost 90% of the resistance decrease for this curve takes place over the shaft rotation from 50% to 100%. Thus, this a left-hand tapered control with decreasing resistance from left to right.

Although curve A is called a "linear control" (50% of total resistance at 50% shaft rotation), notice that the beginning of the curve and its ending are slightly tapered. This is done to prevent the control from suddenly "dropping" the signal when the end of the resistance is reached.

HOW TO DETERMINE THE TAPER OF A VOLUME CONTROL

If you cannot find an exact replacement for an old and worn, or an open, volume control, always determine the taper before you substitute some other type of control. This is especially true where control is effected in the r-f section of a receiver. The correct taper for the replacement may mean the difference between a satisfied customer and a thoroughly dissatisfied one.

If the control is only noisy or worn you can estimate the taper fairly close by opening up the case of the control and taking a few ohmmeter readings directly on the resistance element. From this you should be able to deduce just about how much of the total resistance is concentrated in various parts of the resistance element.

If the control's resistance element is open at some point, you can determine the taper by taking ohmmeter readings between the ends of the element and the damaged point.

A still better method is to make a dial scale calibrated in equal divisions from zero to 100. Then, by means of a pointer knob on the end of the control shaft, rotate the shaft. At every tenth division on the scale, take an ohmmeter reading. Plot the results on a piece of rectangular graph paper. By comparing this graph with the graphs shown in your replacement guide, you can easily find the correct taper for a replacement control.

ADVANTAGES AND DISADVANTAGES OF CONTROL TYPES

ADVANTAGES OF THE WIRE WOUND CONTROL:

1. -- Absolute accuracy of resistance is maintained throughout the life of the control. Wire-wound controls can be made commercially to within a tolerance of 2% plus or minus.

2. -- High current-carrying ability. It is possible to construct wire wound controls which are capable of dissipating several hundred watts of power.

3. -- Low resistance can be obtained. Values as low as one-half ohm can be obtained with the wire-wound type of control.

DISADVANTAGES OF THE WIRE-WOUND CONTROL:

1. -- Difficulty of obtaining taper. Tapers in the wire-wound control have to be wound in sections. Each of these sections is made of a different type and grade of resistance wire; consequently, the break between each section is rather sudden.

2. -- A slight amount of noise is generated when the arm moves from one turn of wire to another. The cause of this noise is due to the fact that the contact arm does not move progressively along

the total length of the resistance wire; instead, it jumps from one point on each adjacent turn of wire to the corresponding point on the next. This means that there is a definite difference of potential for each one of these points,and consequently, the voltage is varied in a series of small jumps rather than uniformly.

3. -- Limited value of maximum resistance. The smallest diameter of wire that can be used in the construction of wire-wound controls is around .001". It is very difficult to handle wire any smaller than this because it breaks too easily. Consequently, values of resistance higher than 150,000 ohms would not only be extremely hard to wind, but would also require such a large amount of winding space that controls of this size would be useless for radio receiver purposes.

ADVANTAGES OF THE CARBON-TYPE CONTROL:

1. -- Any type of taper may be obtained by varying the density and composition of the carbon element.

2. -- Silent operation. The resistance change is progressive and does not jump in minute steps as does the wire-wound type.

3. -- Resistance values of the carbon type may range into many megohms without undue bulkiness or difficulty of manufacture.

DISADVANTAGES OF THE CARBON-TYPE CONTROL:

1. -- Variation of resistance. The usual tolerance for manufacture of the carbon-type control is 20% plus or minus. There is as much as a 40% variation between various samples of commercial controls. Do not be alarmed over this, however, because this will not materially affect the operation of any receiver. A variation of 20% plus or minus for a volume control of 10,000 ohms will make the control resistance lie between 8000 and 12,000 ohms, inclusive. Any value of resistance between these limits will make little difference if such a control is used for replacement -- provided the taper of the replacement control is the same as the original.

2. -- Low current-handling capacity. The usual limit of dissipation for carbon-type controls is one watt or less. However, some carbon controls are capable of providing as high as five watts dissipation.

3. -- Limitation in the minimum value of resistance. It is practically impossible to make carbon controls of less than 500 ohms.

VOLUME CONTROL CIRCUITS

Now that we have covered the general construction and types of controls, we can continue with our study of the specific applications for these controls in actual circuits.

ANTENNA-CIRCUIT CONTROLS: Some early receivers had the volume control connected in what seemed then to be the most logical place -- the antenna circuit. In Fig. 6 you will see four different methods for connecting a control in the antenna circuit. In the cases of circuits (A), (B), (C), and (D), the current developed in the antenna due to an electromagnetic field from a transmitter, flows through the resistance of the control to ground. This current flow in turn develops a voltage across the resistance. Now, the contact arm whose position is

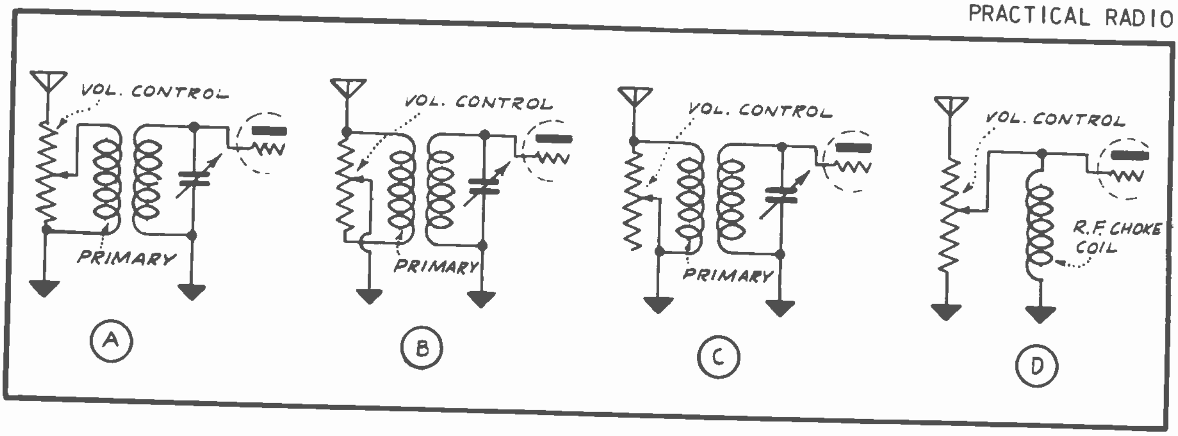


FIG. 6
ANTENNA SHUNT CIRCUITS

varied between the top of the resistance element and ground, will allow a voltage anywhere between maximum and zero to be applied to the grid of the r-f amplifier tube -- directly, as in the case of circuit (D), or indirectly, through induction of a secondary voltage, as in the cases of circuits (A), (B), and (C).

Circuits (A), (C), and (D) are called short-out circuits because the volume control shorts the primary of the antenna coil, or the r-f choke coil as used in circuit (D), when adjusted for zero signal input to the grid of the tube. The value of resistance used in this type of control varies from 2000 ohms up to as high as 20,000 ohms. The value of resistance required depends on the design of the receiver, or more directly, on the impedance of the primary winding used in the antenna coil. If a low-impedance primary is used for the antenna coil, a low resistance may be used for the volume control. If the coil has a high impedance primary, then a volume control of higher resistance value may be used.

A low-impedance primary may be distinguished from a high-impedance type by the number of turns of wire. The first type usually has only a few turns of wire, while the latter may have as many as several hundred turns. When replacing controls in the type of circuits illustrated in Fig. 6, use a control having a resistance of from 2000 to 5000 ohms for a low-impedance primary, and values of 10,000 to 20,000 for a high-impedance primary. Both types must have a left-hand taper.

The circuit at (D) of Fig. 6 is very rarely used, but in case you should ever run across such a circuit, the value of resistance should be around 50,000 ohms with a left-hand taper.

BIAS-TYPE CONTROLS: The bias-type control is the second type of general control circuit. This is also sometimes called a sensitivity control, or a silent-tuning control. It operates by varying the bias on the grid of an r-f tube, or by varying the bias on two or more r-f grids at the same time.

There are two general types of tubes used in the r-f circuits of receivers. These are the "sharp cut-off" type, and the "remote cut-off" type. "Cut-off" is the term applied to the point at which an increase in negative grid voltage causes the plate current of a tube to stop flowing. The 24A is an example of a sharp cut-off tube, while the 35 is a remote cut-off type. The sharp cut-off tube only requires a small increase in grid voltage before the plate current is completely stopped. Remote cut-off tubes, on the other hand, require a very large grid voltage to reduce the plate current to zero. In the case of the two tubes just mentioned, only 9 volts of negative bias are required to reduce the plate current of the 24A tube to zero, in comparison to 40 volts of bias for the type 35 tube.

Now, it is apparent that since our control is in the cathode circuit of an r-f tube, as shown in Fig. 7, it is going to control the bias on the grid of this tube, and thus indirectly, the amount of amplification. Since this tube is the first amplifier of the receiver, the amount of signal allowed to pass this point is going to determine the amount of amplification in the following tubes. Thus, if the tube is biased sufficiently to cause cut-off, negligible current will flow; consequently, no signal will be passed on to the next tube, and the volume will therefore be zero. The use of the control in the cathode circuit accomplishes this.

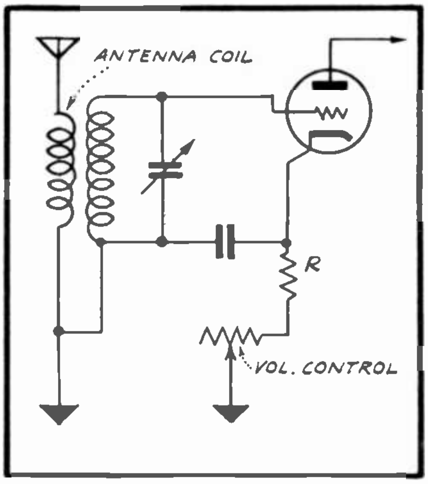


FIG. 7
CIRCUIT OF BIAS TYPE
OF VOLUME CONTROL

Notice that only two terminals are used on the control when connected in the cathode circuit, as illustrated in Fig. 7. As the shaft is turned, more or less of the resistance element is placed in the circuit, thus varying the bias. When the control is adjusted so that all of its resistance is removed from the circuit, we have left only the small fixed resistor R. The purpose of R is to maintain a small bias on the grid of the tube at the minimum resistance setting of the control. This bias is usually that recommended by the tube manufacturer.

If the cathode were to be grounded directly, no negative bias would be available on the grid of the tube. The grid of the tube would then become positive on the positive halves of the signal voltage, and as a consequence, would draw a small amount of grid current. This current would cause distortion of the signal and broad tuning.

The bias type of control is often called a sensitivity control, because it actually controls the sensitivity of the r-f stage in which it is used. In a great many of the larger sets, a sensitivity control is used to reduce the inter-station noise when tuning. When used in this manner, the bias control operates the same as it does when used for controlling volume, with the exception that the amount of resistance in the control is limited to smaller values than those used for controlling volume. Values of 2000 to 10,000 ohms are commonly used for sensitivity controls, while values between 5000 and 150,000 ohms are most generally used for volume controls.

The bias type of volume control has a great many limitations, the main one being that the range of control is sometimes concentrated at one end of the resistance element. This makes the control hard to use,especially in the case of small four or five-tube t-r-f receivers. This type of receiver will very often break into oscillation when the resistance in the cathode circuit reaches a low value. Then again, strong local signals will develop such large grid voltages on the grid of the r-f tube that the tube acts as a small capacity and passes the signal on to the next r-f tube in spite of the fact that there is no plate current flow.

ANTENNA BIAS CONTROLS: A much better method of bias control is obtained by means of the combination shown in Fig. 8. This type of control

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circuit is called the "antenna-bias" type of control. It combines two actions in one. As shown in Fig. 8, one end of the control is connected to the antenna input of the receiver, while the other end of the control is connected to the cathode circuit in the same manner as was shown in Fig. 7. Since the contact arm is connected to ground, it will short the primary of the antenna coil when turned to the left, and at the same time, will introduce all of the element resistance into the cathode circuit. When the contact arm is turned to the right, all of the resistance will be shunted across the primary, and the resistance in the cathode circuit will be only that supplied by the small limiting resistor R.

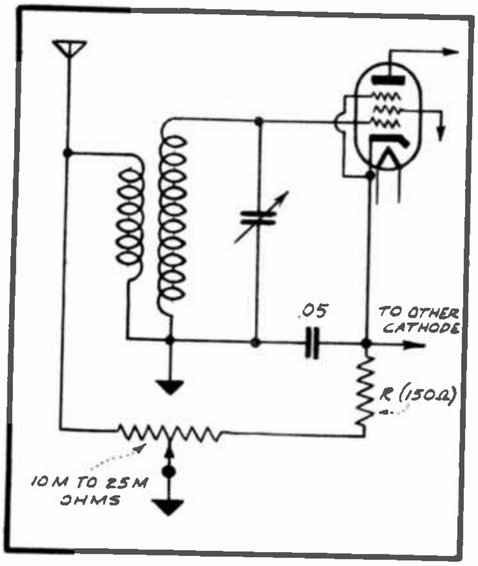

FIG. 8
ANTENNA-BIAS TYPE OF CIRCUIT

Now, since the resistance of the control is very high as compared with the impedance of the antenna coil primary, practically all of the antenna signal current will flow through the primary coil, and consequently will be passed on through the tube. In between the two extreme positions of the contact arm we will have some intermediate value of signal.

Fig. 9 shows a variation of the antenna-bias type of control. Here a bleeder current is used to help produce the bias voltage across the cathode resistance. This bleeder current is obtained by connecting one end of the control to a B+ terminal of the power supply. You can see, then, that the small current which flows through whatever portion of the control resistance is left in the B+ circuit, will develop a voltage across this resistance. The amount of voltage developed depends on the adjustment of the contact arm. If a large amount of control resistance is left connected between cathode and ground, the voltage will be fairly large, because it is a combination of two voltages. One voltage is developed by the plate current flowing through the tube, and the other by the bleeder current.

The purpose of this bleeder current, as part of the bias circuit, is to stabilize the bias voltage. Since the bleeder current remains constant, the voltage developed by its flow thru the control resistance will also remain constant. But the voltage developed by the plate current flow of the tube varies with the signal voltages. Thus, if the signal voltage varies up and down, the bias voltage across the resistance will also vary. However, since the total bias voltage is the sum of the plate current bias and the bleeder current bias, the effect of the variation in plate current on the total bias

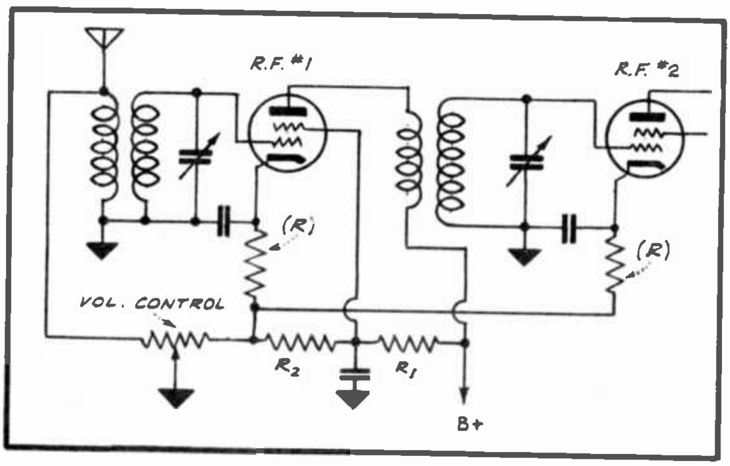

FIG. 9
ANTENNA-BIAS CONTROL WITH BLEEDER CURRENT

is not going to be as great as though the voltage were developed by the plate current alone.

A different value of resistance must be used when the bias on either a sharp cut-off or a remote-cut-off type tube is to be varied. Values from 1500 to 15,000 ohms are common for the sharp cut-off type of tube circuit. For the circuit in which the remote cut-off type of tube is used, values of resistance ranging from 10,000 to 50,000 ohms are used. The exact value of resistance to be used in either case depends on the impedance of the antenna primary and also on the amount of bias voltage that must be varied. For instance, if a type 6C6 tube is being used as the first r-f amplifier, and also if the antenna coil has a low-impedance primary, the value of resistance would not have to be higher than 5000 ohms. On the other hand, if we have a type 6K7 first r-f tube, which is a remote-cut-off type, and the antenna coil has a high-impedance primary, we will have to use at least 25,000 ohms to obtain good control action.

VALUES OF VOLUME CONTROLS MOST USED

In the table below you will find a summary of the resistance values most used in the three types of circuits we have studied so far. You will notice that the type of control is specified, as is also the taper and the circuit in which it operates best.

TABLE I

VOLUME CONTROL APPLICATIONS

Ohms Resistance	Type and Taper	General Use
500	W.W. -- LEFT HAND	ANTENNA SHUNT
1000	W.W. -- LEFT HAND	ANT. OR PRI. SHUNT; LOW-IMPEDANCE PRIMARY
2000	W.W. -- LEFT HAND	ANT. OR PRI. SHUNT; LOW-IMPEDANCE PRIMARY
3000	W.W. -- LEFT HAND	ANT. OR PRI. SHUNT; LOW-IMPEDANCE PRIMARY
5000	CARBON - LEFT HAND	ANT. OR PRI. SHUNT; {HIGH-IMPEDANCE PRIMARY, SHARP CUT-OFF}
7500	CARBON - LEFT HAND	ANT. OR PRI. SHUNT; {HIGH-IMPEDANCE PRIMARY, SHARP CUT-OFF}
10,000	CARBON - LEFT HAND	ANTENNA-SHUNT OR ANTENNA-BIAS; {LOW-IMPEDANCE PRIMARY, SHARP OR REMOTE CUT-OFF}
15,000	CARBON - LEFT HAND	ANTENNA-SHUNT OR ANTENNA-BIAS; {LOW-IMPEDANCE PRIMARY, REMOTE CUT-OFF}
20,000	CARBON - LEFT HAND	ANTENNA-SHUNT OR ANTENNA-BIAS; {HIGH-IMPEDANCE PRIMARY, REMOTE CUT-OFF}
50,000	CARBON - LEFT HAND	ANTENNA-BIAS; HIGH IMPEDANCE, REMOTE CUT-OFF
1000	W.W. -- RIGHT HAND	BIAS; SHARP CUT-OFF
2000	W.W. -- RIGHT HAND	BIAS; SHARP CUT-OFF
3000	W.W. -- RIGHT HAND	BIAS; SHARP CUT-OFF
5000	W.W. -- RIGHT HAND	BIAS; SHARP CUT-OFF
7500	W.W. -- RIGHT HAND	BIAS; SHARP CUT-OFF
10,000	CARBON OR W.W.- RIGHT HAND	BIAS; SHARP CUT-OFF
15,000	CARBON - RIGHT HAND	BIAS; SHARP OR REMOTE CUT-OFF
25,000	CARBON - RIGHT HAND	BIAS; REMOTE CUT-OFF
50,000	CARBON - RIGHT HAND	BIAS OR ANTENNA BIAS; REMOTE CUT-OFF
75,000	CARBON - RIGHT HAND	BIAS OR ANTENNA BIAS; REMOTE CUT-OFF
100,000	CARBON - RIGHT HAND	BIAS OR ANTENNA BIAS; REMOTE CUT-OFF

NOTE: W.W. DESIGNATES WIRE-WOUND

The antenna-bias type of control is the most widely used in this country. This is due to the fact that it finds its greatest use in the small four-and five-tube table-type receivers. In these small sets, the control, being in the r-f circuit, effectively prevents overloading of the detector tube on strong signals. This is a very desirable condition in this type of set, because the greater percentage of these sets use grid bias detectors.

The grid bias type of detector is susceptible to an overload, especially on strong local signals. With the use of the antenna-bias type of control,the signal is reduced at the antenna before it reaches any of the amplifier tubes. This action, in combination with the control of bias on the r-f tube,serves to keep the signal down to a value below that which would overload the detector. In this type of receiver, if the signal voltage were to be controlled after detection had taken place; or more accurately, if the station signal were passed on and amplified by the r-f section of the receiver from its original strength as developed in the antenna, you can readily see that a very strong local station would cause voltages to be applied to the detector tube of sufficient magnitude to block off its action altogether.

In larger receivers, however, methods can be used which are capable of handling conditions we have mentioned in the preceding paragraph. This makes it possible to place the volume control in the audio amplifier section of such a receiver.

CONTROLLING VOLUME IN THE AUDIO CIRCUIT

When we desire to control volume in the audio circuit, it is the best policy to place the volume control at the point where the audio signal is at a low value. In fact,if the volume control can be placed at the point of origin of the audio signal, so much the better. We have mentioned that the high resistance carbon type of control can dissipate only a small amount of power; therefore, if the current flow through the control reaches a value higher than that for which it is rated, the resistance element will be quickly damaged.

APPLICATION IN DIODE DETECTOR CIRCUIT: In Fig. 10 you will see a typical half-wave diode detector circuit. Here the volume control is connected between the lower end of the i-f transformer and ground. Since the upper terminal of the secondary is connected to the two diode plates of the tube, any r-f signal induced in the secondary will be rectified, or converted into d-c. This current flows through the coil, through the volume control to ground, and back through the diode section of the tube, thus completing the circuit.

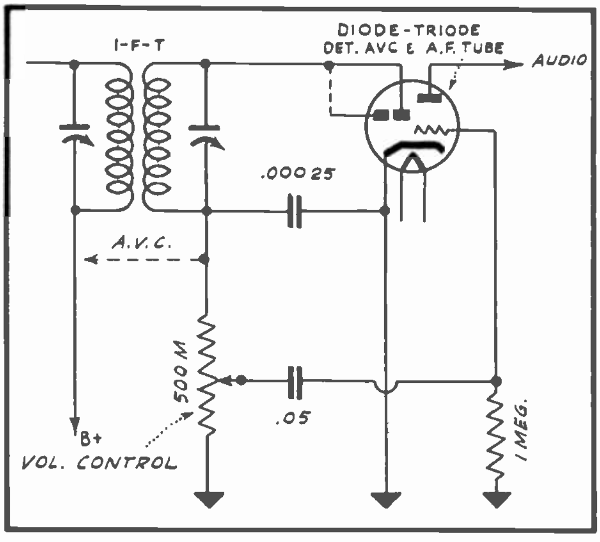

FIG. 10
VOLUME CONTROL IN THE DIODE DETECTOR CIRCUIT

The rectified voltage that appears across the volume control, due to the current flow, is composed of a d-c voltage with an a-c component. This a-c component is the audio voltage that we wish to pass on to the rest of the amplifier. Fig. 11 illustrates graphically this d-c voltage with the a-c fluctuations impressed upon it.

In this type of control circuit, the volume control acts as a variable voltage divider. At any setting of the slider arm between the top and bottom of the resistance element, some value of voltage between maximum and zero will be obtained. Of course, both the d-c and a-c voltages appear across the control element. Since we desire to pass on and amplify only the a-c or audio component, we connect a blocking condenser between the contact arm terminal and the grid of the tube. This condenser allows the audio signal voltage to be passed on to the grid, but blocks the d-c voltage.

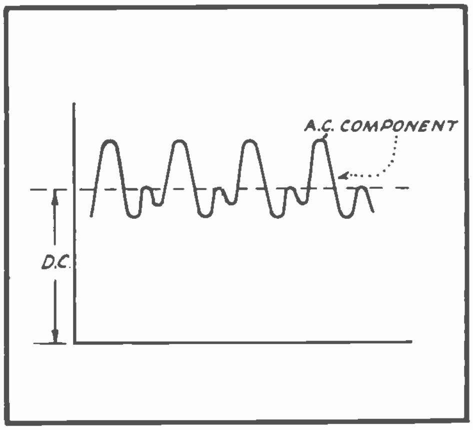

FIG. 11
CURVES SHOWING RELATION OF D-C AND A-C VOLTAGES

APPLICATION IN INFINITE IMPEDANCE DETECTOR CIRCUIT: A newer type of detector circuit that has appeared in commercial receivers of late, especially in the high-fidelity types, is the infinite impedance detector. Since this type of detector requires that its load impedance remain absolutely constant, we cannot place a volume control at the origin of the audio signal as we did with the diode detector. Instead, we must find a point a little farther removed from the detector circuit. This point is usually the grid of the following tube.

Fig. 12 (A) shows the circuit of such an arrangement. Here the volume control again acts as a voltage divider, applying a voltage somewhere between the maximum value at the top of the control and zero at its grounded end. However, notice that the volume control also serves as the grid resistor for the first audio amplifier tube in this case.

The same kind of an arrangement is used at (B) of Fig. 12. The difference in this case is that the audio voltage is taken from the plate end of a load resistor and applied through the blocking condenser to the grid end of the volume control element. The contact arm now varies the voltage received by the grid between the maximum value at the top of the control to zero at the ground point.

APPLICATION IN A MIXER CIRCUIT: This same type of control is used with various other forms of circuits -- one of these applications is shown in Fig. 13. Here two controls are used to simultaneously feed the output from a microphone and phono pickup into the amplifier. This is

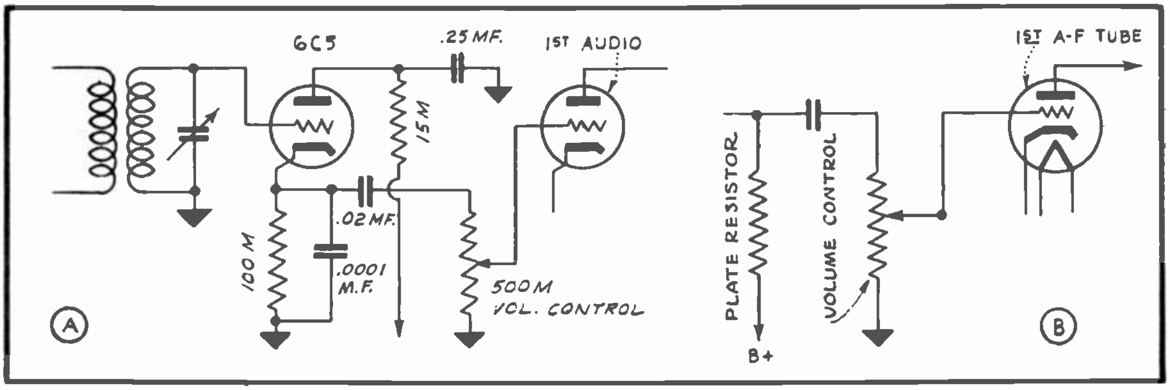

FIG. 12
CIRCUITS TO ILLUSTRATE USE OF THE VOLUME CONTROL AT GRID INPUT

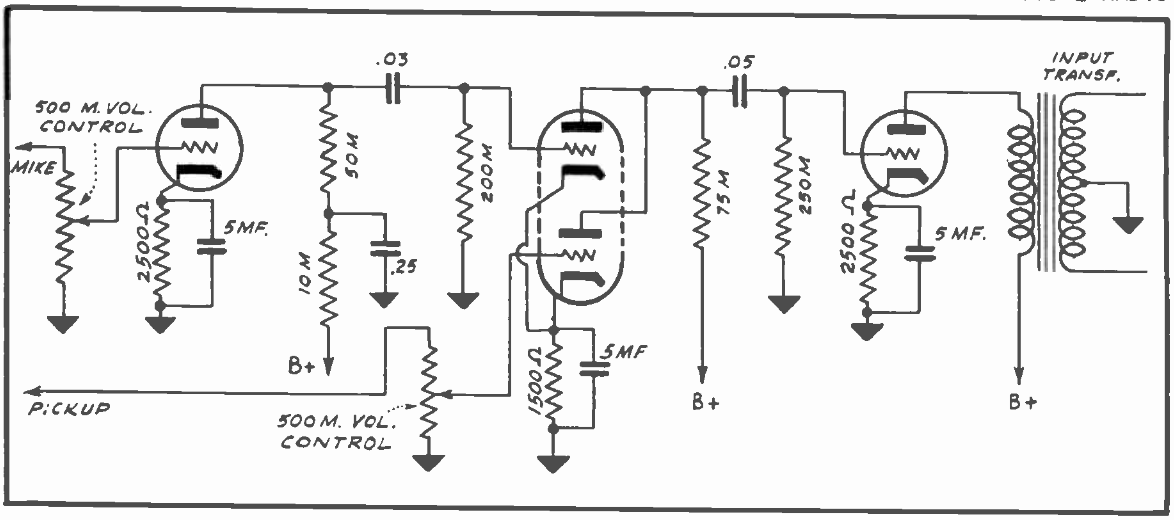

Fig. 13
High and Low Level Dual Input Circuit for Amplifier

called a "mixer" circuit. That is, this circuit makes it possible to amplify two separate sources of input at the same time, and the two controls vary the amount of amplification from either source.

APPLICATION IN TRANSFORMER CIRCUIT: Still another type of volume control circuit is shown in Fig. 14. Here the control is connected across the terminals of an audio-frequency input transformer's secondary winding. The volume control now acts as a voltage divider for the induced voltage set up in the secondary of the transformer. When the contact arm is at the top of the resistance element, maximum voltage is impressed on the grid of the tube. Anywhere in between this top point and the ground point, some value of voltage between maximum and zero will be applied to the grid of the tube.

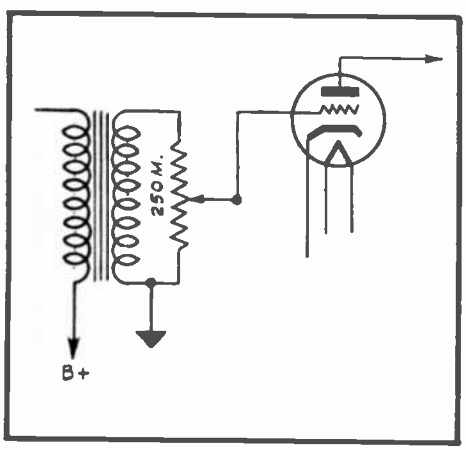

Fig. 14
Transformer Shunt Type of Volume Control

The resistance of a volume control, connected in this manner, is dependent upon the manner in which the primary winding of the transformer is used in the circuit. If the primary is part of a circuit that requires a fairly high resistance, or impedance (such as the plate circuit of a tube), then the volume control should have a resistance of around 100,000 to 250,000 ohms. This type of control cannot be used where the secondary voltage becomes too high. If the voltage is high enough to cause considerable current flow through the control, it will soon become noisy, or entirely useless.

VALUES AND TAPERS FOR CONTROLS USED IN AUDIO CIRCUITS

Now that we have discussed the various methods of applying volume controls in the audio circuit, let us consider briefly the values of resistance and the types of taper used in these applications.

The value of resistance used for the control in Fig. 10 is nearly always 500,000 ohms. Sometimes, a value of 250,000 ohms is used.

The taper is always left hand. In certain cases, the blocking condenser is omitted from this circuit. This is done when the first audio tube is used as a "noise suppression" or "quiet a-v-c" circuit. The d-c voltage developed across the control resistance is then applied to the grid of the tube along with the audio component. This type of circuit requires a linear type of taper because a sharp cut-off type of tube is always used for the "noise suppression" amplifier. Resistance values are the same as for the conventional type of circuit presented in Fig. 10.

The value of control to use in Fig. 12 (A) is dependent upon the value of the cathode load resistance of the detector tube. If the value of this load resistance is around 100,000 ohms, the volume control is 500,000 ohms, and must have a left-hand taper. The same considerations apply to Fig. 12 (B), only that here the resistor in the plate circuit of the preceding tube may be of any value from 25,000 up to 500,000 ohms. A good rule to follow in selecting a volume control for replacement in this circuit is to select one having a resistance nearest to four times the value of the plate resistor. That is, if the plate resistor in Fig. 12 (B) has a resistance of 50,000 ohms, we can use a volume control of 200,000 to 250,000 ohms. If the plate resistor has a value of 250,000 ohms, the value of our replacement control should be 1 megohm. In all cases, use a left-hand taper control.

For the volume controls in Fig. 13, use values recommended by the manufacturer of the microphone or pickup being used.

DUAL-TYPE CONTROLS

There are many other types of circuits and methods in which volume controls are used. Several of these make use of a dual unit on a single shaft. This type of control will be the same as the one illustrated in Fig. 3, or a similar manufacture. In Fig. 15 you are shown three circuits using dual control units.

DUAL ANTENNA-BIAS CONTROL: The circuit at (A) is an old friend, being the same circuit as used in Fig. 8. However, in this new circuit we are using two separate resistance units to accomplish what a single unit did in Fig. 8.

This type of control is used in cases where it is desired to isolate the antenna input from the cathode circuit, or in cases where

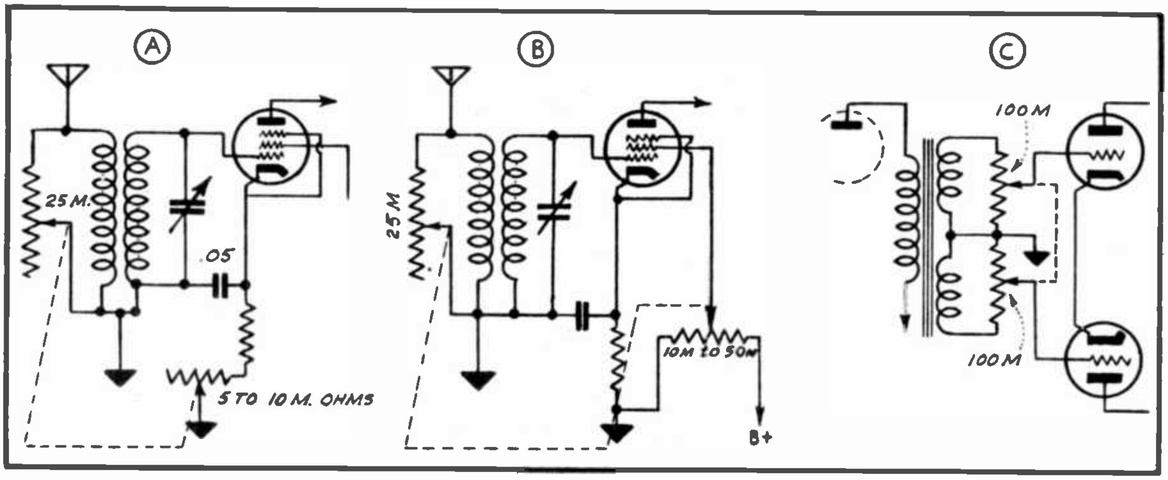

FIG. 15
TYPICAL DUAL CONTROL CIRCUITS

smooth and complete control of the signal cannot be obtained by use of a single control. In this dual resistance control, each unit may have a different value of resistance and taper from the other. The value of resistance and taper for each unit will depend on the requirements of each part of the circuit in which the control is connected. Values of resistance and the necessary taper will follow the data given in Table I of this lesson.

DUAL ANTENNA SCREEN GRID CONTROL: The second circuit (B of Fig. 15) shows a little different method for varying the amplification in the r-f stages. Here the voltage on the screen of a screen-grid tube is controlled, while at the same time the antenna primary is shunted by a short-out type of control unit. This gives us a sort of "double bar-reled" method for controlling amplification in the r-f stages.

The voltage on the screen grid of a tube controls the amplification of the tube in a little different manner than does the bias. The purpose of the screen voltage is to reduce the space charge in a vacuum tube, or to overcome its retarding effect on the electron stream. At the same time, the screen acts as a shield between the grid and the plate, reducing the grid-to-plate capacity to zero. If we vary the screen voltage, it is apparent that we will vary the retarding effect of the space charge. This means that if we reduce the screen voltage from its recommended value, the space charge will reappear in the tube. Since this space charge acts to retard the flow of electrons, you can see that the plate current will be reduced. However, one thing must be remembered -- and that is that the screen voltage cannot be reduced to very small values. At very low values of screen voltage the tube will begin to assume characteristics similar to those of an equivalent triode. The grid-to-plate capacity will reappear, and consequently some small amount of feedback will occur across the tube. If this feedback becomes large enough, the tube will break into sustained oscillation, and the receiver will start howling, or squealing, when tuned to stations.

At (B) of Fig. 15 we are controlling the amount of voltage applied to the screen by varying the setting of the contact arm on the resistance element of the control unit. You will notice that one end of this resistance element is connected to B+, while the other end is connected to ground. This means that the element must carry considerable current. For this reason, this unit always must be of the wire-wound type, capable of dissipating several watts of power.

The other part of the control (the unit shunted across the antenna primary) may be of the carbon type.

The resistance of the screen voltage varying unit of this type of control will be some value between 10,000 and 50,000 ohms. The exact value of resistance will depend on whether the control is connected directly across B+ to ground or whether it is part of a voltage divider circuit. A portion of the resistance element must be so connected that it acts as a limiting value for the screen voltage. That is, a certain amount of resistance must be left in the circuit to supply a minimum screen voltage. This requirement is taken care of in the manufacture of the control, by leaving part of the resistance element on the ground end arranged in such manner that the slider arm is stopped before it makes contact with this part. The taper is usually linear. For the resistance and taper of the antenna shunt unit, follow the data as given in Table I for antenna shunt controls.

DUAL-AUDIO CONTROL: In circuit (C) of Fig. 15, you will see a dual application of the control method used in Fig. 14. Here the dual unit controls the amount of grid voltage applied to the two push-pull tubes.

Both units of this control must be perfectly matched in resistance and taper. If they are unequally matched, one tube will receive a larger or smaller voltage than the other, resulting in unequal amplification by both tubes and distortion in the output of the amplifier.

The methods of applying volume controls to circuits are practically unlimited. Perhaps you may develop a different way to use one that will give even more smooth and easy control of signal voltages.

Always use good common sense in replacing controls. Do not attempt to replace simple controls with more complicated types. The simplest method is nearly always the best method. Try to get an exact replacement if possible. If it is not possible, always consult a good reliable volume control guide for the correct replacement.

Tone Controls

The tone control was developed because the listening tastes of each person differ. Perhaps you might like a predominance of bass in your music; your friend might like to hear all the high notes; then, someone else will probably like a moderate mixture of both bass and high notes. It is certain that unless some method of controlling the amount or quantity of different notes over the audio-frequency scale is incorporated in the operation of a receiver, everybody is not going to be pleased by what he hears from his radio.

The purpose of the tone control is to make it possible for the same receiver to please everyone.

TYPES OF TONE CONTROLS

Tone controls can take one of two different forms. That is, they may be a "losser" type, in which the amount of signal at the unwanted frequencies is decreased (note: "losser" means to decrease by a certain amount), or they can be of the "compensator" type. With the latter type of tone control, the desired frequencies are amplified more than the rest; the result being a gain in amplification rather than a loss.

The losser type of control is sometimes called a "bass" type of control. It derives this name from the fact that by it the high frequencies are reduced, or attenuated, leaving the bass frequencies to be amplified without any reduction.

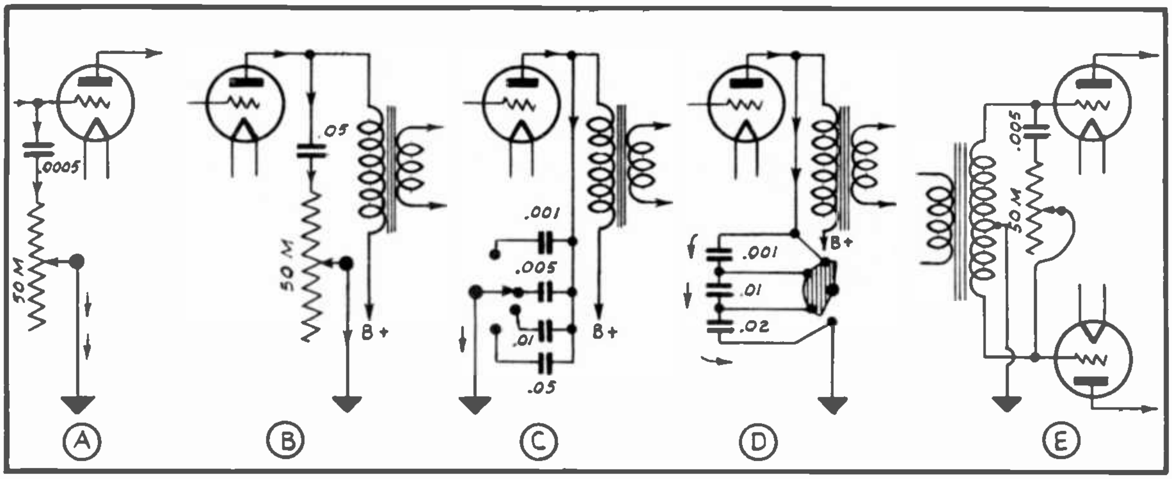

Fig. 16
Typical "Bass" Tone Control Audio Shunt Circuits

APPLICATION OF LOSSER TYPE CONTROLS

In Fig. 16 are shown several circuits illustrating methods of connecting the losser-type control in a receiver circuit. All of these tone-control circuits consist of capacity and resistance in series, or of capacity alone, connected between some point of high audio potential and ground. The only exception is that appearing at (E) of Fig. 16, where the tone control is comprised of a condenser and resistor shunted across the secondary terminals of an audio input transformer. In this circuit the tone control is shunted across two high audio potential points and forms a variable low-impedance path between these two points.

Suppose we examine the reactions of a resistance and condenser when connected in series to determine just how such a combination acts to pass certain frequencies, while blocking the passage of others. In Fig. 17 is shown a graph of capacitive reactance plotted against frequency. Capacitive reactance is the opposition that a capacity presents to the flow of an alternating current. This opposition, or reactance, varies inversely as the frequency -- at low frequencies the reactance is high while at high frequencies it is low. You can see that this is true from your examination of the graph.

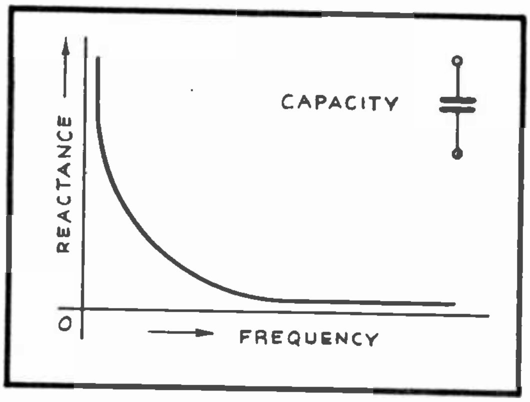

FIG. 17
CURVE OF REACTANCE PLOTTED AGAINST FREQUENCY

Since the reactance of the condenser in our tone-control circuits is high at low frequencies, the signal current of these frequencies will not be shunted through the condenser to ground. At the higher audio frequencies, the reactance of the tone condenser is low; consequently, these frequencies will be shunted through the condenser to ground, and will not be amplified by the rest of the audio circuit.

If a variable resistance is now connected in series with the tone condenser, we can control the total amount of impedance or opposition in the tone-control circuit. With a high value of resistance in series with the condenser, the impedance will be high at all frequencies, and all frequencies will therefore be amplified accordingly. As the tone resistor is reduced in value, the total impedance becomes smaller and smaller, thus allowing more and more of the high frequencies to be bypassed to ground. This leaves a predominance of bass frequencies in the output of the receiver and makes the tone of the receiver sound "bassy."

In order to accomplish the opposite result to that obtained from a control, or to attenuate the low frequencies so that the highs stand out, we use a circuit like that illustrated in Fig. 18 (A). Let us now examine a graph of inductive reactance plotted against frequency to find out what happens in this circuit. This graph is shown in Fig. 18 (B).

You will notice that at low frequencies the reactance of the inductance is low, while at high frequencies it becomes correspondingly larger. If this inductance is now connected at some high audio potential point, the low-frequency signals are going to flow through the small opposition offered by the coil, rather than through the higher resistance offered by the rest of the circuit. "Treble tone control" is the name applied to this method of tone control.

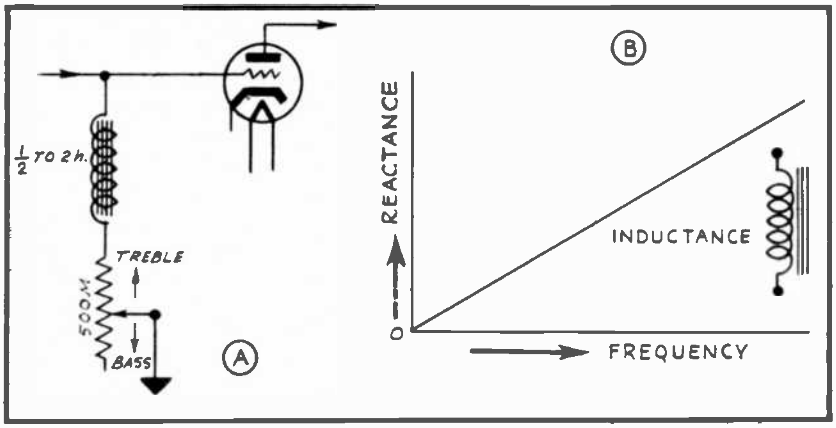

Fig. 18
Treble Tone Control and Reactance Curve

In both the bass and treble types of tone control, the variation in tone is obtained by decreasing the signal voltage of the unwanted frequencies. The effect, or the amount of variation in the reduction of the undesired frequencies, is usually controlled by the use of a carbon-type potentiometer called the "tone control." The most common resistance value for tone controls is around 50,000 ohms, and taper is nearly always left-hand.

In circuit (C) of Fig. 16 no variable resistance is used, but a switch connects condensers of different capacities in and out of the circuit to vary the bypassing of the high frequencies. The same thing is accomplished at (D) of Fig. 16 by using a switch to short-out condensers connected in a series arrangement.

COMBINATION TONE CONTROLS

Combinations of bass and high-frequency (treble) controls are often used to provide a wide range of tone control. Fig. 19 shows one method of accomplishing this. Here we have a capacity and an inductance both connected to the same high audio potential point. A potentiometer, with its center connected to ground, proportions the amount of resistance in either the inductive branch or the capacitive branch. At one end of the resistance, the inductance is connected directly to ground and the condenser has a high resistance connected between it and ground. This means that the low frequencies will be shunted out, or in this position the control acts as a treble tone control.

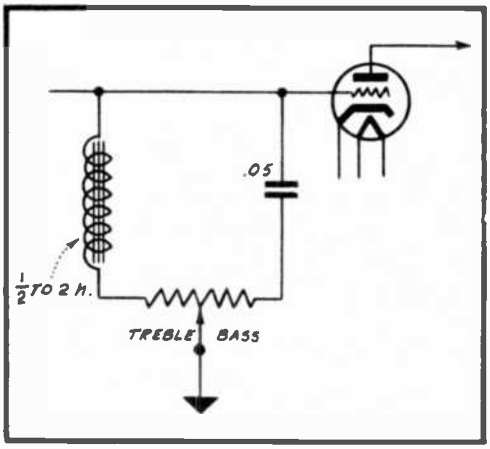

Fig. 19
Combination Treble and Bass Control

At the other end of the resistance the capacity is connected directly to ground, and the resistance is all in series with the inductance. Now, the high frequencies are passed to ground. In between these two points, the combination of inductance-resistance and capacity-resistance is such that neither high nor low frequencies are attenuated, and we have fairly equal amplification of all frequencies.

TONE COMPENSATION CIRCUITS

In some of the later types of receivers, a type of tone compensation has been developed in which the tone circuit is a part of the

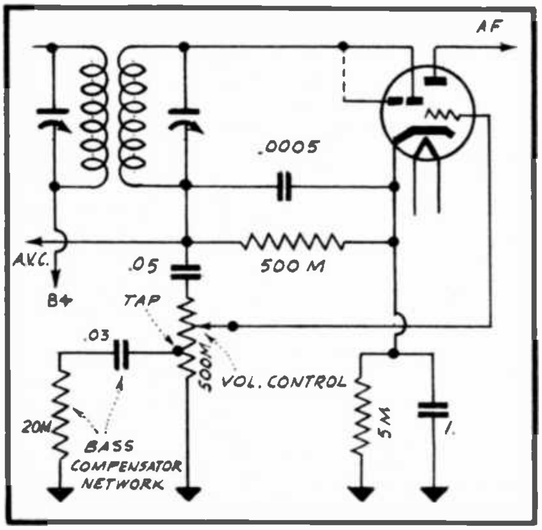

Fig. 20
Bass Compensation Circuit

volume control circuit. Fig. 20 shows a circuit employing this type of tone compensation. You will notice that a tap is brought out from some point on the volume control. This tap is taken off close to the ground-end of the resistance element, so that the compensating portion of the circuit is introduced at reduced volume settings.

The sensitivity of the human ear to low (bass) frequencies diminishes to a much greater extent at low volume. For this reason, a receiver playing at low volume does not seem to have any bass notes. Since the tone compensation introduced by the tapped circuit shown in Fig. 20 begins to take effect as the volume control approaches the low end, the receiver's tone is automatically changed. That is, as the contact arm on the volume control approaches the tone circuit tap on the resistance element, more and more of the high frequencies are bypassed to ground. This allows the low frequencies to be amplified correspondingly more than the high frequencies.

EXAMINATION QUESTIONS

LESSON NO. 31

1. - What is the purpose of the volume control in a radio receiver?

2. - Describe a rheostat; a wire-wound potentiometer; a carbon-type volume control.

3. - Name the two types of taper. Explain briefly how taper is obtained in wire-wound and carbon-type controls.

4. - Give three advantages of the carbon-type control.

5. - What is a "bias type" of volume control?

6. - Describe two types of "short out" volume controls.

7. - How does the "antenna-bias" type of volume control operate?

8. - What is a "treble tone control"? How does it work?

9. - Describe two methods by which volume can be controlled in an audio circuit.

10. - What type of taper would you use for the circuit of Fig. 20? Explain the reason for your selection.

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LESSON NO. 32

AUTOMATIC VOLUME CONTROL AND NOISE SUPPRESSION SYSTEMS

When listening to distant programs with a receiver that does not have an automatic volume control system, we often notice a variation in signal strength.

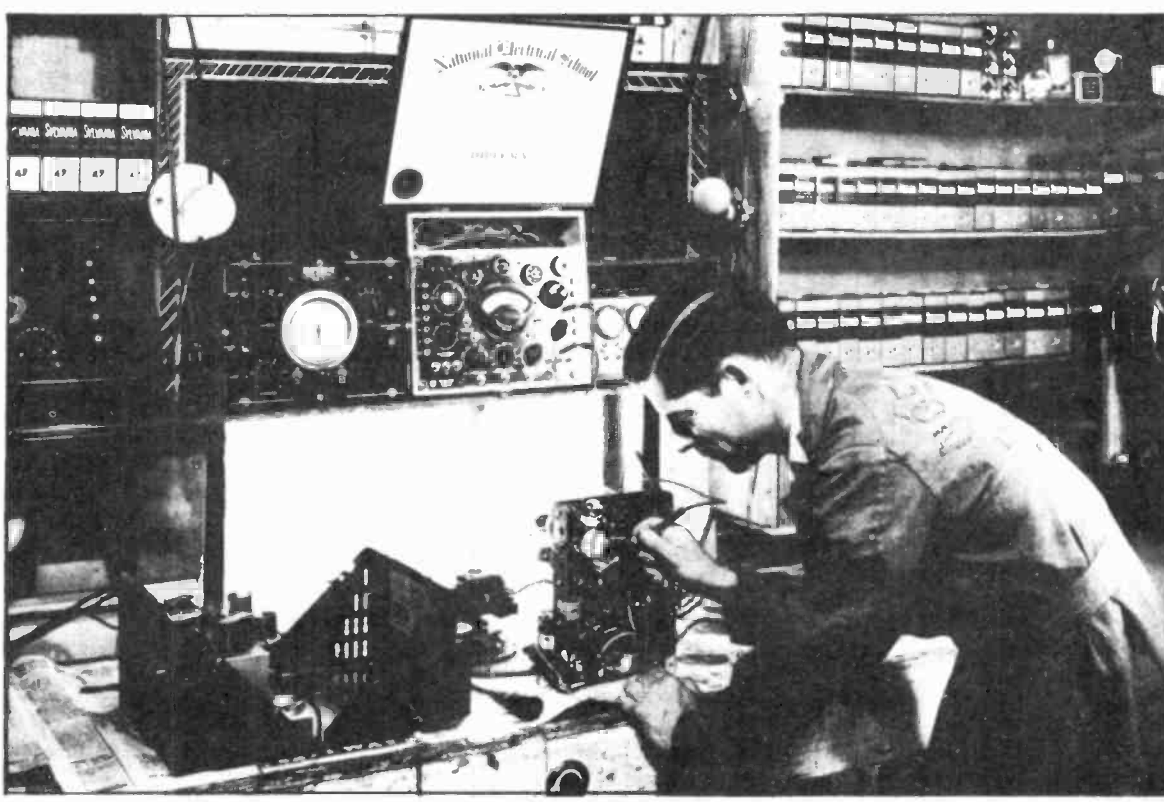

FIG. 1
MEASURING AUTOMATIC VOLUME CONTROL VOLTAGES

This condition is not brought about by any particular defect in the receiver, but is due to changes in atmospheric and geographic conditions which the signal encounters as it travels through space from the transmitter to the receiver. The receiver is simply amplifying whatever signal energy reaches it; and when atmospheric conditions happen to be such as to alter the signal strength that actually arrives at the receiver, the intensity of the reproduced sounds varies correspondingly.

Such a condition is annoying to the radio listener, as it requires him to continually manipulate the volume control in order to maintain a uniform and satisfactory sound level. Receivers which have an automatic volume control system incorporated in their circuits simplify matters in this respect by automatically increasing the sensitivity of the receiver during the reception of weak signals, and decreasing its sensitivity proportionately during the reception of strong signals. Thus, after having once set the manual (hand-operated) volume control for the sound level desired, the automatic volume control takes over the job of maintaining a uniform sound-level regardless of changes in the signal voltage available in the antenna circuit.

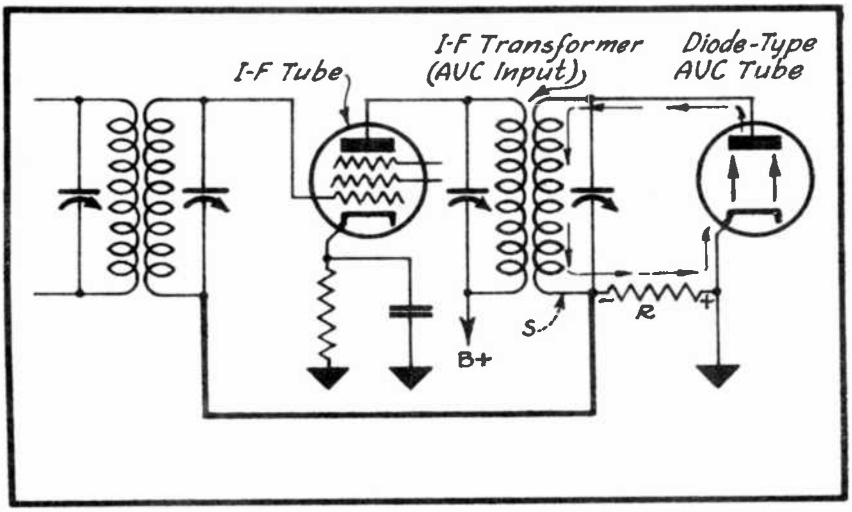

FIG. 2
PRODUCING A-V-C VOLTAGE WITH A DIODE

Briefly, automatic volume control is accomplished by regulating the bias voltage applied to the control grids of the r-f and i-f tubes. This bias voltage is varied in accordance with the strength of the signal that is being received. That is, during the reception of a strong signal, the self-adjusting characteristics of the automatic volume control (a-v-c) circuit applies a greater bias to the r-f and i-f tubes, thereby reducing the gain of these amplifier stages to a predetermined level. During the reception of weak signals, the automatic volume control circuit applies less bias to the r-f and i-f tubes, thus increasing the gain of these stages. To obtain uniform a-v-c action over the intervening range between a very strong signal and a very weak signal, it is necessary to use super-control type tubes -- that is, tubes which have a remote cut-off characteristic (variable-mu tubes).

With these fundamental facts in mind, let us now see how all this is accomplished.

FUNDAMENTAL PRINCIPLES

In Fig. 2 is shown a basic, though incomplete, a-v-c circuit employing a diode. This circuit operates as follows:

When an r-f signal voltage is applied across the input of the diode-type a-v-c tube (upon being induced into the secondary winding S), it will be rectified by the diode, as this tube allows current to pass through it in one direction only. Such being the case, a direct current will flow through the diode circuit during the positive half-cycles of the r-f voltage, as shown by the arrows.

During this process of rectification, current flows from the cathode of the diode to its plate, through the secondary winding (S) of the transformer and through resistor R, back to the cathode. Notice especially that this current flow through R causes a d-c voltage to be developed across it; also, that the direction of the diode current is such as to make the cathode end of resistor R, and the chassis (ground), positive with respect to the coil end of the resistor

Since the diode current varies with the intensity of the r-f signal applied to this tube, the voltage developed across resistor R will also vary accordingly. That is, the stronger the signal, the greater will be the diode current, and the greater will be the voltage developed across resistor R.

The voltage appearing across resistor R can be utilized to automatically bias the control grid of the i-f tube in Fig. 2 by connecting the negative end of the resistor to the control grid circuit of this tube. By thus controlling the bias of the i-f tube, its amplification factor can be controlled also. Therefore, when a strong signal is applied to the a-v-c tube, the increased voltage across R will increase the bias on the i-f tube and thereby reduce its amplification. When a weak signal is applied to the a-v-c tube, the reduced voltage across R will decrease the bias on the i-f tube and thereby increase its amplification. In actual practice, the a-v-c voltage is generally applied to all of the i-f tubes in the receiver, and often to the r-f tubes as well.

SIMPLE DIODE DETECTOR AND A-V-C CIRCUIT

In Fig. 3 is shown a typical a-v-c circuit employing a diode in such a manner as to make possible both detection and automatic volume control. In analyzing the operation of this circuit, let us assume that a modulated r-f carrier signal is applied across points 1 and 2 of the final i-f transformer. As the signal passes through the final resonant circuits composed of L-1, C-1 and L-2, C-2, it is applied directly to the plate and cathode of the combination diode detector and a-v-c tube. Condenser C-3 offers no opposition to this signal, as it has a low reactance at radio frequencies.

The modulated r-f carrier is rectified by the diode, since this tube allows current to pass through it in one direction only. The waveform of the current passing through this tube is like that shown at (A) of Fig. 4.

Condenser C-3 acts in the same manner as a filter condenser in a power supply system. That is, it becomes charged and then discharges during each successive pulse of r-f current. In other words, during positive half-cycles of r-f, the rectified pulse charges condenser C-3; during the negative half-cycles, while no current is flowing, C-3 discharges back into the circuit. This results in the r-f variations being filtered out, causing the final waveform of current to be similar to that shown at (B) of Fig. 4. Since this current flows through resistor R-3 in Fig. 3, the waveform of the voltage appearing across this resistor will also consist of the a-c and d-c components illustrated at (B) of Fig. 4.

If the values of C-3 and R-3 are chosen properly, the a-c component will be an exact reproduction of the audio signal. This audio

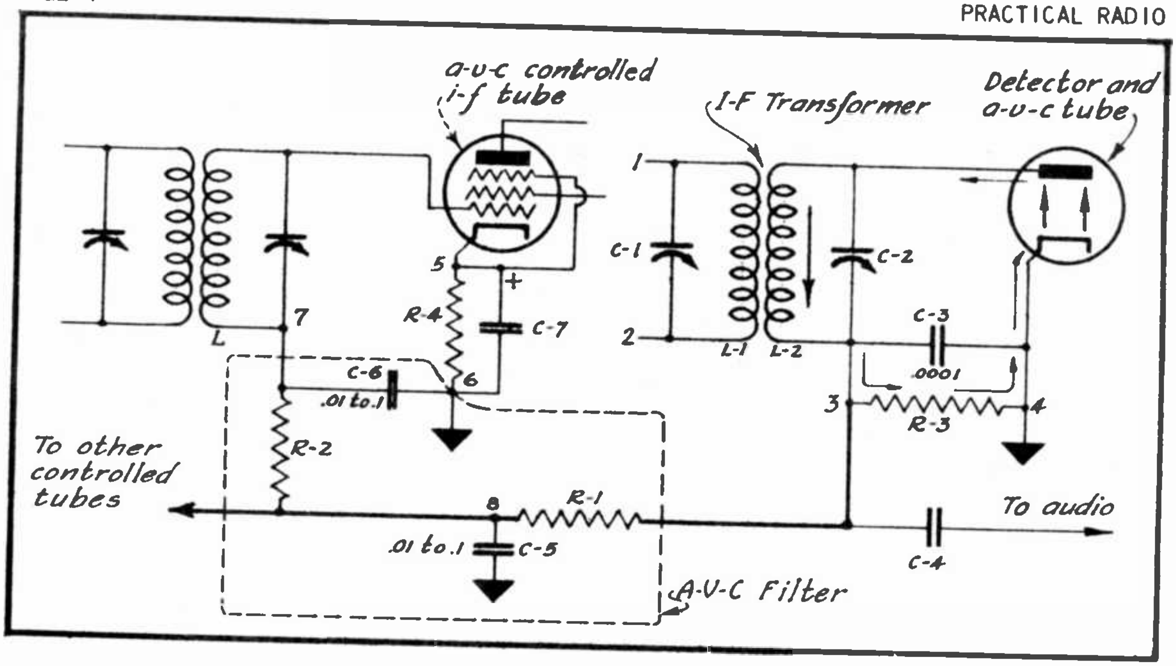

FIG. 3
FUNDAMENTAL A-V-C CIRCUIT

signal is then fed through condenser C-4 to an a-f amplifier (not shown) for further amplification.

Now, let us see how the a-v-c voltage is obtained, by tracing the d-c electron flow through the diode detector circuit shown in Fig. 3. Starting at the cathode of the diode tube, the rectified current will flow toward its plate. It then passes through coil L-2 and resistor R-3 in the direction of the arrows -- making terminal 3 of the resistor negative with respect to ground. Since the d-c component of the voltage between terminals 3 and 4 is proportional to the level of the modulated r-f carrier, these terminals may be used as a source for the desired a-v-c voltage (provided that the low-frequency a-f component is removed).

If the a-f component were applied to the grid of a controlled r-f tube, the r-f carrier signal would be still further modulated; this, of course, would be very undesirable. Therefore, it is necessary to place a filter, or several filters, in the a-v-c leads to keep the a-f signal out of the controlled stages.

FILTERING THE A-V-C VOLTAGE

The fact that the control grids of the r-f tubes are negative, so that no d-c grid current is drawn from the a-v-c circuit, simplifies the problem of filtering the a-v-c voltage. Upon again referring to Fig. 3 you will observe that two a-v-c filters (resistor R-1 in combination with condenser C-5, and resistor R-2 in combination with condenser C-6), are connected in the a-v-c voltage supply circuit, between points 3 and 7. These filters serve to keep the a-f signal voltage out of the a-v-c controlled stages of the r-f amplifier. This filter system operates in the following manner:

Resistor R-1 is high in ohmic value, and therefore offers considerable opposition to the flow of a-c. A large percentage of the small amount of a-c that passes through R-1 takes the low reactance path to ground through C-5 rather than forcing its way through the opposition offered by R-2. In a similar manner, the small amount of a-c that passes through the second filter resistor R-2 passes to ground through the low reactance path offered by C-6. Thus, the voltage at point 7, which is applied to the control grid of the i-f amplifier tube, is practically pure d-c. Condensers have no effect on d-c voltage; also, since no d-c current flows through the filter circuit, resistors R-1 and R-2 will have no effect upon the value of the d-c voltage appearing at point 7.

The flow of d-c plate current through resistor R-4 in the a-v-c controlled stage, produces across R-4 a d-c voltage which makes point 6 negative with respect to the cathode. This voltage drop across cathode resistor R-4 is applied as a bias to the grid of the controlled i-f tube through the ground circuit between points 6 and 4, and thence through R-3, R-1, R-2, and coil L.

When an r-f carrier signal is present in the receiver, the d-c component of the voltage produced thereby across R-3 acts in series with, and aids, the automatic "C" bias voltage produced across R-4. Thus, the a-v-c voltage and the automatic bias voltage add together to make the grid of the a-v-c controlled tube more negative than would be the case without a-v-c.

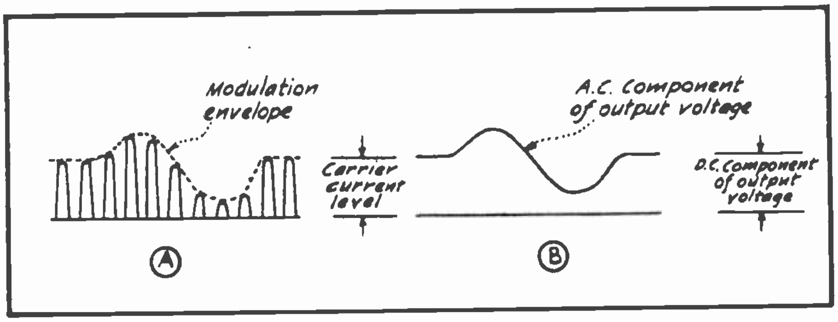

FIG. 4
CURVES SHOWING THE A-C AND D-C COMPONENTS ACROSS THE DIODE LOAD RESISTANCE

An increase in the carrier signal level boosts the d-c component of voltage across R-3, driving the grid of the a-v-c controlled tube more negative and thereby reduces the amplification of this tube sufficiently to keep the signal voltage in the controlled stage of the receiver below the overload value. Remember that a-v-c voltage may thus be applied to all of the i-f tubes of the receiver and also to the r-f tubes if so desired, thereby controlling the gain of all these various stages.

THE R-F RETURN CONDENSER

Condenser C-6, in the circuit shown in Fig. 3, has another important function, and that is to provide a path from point 7 to point 6 for the r-f voltage developed across coil L. If this condenser were omitted, the r-f current would be required to flow through R-2 and C-5 to ground. R-2 would naturally offer considerable opposition to this flow of r-f current, and would thereby cause the grid of the i-f tube to accumulate a high negative potential which would eventually block the tube. Also, there would be the possibility of r-f voltages straying into circuits where they could cause feedback and oscillations. Since the reactance of C-6 is much less than the reactance of the path to ground through R-2 and C-5, the r-f current will take the path to ground through C-6.

TIME-DELAY OF AN A-V-C SYSTEM

An a-v-c system must prevent "blasting" when a receiver is tuned suddenly from a weak to a strong signal, and must also compensate for more or less rapid fading effects.

The d-c component of voltage across R-3 in Fig. 3 changes immediately after a change in carrier level, but it takes a certain amount of time for condenser C-5 in the first a-v-c filter to charge or discharge to a new voltage value. The reason for this is that resistor R-1 offers considerable opposition to any momentary flow of current producing a change in condenser voltage. It thus takes a certain amount of time for point 8 to assume new voltage values. This delay in a-v-c action is commonly expressed as "time-delay."

CALCULATING THE TIME-DELAY

The amount of time-delay introduced by the a-v-c filter R-1 and C-5 depends upon the resistance value of resistor R-1 and the capacity of condenser C-5. This time, when expressed in seconds, is known as the <u>time-constant</u> of the a-v-c filter system, and can be computed quite easily.

In the case of the filter system shown in Fig. 3, this can be done by multiplying the ohmic value of R-1 in ohms by the capacity of C-5 in microfarads, and dividing by 1,000,000. The result will be the time-constant of the circuit in seconds, or the time required for the a-v-c voltage to reach approximately 63 per cent of its final new value after a change in carrier level. Thus, a .1-mf condenser, when used with a 1-megohm resistor, gives a time-constant of one-tenth second. (It is standard practice among engineers to specify time-constants for 63 per cent of the total change, this having proved more convenient than a time-constant based upon a 100% change.) The a-v-c filter made up of R-2 and C-6 likewise introduces a time-delay, which increases the time-constant of the entire a-v-c filter system.

A low time-constant is naturally desirable in order to make the a-v-c system respond as rapidly as possible to changes in carrier level. This can be secured by making the values of R-1, R-2, C-5 and C-6 low, but so doing impairs the filtering action which is essential to the operation of an a-v-c system. Therefore, receiver design engineers resort to a compromise, using a filter system containing values large enough to provide satisfactory filtering, yet small enough to provide a sufficiently short time-delay. A time-constant of one-fifth to one-tenth of a second is considered satisfactory by most engineers for the prevention of blasting and reduction of fading.

The values for condensers C-5 and C-6 in an a-v-c filter system may vary in different receivers from about .01 mf to 0.1 mf. These condensers are inexpensive and provide a sufficiently low reactance to ground for any r-f or i-f signal which may be attempting to flow from the resonant circuit of the final i-f transformer into the a-v-c line. Values of 100,000 ohms to 2 megohms are commonly used for R-1 and R-2. The filter action of a 1-megohm resistor, when used in combination with a 0.1 mf condenser, will reduce the strength of the lowest a-f signal, which tries to get into the r-f and i-f amplifiers, about 100 times. Two of these filter combinations would increase the time-constant from one-tenth second to one-fifth second and would increase the a-f filtering factor to 10,000 times.

SEPARATE DETECTION AND A-V-C ACTION, USING A DUO-DIODE TUBE

Sometimes, a double-diode detector is used in such manner that one diode section serves as a conventional detector and the other for developing the a-v-c bias. Thus, a-v-c action and detection take place in two separate circuits.

This may be accomplished very simply by connecting together the two diode plates, D-1 and D-2 through a small condenser C-1 as shown in Fig. 5. Thus, the a-f voltage developed across R-2 by the flow of current through diode D-1 is delivered to the a-f amplifier through a coupling condenser. Installing a potentiometer at this point provides a means for controlling the speaker volume. Diode D-2 also rectifies the r-f signal, a small portion of which is taken from D-1 through condenser C-1. This diode circuit is completed through resistor R-1. The rectified current flowing in this diode circuit produces a voltage across resistor R-1. The voltage produced across R-1 is of a pulsating nature, containing an average d-c value and an alternating value; the alternating value is composed of the r-f carrier and the a-f; the a-f appears here for the same reason that it appears across R-2. However, for the purpose of a-v-c, all of the alternating components must be eliminated as only d-c voltage is wanted. Therefore, condenser C-2 and resistor R-3 must be installed in the a-v-c bus to filter out this alternating component and leave only the d-c voltage for use in the a-v-c circuit -- the same as already explained relative to Fig. 3.

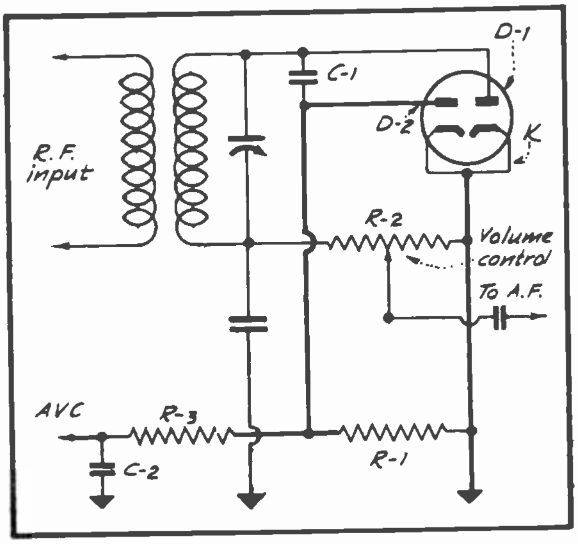

FIG. 5
DETECTION AND A-V-C WITH A DUO-DIODE TUBE

A-V-C WITH COMBINATION DIODE-TYPE TUBES

No amplification is derived from any sort of diode detector. For this reason, dual-purpose tubes were developed in which two diodes and a triode, or two diodes and a pentode, were combined in a single envelope. Since the diode section and the triode (or pentode) section are independent of each other, such a tube can be made to operate as a detector, an a-v-c tube, and a first audio amplifier.

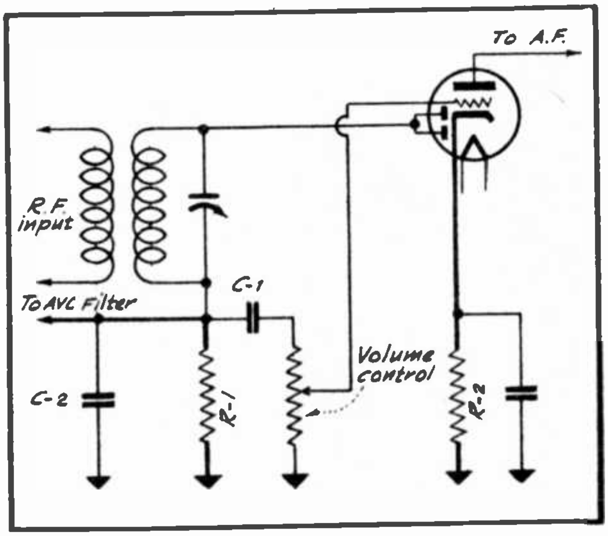

FIG. 6
COMBINATION DETECTION, A-V-C AND A-F AMPLIFICATION

In Fig. 6 is shown a typical circuit offering these three features. In most instances, the two diodes of the tube are connected together as shown, under which conditions they act as a single diode and permit the diode section of the tube to function as a half-wave rectifier. The circuit operates as follows:

The a-v-c voltage is secured from the voltage drop produced across R-1 by the flow of current which is rectified by the diode section of the tube. A lead is extended from the upper or ungrounded end of R-1 to feed the a-v-c voltages to the grids of the r-f and i-f tubes which are to be controlled. R-2 is sufficiently large in value to supply the necessary bias for the triode to act as an amplifier, but is not large enough to prevent signal rectification by the diode section.

Condenser C-2 serves to bypass to ground any remaining r-f ripples present in resistor R-1. The capacity of this condenser is too small to bypass any of the audio frequencies that are also present in this part of the circuit. The latter frequencies are taken from the ungrounded end of resistor R-1 and transferred through the larger condenser C-1 to the grid of the tube to be amplified by this tube's triode section.

DELAYED A-V-C SYSTEMS

One marked disadvantage of the simple a-v-c systems, thus far described, is that they act on all signals reaching the a-v-c tube. Therefore, weak signals cannot receive the full amplification of which the receiver is capable. In other words, the a-v-c system prevents the receiver from using its full amplifying ability due to the fact that any signal, upon entering the receiver's input, decreases the sensitivity of the receiver immediately.

To overcome this limitation, a method of a-v-c has been devised whereby the a-v-c action does not begin until the signal exceeds a certain strength. Since the a-v-c action, in this case, does not become effective until a signal exceeding a certain value is tuned in, this system is called "delayed a-v-c." This feature permits a greater power output to be obtained from weak signals.

FUNDAMENTAL PRINCIPLE: To illustrate the principle involved in delayed a-v-c or d-a-v-c, let us assume that the ordinary simple a-v-c system will become operative and provide a-v-c action when the input at the antenna is 1 microvolt or slightly more. The delayed system, on the other hand, will not become active or effective unless an input signal of, let us say, 50 microvolts is available.

In other words, a d-a-v-c receiver, while responsive to all input signals ranging from 1 to 50 microvolts, will not be a-v-c controlled unless the signal voltage exceeds 50 microvolts. Therefore, the receiver is permitted to operate at maximum sensitivity during the reception of very weak signals.

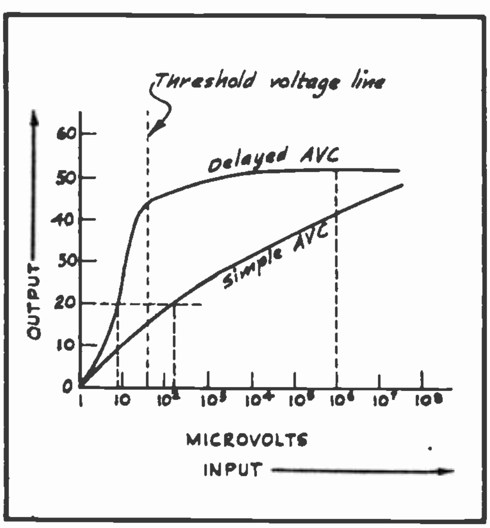

FIG. 7
CURVES SHOWING RELATION BETWEEN SIMPLE AND DELAYED A-V-C

The value of signal strength at which the a-v-c system starts to function is known as the threshold voltage. For values of input signals below the threshold voltage, the full sensitivity of the receiver is available, and the only bias which exists at the control grids of the controlled r-f and i-f tubes is the bias developed by the cathode resistors in these stages. However, in cases where the input signal rises above the threshold voltage, the a-v-c system begins to function, and the gain is effectively controlled so as to provide a fairly constant output.

This action is illustrated graphically in Fig. 7. Here is shown the relative performance of a receiver which incorporates a simple a-v-c system as compared to a similar receiver which incorporates a delayed a-v-c system.

In this graph, the voltage output of the detector is plotted against the input signal, expressed in microvolts. In the input scale of this graph $10^2 = 100$; $10^3 = 1000$; $10^4 = 10,000$; $10^5 = 100,000$; $10^6 = 1,000,000$; $10^7 = 10,000,000$; $10^8 = 100,000,000$ microvolts.

Let us consider first the curve which represents the performance of the simple a-v-c system. Here you will observe that the output of the receiver is appreciably below a desirable value until the input signal reaches a value of 40 or 50 microvolts.

The other curve shows clearly the improved performance obtainable by means of the delay action. In this case you will observe a steep rise in output for signals ranging from 1 to approximately 85 microvolts input, at which point the a-v-c action begins. This is the threshold voltage for the system, and is indicated by the vertical dotted line. With this vertical dotted line as a reference, observe that for voltages below 85 microvolts, the output with the delayed a-v-c system is appreciably greater than with the simple a-v-c system. Notice further, that the output from the delayed system, with an input of only 8 microvolts applied to it, is as great as that available with the ordinary system when the input is as high as 250 microvolts.

As is evident, these systems do not provide comparable outputs until the input signal reaches 1,000,000 microvolts, or 1 volt. Therefore, it is apparent that the delayed a-v-c system provides the required increase in sensitivity at those points where it is most desired; namely, at low values of input signal. It is also significant to observe that for input values above the threshold voltage, the output characteristic with the delayed system is a closer approach to the ideal flat curve than is available with the simple a-v-c system. (A flat curve tells us that the output voltage remains approximately constant even though the signal voltage at the input of the system may vary.)

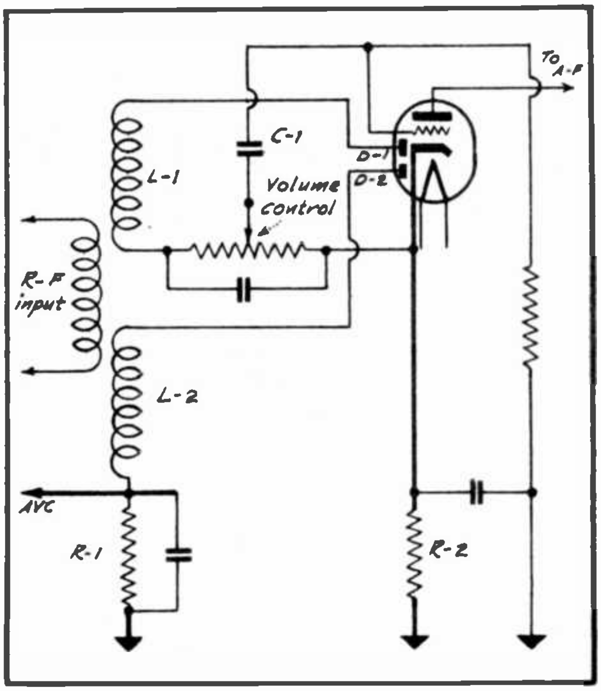

FIG. 8
DELAYED A-V-C CIRCUIT EMPLOYING A DUPLEX-DIODE TRIODE

DELAYED A-V-C CIRCUIT ACTION: Now that you are familiar with the fundamental purpose of delayed a-v-c action, let us next examine the circuit action and details of a typical delayed a-v-c system employing a duplex diode triode tube as a detector, delayed a-v-c rectifier, and first a-f amplifier. Such a circuit is shown in Fig. 8, and it operates in the following manner:

Upon studying this circuit diagram you will observe that the diode detector system is separate from the a-v-c system, and that this is made possible by constructing the secondary of the i-f (or r-f) transformer in two sections, one section for the diode detector circuit and the other for the a-v-c circuit.

The triode portion of the tube secures its bias from the voltage drop produced across R-2 by the flow of plate current through it. The return-circuit of diode D-2 is connected to ground through R-1. Therefore, D-2 is at negative potential with respect to the cathode of the tube by an amount equal to the voltage developed across the bias resistor R-2.

The same degree of coupling exists between each of the two secondary windings of the transformer and their common primary. Therefore, equal signal voltages will be induced in each secondary. The input signal induced in L-1 is rectified by diode D-1, and the a-f component voltage which is developed by the flow of this rectified current thru the volume control resistance is applied to the grid through the coupling condenser C-1. The voltage across the lower section of the secondary winding, L-2, is prevented from being rectified until its peak value is greater than the bias voltage furnished by R-2, because diode plate D-2 will not function when negative. Therefore, diode plate D-2 will produce no a-v-c action unless signals of sufficient strength are received to make it positive with respect to the cathode, and so, enables it to draw current.

The current rectified at such times by diode D-2 will flow thru R-1, producing an emf which is applied as an a-v-c voltage to the grids of the r-f or i-f tubes to be controlled.

SEPARATE A-V-C TUBES

All of the a-v-c systems, described up to now, employed a single tube for both detection and for furnishing the a-v-c control voltage. However, before the diode detector came into widespread use, a triode was often used in a separate a-v-c stage for the purpose of providing the a-v-c voltage.

While there are many variations of such separate a-v-c stages, one basic circuit of this arrangement is shown in Fig. 9. Since a great many of these older receivers are still in use, your knowledge of a-v-c systems would not be complete without your knowing how these circuits operate.

In our analysis of this circuit, let us first consider the condition where no r-f signals are being fed to the grid of the a-v-c tube, which you will observe to be a triode.

Resistors R-1, R-2 and R-3 form a voltage divider network which is connected across the output terminals of the power pack. The electron flow through these resistors is from B- to B+. This makes point "X" negative with respect to point "Z". The grid of the a-v-c tube, being connected to point "X" through grid resistor R-5, is therefore negative with respect to its cathode.

The plate of the a-v-c tube is connected to the a-v-c bus and also to ground at point "Y" through resistor R-4. Notice that point "Y" is nearer the B+ side of the circuit than point "Z"; therefore, point "Y" is positive with respect to point "Z". The values of R-1 and R-2 are so chosen that the a-v-c tube is biased to cut off when there is no r-f signal. Under this condition, no current flows through R-4, and no voltage-drop is produced across it. However, the plate of the a-v-c tube is positive with respect to its cathode by an amount equal to the voltage across R-2. Since there is no voltage-drop across R-4, points "U" and "W" are this time at the same potential -- at ground potential -- and therefore there is no a-v-c voltage between the a-v-c line and ground. A cathode resistor R-6 is used in each controlled stage to provide a normal "C" bias for these stages.

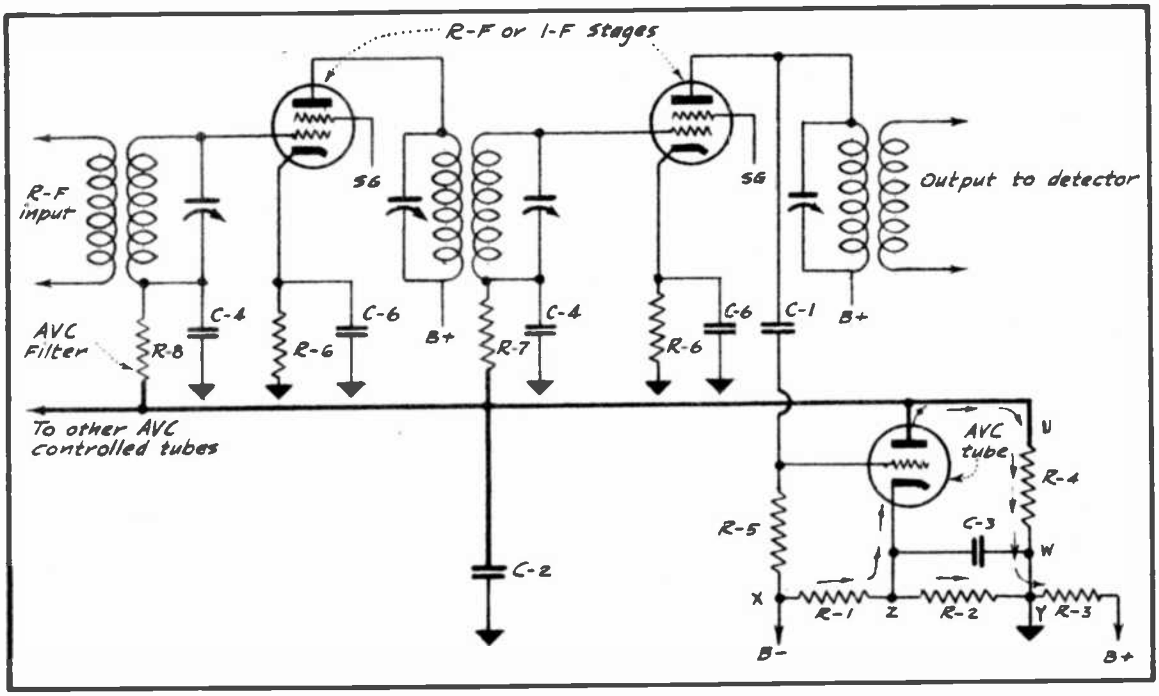

FIG. 9
SIMPLIFIED CIRCUIT OF AN A-V-C SYSTEM USING A SEPARATE A-V-C TUBE

When an r-f signal is applied to the grid of the a-v-c tube thru condenser C-1, it swings the grid in a positive direction on alternate half cycles. This allows a pulsating r-f plate current to flow, varying according to the modulation signal. D-C and a-f components will therefore appear across R-4. The electron flow through R-4 being from point "U" toward point "W", point "U" becomes negative with respect to ground. The r-f component of this plate current is filtered out by C-2 and C-3.

The d-c component, which varies with the r-f carrier level, is fed from point "U" to the grids of the controlled tubes, while the a-v-c filters in each controlled stage filter out the a-f component as explained previously in this lesson. An increase in carrier level at the grid of the a-v-c tube increases the d-c component of voltage across the a-v-c load resistor R-4 just enough to make the grids of the controlled tubes sufficiently more negative to hold the carrier level fairly constant.

AMPLIFIED A-V-C

To obtain a more perfect a-v-c action, it is necessary that the voltage actuating the a-v-c tube be greater than can be obtained with the systems heretofore described. Such a system necessitates amplifying either that portion of the signal which is to be rectified for a-v-c use or the resulting d-c voltage -- hence, the name "amplified a-v-c."

There is no fundamental difference between amplified a-v-c systems and conventional a-v-c systems. In all cases, part of the signal is removed from the i-f amplifier, is amplified, and then fed to the a-v-c tube in the normal manner. That part of the signal which is not removed for a-v-c action may be still further amplified, rectified by the second detector, and passed on to the a-f amplifier in the normal manner. The term "amplified a-v-c" applies only to that function of the receiver which amplifies the part of the signal to be used specifically for a-v-c purposes.

CIRCUIT DETAILS: The amplifying part of the a-v-c section may not necessarily be a separate tube; in fact, many receivers make use of the combination tubes for this purpose. Such a typical circuit is shown in Fig. 10.

As seen, the two diodes are connected together to form a half-wave detector circuit. The a-f and d-c components then appear across R-1 in exactly the same manner as described previously in this lesson. The total voltage across R-1 is fed to the a-f amplifier through the coupling condenser C-1, which passes only the audio component of the voltage. Bypass condenser C-2 serves to keep the r-f out of the audio amplifier, thus preventing "fringe howls."

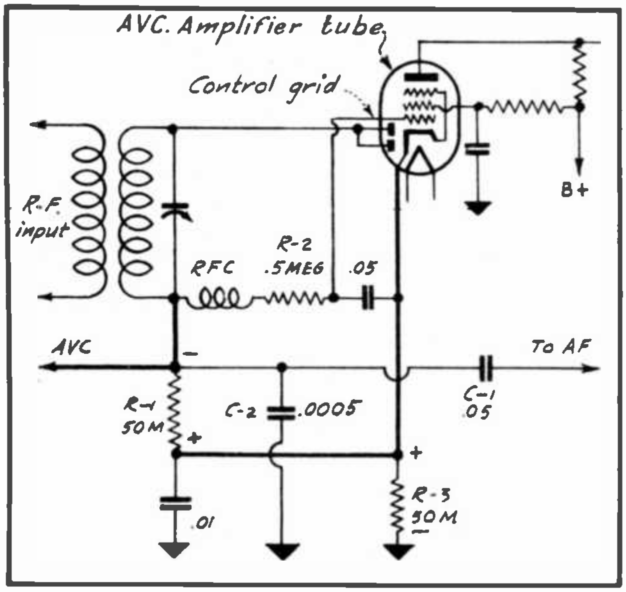

FIG. 10
DUPLEX-DIODE PENTODE FUNCTIONING AS A DETECTOR, A-V-C TUBE, AND A-V-C AMPLIFIER

The d-c component of the voltage across R-1 is applied to the control grid of the pentode portion through resistor R-2 which, together with the r-f choke and .05-mf bypass condenser, serves to prevent any audio voltages from actuating the grid of this tube. The cathode is above ground potential by an amount equal to the voltage-drop produced across the cathode resistor R-3, and any changes in the d-c grid potential of this tube will vary the current through R-3 and thus change the voltage-drop across it. Increasing signal strengths will increase the voltage-drop across R-1, which, in turn, will apply a greater negative d-c voltage to the control grid of the a-v-c tube, thus lowering the plate current through R-3. Hence, the voltage across R-3 will decrease. Since R-1 and R-3 are connected in series insofar as the a-v-c voltage is concerned, simultaneous voltage-changes across R-1 and R-3 will make the total voltage-change between ground and the negative end of R-1 greater than would be the voltage-change developed across R-1 alone. This total voltage appearing between ground and the negative end of R-1 is applied to the grid-return leads of the tubes under a-v-c control in the usual manner.

AMPLIFIED DELAYED A-V-C

Some receivers do not employ separate systems for furnishing delayed a-v-c and amplified a-v-c, but employ a combination amplified delayed a-v-c stage. While such a circuit will naturally employ the principles of both these systems; nevertheless, the delayed a-v-c section in such combination systems differs basically from the systems described previously.

In Fig. 11 is shown an interesting and typical circuit using a duplex-diode pentode, where the pentode section -- used as a triode -- functions as a d-c amplifier.

By closely inspecting this diagram you will observe that the r-f signal carrier is coupled to diode D-1 through the small coupling condenser C-1. Diode D-1 functions as a straight rectifier, and its load resistor R-1 is returned directly to the cathode; hence, there is no delay voltage in this circuit. The rectified voltage produced across R-1 is fed to the grid of the pentode section through the resistance capacity filter composed of R-2 and C-2. Inasmuch as the screen and plate of the pentode section are tied together, and connected to the positive side of the power supply, this part of the tube functions as a triode rather than as a pentode. The cathode of the tube is connected to the center-tap of the power transformer's high-voltage winding (not shown) through a 50,000-ohm resistor, and the power supply circuit in such a receiver is so wired that ground or B- is more positive than is the center-tap of the transformer's high-voltage winding. Therefore, the end of resistor R-3 marked "C-" is at all times negative with respect to ground. The second diode plate D-2 is connected to ground through the 400,000-ohm resistor R-4, and the a-v-c voltage is taken from diode plate D-2 through another 400,000-ohm filter resistor R-5. Let us now analyze the action which takes place under varying conditions of input signal.

When the incoming signal is very small, the voltage developed across R-1 is also small. Therefore, only a small negative voltage is fed through resistor R-2 to the grid of the tube's pentode section. This small amount of bias results in a comparatively high value of plate current flow through the cathode resistor R-3, and the circuit constants are so chosen that the cathode is positive with respect to ground under these conditions of large plate current. Now, since diode plate D-2 is grounded through R-4, it will be negative with respect to the cathode and for this reason no current can flow in this diode circuit through R-4; therefore, no voltage will be produced across R-4. This in turn means that no control voltage will be supplied to the controlled tubes through R-5 under these conditions of low signal input.

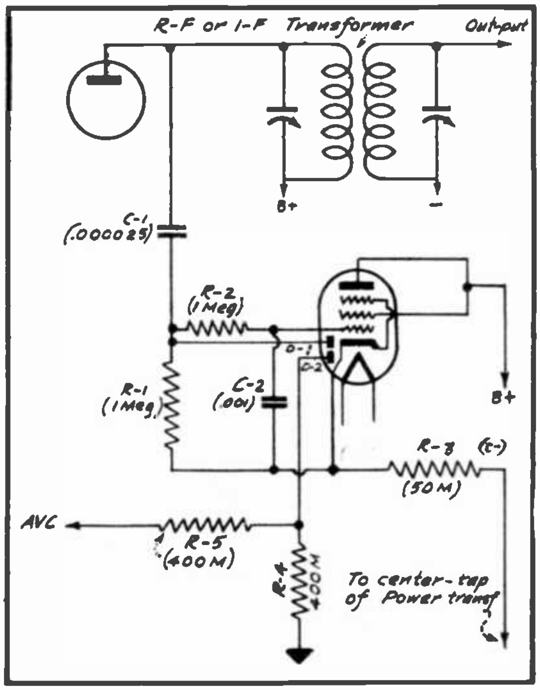

FIG. 11
CIRCUIT FOR AMPLIFIED A-V-C

As the input signal to the receiver is increased, the following changes take place: First, the increased signal applied to D-1 results in an increased value of rectified voltage produced across R-1, which in turn increases the bias of the pentode section. This increased bias on the control grid of the pentode (used as a triode, of course), acts to decrease the value of plate current and this in turn decreases the voltage across R-3.

As mentioned previously, the greater the value of plate current through R-3, the more positive will be the cathode of the tube. It thus follows that the effect of a decreased value of plate current under conditions of comparatively large values of input signal is to make the cathode less positive, or more negative. We see then that larger values of input signal result in smaller values of plate current which make the cathode less positive. Finally, a point is reached where the cathode voltage becomes zero compared to ground, at which time no bias is being applied to diode plate D-2. This is the critical value of signal input at which diode D-2 begins to function.

For input signals beyond this threshold value, the cathode of the tube becomes more and more negative so that increased values of current flow through the resistor R-4. Furthermore, the direction of this current is such that the ungrounded end of R-4 becomes negative. It is this negative voltage, developed across R-4, which serves as the automatic control voltage, and which is distributed to the several controlled tubes through the filter resistor R-5.

We have observed that the operation of the circuit just described is a form of amplified delayed a-v-c action. This is true because the initial rectified voltage which is available across R-1 -- the load of the first rectifier section D-1 -- is impressed on the grid of the a-v-c tube and amplified by this tube before it is applied to the controlled tubes.

We might further point out that the full amplification of the a-v-c tube is utilized, since the change in voltage which appears across R-4 is essentially the same as the change in voltage which appears across the cathode resistor R-3. As you have no doubt noticed by this time, the load for the triode section of the tube is not directly in the plate circuit of the tube, but is the resistor R-3, which is located between the cathode and the center-tap of the high-voltage secondary winding on the power transformer. Thus the plate voltage of the tube, with respect to ground, remains constant for changes in grid voltage, while the voltage at the cathode fluctuates in accordance with changes in the grid bias.

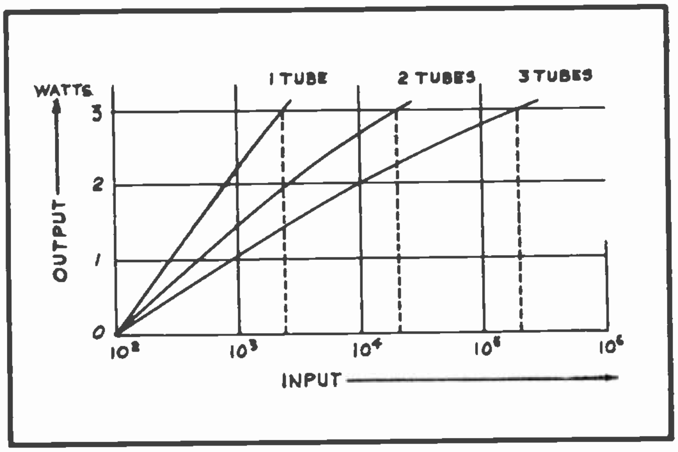

FIG. 12
CURVES SHOWING HOW THE NUMBER OF A-V-C CONTROLLED TUBES AFFECTS PERFORMANCE

NUMBER OF CONTROLLED TUBES

The number of tubes to be controlled in a receiver by the a-v-c system will vary according to the sensitivity of the r-f and i-f stages as a whole. In some small receivers, only one tube may receive the control voltage, while in larger receivers as many as four tubes or stages may be controlled.

The reason for this variation is that a relation exists between the number of tubes that can be controlled by the a-v-c voltage and the over-all performance of the a-v-c system with respect to the uniformity of the output obtained from the receiver. This relation depends on how much the gain of the controlled stages is influenced by changes in control voltage. In Fig. 12 you will see three curves, each showing how an a-v-c system influences the audio output as the number of controlled tubes is increased.

Note that with one tube controlled, a change in signal input of from 100 to 3000 microvolts will produce a change in audio output of approximately three watts. If two tubes are controlled, an input of from 100 to 25,000 microvolts is required to produce the same change in audio output. If three tubes are controlled, a variation of from 100 to 200,000 microvolts is required to produce the same three-watt change in output.

NOISE BETWEEN STATIONS IN A-V-C CONTROLLED RECEIVERS

Since the normal action of an a-v-c system is to decrease the sensitivity of the receiver on strong signals, and since the sensitivity of such a receiver is maximum when the tuning dial is set where no station is being received, reception is usually very "noisy" when the receiver is tuned between stations. This is due to the fact that any natural and man-made electrical disturbances, picked up by the antenna, are amplified by the full amplifying power of the receiver. These "background" noises are very annoying when tuning from one station to another.

To overcome this inter-station noise, the a-v-c system in some receivers is designed to provide an appreciable time-lag. In other words, the a-v-c system will require more time before responding to signal voltage changes. This time-lag is sufficient to keep the sensitivity of the receiver at a low value until the tuning dial, when turned at a normal speed, reaches the next station; this tends to keep noise between stations at a low level. However, because of this time-lag, it is difficult to tune a station to a point of resonance accurately unless a tuning eye or indicator of some kind is used. In addition, a thudding sound or "plop" will be heard in the speaker whenever a station is tuned in.

To provide better performance in this respect, it is desirable to have an a-v-c system that will prevent background noise when tuning between stations. The output of the receiver will then be automatically reduced to zero whenever the receiver is tuned off a station. Such noise suppression circuits or quiet a-v-c systems (q-a-v-c) have been devised. These will now be explained.

NOISE-SUPPRESSION CIRCUIT

In Fig. 13 we have a circuit which incorporates diode detection, delayed a-v-c action, and noise suppression all in the one tube, VT-1. Diode D-1 takes care of detection, and diode D-2 develops the a-v-c voltage. The triode portion of the tube acts as the noise suppressor.

When an r-f signal is induced in the secondary circuit of the i-f transformer, diode D-1 rectifies this signal, causing d-c current to flow through R-3, R-4, to the cathode and back to diode plate D-1. Audio signal voltage is taken from the variable resistance R-4 and applied through a .01-mf condenser (C-1) to the grid of the audio amplifier tube VT-2.

The other diode plate (D-2) is coupled to D-1 by a small condenser C. This allows part of the r-f signal to be impressed on D-2 and rectified. The resulting current flow through resistor R-1 develops an a-v-c voltage which is applied through the .25-megohm filter resistor (R-8) to the grid circuits of the r-f and i-f tubes to which the a-v-c voltage is to be supplied. However, it is to be noted that the cathode of VT-1 is connected to a point in the series of voltage dropping resistors which is 14 volts positive with respect to ground. This means that the ground end of R-1 is going to be 14 volts negative with respect to the cathode. Therefore, no current will flow through diode section D-2 until the impressed r-f voltage reaches a value slightly above 14 volts. This provides the delay action for the a-v-c system.

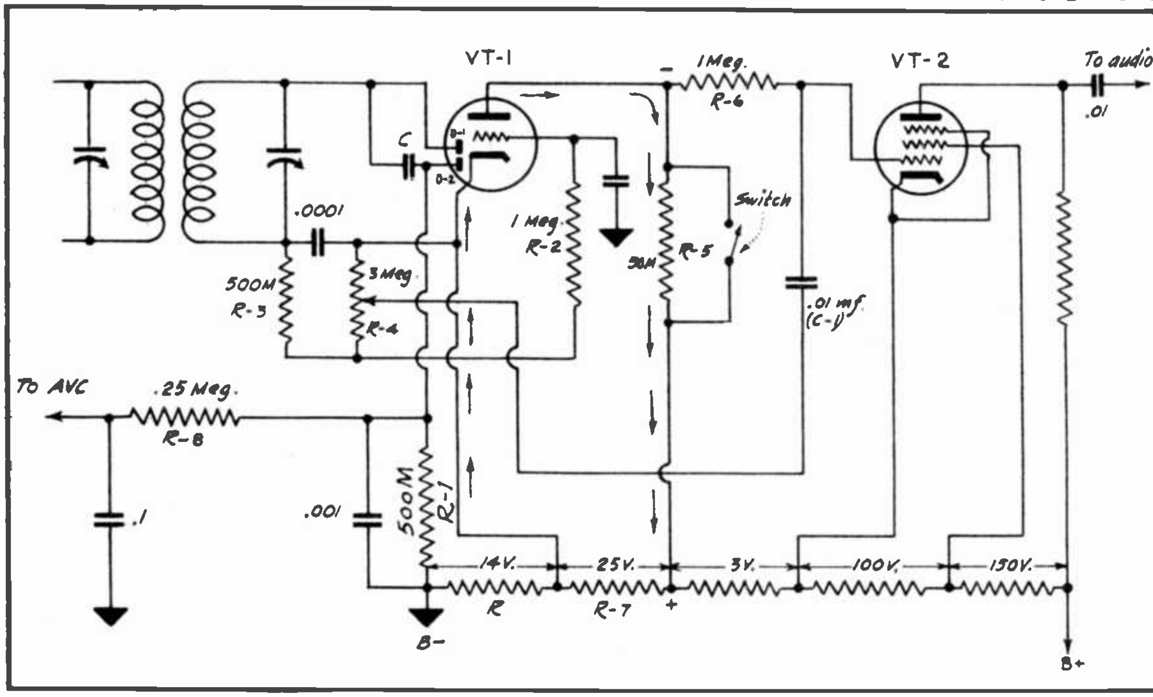

FIG. 13
NOISE-SUPPRESSION, OR QUIET A-V-C, SYSTEM

The grid of VT-1 is connected through a 1-megohm resistor (R-2) to the point at which R-3 and R-4 are united. Now, when no signal is applied to D-1 there will be no current flow through R-3 and R-4, and consequently, there will be no negative voltage on the grid of the tube. Instead, the grid of the tube will be practically at zero voltage with respect to its cathode. This means that a fairly high plate current will flow through the path indicated by the arrows. The direction of this current flow is such that the top end of R-5 becomes very highly negative. Since this negative voltage is impressed upon the control grid of VT-2 through the 1-megohm resistor R-6, it is apparent that this tube will be blocked. Such will be the condition when no signal is being received, or during the intervals between stations.

When the r-f and i-f circuits are tuned to a station so that a signal voltage is applied to the diodes of VT-1, no current will flow through the circuit composed of D-2 and R-1 until the signal reaches a value above 14 volts. However, a direct current does flow through the circuit composed of D-1, R-3, and R-4. This current develops a voltage across R-3 and R-4, making the lower end of R-4 negative with respect to its cathode end. This negative voltage is impressed upon the grid of VT-1 through R-2, causing the plate current flow through this tube to be reduced materially or cut off completely. Thus, the voltage appearing across R-5 will be reduced also, and the bias upon tube VT-2 reduced accordingly. Tube VT-2 will then be able to amplify any audio signal which is applied to its grid through the coupling condenser C-1. This condition develops almost as soon as the tuning section of the receiver is tuned to resonance with a signal.

NOISE SILENCERS AND NOISE LIMITERS

"Noise silencers," or "noise limiters," are similar to the "quiet a-v-c" or noise-suppression circuit, but dissimilar in their action. The first of these devices was known as the Lamb "noise silencer." This circuit was developed primarily for use in amateur and communications-type receivers; but, several circuits have been developed from it, and are being used on some of the newer commercial receivers.

THE LAMB "NOISE SILENCER" CIRCUIT: The circuit diagram of a Lamb "noise silencer" is shown in Fig. 14. The essential parts of the system are shown in heavy black lines. The grid lead of the first i-f transformer divides into two paths -- one going to the control grid of VT-1 and the other to the control grid of VT-2. Thus, any r-f voltage existing in the secondary of this i-f transformer will be impressed on these two grids simultaneously. This voltage may contain noise pulses which are impressed on both grids at the same instant, together with the signal. Let us now analyze the actions taking place in VT-2 and VT-3 and see how the "noise pulse" can be cancelled out, leaving only the signal voltage.

First, it is apparent that any signal applied to the grid of VT-2 will be amplified by this tube and passed on through the i-f transformer to the secondary terminals of L-2. Notice that L-2 is connected as a full-wave rectifier circuit -- each end terminal of the winding being connected to a diode plate. Therefore, current will flow through resistor R-2 during each half of the full cycle of r-f voltage; this current will develop a voltage across R-2, making its upper end negative with respect to its ground end. Keep this voltage in mind because we will come back to it in a moment.

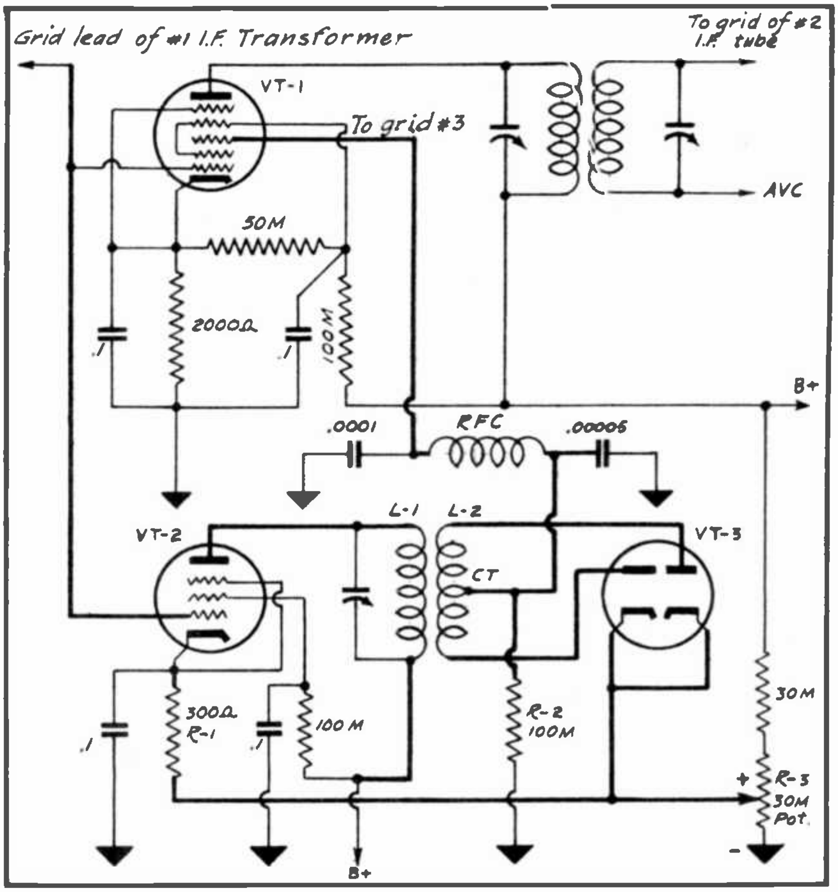

FIG. 14
THE LAMB NOISE SILENCER

Next, note the cathode connections of VT-2 and VT-3. The cathode of VT-2 is connected through a biasing resistor to the variable terminal of potentiometer R-3. Also, the two cathodes of VT-3 are tied together and connected to the arm of potentiometer R-3. The position of the rotating arm on variable resistor R-3 determines two conditions: first, it determines the amount of amplification that VT-2 can produce; and second, it will determine the value of the signal voltage required before the diode plates of VT-3 will be driven sufficiently positive to start drawing current -- in other words, the adjustment of R-3 places a delaying voltage on VT-3.

It is apparent then that R-3 can be adjusted to a point where any r-f signal on the grid of VT-2 will not be amplified enough to drive the diode plates of VT-3 positive; yet, the adjustment is such that the amplified voltage is very close to the threshold voltage, or the voltage that will cause the diodes to become positive. Now, any noise signal appears as a very sharp and exaggerated peak in the audio envelope of the r-f carrier, and the value of this noise peak is high enough to drive the diode plates positive. Thus, for the instant of the noise peak endurance, there is a sudden pulse of current through R-2. This sudden current pulse develops a voltage across R-2 which is applied as a negative voltage through the radio-frequency choke (rfc) to grid #3 of VT-1. The value of this momentary voltage causes grid #3 of VT-1 to become sufficiently negative to counteract the sharp peak in plate current that would be produced in this tube by the noise signal.

The action of the noise silencer is shown graphically in Fig.15. Notice at (A) how the noise appears as a very sharp peak in the audio envelope. If this signal were to be rectified, and passed on to the audio amplifier, the noise would appear as a loud crackle. Notice also that the noise silencer is adjusted so that it does not come into operation until the signal voltage reaches the value indicated by the dotted lines at (B) of Fig. 15.

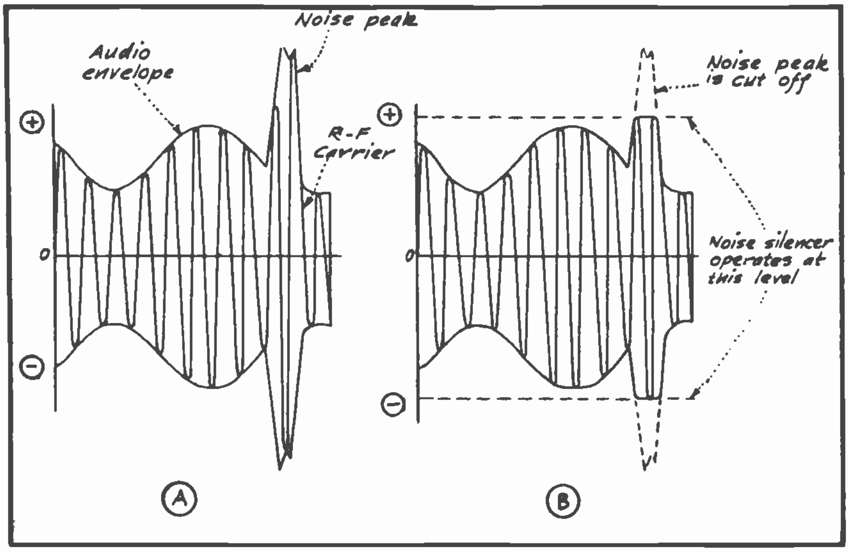

Fig. 15
Noise as impressed on and eliminated from Signal

Since the noise modulation rises to a value considerably above the operating level of the silencer, a negative voltage will be developed across R-2 in Fig. 14 at the instant that the threshold point, or the operating level indicated at (B) of Fig. 15, is reached. This negative voltage reduces the amplification of VT-1 for the duration of the noise peak and prevents the noise signal from being amplified above the limiting level.

Now, you can see that the term "noise silencer" is not an accurate description of the action that occurs in this type of circuit. A more truthful term would be "noise limiter"; because, as you have seen, the noise is not completely eliminated -- rather, it is reduced to a level almost equal to the highest audio modulation peak so that it only appears as a slight background crackle instead of a very pronounced one.

The broadcast band is not troubled by static and man-made interference to as great an extent as are the shortwave bands. Some of the better quality commercial receivers have a noise limiter incorporated in their circuits with provision for switching it in or out. These noise limiters are not as complex as the "Lamb silencer" but they are beneficial, especially in localities where the interference problem is very acute.

NOISE LIMITER OF A COMMERCIAL RECEIVER: In Fig. 16 are shown the final i-f transformer and a duo-diode tube of a receiver. One diode section is used as a detector and the other as the noise limiter. The arrangement operates as follows:

Any r-f signal induced in the secondary of the i-f transformer will be rectified by diode section D-1 of the tube. This rectified voltage consists of an average rectified carrier voltage and the audio modulation with all the noise or interference peaks.

Diode D-2 is connected to point 1 through the 1-megohm resistor R-3, and the cathode is connected to point 2 of the resistor network. Now, if an unmodulated carrier voltage appears in winding L-1, current will flow through R-2 and R-1 in such a direction as to make point 1 negative with respect to point 3 (ground). Point 2 will be somewhat less negative than point 1. This means that the higher negative voltage at point 1 will be impressed on diode D-2. No current will flow through this section of the tube as long as this condition exists. Furthermore, condenser C, being connected between D-2 and ground, will be charged in such a direction that its ungrounded end is negative with respect to its grounded end -- and it will remain charged in this direction as long as the voltage at point 1 remains unchanged at this highly negative value.

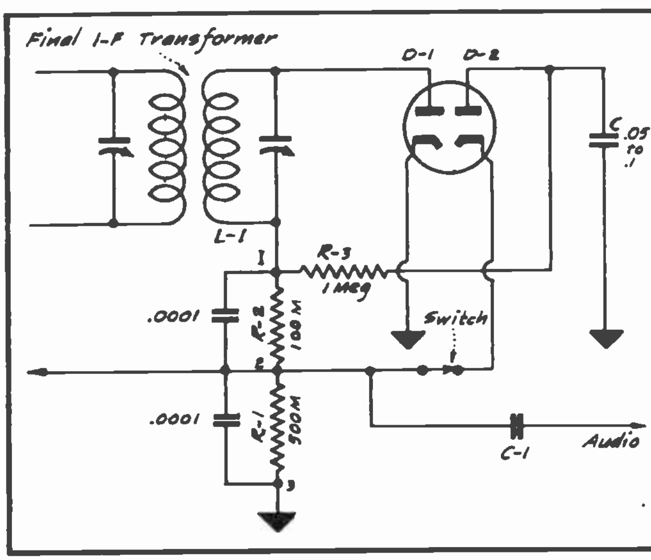

FIG. 16
THE DICKERT "NOISE LIMITER"

Now, let us suppose that the audio and noise modulations are being impressed on the carrier. Conditions in the circuit of D-2 will then remain practically the same as when no modulation existed, with the exception that condenser C now charges up to a voltage which is the average of the modulating envelope and remains in this condition, retaining the same polarity as previously.

Condenser C remains charged to the average of the modulation voltage because of the time-constant of resistor R-3 and C. Notice that the time constant of R-3 and C is from .05 to .1 second. In comparison with the changes in audio modulation during that time, you can see that C is not going to have time to alter its voltage very much for each cycle of modulating voltage. The only thing it can do is to charge up to the average value and remain at that point. The value of R-2 is chosen so that the voltage-drop between points 1 and 2 will be approximately equal to the voltage developed across C. As long as the voltage drop across R-2 does not exceed this value. D-2 will remain negative with respect to its cathode.

Now, look at diagram (A) of Fig. 15 again. Observe that the noise peak exceeds the average value of the audio modulation by a great deal. If this noise peak is rectified and impressed across R-2 and R-1, it will last for only a fraction of the time required for any change in audio modulation. Therefore, the time-constant of R-3 and C will prevent this noise peak from making any change in the value of voltage across C; however, the difference in voltage drop between points 1 and 2 does change. In other words, while the voltage across C remains constant, the voltage at point 2 becomes more negative. Therefore, D-2 will become positive with respect to point 2, and current will flow from the cathode to D-2 during the instant of the noise peak.

When plate current flows in a diode, its plate resistance drops considerably. For instance, the plate resistance of diode section D-2 may drop to several hundred ohms. This means, then, that point 2 is going to be connected to ground through a very small resistance (plate resistance of diode section D-2) and condenser C. Since noise peaks are always of a high frequency order, the value of C in series with the small plate resistance will act to bypass the audible noise voltage from point 2 to ground during the instant of the noise peak. Thus the noise impulse is prevented from being passed across the coupling condenser C-1 to the grid of the following audio tube.

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EXAMINATION QUESTIONS

LESSON NO. 32

1. - (a) What is meant by amplified a-v-c?
   (b) How is it obtained?

2. - What is the principle by which noise is eliminated by a noise silencer, or noise limiter, circuit?

3. - How is the time-delay of an a-v-c filter determined?

4. - What type of tube must be used in the controlled stages in order to obtain proper a-v-c action?

5. - What is inter-station noise, and why is it desirable to suppress it?

6. - Draw a circuit diagram, showing how a single tube may function as a detector, a-v-c tube and audio amplifier.

7. - (a) Why is delayed a-v-c action desirable in certain instances?
   (b) Describe briefly the principle of a delayed a-v-c system.

8. - Is the ground end of the diode load resistor positive or negative with respect to the ungrounded end of this resistor?

9. - Draw a circuit diagram of a noise silencer circuit.

10. - How does the number of tubes controlled by a-v-c affect the performance of a receiver?

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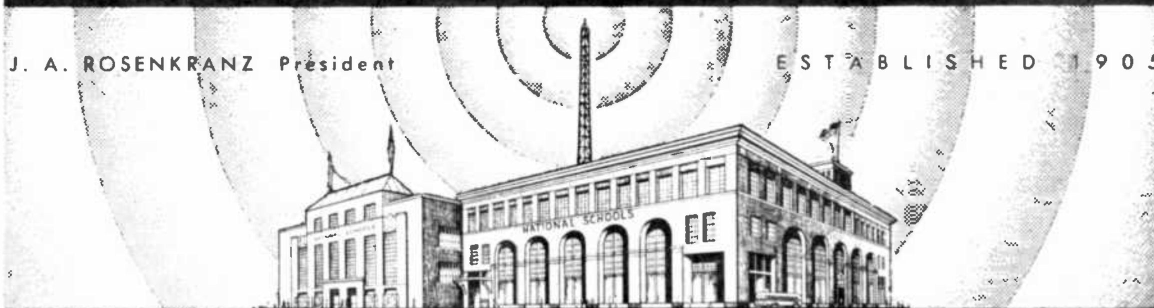

NATIONAL SCHOOLS ★ LOS ANGELES 37, CALIF.

LESSON NO. 33

SERVICING STORAGE BATTERIES

STORAGE BATTERIES ARE USED EXTENSIVELY IN THE FIELD OF RADIO AND ELECTRONICS. SO, IN THIS LESSON YOU WILL LEARN HOW TO KEEP A STORAGE BATTERY AT PEAK EFFICIENCY. FIRST, LET US CONSIDER THE CARE WHICH A NORMAL STORAGE BATTERY, SUCH AS THE ONE IN FIG. 1, REQUIRES IN ORDER TO PREVENT IT FROM DEVELOPING MANY OF THE SERIOUS TROUBLES TO WHICH IT IS CONTINUALLY SUBJECTED. AMONG THE IMPORTANT FACTORS, WE FIND THAT IT IS ESSENTIAL TO ALWAYS KEEP THE OUTSIDE OF THE BATTERY CLEAN AND DRY.

KEEPING THE BATTERY CLEAN

THERE SHOULD BE NO DOUBT IN YOUR MIND AS TO WHY THIS PRECAUTION IS SO NECESSARY, IF YOU WILL ONLY CONSIDER THE FACT THAT MOISTURE AND DIRT FORM A COMBINATION WHICH HAS SUFFICIENTLY GOOD ELECTRICAL CONDUCTING QUALITIES TO PERMIT A LEAKAGE OF CURRENT BETWEEN THE CELLS. CONTINUOUS CURRENT LEAKAGE OF THIS NATURE WILL IN DUE TIME CAUSE A GOOD BATTERY TO DISCHARGE ITSELF.

FIG. 1
STORAGE BATTERY

IT IS A GOOD POLICY TO OCCASIONALLY WIPE THE TOP OF THE BATTERY CLEAN WITH A RAG MOISTENED WITH AMMONIA, OR A SOLUTION OF BAKING SODA AND WATER. THE REASON FOR DOING THIS IS THAT AMMONIA AND BAKING SODA WILL COUNTERACT OR NEUTRALIZE ANY ACID WHICH MAY BE PRESENT ON TOP OF THE BATTERY.

CORRECTING CORRODED TERMINALS

IF YOU CAREFULLY EXAMINE A STORAGE BATTERY WHICH HAS BEEN NEGLECTED, YOU WILL NO-

TICE THAT A FLUFFY, GREENISH LOOKING SUBSTANCE HAS COLLECTED AROUND THE TERMINALS. THIS SUBSTANCE IS CAUSED BY CORROSION, WHICH IS DUE TO THE ACTION OF THE ACID ON THE METALLIC IMPURITIES WHICH ARE PRESENT ON THE TERMINALS.

SHOULD THIS CORROSION BE ALLOWED TO CONTINUE, THEN THE CONNECTION WILL SOON BE ENTIRELY EATEN AWAY SO THAT EITHER AN EXTREMELY HIGH ELECTRICAL RESISTANCE WILL BE OFFERED BY THE JOINT OR ELSE THE JOINT MAY EVEN BECOME OPEN CIRCUITED ALTOGETHER.

WHEN YOU FIND SUCH A CORRODED CONDITION, IT IS NECESSARY FOR YOU TO REMEDY IT IMMEDIATELY AND ALTHOUGH IT IS A SIMPLE MATTER TO DO THIS, YET IT IS A MOST IMPORTANT ONE. THE FIRST THING TO DO, WHEN YOU WISH TO REMEDY THIS CONDITION, IS TO SCRAPE OFF ALL OF THIS SUBSTANCE, BEING CAREFUL, HOWEVER, NOT TO PERMIT ANY OF IT FROM FINDING ITS WAY INTO ANY OF THE CELLS. IN FACT, IF THE TERMINAL IS CORRODED EXTREMELY BAD, IT WILL BE NECESSARY TO REMOVE THE CONNECTION WHILE SCRAPING SO THAT ALL SURFACES WILL BECOME BRIGHT AGAIN BEFORE REPLACING THE CONNECTION.

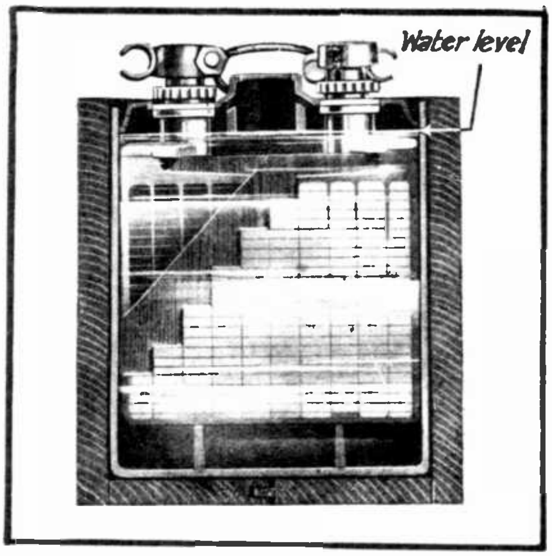

FIG. 2
Level of the Electrolyte.

SOMETIMES, TERMINALS BECOME SO BADLY EATEN AWAY THAT IT IS NECESSARY TO REPLACE THEM WITH AN ENTIRELY NEW CONNECTION.

AFTER THE CORRODED TERMINAL HAS BEEN CAREFULLY CLEANED, IT SHOULD BE WIPED WITH A CLOTH MOISTENED WITH AMMONIA OR A SOLUTION OF BAKING SODA AND WATER. THE CONNECTION SHOULD THEN BE THOROUGHLY TIGHTENED AND A COATING OF VASELINE SHOULD BE APPLIED TO IT.

"A STICH IN TIME, SAVES NINE"

IF A SIMPLE JOB AS THIS IS DONE IN TIME, IT WILL PREVENT THE FAILURE OF THE BATTERY, WHICH WAS BOUND TO COME SOONER OR LATER BECAUSE OF THIS DEVELOPING CONDITION.

THE BATTERY NEEDS WATER

A CAMEL CAN CONTINUE DOING ACTIVE WORK FOR A CONSIDERABLE TIME WITHOUT NEEDING A DRINK, HOWEVER, THE TIME COMES SOON WHEN HE TOO MUST HAVE A DRINK OF WATER IN ORDER TO KEEP GOING. WE HAVE A SIMILAR CONDITION PRESENT IN THE STORAGE BATTERY BECAUSE THIS UNIT DOESN'T REQUIRE AN ADDITION OF WATER EVERY DAY BUT YET THE TIME DOES COME WHEN WATER MUST BE ADDED TO EACH CELL.

THE CORRECT LEVEL OF THE ELECTROLYTE

IT IS ADVISABLE TO REMOVE THE VENT PLUGS FROM EACH CELL ABOUT EVERY

TWO WEEKS DURING THE WINTER MONTHS AND ABOUT EVERY WEEK DURING THE SUMMER MONTHS, SO THAT THE LEVEL OF THE ELECTROLYTE IN EACH OF THE CELLS CAN BE INSPECTED. THE LEVEL OF THE ELECTROLYTE SHOULD NEVER BE ALLOWED TO BECOME LOWER THAN A POINT ½" ABOVE THE TOP OF THE PLATES, AS SHOWN IN FIG. 2.

USE DISTILLED WATER

WHEN IT BECOMES NECESSARY TO RAISE THE LEVEL OF THE ELECTROLYTE IN A CELL, NOTHING SHOULD BE ADDED EXCEPT DISTILLED WATER. ANY OTHER WATER, ALTHOUGH IT MAY BE EXCELLENT DRINKING WATER, IS NOT SUITABLE FOR BATTERY PURPOSES BECAUSE IT CONTAINS MINERALS AND VEGETABLE MATTER WHICH WHEN BROUGHT IN CONTACT WITH THE ACID WITHIN THE CELL, WOULD PRODUCE VERY UNDESIRABLE EFFECTS. DISTILLED WATER DOES NOT CONTAIN ANY MINERALS OR PRODUCTS OF VEGETATION AND THEREFORE IT IS THE ONLY KIND OF WATER WHICH SHOULD BE USED IN A CELL, IF GOOD RESULTS ARE TO BE EXPECTED.

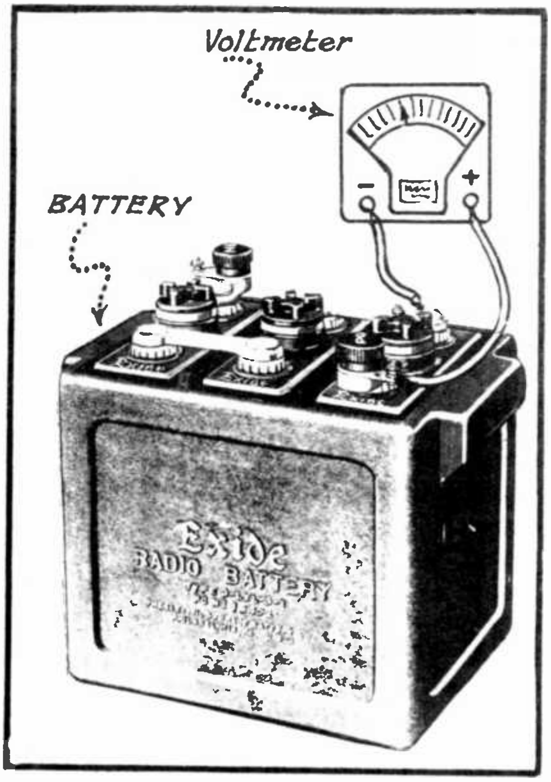

FIG. 7
Testing the Cell Voltage.

THE WATER EVAPORATES

PROBABLY YOU ARE THINKING THAT IF WE ONLY ADD PURE WATER, OUR ELECTROLYTE WILL GRADUALLY BECOME WEAKER AND WEAKER BUT YOU SEE, IT IS THE WATER OF THE ELECTROLYTE WHICH EVAPORATES AND NOT THE ACID. NOT ONLY DOES THE WATER EVAPORATE DUE TO ORDINARY CAUSES BUT WHILE THE BATTERY IS BEING CHARGED, THE CHEMICAL COMPOSITION OF THE WATER IS FREQUENTLY BROKEN UP INTO HYDROGEN GAS AND OXYGEN GAS, WHICH ARE REALLY THE TWO ELEMENTS OF WHICH WATER IS COMPOSED.

METHOD OF ADDING WATER TO THE CELLS

WHEN ADDING WATER, YOU MUST BE CAREFUL THAT THE WATER DOES NOT COME IN CONTACT WITH ANY METALLIC SUBSTANCES AND THIS CAN BE DONE VERY EASILY BY KEEPING THE WATER IN A GLASS CONTAINER AND SQUIRTING THE WATER INTO THE CELLS BY MEANS OF A RUBBER SYRINGE OR ELSE THE HYDROMETER SYRINGE, WHICH YOU SAW IN AN EARLIER LESSON.

TESTING THE SPECIFIC GRAVITY OF THE ELECTROLYTE

ABOUT EVERY TWO WEEKS, THE SPECIFIC GRAVITY OF THE ELECTROLYTE SHOULD BE CHECKED BY MEANS OF THE HYDROMETER AND SHOULD YOU FIND THE SPECIFIC GRAVITY TO HAVE FALLEN TO A READING OF 1.150, THEN IT BECOMES NECESSARY TO TAKE ACTIVE STEPS.

FIRST, OF COURSE, WE MUST DETERMINE WHETHER THIS LOW GRAVITY IS DUE MERELY BECAUSE THE BATTERY IS IN A DISCHARGED CONDITION OR WHETHER THE ELECTROLYTE ITSELF IS OUT OF PROPORTION. TO DETERMINE THIS, A VOLTMETER

SHOULD BE USED IN CONJUNCTION WITH THE HYDROMETER AND IF THE CELL VOLTAGES ARE PROPORTIONAL TO THE HYDROMETER READINGS, THEN IT IS JUST NECESSARY TO RECHARGE THE BATTERY. HOWEVER, IF THE CELL VOLTAGES ARE OUT OF PROPORTION TO THE HYDROMETER READINGS, THEN IT EVEN BECOMES NECESSARY TO RE-BALANCE THE ELECTROLYTE.

RELATIONS BETWEEN CELL VOLTAGE & SPECIFIC GRAVITY READINGS

TO ILLUSTRATE THIS POINT STILL CLEARER, LET US ASSUME THAT WHEN WE TEST THE SPECIFIC GRAVITY OF A CELL WITH A HYDROMETER, WE FIND THE GRAVITY TO BE 1.275. THEN WHEN WE TAKE A VOLTMETER AND TEST THE CELL VOLTAGE AS SHOWN IN FIG. 3, WE FIND IT TO BE 2.1 VOLTS. THIS RELATIONSHIP BETWEEN THE SPECIFIC GRAVITY READING AND VOLTMETER READING, WOULD TELL US THAT THE CELL IS IN A GOOD CHARGED CONDITION.

NEXT, LET US SUPPOSE THAT WE SHOULD TEST A CELL, FINDING ITS SPECIFIC GRAVITY TO BE 1.275 WHILE THE CELL VOLTAGE IS ONLY 1.9 VOLTS. THIS WOULD INDICATE THAT THE SPECIFIC GRAVITY OF THE CELL IS TOO HIGH FOR THE EXISTING VOLTAGE AND SUCH A CONDITION WOULD CALL FOR A RE-BALANCING OF THE ELECTROLYTE; AS WELL AS A RE-CHARGE.

SHOULD YOU FIND THE SPECIFIC GRAVITY TO BE ABOUT 1.200 WITH A CELL VOLTAGE OF 2.1 VOLTS, THEN THE SPECIFIC GRAVITY IS TOO LOW FOR THE EXISTING VOLTAGE AND THIS WOULD LIKEWISE REQUIRE A RE-BALANCING OF THE ELECTROLYTE. HOWEVER, IF THE SPECIFIC GRAVITY READINGS SHOULD BE 1.150 AND THE CELL VOLTAGES 1.75 VOLTS, THEN THE BATTERY SIMPLY REQUIRES A RECHARGE, WHICH WILL AGAIN BRING IT UP TO NORMAL.

CHECKING THE SPECIFIC GRAVITY BEFORE ADDING ANY WATER

WHEN CHECKING THE SPECIFIC GRAVITY OF A CELL, ALWAYS CHECK IT BEFORE YOU ADD ANY WATER TO REPLACE EVAPORATION. THE REASON FOR THIS IS THAT THE WATER WILL NOT IMMEDIATELY MIX THOROUGHLY WITH THE ACID AND YOU WOULD THEREFORE OBTAIN A LOWER HYDROMETER READING THAN WOULD ACTUALLY EXIST AFTER THE WATER AND ACID HAVE HAD A CHANCE TO MIX.

BATTERIES REQUIRING A RECHARGE

LET US ASSUME THAT BY MAKING THE HYDROMETER AND CELL VOLTAGE TESTS ON EACH OF THE CELLS, WE HAVE DETERMINED THAT THE BATTERY SIMPLY REQUIRES TO BE CHARGED. THAT IS, IT HAS BECOME RUN DOWN OR DISCHARGED SO THAT THE SPECIFIC GRAVITY READING OF EACH CELL IS LOW (APPROACHING THAT OF WATER) AND THE PLATES CONTAIN A GREAT DEAL OF SULPHATE.

HOWEVER, AS SOON AS THE CHEMICAL CHANGE WITHIN THE CELLS HAS REACHED A CERTAIN POINT, THE BATTERY IS NO LONGER EFFICIENT. IN FACT, IF WE SHOULD STILL FORCE THE BATTERY TO CONTINUE DISCHARGING UNTIL THE VOLTAGE OF EACH OF ITS CELLS DROPS BELOW 1.7 OR 1.5 VOLTS, AND ITS SPECIFIC GRAVITY BELOW 1.150, WE ARE PERMITTING SERIOUS TROUBLE TO DEVELOP WITHIN THE CELL.

REVERSED CHEMICAL ACTION

OUR NEXT STEP THEN IS TO CAUSE A CHEMICAL ACTION TO TAKE PLACE SO THAT

THE SULPHATE IS DRIVEN OUT OF THE PLATES AND INTO THE ELECTROLYTE AND IN THIS WAY RESTORE OUR BATTERY TO A CHARGED CONDITION SO THAT IT WILL AGAIN BE READY TO SUPPLY US WITH AN ELECTRICAL CURRENT. WE CALL THIS RESTORATION OR REJUVINATING ACTION "CHARGING THE BATTERY".

IN ORDER TO CHARGE THE BATTERY, IT IS NECESSARY TO DO JUST THE OPPOSITE TO WHAT TOOK PLACE DURING THE DISCHARGE OF THE BATTERY. THAT IS, WE MUST PASS AN ELECTRIC CURRENT THROUGH THE BATTERY IN A DIRECTION OPPOSITE TO THAT IN WHICH THE CURRENT FLOWED WHILE THE BATTERY WAS DISCHARGING. LET US NOW SEE HOW WE CAN ACCOMPLISH THIS.

A DIRECT CURRENT FOR CHARGING PURPOSES

FIRST, IT IS NECESSARY TO HAVE A DIRECT CURRENT AT OUR DISPOSAL AND THIS TYPE OF CURRENT, YOU WILL REMEMBER, ALWAYS TRAVELS IN ONE DIRECTION ONLY.

IN SOME LOCALITIES THIS TYPE OF CURRENT IS SUPPLIED TO THE VARIOUS BUILDINGS BY A CENTRAL POWER PLANT. IN SUCH A CASE, WE CAN USE THIS CURRENT FROM THE POWER LINES, HOWEVER, WE MUST TAKE CERTAIN CONDITIONS INTO CONSIDERATION.

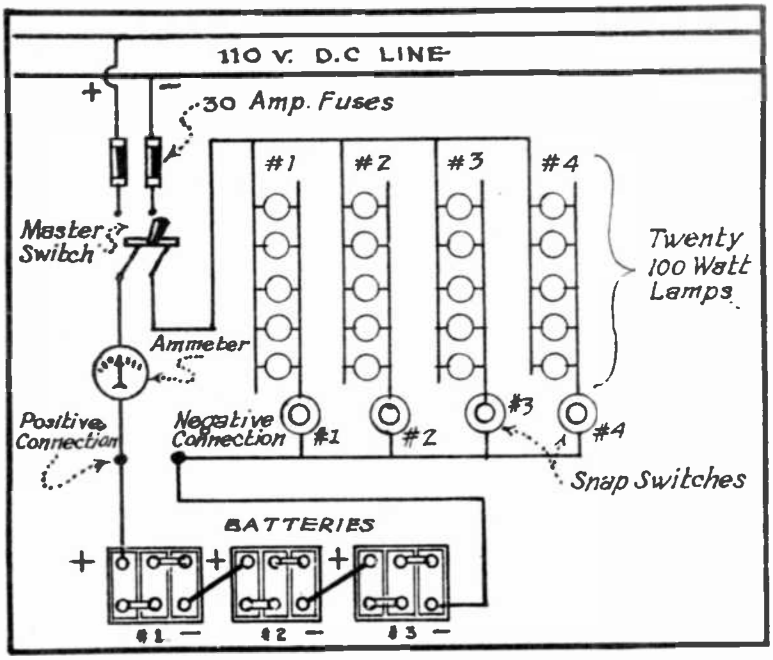

FIG. 4
Battery Charging When D.C. is Available.

IN FIG. 4 YOU WILL SEE HOW WE CAN GET A SUITABLE BATTERY CHARGING CURRENT BY THIS MEANS.

USING D.C. DIRECT FROM POWER LINES

HERE YOU WILL SEE THAT TWO WIRES LEAD FROM THE 110 V-D. C., LINE, THROUGH THE FUSES TO THE TERMINALS OF THE SINGLE THROW, DOUBLE POLE SWITCH. AS LONG AS THIS MASTER SWITCH IS OPEN, NO CURRENT WILL FLOW THROUGH THE BATTERIES.

NOW WHEN THE MASTER SWITCH IS CLOSED, CURRENT WILL FLOW FROM THE POSITIVE SIDE OF THE 110 V. LINE, THROUGH THE SWITCH, AMMETER AND TO THE POSITIVE CONNECTION. NEXT, OBSERVE THAT THREE BATTERIES HAPPEN TO BE CONNECTED IN SERIES. THAT IS, THE (-) TERMINAL OF ONE IS CONNECTED TO THE (+) TERMINAL OF THE NEXT AND SO ON. ALSO NOTICE THAT THE (+) TERMINAL OF BATTERY #1 IS CONNECTED TO THE POSITIVE CONNECTION OF THE LINE.

THE CHARGING CURRENT PASSES THROUGH THE BATTERIES

THE VOLTAGE OR PRESSURE OF THE LINE IS GREATER THAN THAT OF THE BATTERIES IN SERIES SO THAT THE CURRENT FROM THE LINE WILL BE FORCED INTO THE POSITIVE TERMINAL OF BATTERY #1, THROUGH ALL THE CELLS OF BATTERY #1 AND

IT LEAVES BATTERY #1 FROM THE (-) TERMINAL. SINCE THE NEGATIVE TERMINAL OF BATTERY #1 IS CONNECTED TO THE POSITIVE TERMINAL OF BATTERY #2 BY MEANS OF A WIRE, THE CURRENT WILL CONTINUE ON ITS JOURNEY THROUGH THIS WIRE, AND WILL THEN PASS THROUGH BATTERY #2, FROM THE POSITIVE TO NEGATIVE TERMINAL, JUST AS IT DID THROUGH BATTERY #1.

FROM BATTERY #2, THE CURRENT FLOWS THROUGH BATTERY #3 AND BECAUSE OF THE NEGATIVE TERMINAL OF BATTERY #3 BEING CONNECTED TO THE NEGATIVE CONNECTION OF THE LINE, THE CURRENT WILL FLOW TO THIS LATTER POINT.

SO FAR WE HAVE GOTTEN OUR DIRECT CURRENT TO PASS THROUGH THREE BATTERIES AT ONE TIME, IN THE PROPER DIRECTION SO THAT THE CHEMICAL ACTION WITHIN THE BATTERIES WILL BE REVERSED AND THE BATTERIES CHARGED. HOWEVER, WE STILL HAVE SOME IMPORTANT PROBLEMS TO CONFRONT BEFORE THIS CIRCUIT IS COMPLETE, SO LET US CONTINUE TRAILING OUR CURRENT FROM THE NEGATIVE CONNECTION OF THE LINE THROUGH THE BALANCE OF THE SYSTEM.

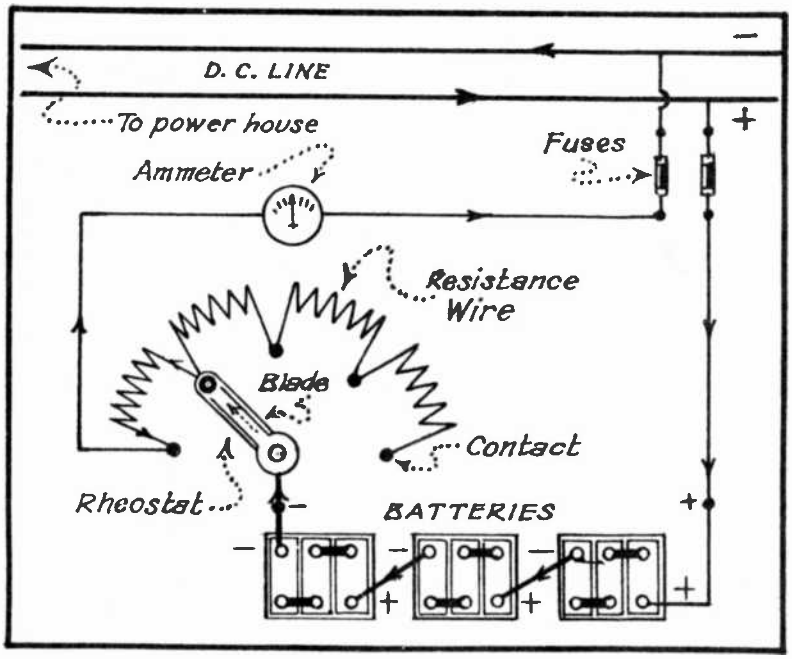

FIG. 5

Controlling the Charge With a Rheostat.

THE SNAP SWITCH

FOUR SNAP SWITCHES ARE CONNECTED TO THE WIRE LEADING FROM THIS NEGATIVE CONNECTION AND THEREFORE, THE CURRENT WILL CONTINUE ON ITS JOURNEY, FLOWING THRU WHICHEVER OF THESE SNAP SWITCHES HAPPENS TO BE CLOSED. LET US FIRST ASSUME THAT ONLY SWITCH #1 IS CLOSED, WHILE THE OTHER SNAP SWITCHES ARE OPEN. BECAUSE OF THIS CONDITION, THE CURRENT WILL ALL FLOW THROUGH SNAP SWITCH #1 AND THENCE IT WILL DIVIDE ITSELF BETWEEN THE FIVE LAMPS, WHICH ARE OF EQUAL RESISTANCE, AND THEN IT WILL FLOW THROUGH THE WIRE LEADING TO THE NEGATIVE SIDE OF THE MASTER SWITCH AND BACK TO THE NEGATIVE LINE OF THE 110 VOLT D.C. POWER LINE.

THIS, YOU WILL SEE, GIVES US A COMPLETE CIRCUIT THROUGH WHICH A DIRECT CURRENT WILL FLOW AND ALL DURING THIS FLOWING OF THE CURRENT, THE BATTERIES ARE GRADUALLY BEING CHARGED, DUE TO THE CURRENT BEING FORCED THROUGH THEM IN THE PROPER DIRECTION.

THE PURPOSE OF THE LAMPS

SO FAR WE HAVEN'T CONSIDERED WHAT THE TWENTY LAMPS ARE FOR, SO NOW LET US GET THIS POINT SETTLED. FIRST, IT IS NOT ONLY NECESSARY TO SEND A DIRECT CURRENT THROUGH THE BATTERIES IN ORDER TO CHARGE THEM BUT THE CHARGING CURRENT MUST BE CONTROLLED. GENERALLY SPEAKING, BATTERIES SHOULD BE charged at the rate of about ½ ampere per plate per cell. That is, an 11 plate battery should be charged at the rate of about 5.5 amperes for best results.

Now, any lamp offers a definite resistance to current flow and by connecting the lamps as in group #1, the current can divide itself among the five lamps. Then if each lamp offers sufficient resistance so that only about 1 ampere can flow through it, then 5 lamps, as connected in group #1, offer five of such paths and thereby makes the flow of current five times as easy. That is, only 1/5 of the resistance is encountered by the flowing current to that which is offered by only one lamp. Therefore, instead of 1 ampere flowing through this circuit, there will be 5 amperes.

Since all the current, which flows through the batteries must also pass through lamp group #1, this lamp group controls the current flow so that 110 Volts can only force about 5 amperes through the system.

AN ADJUSTMENT REQUIRED WHEN MORE BATTERIES ARE ADDED

Now if more batteries should be connected in series in order to be charged, they would offer still more resistance for the current flow, so that if we just left lamp group #1 burning, our charging rate would drop, so we can now ALSO close the circuit through lamp group #2 by turning on switch #2. This would again reduce the resistance through the lamps so that more current could flow through the batteries than with only the lamps of group #1 burning.

So you see, by watching the ammeter, we can regulate the number of lights, which are burning, and in this way control the rate at which our batteries are being charged.

CONTROLLING THE RATE OF CHARGE WITH A RHEOSTAT

In Fig. 5 still another way of controlling the current flow through a battery charging circuit, which is using direct current as supplied by a power company, is illustrated. In this case instead of controlling the charging current with a group of lamps, we use a device known as a RHEOSTAT. The rheostat consists of a group of wire coils, which are connected to contacts at certain intervals. A blade is rotated by the operator by means of a handle. The tip of this blade makes contact with one of the equally spaced contacts at a time, as the blade is rotated.

The farther that the blade is turned to the right, the more resistance wire will be added to the circuit so that the current flow will be retarded that much more. Hence by watching the ammeter, the rheostat can be set so that the proper amount of current will be flowing through the charging batteries. The current in this case, will flow in the direction of the arrows.

SOME POWER HOUSES SUPPLY ALTERNATING CURRENT

Now suppose that the power house in your vicinity doesn't furnish direct current but supplies ALTERNATING CURRENT instead. This is really

THE CASE IN MOST PLACES AT THE PRESENT TIME, SO WE MUST HAVE SOME MEANS OF OBTAINING A DIRECT CURRENT FOR BATTERY CHARGING.

THE REASON WHY ALTERNATING CURRENT WILL NOT CHARGE A BATTERY

THE TROUBLE WITH ALTERNATING CURRENT IS THIS: IT FLOWS FIRST IN ONE DIRECTION AND THEN SIMPLY TURNS AROUND AND REVERSES ITSELF SO THAT IT FLOWS IN THE OPPOSITE DIRECTION. IF WE SHOULD TRY TO USE THIS KIND OF A CURRENT FOR BATTERY CHARGING, WE WOULD FIND THAT DURING THE INSTANT THE CURRENT WAS FLOWING IN ONE DIRECTION, IT WOULD PROVIDE A CHARGING CURRENT ALRIGHT, BUT AS SOON AS IT TURNS AROUND AND FLOWS THE OPPOSITE WAY, IT WOULD DISCHARGE THE BATTERY. CONSEQUENTLY, SINCE IT FLOWS BACK AND FORTH ABOUT 60 TIMES EVERY SECOND, WE COULD NOT USE IT FOR BATTERY CHARGING AS IT IS, BECAUSE WE NEED A CURRENT WHICH ONLY FLOWS IN ONE DIRECTION ALL THE TIME.

THE RECTIFIER

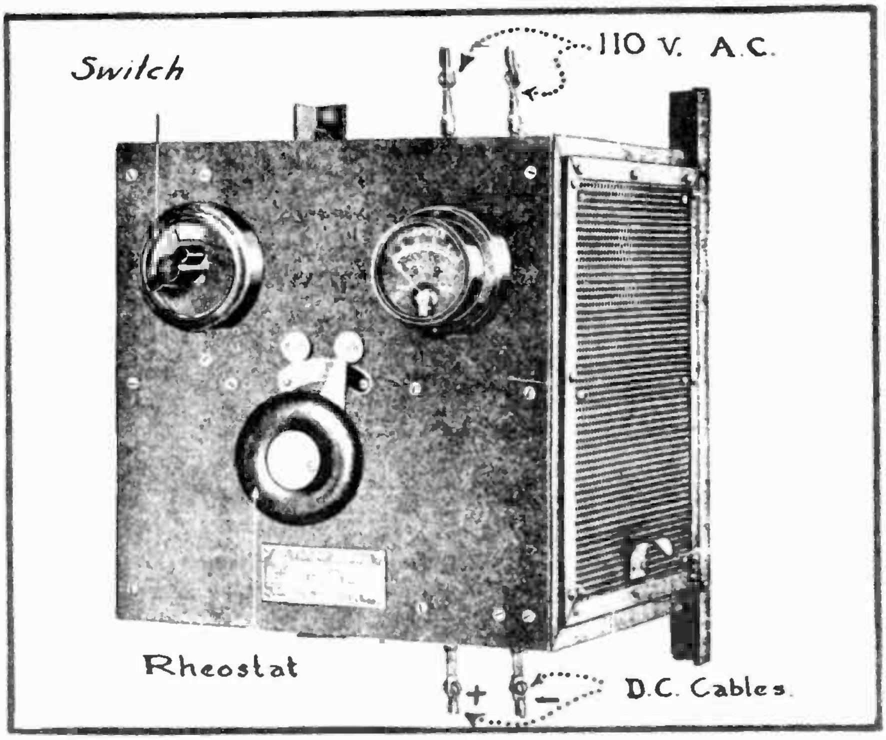

FIG. 6
A Typical Tungar Rectifier.

WE MUST GET AROUND THIS CONDITION SOMEHOW, SO WE USE A UNIT, WHICH IS KNOWN AS A RECITIFIER, AND SOMETIMES WE JUST CALL IT A BATTERY CHARGER.

THERE ARE VARIOUS TYPES OF RECTIFIERS, BUT THEY ALL SERVE THE SAME PURPOSE WHICH IS TO MAKE USE OF THE SUPPLIED ALTERNATING CURRENT IN SUCH A WAY THAT A DIRECT CURRENT CAN BE PRODUCED WITH WHICH TO CHARGE THE BATTERIES.

THE TUNGAR RECTIFIER

IN FIG. 6 YOU WILL SEE A CHARGER WHICH IS CAPABLE OF CHARGING TEN BATTERIES AT ONE TIME AND IT IS KNOWN AS THE TUNGAR RECTIFIER.

THE TWO LEADS, WHICH PROTRUDE FROM THE TOP OF THE CHARGER, ARE CONNECTED TO THE ALTERNATING CURRENT LINE AND THE TWO LEADS, WHICH PROTRUDE FROM THE BOTTOM OF THE CHARGER, OFFER THE CONNECTION TO WHICH THE BATTERIES ARE CONNECTED. IN FIG. 7 YOU WILL SEE WHAT THE INSIDE OF THIS SAME CHARGER LOOKS LIKE.

THE TUNGAR RECTIFIER AT WORK

ALTHOUGH THIS RECTIFIER CHARGES TEN BATTERIES AT THE SAME TIME, IT CAN ALSO BE CONNECTED SO THAT IT WILL CHARGE A FEWER NUMBER. FIG. 8 SHOWS HOW THIS CHARGER IS CONNECTED WHEN CHARGING ONLY SIX BATTERIES. NOTICE THAT ALL OF THE BATTERIES ARE CONNECTED IN SERIES AND THE POSITIVE TERMINAL OF ONE OF THE END BATTERIES IS CONNECTED TO THE POSITIVE TERMINAL OF THE RECTIFIER, WHEREAS THE NEGATIVE TERMINAL OF THE OTHER END BATTERY IS CONNECTED TO THE NEGATIVE TERMINAL OF THE RECTIFIER.

YOU MUST REMEMBER, HOWEVER, NOT TO CONNECT MORE BATTERIES TO A CHARGING CIRCUIT, THAN THE CHARGER IS CAPABLE OF HANDLING. ALL RECTIFIERS ARE PROVIDED WITH A NAME PLATE, WHICH STATES THE LOAD FOR WHICH THE PARTICULAR RECTIFIER WAS DESIGNED.

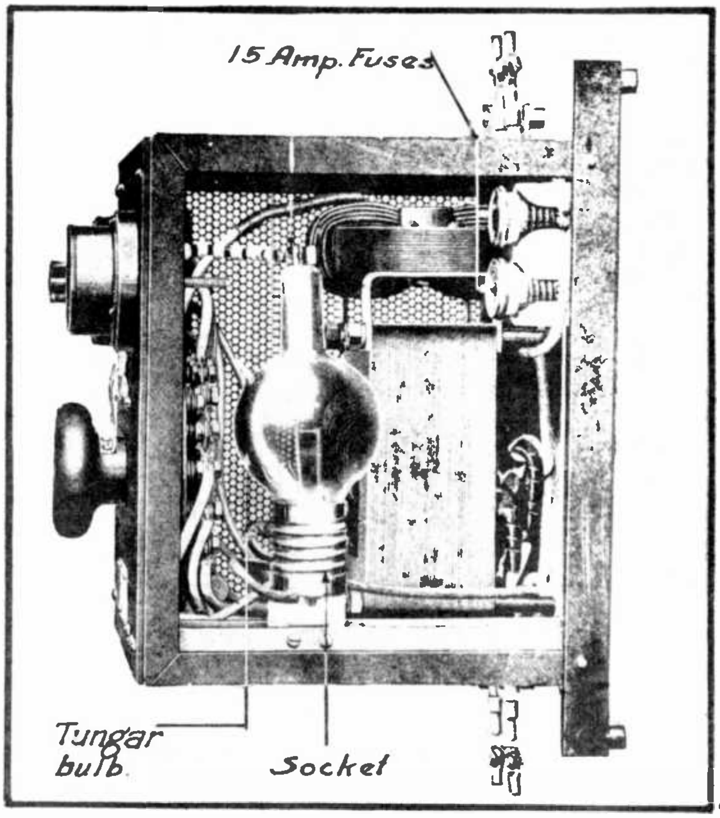

FIG. 7

Inside of the Same Tungar Rectifier.

OPERATING THE TUNGAR SET

WITH OUR BATTERIES CONNECTED AS SHOWN IN FIG. 8, THE FIRST THING THAT WE DO IS TO REMOVE THE VENT PLUGS AND ALSO SEE THAT THE HANDLE OF THE RHEOSTAT IS TURNED TO THE POSITION OFFERING THE MAXIMUM AMOUNT OF RESISTANCE SO THAT PRACTICALLY NO CURRENT CAN FLOW. THE SWITCH OF THE RECTIFIER IS THEN TURNED ON AND AS SOON AS THE BULB INSIDE OF THE RECTIFIER BECOMES ILLUMINATED, THEN THE RHEOSTAT HANDLE SHOULD GRADUALLY BE TURNED UNTIL THE AMMETER NEEDLE COMES UP TO 5 OR 6 AMPERES.

SOME OF THESE BULB RECTIFIERS DO NOT HAVE A SEPARATE SNAP SWITCH AND THE CIRCUIT IS AUTOMATICALLY OPEN CIRCUITED WHEN THE RHEOSTAT IS IN THE "OFF" POSITION.

ALTHOUGH AN ALTERNATING CURRENT IS FLOWING FROM THE POWER LINES THRU THE RECTIFIER, YET A PULSATING DIRECT CURRENT IS FLOWING THROUGH THE BATTERIES, AS INDICATED BY THE ARROWS IN FIG. 8.

SUFFICIENT WATER IN BATTERIES WHILE ON CHARGE

DURING THE PROCESS OF CHARGING, IT IS NECESSARY TO SEE THAT THE CELLS ARE ALL SUPPLIED WITH THE REQUIRED AMOUNT OF DISTILLED WATER SO THAT THE PLATES WILL BE COVERED. THE BATTERIES CAN NOW BE LEFT ALONE, WHILE THEY ARE GRADUALLY BEING CHARGED, HOWEVER, THE SYSTEM SHOULD BE INSPECTED OCCASIONALLY TO BE SURE THAT THE CURRENT FLOW IS CORRECT AND THAT THE BATTERIES ARE NOT IN NEED OF WATER.

THE LENGTH OF TIME REQUIRED FOR A CHARGE

NOW THE QUESTION PROBABLY ARISES IN YOUR MIND AS TO HOW LONG THE BATTERIES WILL HAVE TO BE CHARGED UNTIL THEY REACH A FULLY CHARGED CONDITION. THIS, OF COURSE, DEPENDS UPON THE TYPE OF CHARGER USED, AS WELL AS THE CONDITION OF THE BATTERIES THEMSELVES. HOWEVER, THE CHARGER SHOWN IN FIGS. 6 AND 7 WILL CHARGE THE AVERAGE BATTERY IN ABOUT 24 HOURS. THERE ARE ALSO SOME TUNGAR SETS WHICH WILL CHARGE THE AVERAGE BATTERY IN ABOUT 12 TO 16 HOURS BUT IN THIS CASE, TWICE THE CHARGING RATE OF THE SMALLER CHARGER IS USED.

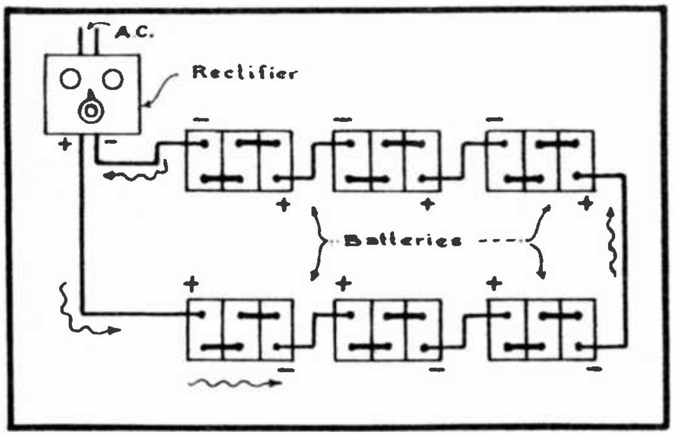

FIG. 8
Tungar Rectifier Charging 6 Batteries

AS WE GO ALONG, YOU WILL SEE THAT SOME CHARGERS WILL EVEN COMPLETELY CHARGE THE AVERAGE BATTERY IN A STILL SHORTER TIME.

WE DON'T FIGURE THE EXTENT OF CHARGE ACCORDING TO TIME

THESE FIGURES WILL GIVE YOU SOMEWHAT OF AN IDEA AS TO HOW LONG A TUNGAR RECTIFIER WILL TAKE TO CHARGE THE AVERAGE BATTERY BUT SINCE THE CONDITION OF ALL THE VARIOUS BATTERIES VARY MORE OR LESS, WE DO NOT JUDGE THEIR CONDITION OF CHARGE ACCORDING TO TIME. INSTEAD OF SUCH A METHOD, WE DETERMINE EACH INDIVIDUAL BATTERY'S CONDITION BY MEANS OF TESTS.

WHEN IS A BATTERY CHARGED?

LET US SUPPOSE, FOR EXAMPLE, THAT OUR BATTERY HAS BEEN CHARGING FOR ABOUT 10 HOURS. WE WILL TAKE OUR HYDROMETER AND TEST THE ELECTROLYTE OF EACH CELL AND THEN WE WILL MAKE A VOLTMETER TEST ON EACH CELL. IF THE SPECIFIC GRAVITY HASN'T COME UP TO 1.280 OR 1.300 AND THE CELL VOLTAGES HAVEN'T COME UP TO ABOUT 2.5 VOLTS WHILE THE CHARGER IS STILL OPERATING, WE WILL PERMIT THE BATTERY TO CONTINUE TO CHARGE.

YOU WILL FIND THAT AS A GENERAL RULE, THE BATTERY'S CHARGE WILL INCREASE FASTER DURING THE BEGINNING OF THE CHARGE THAN IT WILL NEAR THE END OF THE CHARGE.

GASSING OF CELLS

YOU WILL ALSO FIND THAT AT THE END OF THE CHARGE, BUBBLES WILL RISE

IN THE ELECTROLYTE, JUST AS IF THE CELL WERE BOILING. THIS IS DUE TO THE FACT THAT THE SULPHATE HAS PRACTICALLY ALL BEEN DRIVEN OUT OF THE PLATES AND COMBINED WITH THE WATER BUT SINCE NO ADDITIONAL SULPHATE WILL COMBINE WITH THE WATER, THE ELECTRIC CURRENT OF THE CHARGER WILL DECOMPOSE THE WATER INTO THE TWO GASES, HYDROGEN AND OXYGEN. THESE GASES THEN RISE TO THE SURFACE IN THE FORM OF BUBBLES AND WE CALL THIS ACTION GASSING.

YOU MUST BE VERY CAREFUL NOT TO GET ANY FLAME NEAR SUCH A GASSING CELL, AS HYDROGEN WHEN IGNITED, WILL CAUSE A MINIATURE EXPLOSION, WHICH MIGHT EVEN BLOW OFF THE TOP OF THE BATTERY.

SOMETIMES BUBBLES WILL ALSO BE CAUSED BY TOO HIGH A CHARGING RATE. AT ANY RATE, DON'T ALLOW GASSING TO CONTINUE BECAUSE IT IS JUST A WASTE OF CURRENT, A WASTE OF WATER, AND AT THE SAME TIME, IT IS INJURIOUS TO THE BATTERY IN GENERAL.

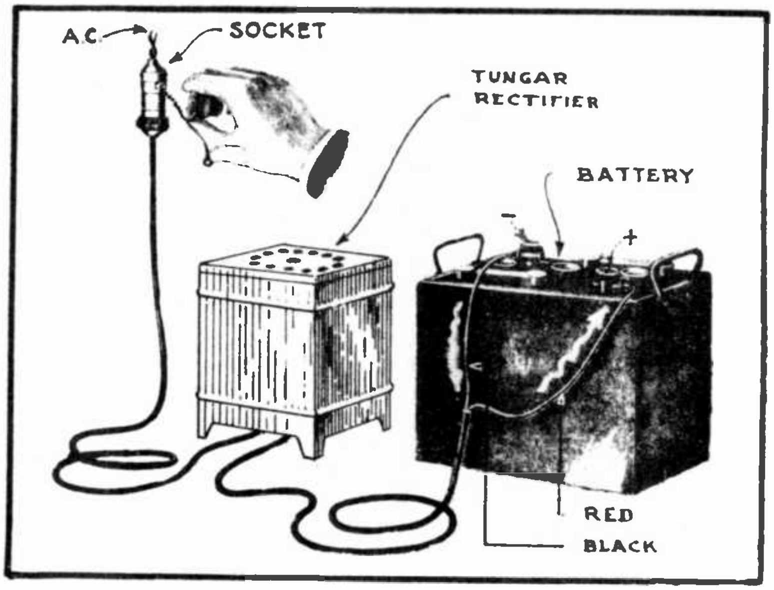

FIG. 9

Tungar Set for Home Use

THE FULLY CHARGED BATTERY

SO YOU SEE, JUST KEEP THE BATTERY CHARGING UNTIL ALL THE CELL VOLTAGES COME UP TO ABOUT 2.5 VOLTS WHILE STILL ON THE LINE AND THE SPECIFIC GRAVITY TO ABOUT 1.280 OR 1.300. WHEN THIS CONDITION IS REACHED, THE BATTERY IS FULLY CHARGED AND READY TO BE TAKEN FROM THE CHARGING LINE. AFTER IT IS REMOVED FROM THE LINE, YOU WILL FIND THE CELL VOLTAGES TO DROP TO 2.2 VOLTS.

BALANCING AN ELECTROLYTE, WHOSE GRAVITY IS TOO LOW

AT TIMES, YOU WILL FIND THAT THE CELL VOLTAGES WILL COME UP TO PAR BUT THE SPECIFIC GRAVITY IS STILL LOW OR VICE VERSA. IF THIS IS THE CASE, ALLOW THE BATTERY TO CONTINUE CHARGING UNTIL NEITHER THE CELL VOLTAGES NOR THE SPECIFIC GRAVITY WILL RISE HIGHER. THEN IF YOU SHOULD FIND THAT THE CELL VOLTAGES WILL COME UP TO THEIR REQUIRED POINT BUT THE SPECIFIC GRAVITY IS TOO LOW, WITHDRAW SOME OF THE ELECTROLYTE FROM THE LOW GRAVITY CELL OR CELLS BY MEANS OF A SYRINGE. GENERALLY, IT IS ADVISABLE TO WITHDRAW ENOUGH OF THE ELECTROLYTE SO THAT THE LEVEL WILL DROP TO THE TOP OF THE SEPERATORS. NOW YOUR NEXT STEP IS TO REPLACE THIS REMOVED ELECTROLYTE WITH AN EQUAL AMOUNT OF SULPHURIC ACID, WHICH HAS A SPECIFIC GRAVITY OF 1.400 (THIS IS THE STRENGTH OF ACID THE BATTERY MAN BUYS.) HAVING REPLACED THE AMOUNT OF ELECTROLYTE YOU HAVE WITHDRAWN, WITH AN EQUAL AMOUNT OF 1.400 SULPHURIC ACID, ALLOW THE BATTERY TO CONTINUE CHARGING FOR ANOTHER HOUR.

THIS HOUR'S CHARGE WILL PERMIT THE ADDED SULPHURIC ACID TO MIX THOR

OUGHLY WITH THE REST OF THE ELECTROLYTE WHICH WAS ALREADY IN THE CELL. AFTER THIS HOUR OF CHARGING, TEST THE ELECTROLYTE AGAIN AND IF THE SPECIFIC GRAVITY IS STILL TOO LOW, REPEAT THE ADDITION OF 1.400 ACID IN THE SAME CAREFUL MANNER AS WAS JUST SHOWN YOU. THEN AFTER ANOTHER HOUR'S CHARGE, TEST THE ELECTROLYTE AGAIN AND YOU JUST CONTINUE BALANCING THE ELECTROLYTE IN THIS WAY UNTIL THE HYDROMETER READING COMES UP TO 1.280 OR 1.300 WHEN THE CELL VOLTAGES ARE 2.5 VOLTS (WHILE ON THE LINE).

BALANCING AN ELECTROLYTE, WHOSE SPECIFIC GRAVITY IS TOO HIGH

SHOULD YOU, HOWEVER, FIND THAT THE SPECIFIC GRAVITY OF THE ELECTROLYTE IS TOO HIGH, AFTER THE CHARGING LIMIT HAS BEEN REACHED, THEN DRAW OFF SUFFICIENT ELECTROLYTE SO THAT ITS LEVEL WILL BE JUST EVEN WITH THE TOPS OF THE SEPARATORS. REPLACE THIS WITHDRAWN ELECTROLYTE WITH AN EQUAL VOLUME OF DISTILLED WATER. CONTINUE CHARGING FOR ANOTHER HOUR AND TEST THE ELECTROLYTE AGAIN AND IF YOU STILL FIND THE READING TOO HIGH, DILUTE IT ONCE MORE IN THE SAME CAREFUL MANNER. BY BALANCING THE ELECTROLYTE GRADUALLY IN THIS WAY, YOU WILL OBTAIN MUCH MORE ACCURATE RESULTS, THAN BY JUST HAPHAZARDLY GUESSING AT THE REQUIRED AMOUNTS OF ACID OR WATER TO ADD.

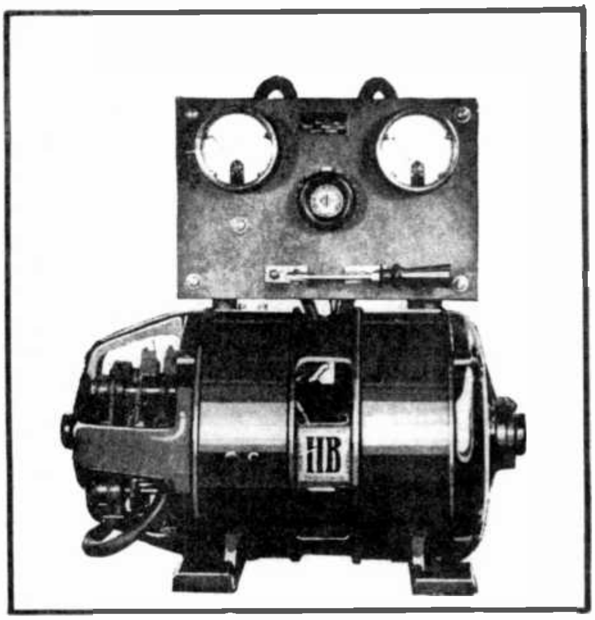

FIG. 10

A Typical Motor-Generator Set for Battery Charging.

REMOVING THE CHARGED BATTERY FROM THE LINE

AFTER THE BATTERY IS FULLY CHARGED, SO THAT THE VOLTAGE IS UP AND THE SPECIFIC GRAVITY OF THE ELECTROLYTE IS CORRECT, TURN BACK THE RHEOSTAT SO THAT NO CURRENT FLOWS AND SNAP OFF THE SWITCH OF THE RECTIFIER.

NOW REMOVE THE BATTERY FROM THE LINE AND SEE TO IT THAT THE WATER LEVEL IS CORRECT IN EACH CELL. REPLACE THE VENT PLUGS, WASH OFF THE OUTSIDE OF THE BATTERY WITH A SOLUTION OF WATER AND SODA OR AMMONIA, AND THE BATTERY IS NOW READY TO GO BACK INTO ACTIVE SERVICE.

THE TUNGAR SET FOR HOME USE

IN FIG. 9 YOU WILL SEE A SMALL TUNGAR BULB RECTIFIER, WHICH CAN BE ADVANTAGEOUSLY USED AROUND A HOME TO CHARGE ONE BATTERY AT A TIME. IN THIS WAY, A MOTORIST CAN RECHARGE HIS AUTOMOBILE BATTERY; THE RADIO FAN, HIS RADIO BATTERY, ETC.

THE RED WIRE OF THIS CHARGER IS CONNECTED TO THE POSITIVE TERMINAL OF THE BATTERY AND THE BLACK WIRE IS CONNECTED TO THE NEGATIVE TERMINAL OF THE BATTERY. BY TURNING ON THE CHARGER, ALTERNATING CURRENT IS USED IN THE PROPER MANNER SO THAT A DIRECT CURRENT WILL CHARGE THE BATTERY. THE CHARGING CURRENT WILL FLOW IN THE DIRECTION AS INDICATED BY THE ARROWS.

THE MOTOR GENERATOR SET

SO FAR, WE HAVE ONLY CONSIDERED THE SLOW METHOD OF CHARGING BATTERIES, BUT IN FIG. 10 YOU WILL SEE A MOTOR-GENERATOR CHARGING SET, WHICH WILL CHARGE THE BATTERIES MUCH QUICKER THAN THE TUNGAR RECTIFIER.

THE MOTOR-GENERATOR SET OR M.G. SET, AS THE ELECTRICAL MAN CALLS IT, CONSISTS OF AN ELECTRIC MOTOR, WHICH IS OPERATED BY MEANS OF ALTERNATING CURRENT, SUCH AS SUPPLIED BY THE POWER COMPANY. THIS ELECTRIC MOTOR IS COUPLED DIRECTLY TO A DIRECT CURRENT GENERATOR SO THAT AS THE A.C. (ALTERNATING CURRENT) MOTOR IS CAUSED TO ROTATE BY A.C. CURRENT, IT WILL OPERATE THE D.C. GENERATOR, WHICH IN TURN WILL SUPPLY THE BATTERIES WITH A DIRECT CURRENT.

IN OTHER WORDS, ALL THE A.C. MOTOR DOES IS TO OPERATE THE D.C. GENERATOR AND THE GENERATOR ACTUALLY SUPPLIES THE BATTERIES WITH THE CHARGING CURRENT.

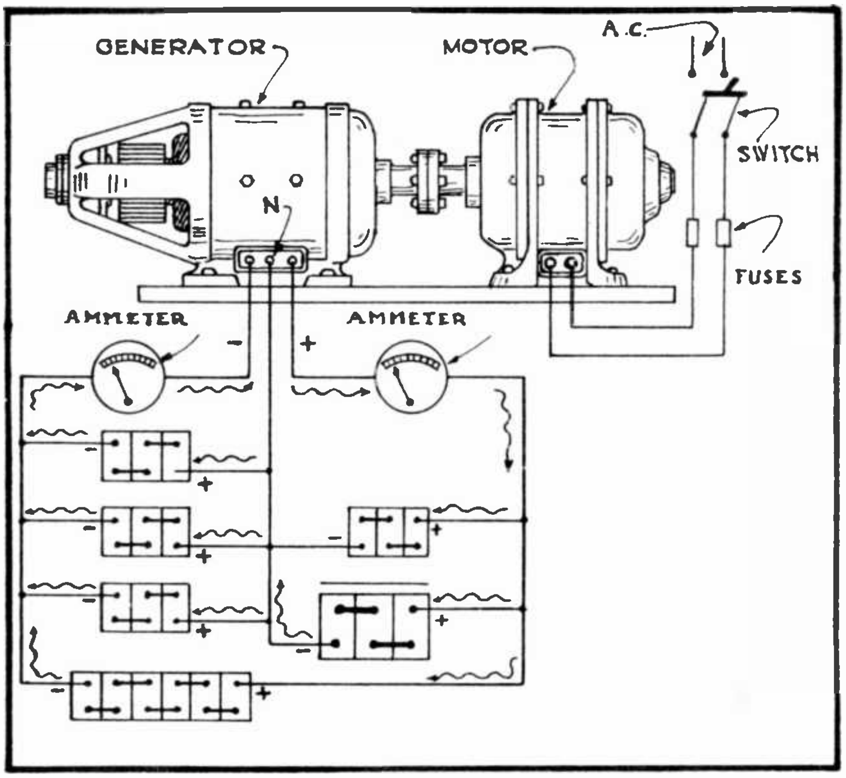

FIG. 11
The Charging Circuit of an M. G. Set.

CHARGING BATTERIES WITH M.G. SET

IN FIG. 11 YOU WILL SEE HOW SIX DIFFERENT BATTERIES ARE ALL CONNECTED TO THIS M.G. SET AT ONE TIME. NOTICE THAT ONE WIRE, WHICH COMES FROM THE GENERATOR, IS POSITIVE (+), ANOTHER IS NEGATIVE (-) AND THE CENTER ONE IS NEUTRAL (N). INSTEAD OF THESE CONDUCTORS BEING FLEXIBLE WIRE, YOU WILL GENERALLY FIND THEM TO BE RIGID COPPER RODS ABOUT 3/4" IN DIAMETER AND WE CALL THEM BUSS BARS.

OBSERVE CAREFULLY THAT THE A.C. LINES HAVE NO ELECTRICAL CONNECTION WHATEVER WITH THE BATTERY CHARGING CIRCUIT. THEY JUST SUPPLY THE MOTOR WITH CURRENT AND THAT IS ALL.

TRACING THE CHARGING CURRENT

WHEN THE SET IS IN OPERATION, THE CHARGING CURRENT WILL FLOW FROM THE (+) TERMINAL OF THE GENERATOR, THROUGH THE RIGHT HAND AMMETER AND THEN IT DIVIDES ITSELF BETWEEN THE DIFFERENT BATTERIES, RETURNING TO THE GENERATOR THROUGH THE NEGATIVE (-) TERMINAL. THE NEUTRAL (N) BUSS BAR CAN EITHER BE POSITIVE OR NEGATIVE, DEPENDING UPON THE EXISTING CONDITIONS.

BATTERIES ARE CHARGED ACCORDING TO THEIR OWN RESISTANCE

SINCE YOU ALREADY KNOW THAT THE LESS RESISTANCE WHICH A CIRCUIT OFFERS, THE MORE CURRENT WILL FLOW THROUGH IT, IT IS OBVIOUS THAT THE CURRENT WILL DIVIDE BETWEEN THE DIFFERENT BATTERIES IN PROPORTION TO THE RESISTANCE WHICH EACH OFFERS.

THE VOLTAGE OF THE M.G. SET IS KEPT CONSTANT

THE VOLTAGE OF THIS CHARGING OUTFIT IS KEPT CONSTANT, BEING 15 VOLTS ACROSS THE OUTER (+) AND (-) BUSS BARS AND 7½ VOLTS BETWEEN EITHER OF THESE BUSS BARS AND THE NEUTRAL (N) BUSS BAR. SO IF THE RESISTANCE OF THE DIFFERENT BATTERIES VARY DUE TO SIZE, CONDITION, ETC., IT IS EVIDENT THAT MOST OF THE CURRENT WILL FLOW THROUGH THE BATTERIES, WHICH HAVE THE LOWEST RESISTANCE. THEREFORE, IT IS LIKEWISE TRUE THAT A DISCHARGED BATTERY WILL TAKE A HIGHER CHARGING RATE THAN A FULLY CHARGED BATTERY BECAUSE A DISCHARGED BATTERY OFFERS LESS RESISTANCE OR OPPOSING VOLTAGE TO THE CHARGING CURRENT.

EACH BATTERY CONTROLS ITS OWN CHARGING RATE

SINCE THE CHARGING RATE OF EACH BATTERY IS REDUCED AS THE STATE OF CHARGE OF THE BATTERY IS INCREASED, YOU CAN SEE THAT THE BATTERY ITSELF WILL CONTROL ITS OWN CHARGING RATE, PROVIDED THAT THE VOLTAGE OF THE CHARGING CIRCUIT IS KEPT CONSTANT.

BECAUSE OF THE COMPARATIVELY HIGH RATE OF CHARGE, WHICH IS FORCED THROUGH THE CHARGING BATTERY, IT IS POSSIBLE TO CHARGE AN AVERAGE BATTERY IN ABOUT 8 HOURS. THIS METHOD OF CHARGING IS OFTEN SPOKEN OF AS THE 8 HOUR CHARGE, CONSTANT-POTENTIAL CHARGING, AND PARALLEL CHARGING.

ALTHOUGH THERE ARE STILL OTHER TYPES OF CHARGERS, YET THOSE DISCUSSED IN THIS LESSON ARE THE ONES WHICH ARE MOST COMMONLY USED.

ADDITIONAL INFORMATION

SO FAR, WE HAVE DISCUSSED ONLY CASES WHERE THE BATTERY WAS IN A NORMAL CONDITION AND DISCHARGED. CONSEQUENTLY EVERYTHING WENT ALONG SMOOTHLY, BUT THIS CONDITION IS MORE OR LESS IDEALISTIC.

IN ACTUAL PRACTICE, THE BATTERY BUSINESS OFFERS A NUMBER OF PROBLEMS, WHICH MUST BE DEALT WITH INTELLIGENTLY. SO IN THE NEXT LESSON, WE WILL GO INTO THE SERVICING OF THE MANY OF THE SERIOUS BATTERY TROUBLES, AS WELL AS TO SHOW YOU MANY HELPFUL TRICKS IN DEALING WITH BATTERIES, WHICH DO NOT RESPOND TO THE ACTIONS OF THE CHARGER AS EAGERLY AS THEY DO UNDER NORMAL CONDITIONS.

AFTER YOU HAVE ANSWERED THE EXAMINATION QUESTIONS, WHICH HAVE BEEN PREPARED FOR YOU IN THIS LESSON, WE WILL CONTINUE IN THE NEXT LESSON, BY SOLVING MANY OF THE BATTERY TROUBLES, WHICH ARE BROUGHT TO THE EXPERT TO BE CORRECTED.

THE EDISON STORAGE BATTERY

UP TO THIS TIME, THE ONLY STORAGE BATTERY WITH WHICH WE DEALT, WAS THE LEAD-ACID TYPE. HOWEVER, IN ADDITION TO THIS UNIT, ANOTHER FORM OF STORAGE BATTERY IS BEING MANUFACTURED AND IS KNOWN AS THE EDISON STORAGE BATTERY. A CUT-AWAY ILLUSTRATION OF ONE EDISON STORAGE CELL IS SHOWN YOU IN FIG. 12.

THE POSITIVE PLATES IN THIS CELL CONSIST OF CYLINDRICAL TUBES OF NICKLEPLATED, PERFORATED, SPIRALLY SEAMED THIN STEEL RIBBON, FILLED WITH ALTERNATE LAYERS OF A SPECIALLY PREPARED NICKEL HYDRATE AND FLAKES OF PURE METALLIC NICKLE; THE FORMER BEING THE INITIAL STATE OF THE POSITIVE ACTIVE MATERIAL, WHILE THE LATTER IS THE CONDUCTIVE MEDIUM.

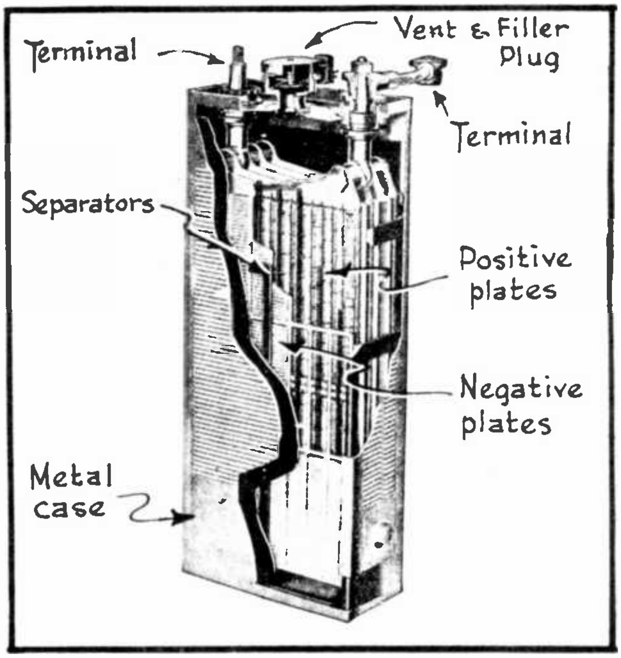

FIG. 12
The Edison Storage Cell.

THE NEGATIVE PLATES CONSIST OF RECTANGULAR POCKETS OF NICKLE PLATED, PERFORATED STEEL RIBBON FILLED WITH A SOLID MASS OF SPECIALLY PREPARED ELECTRO-CHEMICALLY ACTIVE IRON OXIDE AND A SMALL AMOUNT OF MERCURY OXIDE EVENLY DISTRIBUTED; THE FORMER BEING THE INITIAL STATE OF THE ACTIVE MATERIAL WHILE THE LATTER SERVES AS THE CONDUCTING MEDIUM.

THE ELECTROLYTE IS AN ALKALINE SOLUTION CONSISTING OF SPECIALLY PREPARED POTASSUIM AND LITHIUM HYDROXIDE IN DISTILLED WATER.

THE AVERAGE VOLTAGE PRODUCED BY THE EDISON STORAGE CELL IS 1.2 VOLTS AND TO INCREASE, THE VOLTAGE, CELLS CAN BE CONNECTED IN SERIES.

THE CHIEF ADVANTAGES OF THE EDISON STORAGE OVER THE LEAD-ACID CELL ARE ITS LIGHT WEIGHT, ENDURANCE, RELIABILITY AND RUGGEDNESS. HOWEVER, ITS INITIAL COST IS GREATER THAN THAT OF THE LEAD-ACID TYPE STORAGE BATTERY.

THE EDISON BATTERY, WHEN DISCHARGED, CAN OF COURSE BE RECHARGED IN THE SAME MANNER AS ALREADY DESCRIBED RELATIVE TO THE LEAD-ACID TYPE STORAGE BATTERIES. DISTILLED WATER SHOULD BE USED TO REPLACE EVAPORATION.

DIRECTION OF CURRENT FLOW IN BATTERY CHARGING

EARLY IN THIS COURSE YOU WERE INFORMED THAT IT IS NOW THE OPINION OF MOST SCIENTISTS, PHYSICISTS, AND OTHER AUTHORITIES THAT AN ELECTRON OR CURRENT FLOW ALWAYS MOVES THROUGH A CIRCUIT IN A NEGATIVE-TO-POSITIVE DIRECTION. HOWEVER, IN SOME APPLICATIONS OF INDUSTRIAL ELECTRICITY (PARTICULARLY BATTERY CHARGING) THE OLD POSITIVE-TO-NEGATIVE THEORY OF CURRENT FLOW IS STILL USED BY MANY ELECTRICIANS AND MANUFACTURERS OF ELECTRICAL MACHINERY.

BECAUSE WE WANT YOU TO BECOME USED TO READING DIAGRAMS WHICH EMPLOY EITHER OF THESE TWO OPPOSITE THEORIES OF CURRENT FLOW, SO THAT YOU WILL NOT BE AT A LOSS SHOULD YOU, AT SOME FUTURE TIME, HAVE TO DEAL WITH PERSONS, DIAGRAMS, OR LITERATURE WHICH RETAIN THE OLD POSITIVE-TO-NEGATIVE CONCEPTION, WE HAVE USED THIS THEORY IN OUR DISCUSSION ON BATTERY CHARGING. DO NOT LET THIS CONFUSE OR "BOTHER" YOU.

EXAMINATION QUESTIONS

LESSON NO. 33

1. - WHY IS IT SO IMPORTANT TO KEEP THE OUTSIDE OF THE BATTERY CLEAN?

2. - HOW WOULD YOU TAKE CARE OF A CORRODED BATTERY TERMINAL?

3. - HOW CAN YOU TELL WHEN A CELL REQUIRES WATER? WHAT KIND OF WATER WOULD YOU USE AND HOW WOULD YOU ADD IT TO THE CELL?

4. - WHAT TESTS WOULD YOU MAKE TO DETERMINE THE STATE OF CHARGE OF EACH OF THE CELLS IN A LEAD-ACID STORAGE BATTERY?

5. - BRIEFLY DESCRIBE ONE WAY HOW YOU CAN CHARGE BATTERIES WITH D.C. WHEN IT IS SUPPLIED BY THE POWER LINES.

6. - WHY ARE RECTIFIERS USED FOR BATTERY CHARGING?

7. - HOW CAN YOU TELL WHEN A STORAGE BATTERY HAS FINISHED ITS CHARGE ON THE LINE?

8. - WHEN DOES IT BECOME NECESSARY TO BALANCE THE ELECTROLYTE? HOW WOULD YOU DO THIS?

9. - BRIEFLY DESCRIBE HOW BATTERIES ARE CHARGED WITH THE M. G. SET WHICH IS DESCRIBED IN THIS LESSON.

10. - HOW DOES THE M.G. CHARGING METHOD DIFFER FROM THAT USING A TUNGAR RECTIFIER?

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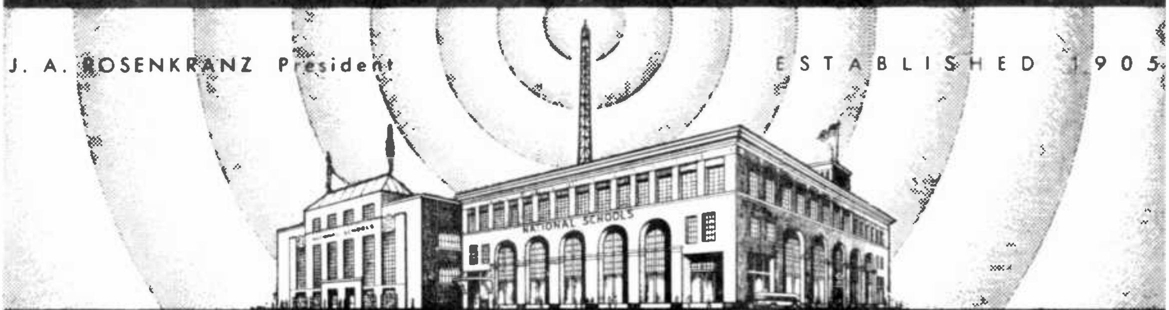

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LESSON NO. 34

BATTERY TROUBLES

If you have had any contact at all with storage batteries or even with other people, who make use of storage batteries in one way or another, you have often heard about one person obtaining considerably more "trouble-free" battery service than another person. In fact, the same persons may have identical batteries to start with and yet one party is constantly having his battery repaired, whereas the other party is always happy, due to the marvelous efficiency of his battery. Why is this so? Well, you are going to be shown the reason for this right here.

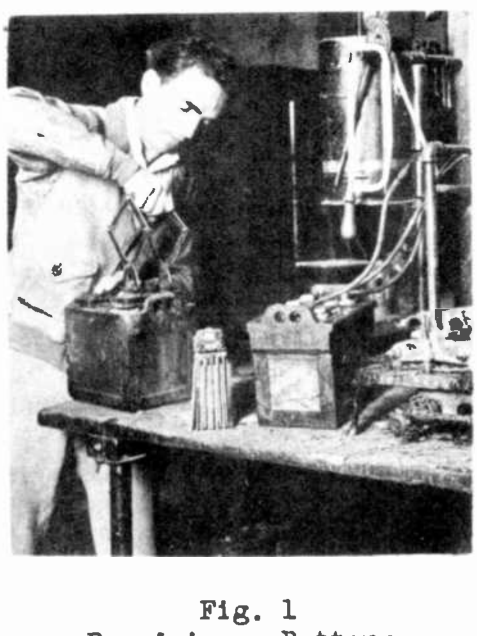

Fig. 1
Repairing a Battery

BATTERIES DEMAND ATTENTION

Batteries are like people, they will stand just so much strain and abuse but no more. Should you try and go about your daily tasks without treating yourself to a drink or food occasionally, you would gradually become weaker and weaker, and if you should continue this fast long enough you would finally die. Even though batteries are by no means alive, as we ordinarily consider life, yet they are decidedly active and demand proper attention, just as well as we humans do. Time after time, you will be able to trace back the history of a "lifeless" battery and find its condition due to neglect by its owner. Now, let us analyze battery troubles developing from neglect.

BATTERY CLEANLINESS

FIRST, SHOULD YOU PERMIT DIRT TO ACCUMULATE ON TOP OF THE BATTERY, A SUITABLE ELECTRICAL PATH IS LIKELY TO FORM, WHICH WILL PERMIT THE BATTERY TO GRADUALLY DISCHARGE ITSELF, AS YOU WERE ALREADY TOLD IN THE LAST LESSON.

THE FORMATION OF LEAD-SULPHATE COATING

IF THE ELECTROLYTE LEVEL IS NEGLECTED, THEN THE WATER WILL CONTINUE TO EVAPORATE AND IN DOING SO, THE ELECTROLYTE WILL BECOME STRONGER, AS WELL AS DROPPING TO AN ABNORMALLY LOW LEVEL. BY PERMITTING PLATES TO BE PARTIALLY EXPOSED TO THE EFFECTS OF THE AIR IN THIS WAY, THE EXPOSED PORTION OF THEM WILL HARDEN AND A COATING OF THICK LEAD-SULPHATE (A WHITE CHALKY-LOOKING SUBSTANCE) WILL FORM ON THEM. YOU WILL SEE SUCH A GROUP OF BADLY SULPHATED NEGATIVE PLATES IN FIG. 2.

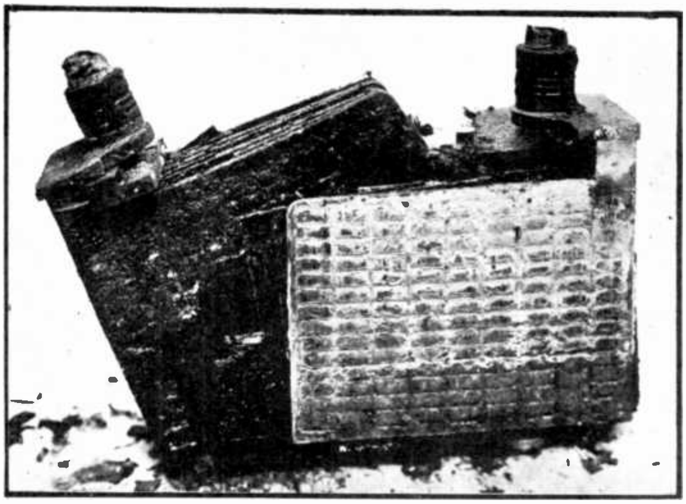

Fig. 2
Badly Sulphated and Disintegrated Plates

AN ACID OF EXTREMELY HIGH SPECIFIC GRAVITY WILL ALSO CAUSE THE PLATES TO BECOME SULPHATED. SO, BY HAVING THE COMBINED EFFECTS OF A STRONG ACID, CAUSED BY WATER EVAPORATION, AS WELL AS A LOW ELECTROLYTE LEVEL, THERE SHOULD BE NO DOUBT IN YOUR MIND THAT THE PLATES ARE BOUND TO BECOME SULPHATED.

ANOTHER COMMON CAUSE FOR SULPHATED PLATES, IS THAT THE BATTERY HAS BEEN LEFT IN A DISCHARGED CONDITION FOR TOO LONG A TIME, OR ELSE OVER-DISCHARGED. BY OVER-DISCHARGING, WE MEAN THAT THE BATTERY WAS FORCED TO REMAIN IN SERVICE AFTER ITS SPECIFIC GRAVITY HAS DROPPED TO A POINT BELOW 1.150 AND ITS CELL VOLTAGES BELOW 1.6 VOLTS.

THE NORMAL LEAD-SULPHATE FORMATION

KNOWING THAT SULPHATION IS EXTREMELY DETRIMENTAL TO BATTERY EFFICIENCY, LET US NOW SEE JUST EXACTLY WHY IT ACTS IN THIS PECULIAR WAY. YOU HAVE ALREADY LEARNED THAT AS A BATTERY DISCHARGES, THE CHEMICAL CHANGES ARE SUCH THAT THE SULPHATE GOES OUT OF THE ELECTROLYTE AND GOES INTO THE ACTIVE MATERIAL OF THE PLATES, THEREBY CAUSING A DEPOSIT OF LEAD-SULPHATE TO FORM ON THE SURFACE OF THE PLATES.

DURING THE NORMAL DISCHARGE OF THE BATTERY, THIS LEAD-SULPHATE IS SOFT AND POROUS AND FOR THIS REASON, THE ELECTROLYTE STILL HAS ACCESS TO THE ACTIVE MATERIAL OF THE PLATES. WITH THE LEAD-SULPHATE IN THIS SOFT FORM, IT CAN READILY BE DRIVEN FROM THE PLATES DURING THE TIME THE BATTERY IS BEING CHARGED. A CONDITION SUCH AS THIS IS NORMAL, AS FAR AS THE

OPERATION OF THE BATTERY IS CONCERNED.

THE EFFECTS OF HARDENED LEAD SULPHATE

NOW IF WE SHOULD PERMIT THIS SULPHATE TO FORM IN TOO GREAT AN ABUNDANCE ON THE PLATES AND BECOME HARD, IT WOULD NATURALLY LOSE ITS POROSITY AND THEREBY FORM A COMPARATIVELY SOLID COATING OVER THE SURFACE OF THE PLATES. LEAD SULPHATE, ITSELF, IS A POOR ELECTRICAL CONDUCTOR, SO IT NOT ONLY PREVENTS THE ELECTROLYTE FROM COMING INTO CONTACT WITH THE ACTIVE MATERIAL OF THE PLATES BUT IT ALSO OFFERS A HIGH ELECTRICAL RESISTANCE.

SHOULD A LARGE CURRENT BE FORCED TO FLOW THROUGH SULPHATED PLATES, THE RESISTANCE OFFERED BY THE LEAD SULPHATE COATING WOULD CAUSE HEAT TO BE GENERATED AND THIS HEAT WOULD IN TURN CAUSE THE ACID TO BECOME HOT AND HOT ACID IS EXTREMELY ACTIVE AND WILL IN A SHORT TIME DESTROY THE GOOD QUALITIES OF THE LEAD-ACID CELL.

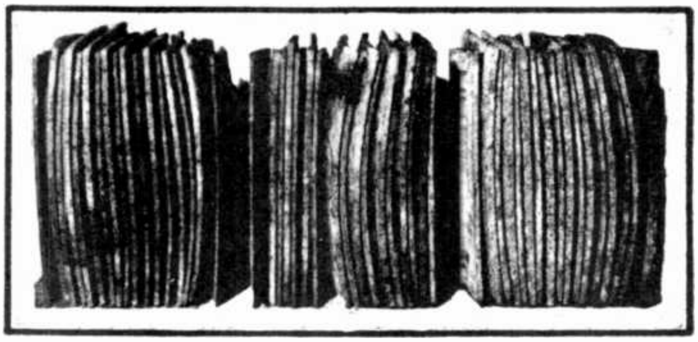

FIG. 3
Buckled Plates.

YOUR INTEREST IS NO DOUBT NOW AROUSED AS TO HOW WE CAN REMOVE LEAD SULPHATE DEPOSITS FROM SUCH AN AFFLICTED BATTERY, SO WHEN YOU COME TO THE LATTER PART OF THIS LESSON, YOU WILL BE TOLD WHAT TO DO WHEN YOU ARE CONFRONTED WITH SUCH A PROBLEM.

BUCKLED PLATES

ANOTHER SERIOUS PLATE TROUBLE IS BUCKLING, YOU WILL SEE A SET OF BUCKLED PLATES IN FIG. 3 AND YOU WILL FIND SEVERAL DIFFERENT ACTIONS CAPABLE OF CAUSING SUCH A CONDITION.

FIRST, IF A CELL IS PERMITTED TO OVER-DISCHARGE, LARGE ACCUMULATIONS OF LEAD SULPHATE WILL FORM ON THE PLATES. THESE SULPHATE DEPOSITS WILL NATURALLY NOT REMAIN UNIFORM AND CONSEQUENTLY THE PORTIONS OF THE PLATES, WHICH ARE STILL ACCESSABLE TO THE ACTION OF THE ELECTROLYTE, WILL BE CARRYING THE BURDEN OF CONDUCTING THE CURRENT.

DUE TO THIS REDUCTION IN PLATE AREA, THE SMALL SPACES, WHICH ARE STILL ACTIVE, WILL BECOME OVER-HEATED AND AN UNEQUAL DISTRIBUTION OF HEAT WILL NATURALLY CAUSE THE PLATES TO WARP OR BUCKLE.

IT IS LIKEWISE TRUE THAT UNEVEN DISTRIBUTION OF LEAD SULPHATE DEPOSITS CAN CAUSE THE PLATES TO LOSE THEIR NORMAL SHAPE.

YOU WILL ALSO FIND BUCKLING TO BE CAUSED BY EXCESSIVELY HIGH RATES OF CHARGE AND DISCHARGE, WHICH WILL OF COURSE PRODUCE AN ABNORMAL AMOUNT OF HEAT, WHICH MAY RESULT IN A DEFORMATION OF THE PLATES. IN FACT, SHORT CIRCUITING A CELL OR BATTERY IS ONE OF THE EVILS, WHICH ARE CAPABLE OF BRINGING ABOUT BUCKLED PLATES.

SOMETIMES YOU WILL COME ACROSS A CELL WITH A SET OF BUCKLED PLATES,

WHICH WERE CAUSED BY AN ACCIDENTAL SHORT CIRCUIT WITHIN THE CELL ITSELF. SUCH A SHORT CAN READILY BE PRODUCED IF ANY PORTION OF A SEPARATOR SHOULD FALL DOWN ON THE JOB SO THAT A CONTACT IS ESTABLISHED BETWEEN A POSITIVE AND NEGATIVE PLATE. IT ONLY TAKES ONE SUCH CONTACT TO SHORT OUT AN ENTIRE CELL BECAUSE ALL POSITIVE AND ALL NEGATIVE PLATES ARE MECHANICALLY CONNECTED TO ONE ANOTHER.

EFFECT OF BUCKLED PLATES

WHEN PLATES BECOME BUCKLED, OUR CORRECTIVE MEASURES ARE GOVERNED BY THE EXTENT OF THEIR BUCKLING. THAT IS, IF THE AMOUNT OF BUCKLING IS ONLY SLIGHT, THEN THE CELL AND BATTERY MAY CONTINUE THEIR USEFUL WORK FOR A PRACTICALLY UNLIMITED LENGTH OF TIME. SHOULD WE ON THE OTHER HAND, PERMIT BADLY BUCKLED PLATES TO REMAIN IN A CELL, THEY WILL IN DUE TIME EXERT UNEQUAL PRESSURES AGAINST THE SEPARATORS AND THEREBY CAUSE THE SEPARATORS TO BECOME WORN THROUGH, SO THAT AN ELECTRICAL CONNECTION WILL BE ESTABLISHED BETWEEN THE POSITIVE AND NEGATIVE PLATE GROUPS. THIS WOULD, OF COURSE, MEAN THE PRESENCE OF A SHORT CIRCUIT.

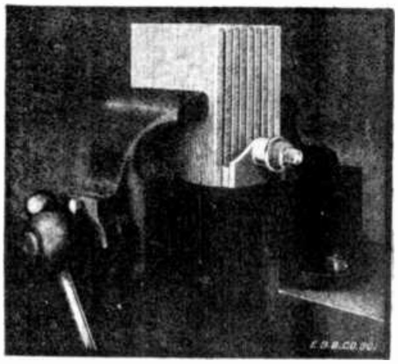

FIG. 4
Straightening Buckled Plates.

STRAIGHTENING BUCKLED PLATES

SHOULD THE EXTENT OF BUCKLING NOT BE TOO GREAT, THEN THE PLATE GROUP WITH THE BUCKLED PLATES CAN BE PLACED IN A VICE, AS SHOWN IN FIG. 4. NOTICE THAT THE SPACES BETWEEN THE PLATES ARE FILLED BY MEANS OF BOARDS, WHICH ARE CALLED TRANSIT BOARDS. THERE IS ALSO SUCH A BOARD RESTING AGAINST THE OUTER SURFACE OF EACH OF THE OUTER PLATES. THE BRITTLE STRUCTURE OF THE ACTIVE MATERIAL ON THE POSITIVE PLATES DOES NOT GENERALLY PERMIT STRAIGHTENING BUT THE NEGATIVE PLATES, WHEN IN A CHARGED CONDITION CAN BE STRAIGHTENED QUITE READILY.

WHEN PRESSURE IS APPLIED BY THE VICE, THE COMPARATIVELY PLIABLE NEGATIVE PLATES WILL YIELD TO THIS PRESSURE AND A GOOD JOB OF STRAIGHTENING CAN BE ACCOMPLISHED.

IN CASES WHERE EXTREME BUCKLING IS FOUND, IT WILL BE NECESSARY TO REPLACE THE BUCKLED PLATES WITH NEW ONES.

SHEDDING OF THE PLATES

IN FIG. 5, YOU WILL SEE STILL ANOTHER DEFECTIVE PLATE CONDITION, WHICH WE CALL SHEDDING. THIS DISEASED CONDITION MAKES ITSELF KNOWN BY THE FACT THAT THE PASTE OR ACTIVE MATERIAL CRUMBLES OFF THE GRIDS OR SUPPORTING MEMBERS. THIS ACTION IS FREQUENTLY FOUND IN OLD BATTERIES AND MAY GENERALLY BE BLAMED ON OLD AGE. HOWEVER, RELATIVELY YOUNG BATTERIES CAN "CATCH" THIS SICKNESS AND IN THIS CASE IT MAY BE CAUSED BY EXCESSIVE ACCUMULATION OF LEAD SULPHATE, OVER-DISCHARGING, AND OVER-CHARGING.

BY OVER-CHARGING, WE MEAN THAT IN SPITE OF THE BATTERY ALREADY BEING FULLY CHARGED, WE JUST STUBBORNLY TRY TO "RAM" AN EXCESSIVE AMOUNT OF CHARGE INTO IT. REMEMBER, YOU CAN'T "OVER-STUFF" A BATTERY, AND GET AWAY

WITH IT, ANYMORE THAN YOU CAN CONTINUALLY OVER-EAT AND EXPECT TO STAY IN GOOD HEALTH.

THE NORMAL AMOUNT OF SHEDDING

IN REGARDS TO SHEDDING OF THE PLATES, YOU MUST, OF COURSE, BEAR IN MIND THAT A SLIGHT AMOUNT OF SHEDDING IS PERFECTLY NATURAL BUT WHAT WE WANT TO AVOID IS THE EXCESSIVE AMOUNT OF SHEDDING. YOU SEE, ONE OF THE REASONS WHY WE ALWAYS PLACE THE SEPARATORS IN SUCH A POSITION SO THAT THE GROOVES ARE NEXT TO THE POSITIVE PLATES AND IN A VERTICAL OR UP AND DOWN PLANE, IS SO THAT THESE GROOVES WILL PERMIT THE SHEDDED MATERIAL FROM THE POSITIVE PLATES TO WORK ITS WAY DOWNWARDS INTO THE SEDIMENT BASINS AT THE BOTTOM OF THE JAR OF THE CELL. IT IS THE POSITIVE PLATES, WHICH ARE MOSTLY SUBJECT TO SHEDDING, RATHER THAN THE NEGATIVE PLATES

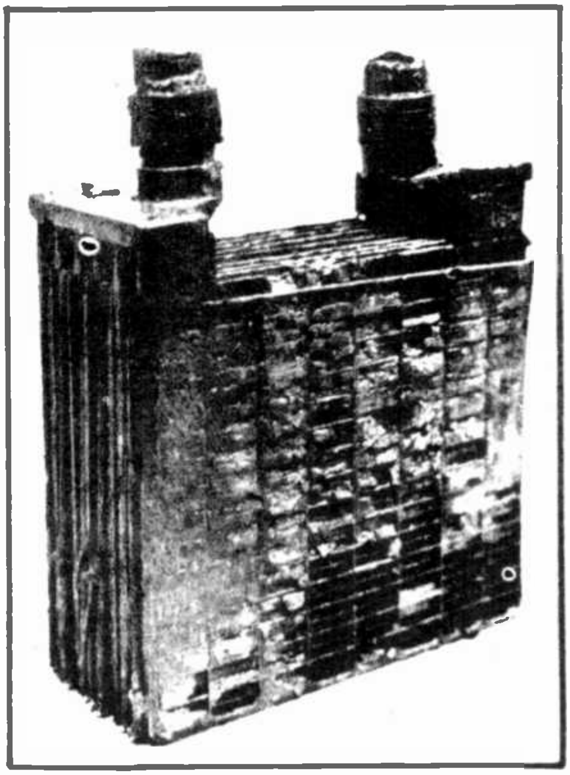

FIG. 5
Shedding Plates.

THE EFFECTS OF SHEDDING

AS THE PROCESS OF SHEDDING CONTINUES, MORE AND MORE OF THE ACTIVE MATERIAL WILL BE LOST FROM THE PLATES, SO THAT THE CAPACITY OF THE CELLS WILL BE CORRESPONDINGLY REDUCED, AND EVENTUALLY, SUFFICIENT ACTIVE MATERIAL WILL BE LOST FROM THE PLATES, SO THAT THE ONLY REMEDY LEFT IS TO REPLACE THESE SHEDDED PLATES WITH NEW ONES.

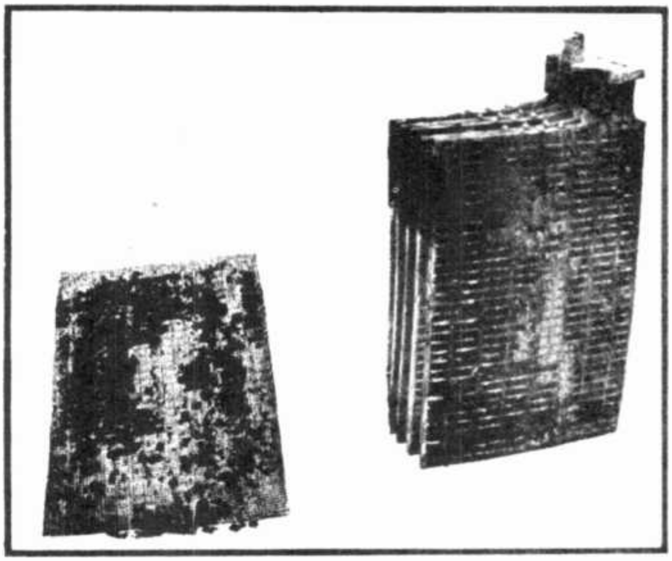

FIG. 6
Group Removed from a Frozen Cell. (Note active material on separators.)

FROZEN BATTERIES

ONE OF THE MOST IN-EXCUSABLE BATTERY TROUBLES IS A FROZEN BATTERY AND THIS CONDITION IS A DIRECT RESULT OF UTTER NEGLECT ON THE PART OF THE OWNER. TO PROVE THIS TO YOU, WE ARE GIVING YOU SOME FACTS WHICH SHOW THE RELATION BETWEEN FREEZING POINTS OF ELECTROLYTES AND THEIR SPECIFIC GRAVITY. HERE THEY ARE:

A BATTERY, WHICH IS DISCHARGED SUFFICIENTLY SO THAT ITS SPECIFIC GRAVITY IS 1.150, WILL FREEZE AT A TEMPERATURE OF ABOUT 5°F. ABOVE ZERO. HOWEVER, A BATTERY, WHOSE ELECTROLYTE HAS A SPECIFIC GRAVITY

OF 1.280, WILL FREEZE AT THE VERY LOW TEMPERATURE OF ABOUT 92°F. BELOW ZERO. SOME DIFFERENCE, ISN'T THERE? THIS SHOWS THAT THERE ISN'T MUCH CHANCE OF A CHARGED BATTERY BECOMING FROZEN BUT IT DOESN'T HAVE TO BE SO VERY COLD IN ORDER TO FREEZE A PARTIALLY OR COMPLETELY DISCHARGED BATTERY.

WHEN THE ELECTROLYTE FREEZES IN A LOW BATTERY, IT WILL NATURALLY EXPAND JUST LIKE WATER DOES WHEN IT TURNS TO ICE. SINCE THE PLATES ARE FILLED WITH A CERTAIN AMOUNT OF ELECTROLYTE, THIS EXPANSION OF THE FREEZING ELECTROLYTE WILL TEND TO FORCE THE ACTIVE MATERIAL OUT OF THE GRIDS. MISPLACED ACTIVE MATERIAL CAN, OF COURSE, ONLY BE REPLACED IN THE CELL BY EQUIPPING THE CELL WITH A NEW SET OF PLATES OR ELSE BUYING A NEW BATTERY. YOU WILL SEE THE EFFECTS OF A FROZEN CELL IN FIG. 6.

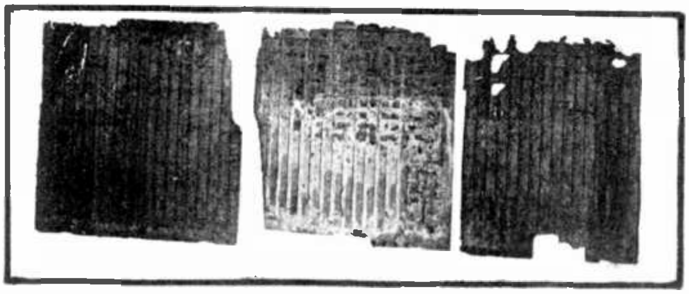

FIG. 7
Worn Wooded Separators.

THE BREAKING DOWN OF SEPARATORS

ABOUT THE FIRST PARTS TO BREAK DOWN IN AN AVERAGE BATTERY ARE THE SEPARATORS, PROVIDED THAT THEY ARE WOODEN ONES. WOODEN SEPARATORS, ARE SUBJECT TO ROTTING. THIS IS BROUGHT ABOUT BY THEIR CONTINUAL CONTACT WITH THE ACTIVE ACID, ESPECIALLY IF ANY FAULTY CONDITIONS EXIST WHICH WILL CAUSE THE ACID TO BECOME WARMER THAN NORMAL.

SEPARATORS ARE ALSO FREQUENTLY WORN THROUGH, IF THE ELEMENTS ARE LOOSELY FITTED INTO THE JARS. THAT IS, IF THE ELEMENTS HAVE A CHANCE TO BE JARRED AROUND, THE RESULTING FRICTION BETWEEN PLATES WILL IN A SHORT TIME RUB A HOLE THROUGH A SEPARATOR AND THEREBY CAUSE THE CELL TO BE SHORT CIRCUITED. BUCKLED PLATES, YOU WILL REMEMBER, WILL ALSO CAUSE WORN SPOTS IN SEPARATORS. IN FIG. 7 AND 8 SOME BADLY WORN WOODEN SEPARATORS ARE SHOWN.

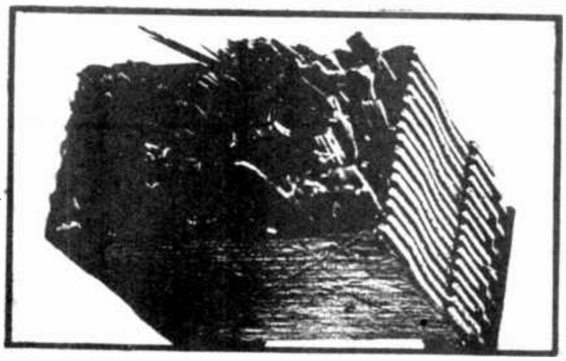

FIG. 8
Rotted Separators.

"TREEING"

ANOTHER PECULIAR CHARACTERISTIC OF WOODEN SEPARATORS IS KNOWN AS "TREEING". THIS NAME IS GIVEN TO A GROWTH OF FOREIGN MATERIALS, WHICH SOMETIMES TEND TO BUILD UP ON THE SEPARATORS AND WILL IN TIME RESULT IN A SHORT CIRCUIT.

WHENEVER WOODEN SEPARATORS SHOW THE SLIGHTEST DEFECTS, AFTER A CELL HAS BEEN DISMANTLED, YOU SHOULD NEVER HESITATE ABOUT REPLACING THEM WITH NEW ONES. DUE TO THE LOW COST OF WOODEN SEPARATORS, ONE IS NEVER JUSTIFIED IN REBUILDING A CELL AND DEPENDING UPON OLD SEPARATORS TO STAND UP UNDER THE RESPONSIBILITY, WHICH IS PLACED UPON THEM.

VARIOUS PATENTED SEPARATORS, SUCH AS RUBBER, ETC., ARE NOT AS SUSCEPTIBLE TO SUCH A RAPID BREAK-DOWN, AS IS THE CASE WITH WOODEN SEPARATORS.

THE MOST COMMON TROUBLE FOUND IN WOODEN CASES

NOW A WORD ABOUT THE TROUBLES FOUND IN BATTERY CASES. WOODEN CASES ARE SUBJECT TO ROTTING, WHICH IS DUE TO THE ACTION OF SPILT ACID UPON THE WOOD. THIS CONDITION CAN BE PREVENTED IF THE OUTSIDE OF THE CASE IS WASHED WITH A SODA OR AMMONIA SOLUTION ABOUT 3 TIMES A YEAR AND THEN FOLLOWED BY A COAT OF ACID RESISTING BATTERY PAINT. HOWEVER, WHEN IT IS ALREADY TOO LATE AND THE CASE IS ROTTED TO SUCH AN EXTENT THAT IT IS ALREADY FALLING APART, THEN THE ONLY LOGICAL REMEDY IS TO REPLACE IT WITH A NEW ONE.

THE MOST COMMON TROUBLE FOUND IN COMPOSITION CASES

RUBBER BATTERY CASES ARE SUBJECT TO SPREADING AT THE ENDS, WHICH IS CAUSED WHEN A BATTERY IS HELD IN PLACE TOO RIGIDLY BY MEANS OF OVER-TIGHT HOLD DOWN CLAMPS. IN FIG. 9 YOU WILL SEE A BATTERY WHICH IS HELD IN POSITION WITH HOLD-DOWN CLAMPS OR BOLTS.

SOMETIMES SUCH A SPREAD CASE CAN BE PRESSED BACK INTO ITS NORMAL SHAPE AGAIN BY MEANS OF THE APPLICATION OF HEAT, AFTER WHICH IT IS ALLOWED TO COOL IN ITS RE-SET POSITION.

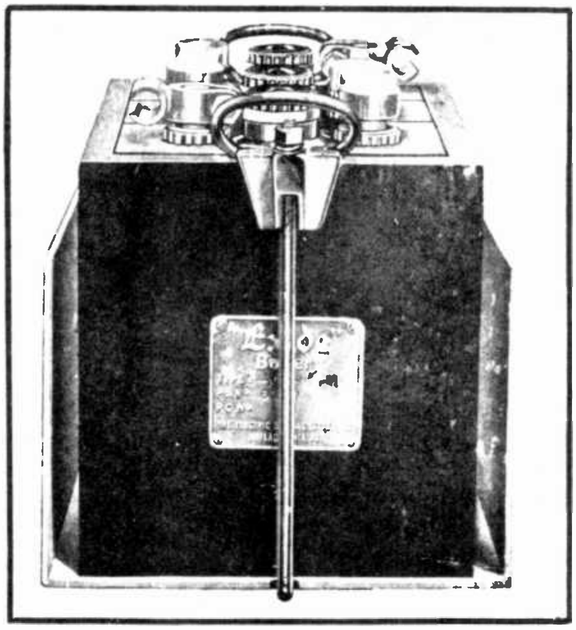

FIG. 9
Battery Held in Place With Bolts.

IF THE CONDITION OF THE CASE IS SUCH THAT IT WILL NOT PERMIT THIS OPERATION, THEN IT IS NECESSARY TO REPLACE IT WITH A NEW ONE.

THE HIGH RATE DISCHARGE TESTER

SO FAR, THE ONLY BATTERY TESTING INSTRUMENTS WITH WHICH YOU HAVE BEEN MADE FAMILIAR WERE THE VOLTMETER AND THE HYDROMETER. HOWEVER, TO DETERMINE BATTERY TROUBLES, WE ALSO FIND IT NECESSARY TO USE OTHER INSTRUMENTS. AMONG THESE USEFUL INSTRUMENTS, WE FIRST FIND THE HIGH RATE DISCHARGE TESTER.

BY LOOKING AT FIG. 10, YOU WILL NOTICE THAT THIS INSTRUMENT CONSISTS OF TWO SHARP METALLIC PRONGS, WITH A WOODEN HANDLE. THESE TWO PRONGS ARE ELECTRICALLY CONNECTED TOGETHER NEAR THEIR CENTER BY MEANS OF A HEAVY PIECE OF NICHROME WIRE. IN FACT, THIS HEAVY WIRE IS FREQUENTLY IN THE FORM OF A RIGID RIBBON.

JUST ABOVE THIS CONNECTING WIRE, YOU WILL SEE A SMALL VOLTMETER, SO MOUNTED THAT WHEN YOU GRIP THE HANDLE, YOU CAN SEE THE DIAL OF THE METER VERY EASILY. IF YOU WILL FOLLOW CAREFULLY, YOU WILL IMMEDIATELY SEE WHY

THIS INSTRUMENT IS SO VALUABLE FOR BATTERY TESTING PURPOSES.

THE REASON FOR MAKING A HIGH RATE DISCHARGE TEST

WHEN WE MERELY TEST THE CELL VOLTAGE WITH AN ORDINARY VOLTMETER, THE CELL IS NOT BEING PUT UNDER ANY LOAD. FOR THIS REASON, ANY DEFECT, SUCH AS A POORLY WELDED JOINT, LOW CAPACITY (SHEDDED) PLATES, ETC., WILL NOT NECESSARILY BE INDICATED BY THE CONVENTIONAL VOLTMETER READING. WE FIND, HOWEVER, THAT BY USING THE HIGH RATE DISCHARGE TESTER AND FIRMLY JABBING ITS POINTS INTO THE TWO TERMINALS OF A SINGLE CELL, THEN THE CELL WILL BE DISCHARGING AT A COMPARATIVELY HIGH RATE (ABOUT 150 TO 200 AMPS.)

FIG.10
A High Rate Discharge Tester.

THIS HIGH RATE OF DISCHARGE IS DUE TO THE FACT THAT THE NICHROME BAND SERVES SOMEWHAT AS A SHORT ACROSS THE PRONGS BUT YET THE RESISTANCE OF THIS WIRE IS SUCH SO THAT A 100% SHORT CIRCUIT WILL NOT BE PRODUCED ACROSS THE CELL.

THE REQUIRED READINGS OF THE HIGH RATE DISCHARGE TEST

BECAUSE OF THE HIGH RATE OF DISCHARGE DURING THIS TEST, IT IS IMPERATIVE THAT WE DO NOT CONTINUE IT FOR TOO LONG A TIME. WHILE THIS DISCHARGE IS GOING ON, THE ATTACHED VOLTMETER IS WATCHED AND IF THE READING IS NOT BELOW 1.75 VOLTS AND THE READINGS OF THE VARIOUS CELLS DO NOT VARY BY MORE THAN 0.1 VOLTS, THEN THE BATTERY IS MECHANICALLY CORRECT.

SHOULD THERE, ON THE OTHER HAND, BE A POORLY WELDED JOINT, LOW CAPACITY CELL, ETC., WHEN THIS TEST IS MADE, THEN THE VOLTMETER WILL IMMEDIATELY INDICATE A READING LOWER THAN THAT REQUIRED FOR A NORMAL CELL.

FOR EXAMPLE, LET US SUPPOSE THAT ONLY AN ORDINARY VOLTMETER TEST IS TAKEN OF THE CELL. IN THIS CASE, AN EXTREMELY SMALL AMOUNT OF CURRENT IS ONLY CALLED UPON TO FLOW THROUGH THE HIGH RESISTANCE WINDING OF THE METER, SO THAT A READING WILL BE OBTAINED. DUE TO THIS VERY LOW CURRENT FLOW, A POORLY FITTED JOINT WILL VERY OFTEN PERMIT THIS SMALL AMOUNT OF CURRENT TO FLOW THROUGH IT WITHOUT PRESENTING ANY NOTICEABLE EFFECTS.

SHOULD THIS SAME JOINT, HOWEVER, BE FORCED TO PERMIT A HEAVY CURRENT TO FLOW THRU IT, IT WILL NOT STAND UP UNDER THE BIG LOAD AND THEREFORE, THIS CONDITION WILL QUICKLY MAKE ITSELF KNOWN WHEN THE HIGH RATE DISCHARGE TEST IS MADE.

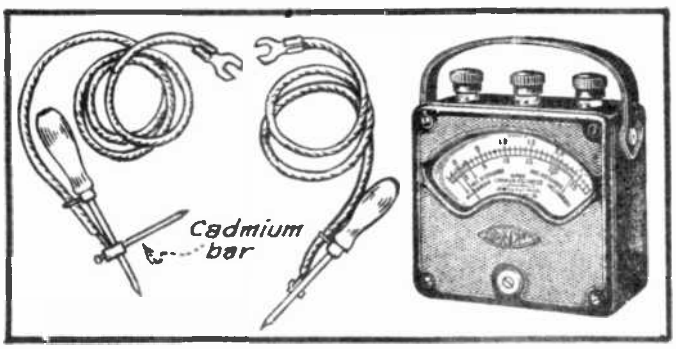

FIG. 11
The Cadmium. Test Voltmeter & Leads.

THE CADMIUM TEST VOLTMETER

With all the tests, which we are able to make so far, we cannot as yet determine whether it is the positive group or the negative group, which is at fault in a defective cell. Therefore, let us now proceed and see how we can distinguish the short comings of either of the plate groups, without actually having to first dis-assemble the cell.

To do this job, we use an instrument, which is known as the Cadmium Test voltmeter and it will give satisfactory results, provided that it is used properly. The meter is generally supplied with an upper and lower scale and in this case, the lower scale can be used for reading voltages of various electrical units, as long as their voltage does not exceed 28 volts. The upper scale is used for reading voltages up to 2.8 volts and it is this scale, in which we are for the present chiefly interested.

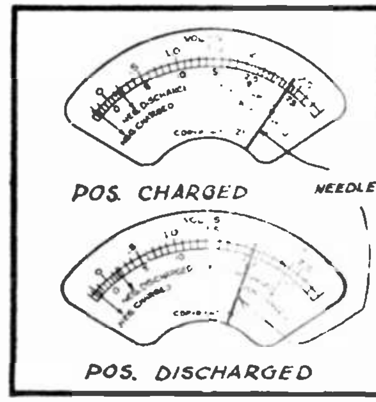

FIG. 12
Cadmium Test Voltmeter-Charged & Discharged Positive Group.

THE TEST LEADS

Two test points, with wooden handles, are connected to the meter by means of long, flexible, insulated wires. One of these test points has a stick of cadmium attached to it in such a manner, so that the cadmium stick is at the right angles to the test point, as you will observe in Fig. 11.

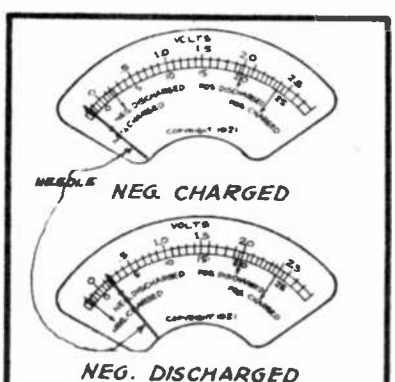

FIG. 13
Charged & Discharched Negative Group.

The test point, which has the cadmium attached to it, is connected to the terminal of the meter which is labeled 2.5V. The other test point is connected to the terminal of the meter, which is labeled with an (+) sign.

With our connections to the meter thus made, we are ready to make some tests. However, to obtain results with this instrument, the battery must either be undergoing the process of a charge or else a discharge. That is, we must make these tests while the battery is connected to the charging line or else actually working by causing a current flow.

TESTING THE POSITIVE PLATE GROUP

Generally we make this test while the battery is being charged and we proceed by inserting the cadmium stick into the electrolyte, being carefuly, however, that it does not come in contact with any of the plates. As soon as the cadmium stick has been immersed for a few seconds, we touch the other test point to the positive post of the cell.

While we are doing this, we take note of the reading on the scale of the meter and if we find that the needle comes to rest at the point labeled "Pos. Charged", which is really equivalent to 2.4 volts, then we

KNOW THAT THE POSITIVE GROUP OF THAT PARTICULAR CELL IS CHARGED. THIS IS ILLUSTRATED IN FIG. 12.

SHOULD WE, HOWEVER, MAKE THIS SAME TEST AND ONLY OBTAIN A READING OF 2.3 VOLTS, THEN THE POSITIVE PLATE GROUP IS 3/4 CHARGED; A VOLTAGE OF 2.2 VOLTS WOULD INDICATE THAT THE POSITIVE GROUP IS ½ CHARGED; A READING OF 2.1 VOLTS WOULD TELL US THAT THEY ARE ONLY ¼ CHARGED; AND 2.0 VOLTS WOULD MEAN THAT THE POSITIVE GROUP IS DISCHARGED.

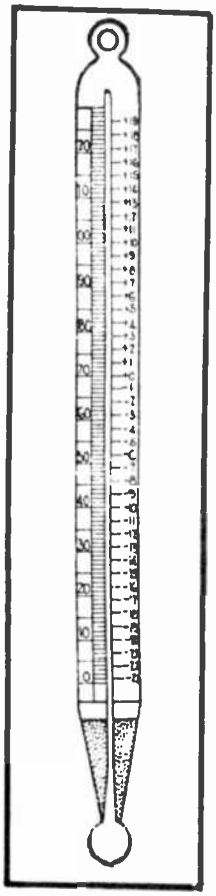

FIG. 14
A Correction Thermometer.

TESTING THE NEGATIVE PLATE GROUP

IN ORDER TO TEST THE NEGATIVE PLATE GROUP IN A SIMILAR MANNER, WE LEAVE THE CADMIUM STICK WITHIN THE ELECTROLYTE, JUST AS WE ALREADY HAVE IT BUT WE BRING OUR OTHER TEST POINT IN CONTACT WITH THE NEGATIVE POST OF THE CELL. NOW WE WATCH THE METER AND IF WE FIND THE READING TO BE 0.175 VOLTS (TO THE LEFT OF ZERO OR THE POINT MARKED "NEG. CHARGED") WE KNOW THAT THE NEGATIVE PLATE GROUP IS FULLY CHARGED. THIS IS ILLUSTRATION IN FIG. 13.

SHOULD WE, HOWEVER, FIND THE READING TO BE 0, THEN THE NEGATIVE GROUP IS ONLY ½ CHARGED AND SHOULD THE READING BE AROUND 0.15 OR 0.18 VOLTS TO THE RIGHT OF ZERO THEN THE NEGATIVE GROUP IS COMPLETELY DISCHARGED.

WITH A TEST, SUCH AS THIS, WE CAN DETERMINE WHICH PARTICULAR PLATE GROUP IS CAUSING ANY CELL FROM REACHING A FULLY CHARGED CONDITION WHILE ON THE CHARGING LINE.

WHAT THE READINGS MEAN

LET US SEE, FOR EXAMPLE JUST WHAT SUCH READINGS INDICATE IF WE USE THEM TOGETHER, SO AS TO OBTAIN THE ACTUAL VOLTAGE OF A CELL. ASSUMING THAT THE CADMIUM TEST FOR THE POSITIVE GROUP INDICATES 2.4 VOLTS AND THE TEST FOR THE NEGATIVE GROUP OF THE SAME CELL INDICATES A VOLTAGE OF -0.17, THEN THE ACTUAL VOLTAGE OF THE CELL WOULD BE 2.4 ADDED TO 0.17 OR 2.57 VOLTS, WHILE STILL ON THE CHARGING LINE.

ON THE OTHER HAND, IF THE READINGS WERE ONLY 2.0 VOLTS FOR THE POSITIVE GROUP AND +0.15 FOR THE NEGATIVE GROUP, THEN OUR ACTUAL CELL VOLTAGE WOULD ONLY BE THE DIFFERENCE BETWEEN 2.0 AND 0.15 OR 1.85 VOLTS WHILE ON THE CHARGING LINE. THIS, OF COURSE, WOULD BE A DISCHARGED CELL. WITH SEPARATE READINGS THUS OBTAINED, IF WE FIND THE POSITIVE GROUP VOLTAGE TEST NORMAL AND THE NEGATIVE GROUP VOLTAGE TEST BELOW NORMAL, WE KNOW THAT THE LOW CELL VOLTAGE IS DUE TO A FAULTY NEGATIVE PLATE GROUP AND VICE VERSA.

THE ACTION OF SULPHATED BATTERIES WHEN ON THE CHARGING LINE

WE HAVEN'T YET CONSIDERED HOW SOME OF THESE FAULTY BATTERIES ACT ON THE CHARGING LINE, SO THIS IS OUR NEXT STEP. YOU WILL REMEMBER THAT IN OUR DISCUSSION OF SULPHATED PLATES, YOU WERE TOLD THAT LEAD SULPHATE PRODUCED CONSIDERABLE ELECTRICAL RESISTANCE. WITH THIS IN MIND, CONSIDER FOR A SECOND WHAT HAPPENS WHEN AN EXCESSIVELY HIGH CHARGING RATE IS FORCED THRU

SUCH A BATTERY, WHICH IS AFFLICTED WITH PLATES COVERED WITH A HIGH RESISTANCE LEAD SULPHATE COATING.

SUCH A CONDITION WILL CAUSE THE BATTERY TO BECOME HOT BECAUSE WHENEVER CURRENT IS FORCED TO FLOW THROUGH A CONDUCTOR OF CONSIDERABLE RESISTANCE, THE CONDUCTOR WILL BECOME HOT. BESIDES THIS, THE SULPHATE COATING ONLY ALLOWS A LIMITED SPACE OF THE PLATE AREA TO BE EFFECTIVE AND THIS WILL ALSO REDUCE THE CAPACITY OF THE PLATES IN REGARDS TO THEIR ABILITY TO CARRY A CURRENT AND THEREFORE, THIS ACTION WILL ALSO PRODUCE HEAT.

FROM THESE FACTS, IT IS OBVIOUS THAT SULPHATED BATTERIES WILL HEAT WHILE ON THE CHARGING LINE, EVEN THOUGH THE CHARGING RATE IS LOW ENOUGH SO THAT THE TEMPERATURE OF THE AVERAGE BATTERIES WILL NOT RISE ABOVE NORMAL. THE QUESTION NOW ARISES AS TO WHAT TEMPERATURE LIMIT WE SHOULD PERMIT A BATTERY TO REACH AND ALSO WHAT ACTION WE SHALL TAKE TO PREVENT A BATTERY FROM BECOMING OVER HEATED.

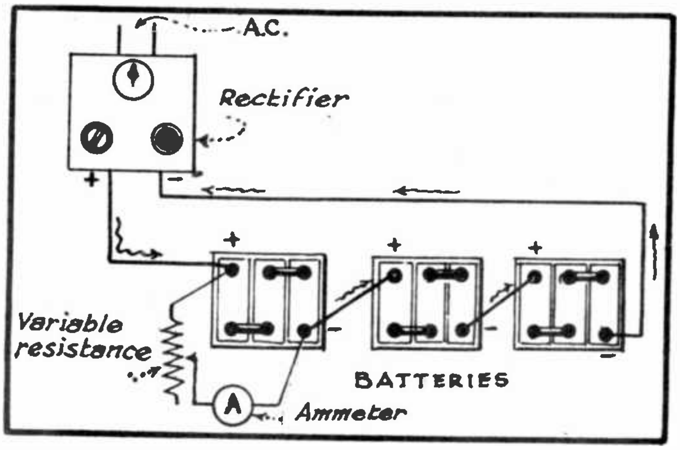

FIG. 15
Reducing the Charging Rate Thru a Heating Battery on a Series Circuit.

CONSIDERING BATTERY TEMPERATURES

IN BATTERY WORK, WE CONSIDER A TEMPERATURE OF 70° F. AS THE NORMAL TEMPERATURE, HOWEVER, BATTERY TEMPERATURES WILL NATURALLY VARY DUE TO ATMOSPHERIC CONDITIONS, THE AMOUNT OF CURRENT PASSING THRU THE BATTERY, ETC. THE DANGER POINT IS REACHED AT ABOUT 110° F. AND A BATTERY SHOULD NEVER BE PERMITTED TO RISE TO A TEMPERATURE ABOVE 110° F.

THE THERMOMETER

SO YOU SEE, WHEN A SULPHATED BATTERY IS ON THE CHARGING LINE, OR FOR THAT MATTER ANY BATTERY, WE MUST GUARD AGAINST EXCESSIVE TEMPERATURES. IN ORDER TO DETERMINE THE TEMPERATURE OF ANY CELL WHILE CHARGING, WE SIMPLY INSERT A THERMOMETER, SUCH AS THE ONE SHOWN IN FIG. 14, INTO THE ELECTROLYTE. AS SOON AS THE TEMPERATURE READING IS THUS OBTAINED, WE WILL REMOVE THE THERMOMETER FROM THE ELECTROLYTE AND ACT ACCORDINGLY, AS YOU WILL NOW BE SHOWN.

PREVENTING A BATTERY FROM OVERHEATING IN A SERIES CIRCUIT

LET US ASSUME THAT A CERTAIN BATTERY, WHICH IS CONNECTED IN A SERIES CHARGING CIRCUIT, SUCH AS IN FIG. 15, IS BECOMING OVER-HEATED, WHEREAS THE REST OF THE BATTERIES ON THE CHARGING LINE ARE STILL AT A PERFECTLY SAFE TEMPERATURE. IT IS OBVIOUS THAT IN THIS CASE, WE WOULD NOT REDUCE THE CHARGING RATE OF THE ENTIRE SYSTEM BECAUSE THIS WOULD SLOW UP THE CHARGING OPERATION OF THE WHOLE ARRANGEMENT AND THIS IS UNNECESSARY, AS WELL AS A WASTE OF TIME.

THEREFORE, IF WE DO NOT WISH TO REMOVE THE HEATING BATTERY FROM THE LINE ALTOGETHER AND PERMIT IT TO COOL BEFORE CONTINUING ITS CHARGE, ALL THAT MUST BE DONE IS TO CONNECT A RESISTANCE UNIT ACROSS IT, AS SHOWN IN FIG. 15. IT IS ALSO A GOOD POLICY TO CONNECT A SEPARATE AMMETER IN SERIES WITH THE VARIABLE RESISTANCE, FOR IN THIS WAY YOU WILL KNOW JUST HOW MUCH CURRENT IS FLOWING THROUGH THE RESISTANCE.

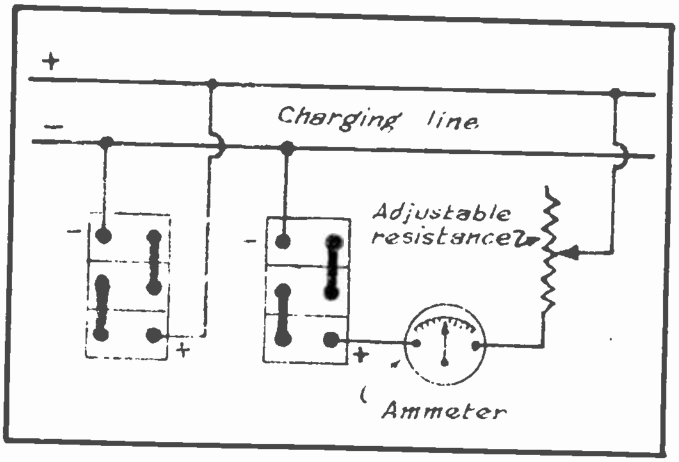

FIG. 16

Reducing the Charging Rate Thru a Heating Battery on a Parallel Circuit.

THE PURPOSE OF THE RESISTANCE

BY CONNECTING THE RESISTANCE IN THIS WAY, OR AS WE SHOULD SAY, IN PARALLEL WITH THE HEATING BATTERY, THE CHARGING CURRENT CAN DIVIDE AT THE BATTERY. THAT IS, PART OF IT WILL FLOW THROUGH THE BATTERY AND PART OF IT WILL FLOW THROUGH THE RESISTANCE BUT ALL OF IT WILL FLOW THROUGH THE REST OF THE BATTERIES.

THE PURPOSE OF THE SEPARATE AMMETER

THE PURPOSE OF THE SEPARATE AMMETER IS THIS: IF WE ONLY HAD THE RESISTANCE CONNECTED ACROSS THE HOT BATTERY, WE WOULDN'T KNOW WHAT PORTION OF THE CURRENT IS FLOWING THROUGH THE RESISTANCE AND WHAT PORTION IS FLOWING THROUGH THE BATTERY. HOWEVER, BY MEANS OF THE SEPARATE AMMETER, WE CAN TELL HOW MUCH OF THE CURRENT IS FLOWING THROUGH THE RESISTANCE AND, THEREFORE, WE CAN READILY TELL HOW MUCH IS FLOWING THROUGH THE HOT BATTERY BY SIMPLY SUBTRACTING THE READING OF THE SEPARATE AMMETER FROM THE READING OF THE CHARGER'S AMMETER. THAT IS, IF 3 AMPS. ARE FLOWING THROUGH THE RESISTANCE THEN 6 MINUS 3 OR 3 AMPS. ARE FLOWING THROUGH THE HOT BATTERY, PROVIDING THAT THE CHARGER IS "PUTTING OUT" 6 AMPS. THE OTHER BATTERIES, HOWEVER, WILL RECEIVE THEIR FULL QUOTA OR 6 AMPS. BECAUSE THE PARALLEL PATHS OF THE FIRST BATTERY, JOIN AT THE NEGATIVE TERMINAL OF THE SAME BATTERY.

BY HAVING THE RESISTANCE UNIT VARIABLE, THAT IS, ADJUSTABLE, YOU CAN REGULATE THE CURRENT FLOW THROUGH THE HOT BATTERY.

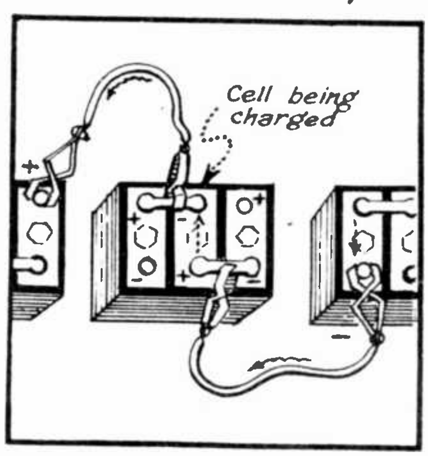

FIG. 17

Charging a Single Cell.

PREVENTING A BATTERY FROM OVER-HEATING IN A PARALLEL CIRCUIT

IN CASE THAT YOU ARE OPERATING A PARALLEL CHARGER INSTEAD OF A SERIES CHARGER, THEN YOU CONNECT THE AMMETER AND RESISTANCE IN SERIES WITH THE HOT BATTERY, AS SHOWN IN FIG. 16. HERE THE CHARGING CURRENT WILL COME FROM THE (+) BUSS BAR AND THENCE THROUGH THE RESISTANCE UNIT, AMMETER, BATTERY, AND BACK TO THE (-) BUSS BAR OF THE CHARGING LINE. BY CONTROLLING THE AMOUNT OF RESISTANCE, THE CHARGING RATE THROUGH THE HEATED BATTERY CAN LIKEWISE

BE CONTROLLED. THE NORMAL BATTERY, HAVING NO RESISTANCE CONNECTED TO IT, WILL, THEREFORE, RECEIVE ITS FULL AMOUNT OF CHARGING CURRENT.

CHARGING ONE CELL IN A SERIES CIRCUIT

SOMETIMES WHEN YOU ONLY WISH TO CHARGE ONE CELL OF A BATTERY, AS MAY BE THE CASE WHEN ALL THE OTHER CELLS ARE PERFECT BUT THE ONE CELL HAVING HAD TO BE REBUILT BECAUSE OF SOME FAULT, THEN YOU CAN CHARGE THIS ONE CELL AS SHOWN IN FIG. 17, WHEN A SERIES CHARGING CIRCUIT IS BEING USED.

CHARGING ONE CELL IN A PARALLEL CIRCUIT

TO CHARGE ONE CELL OF A BATTERY WHEN A PARALLEL CHARGING CIRCUIT IS USED, YOU CAN CONNECT THE CELL TO THE CHARGING LINE, AS SHOWN IN FIG. 18 WITH AN AMMETER AND VARIABLE RESISTANCE IN SERIES.

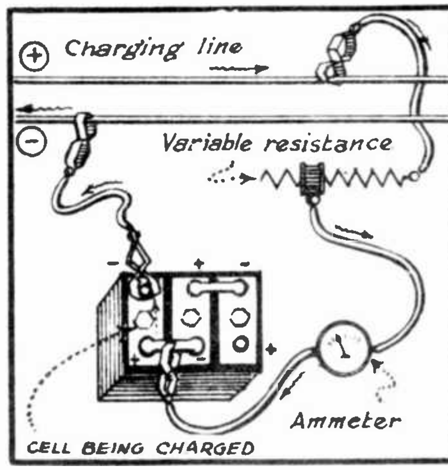

FIG. 18
Charging a Single Cell on a Parallel Charging Circuit.

CYCLING BATTERIES

IN THE EARLIER PART OF THIS LESSON, YOU WERE TOLD THAT YOU WOULD BE SHOWN A METHOD OF BRINGING SULPHATED BATTERIES BACK TO A MORE ACTIVE SERVICE. IF THE STATE OF SULPHATION IS NOT TOO BAD, WE RESORT TO THE PROCESS KNOWN AS CYCLING BUT IN EXTREME CASES OF SULPHATED PLATES, EITHER NEW PLATES OR ELSE A NEW BATTERY WILL BE REQUIRED.

TO CYCLE A BATTERY, WE FIRST CHARGE IT AT A SLOW RATE UNTIL ITS STATE OF CHARGE WILL COME UP TO AS NEARLY A FULLY CHARGED CONDITION AS POSSIBLE. THEN WE DISCHARGE IT AT A CONTROLLED RATE BY MEANS OF SOME KIND OF A RESISTANCE. THE RATE OF DISCHARGE SHOULD BE ABOUT 2 OR 3 AMPERES PER POSITIVE PLATE PER CELL. THAT IS, WE CAN DISCHARGE AN 11 PLATE BATTERY AT THE RATE OF ABOUT 15 AMPS.

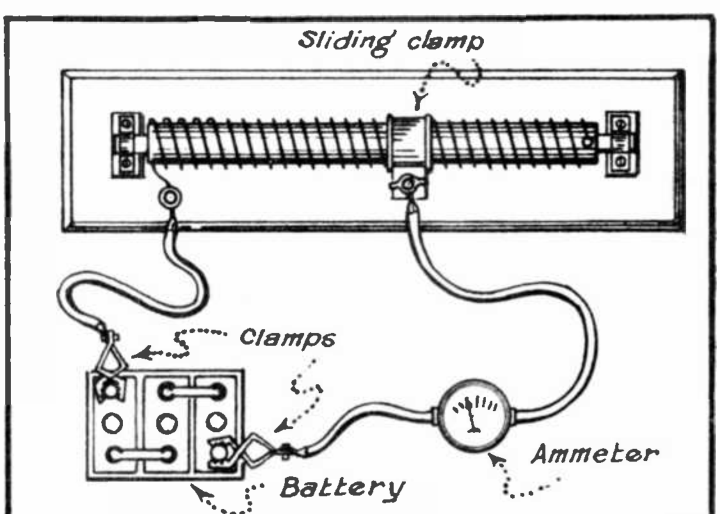

FIG. 19
Discharging a Battery by Means of a Variable Resistance Unit.

CONTROLLING THE RATE OF DISCHARGE

TO CONTROL THE RATE OF DISCHARGE, SEVERAL DEVICES CAN BE USED. A MOST COMMON ONE IS SHOWN IN FIG. 19 AND IN THIS CASE, A VARIABLE RESISTANCE UNIT, WITH AN AMMETER IN SERIES IS CONNECTED ACROSS THE TERMINALS OF THE BATTERY. THIS WILL OFFER A COMPLETE CIRCUIT SO THAT THE BATTERY WILL DISCHARGE ITSELF. THIS SIMPLE RESISTANCE UNIT, SIMPLY CONSISTS OF A $1\frac{1}{4}$"

PIPE WHICH IS COVERED WITH ASBESTOS AND WRAPPED WITH #14 IRON WIRE, THE TURNS BEING SPACED SO AS NOT TO TOUCH EACH OTHER. THE RATE OF DISCHARGE IS REGULATED BY MOVING A SLIDING CONTACT TO THE REQUIRED POSITION, SO THAT THE CORRECT AMOUNT OF RESISTANCE (IRON WIRE) WILL BE INCLUDED IN THE CIRCUIT.

WE PERMIT THE BATTERY TO CONTINUE DISCHARGING IN THIS WAY, UNTIL THE VOLTAGE OF EACH CELL REACHES A POINT OF ABOUT 1.6 OR 1.7 VOLTS, BUT NEVER LOWER. THE BATTERY IS THEN DISCONNECTED FROM THE RESISTANCE AND THEN AGAIN CONNECTED TO THE CHARGING LINE.

THIS PROCESS OF CHARGING AND DISCHARGING IS CONTINUED UNTIL THE BATTERY WILL SUBMIT TO BEING FULLY CHARGED AND ALSO HOLDING ITS CHARGE. IT MAY TAKE THREE OR FOUR OF THESE CYCLES (CHARGES & DISCHARGES) TO GET RID OF MOST OF THE LEAD SULPHATE COATING, WHICH WAS ON THE PLATES. NEW BATTERIES OR BATTERIES PROVIDED WITH NEW PLATES, MUST ALSO BE CYCLED IN THIS WAY BEFORE THEY ARE PUT INTO ACTIVE SERVICE.

THE CORRECTION THERMOMETER

LET US NOW CONSIDER ANOTHER IMPORTANT USE OF THE THERMOMETER, WHICH WAS SHOWN YOU IN FIG. 14. NOTICE THAT TO THE RIGHT OF THE TEMPERATURE GRADUATIONS, A COLUMN OF FIGURES IS ARRANGED, THE ZERO FIGURE BEING EVEN WITH THE 70° MARK. THEN AT INTERVALS OF EVERY THREE DEGREES ABOVE 70°, YOU WILL SEE THE FIGURES +1, +2, +3, ETC; WHERES BELOW 70°, YOU WILL SEE THE FIGURES -1, -2, -3, ETC. SPACED EQUALLY OR AT INTERVALS OF 3 DEGREES.

THESE FIGURES ARE USED FOR MAKING TEMPERATURE CORRECTIONS WHEN HYDROMETER READINGS ARE TAKEN. THE REASON FOR THIS IS THAT THE HYDROMETER WAS DESIGNED AND CALIBRATED TO READ CORRECTLY AT A NORMAL TEMPERATURE OF 70°F. CONSEQUENTLY, AT TEMPERATURES ABOVE OR BELOW 70°F, THE HYDROMETER READINGS WILL BE IN ERROR.

TO USE THIS CORRECTION THERMOMETER, YOU FIRST TEST THE SPECIFIC GRAVITY OF THE ELECTROLYTE IN THE CONVENTIONAL MANNER AND THEN AFTER RETURNING THE TESTED ELECTROLYTE TO THE CELL FROM WHICH IT WAS WITHDRAWN, YOU INSERT THE THERMOMETER INTO THE ELECTROLYTE. IF THE THERMOMETER READING SHOULD BE 100°F., YOU WILL FIND THE NUMBER +10 RIGHT NEXT TO IT. THIS MEANS THAT IN ORDER TO OBTAIN A CORRECT SPECIFIC GRAVITY READING, 10 POINTS WILL HAVE TO BE ADDED TO THE ACTUAL HYDROMETER READING. THAT IS, IF THE HYDROMETER READING IS 1.250 AT A TEMPERATURE OF 100°F., THEN THE CORRECT SPECIFIC GRAVITY IS 1.250+10 POINTS, WHICH EQUALS 1.260.

WHEN THE TEMPERATURE OF THE ELECTROLYTE IS BELOW 70° F. SAY FOR INSTANCE 40°F., THEN WE MUST SUBTACT 10 POINTS FROM THE HYDROMETER READING. THIS WOULD MEAN THAT IF THE HYDROMETER READING IS 1.250 AT 40°F, THEN THE CORRECT SPECIFIC GRAVITY IS 1.250 MINUS 10 POINTS OR 1.240. IN OTHER WORDS, FOR EVERY THREE DEGREES ABOVE 70°F., ONE POINT IS ADDED TO THE HYDROMETER READING AND FOR EVERY THREE DEGREES BELOW 70° F., ONE POINT IS SUBTRACTED FROM THE HYDROMETER READING, IN ORDER TO OBTAIN A CORRECT VALUE FOR THE SPECIFIC GRAVITY.

FROM THIS EXPLANATION YOU WILL SEE HOW IT IS POSSIBLE TO OBTAIN AN ABSOLUTELY ACCURATE SPECIFIC GRAVITY READING REGARDLESS OF THE ELECTROLYTE'S TEMPERATURE AT THE TIME THE READING IS TAKEN.

CIRCUIT OF TEN-BATTERY TUNGAR RECTIFIER

NO DOUBT, YOU ARE INTERESTED IN THE CONSTRUCTIONAL FEATURES OF A COMMERCIAL TUNGAR BATTERY CHARGER, SO IN FIG. 20 WE ARE SHOWING YOU THE INTERNAL WIRING FOR A TYPICAL TUNGAR RECTIFIER WHICH IS CAPABLE OF HANDLING TEN BATTERIES AT ONE TIME.

WITH THE SPECIAL SWITCH IN THE CLOSED POSITION, THE A-C LINE IS CONNECTED ACROSS THE PRIMARY WINDING OF THE CHARGER'S TRANSFORMER AT TERMINALS 1, 2, 3 AND 4 WHILE THE D-C PART OF THE CIRCUIT IS ALSO COMPLETED AT THE SAME TIME ACROSS TERMINALS 5 AND 6.

A STEP-UP IN VOLTAGE IS OBTAINED AT THE SECONDARY WINDING OF THE TRANSFORMER BUT THE MANY POINTS AT WHICH TAPS ARE TAKEN OFF THIS WINDING MAKES A VARIETY OF LOWER SECONDARY VOLTAGES AVAILABLE. FOR INSTANCE, THAT PORTION OF THE SECONDARY WINDING INCLUDED BETWEEN ITS RIGHT END AND THE TAP NEXT TO IT FURNISHES A LOW VOLTAGE WITH WHICH TO HEAT THE FILAMENT OF THE TUNGAR BULB OR TUBE.

THE VARIOUS CONTACT BUTTONS OF THE DIAL SWITCH, WHICH ARE NUMBERED FROM 1 TO 15 IN CONSECUTIVE ORDER AND CONNECTED TO THE TAPS OF THE SECONDARY WINDING WHICH ARE CORRESPONDINGLY NUMBERED, OFFER A MEANS WHEREBY THE EFFECTIVE PLATE VOLTAGE AT THE TUNGAR BULB CAN BE REGULATED SIMPLY BY CHANGING THE POSITION OF THE DIAL SWITCH'S CONTROL ARM. THE CHARGING CURRENT IS INCREASED AS THE PLATE VOLTAGE UPON THE BULB IS INCREASED BY MEANS OF THE DIAL SWITCH.

THE TUNGAR BULB ITSELF HAS A FILAMENT AND A PLATE AS ITS ACTIVE ELEMENTS AND THUS FUNCTIONS AS A CONVENTIONAL HALF-WAVE RECTIFIER. ITS CONSTRUCTION, HOWEVER, IS SUCH THAT IT CAN PASS A NORMAL DIRECT CURRENT OF ABOUT 6 AMPERES.

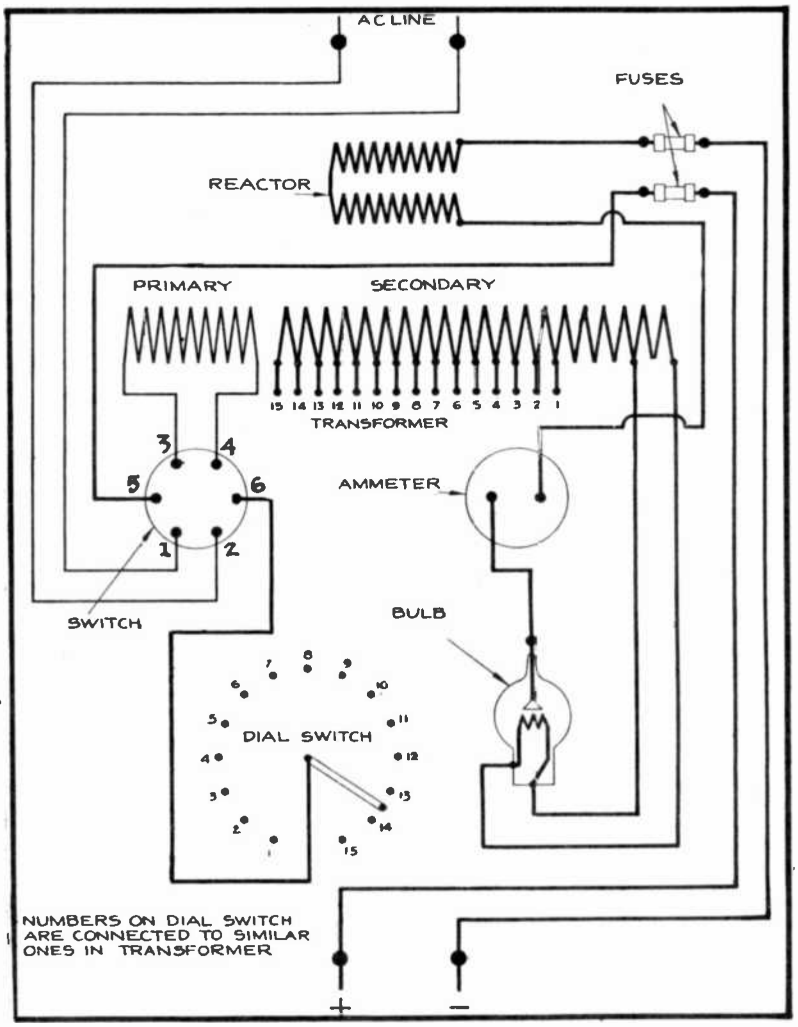

Fig. 20
Wiring Diagram of a Tungar Battery-charging Set

THE AMMETER IS CONNECTED IN SERIES WITH THE D-C CIRCUIT SO AS TO INDICATE THE CHARGING CURRENT AND THE REACTOR IS NOTHING MORE THAN A SPECIAL FILTER CHOKE, USED TO ASSIST IN OBTAINING A MORE UNIFORM CHARGING CURRENT.

UPON COMPLETING THIS GROUP OF STORAGE BATTERY LESSONS, YOU SHOULD NOW HAVE A GOOD PRACTICAL KNOWLEDGE OF THIS TYPE OF BATTERY FROM A STANDPOINT OF BOTH CONSTRUCTION AND SERVICING.

EVEN THOUGH YOU MAY NOT INTEND TO ACTUALLY ENGAGE IN THE BATTERY BUSINESS, YOU SHOULD NEVERTHELESS FIND THESE BATTERY LESSONS TO BE OF VALUE TO YOU. AFTER ALL, THE STORAGE BATTERY PLAYS AN IMPORTANT PART IN YOUR CHOSEN FIELD AND BY HAVING THIS INFORMATION, YOUR GENERAL KNOWLEDGE OF THE SUBJECT IS EXPANDED.

EXAMINATION QUESTIONS

LESSON NO. 34

1. - HOW DOES A HARDENED COATING OF LEAD SULPHATE AFFECT A CELL AND ITS PLATES?

2. - WHAT IS MEANT BY THE TERM BUCKLED PLATES? HOW MAY THIS CONDITION BE CAUSED AND WHAT WOULD YOU DO IF YOU HAD TO CORRECT SUCH A FAULTY CONDITION?

3. - HOW WILL AN EXCESSIVE AMOUNT OF SHEDDING AFFECT A CELL?

4. - AT ABOUT WHAT TEMPERATURE WILL A DISCHARGED BATTERY FREEZE? AT ABOUT WHAT TEMPERATURE WILL A FULLY-CHARGED BATTERY FREEZE?

5. - IF YOU SHOULD DISASSEMBLE A CELL, WOULD YOU PUT THE SAME WOODEN SEPARATORS BACK INTO THE CELL?

6. - WHY IS A HIGH-RATE DISCHARGE TESTER USED?

7. - (A) WHAT IS THE OBJECT OF MAKING A CADMIUM VOLT TEST?
(B) CAN THIS TEST BE MADE AND ACCURATE RESULTS OBTAINED IF THE BATTERY IS STANDING IDLE?

8. - WHAT IS THE HIGHEST TEMPERATURE WHICH A BATTERY SHOULD BE ALLOWED TO REACH?

9. - WHY ARE BATTERIES SOMETIMES CYCLED?

10. - WHY IS THE CORRECTION THERMOMETER USED?

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LESSON NO. 35

TUNING INDICATORS

Many receivers are equipped with a device whereby the set-owner can see at a glance whether or not he has tuned his radio properly for reception of the desired program. By this means, he is able to tune more accurately than by relying on his sense of hearing.

Such devices which provide a visual indication of the accuracy of tuning are generally known as RESONANCE INDICATORS or TUNING INDICATORS. However, additional distinctive names have been given them by manufacturers for the purpose of "trade-marking" them as to type. Tuning indicators are therefore variously known as the shadow-tuner, tune-a-lite, flash-o-graph, tuning-eye, etc. These and others are all described in this lesson.

Tuning indicators -- being visual devices -- are generally placed as near as possible to the receiver's tuning dial or else incorporated in it. This is done so that the operator can continually observe the indicator as different stations are being tuned in. A typical arrangement is shown in Fig. 1, where the tuning indicator is located directly above the tuning dial. Tuning indicators are advantageous on super heterodynes that are equipped with an a-v-c system.

FIG. 1
CATHODE-RAY TUNING INDICATOR
PLACED ABOVE TUNING DIAL

FUNDAMENTAL PRINCIPLES

Tuning indicators are generally connected in some portion of the r-f or i-f stages of the receiver, as in dealing with the operation of tuning indicators we are directly concerned with the tuning of the r-f stages.

From your study of a-v-c systems in a previous lesson, you will recall that the grid bias of certain r-f and i-f amplifier tubes is increased by a-v-c action in proportion to the signal strength, and that the amplification factor of the tubes decreases as a consequence. Also, when the grid bias of any tube is made more NEGATIVE, the plate current of the tube DECREASES -- the decrease in plate current being nearly proportional to the increase in negative bias.

This means that if a device for measuring current is connected in the plate circuit of one or more tubes under control, the current through the device will decrease in proportion to the strength of the signal being received. That is, the stronger the signal, the greater will be the deflection of the indicator; and, since the strongest signal is always obtained when the tuning circuits are in exact resonance with the incoming signal-frequency, the meter reading will show whether or not the receiver is tuned to exact resonance with the signal being received. It will then not be necessary for the operator to depend solely upon his sense of hearing to ascertain when a condition of exact resonance is obtained.

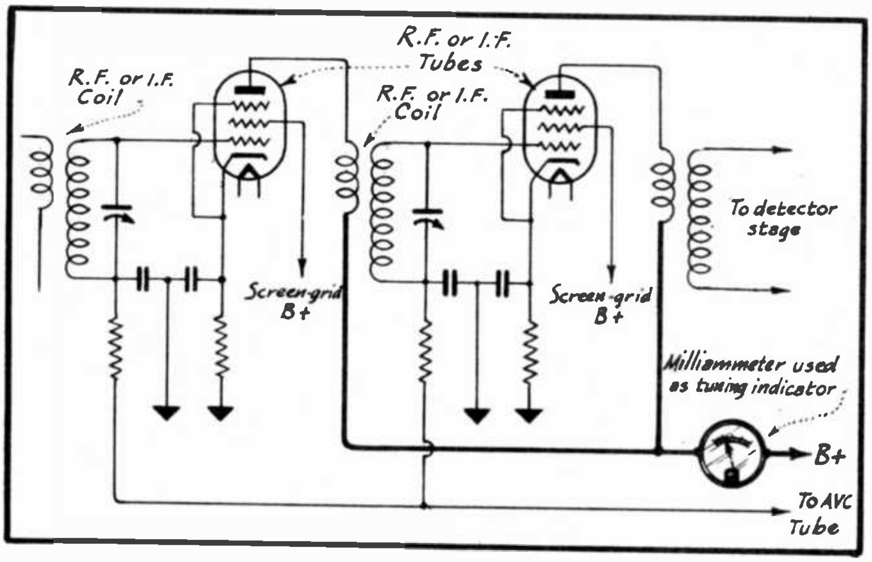

FIG. 2
APPLICATION OF A D-C MILLIAMMETER AS A TUNING INDICATOR

TUNING METERS

The circuit as presented in Fig. 2 illustrates how this principle may be applied in practice. Let us suppose, for example, that the combined plate current of the two tubes controlled by a-v-c is 20 ma. when no signal is being received. Let us further assume that the grid bias is at a minimum value of 3 volts.

When a sufficiently strong signal is tuned in, the grid bias increases automatically because of the a-v-c action -- for instance, to 25 volts. The plate current then will drop to some lower value -- for example, 5 ma. Thus, it is seen that the strength of the r-f or i-f signal which is applied to the grid of these tubes varies the plate current in a definite manner.

Therefore, if an ordinary d-c milliammeter is connected in the common plate circuit of these two a-v-c controlled tubes, it will register the total plate current flowing through it. Then, since the plate current of the controlled tubes will vary with the signal input and a-v-c controlled bias, as already explained, the meter reading will be minimum when the circuits are tuned to resonance with the signal and will approach a maximum as the circuits are detuned from resonance.

To tune a receiver that is equipped with this type of resonance indicator, it is necessary to first set the dial at the approximate point for tuning-in the station desired, and then, while watching the meter, to adjust the tuning dial carefully until the meter indicates a MINIMUM reading.

The scale of a tuning meter is generally reversed, or else the meter is mounted upside down, so that it reads BACKWARD to the conventional type of testing meter. Then, as the plate current decreases, the meter needle will swing toward the right instead of toward the left. This action appears to be more natural to those who are not familiar with the technicalities of radio, and enables the manufacturer to instruct the set-owner to simply adjust his tuning dial so that the needle of the tuning meter swings farthest to the right.

The more commonly used scale arrangements for tuning meters are shown in Fig.3. All of the meters here shown are ordinary low-reading d-c milliammeters, with the exception that the scale-calibrations are indicative of resonance conditions in the circuits rather than of the actual amount of current flowing through the instrument.

The meter shown at (A) is placed in an inverted position, and the direction of needle-swing for minimum plate current is indicated by the arrow marked "TUNE FOR GREATEST SWING." Hence, exact resonance exists when the needle reaches its maximum position toward the right for any given station.

The meters shown at (B) and (C) of Fig. 3 have reversed calibrations designating various figurative or quantitative units, such as degrees, decibels (db), or numbers. The latter are usually referred to as "R" or "S" units -- these letters being selected by the particular manufacturer to represent "resonance" or "signal strength".

This method of indicating resonance, and the amount of signal strength, has become standard with manufacturers that use meters as tuning indicators.

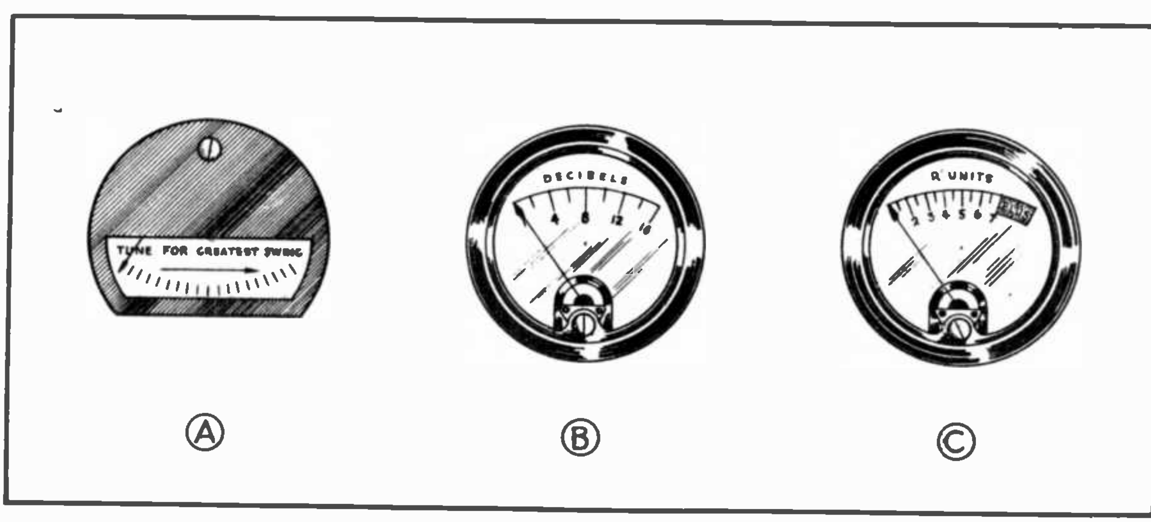

FIG. 3
THREE COMMON TUNING-METER CALIBRATIONS

Tuning meters are used extensively on amateur and communication type receivers, due to their sensitiveness to weak signals and also because they can be calibrated accurately and read with precision.

SHADOWGRAPH TUNING INDICATOR

The shadowgraph tuning indicator is a unique device which indicates the condition of resonance by means of a shadow on a luminous screen. When the receiver is tuned to resonance with a station, the shadow is narrowest; as the receiver is detuned from the station, the shadow becomes wider.

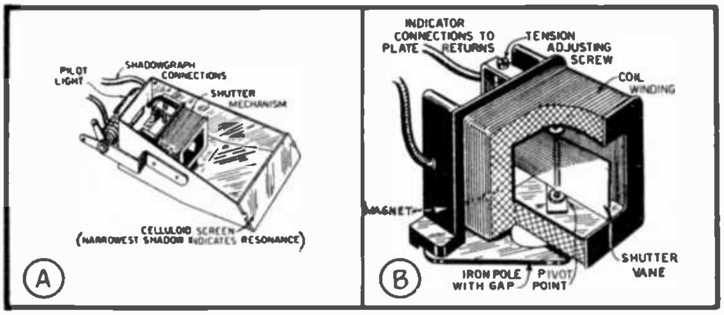

FIG. 4
DETAILS OF SHADOWGRAPH TUNING INDICATOR

This type of tuning indicator is somewhat similar to the milliammeter just described, and is also connected in the circuit in a similar manner. However, it differs somewhat as to mechanical construction in that the needle is replaced by a shutter that intercepts a beam of light which is focused on a translucent (transparent) screen.

The constructional details of this tuning indicator are shown in Fig. 4, where you will observe that the complete unit is housed in a small wedge-shaped metal box, as shown at (A). A celluloid screen is placed at the narrow end of the box -- light furnished by a pilot lamp at the other end of the box being focused upon it.

The operating mechanism is shown at (B) of Fig. 4, and is placed at the rear of the box between the lamp and screen as shown at (A). This unit comprises a coil of wire, a metal deflecting vane (shutter), and a permanent magnet. The shutter is pivoted inside of the coil, as shown at (B) of Fig. 4.

When no current flows through the coil, the vane will be held in the position shown at (A) of Fig. 5, under the influence of the permanent magnet. This is the neutral position.

When the pilot lamp is in operation, light emitted by it will pass through a rectangular slit in the rear of the box and will illuminate the screen. The entire screen is thus illuminated except for a thin shadow of the vane.

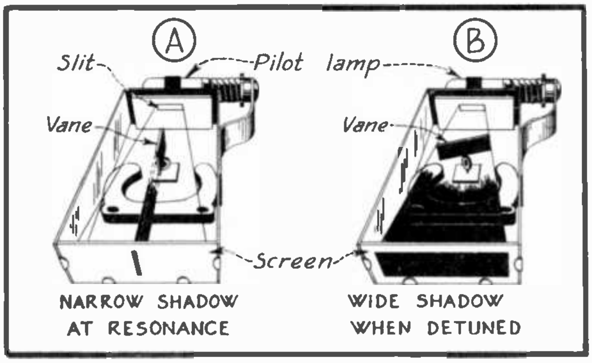

FIG. 5
HOW THE SHADOW-WIDTH IS VARIED

Now, if the shutter vane is turned on its pivot slightly to the right or left, the light from the pilot lamp will be intercepted somewhat more, causing a wider shadow to appear on the screen. The more nearly that the shutter vane is turned to a position at right angles to its normal or neutral position, the wider will be the shadow on the screen. See (B) of Fig. 5.

If current is now sent through the coil, an additional magnetic field will be produced -- this field will be at right angles to that created by the permanent magnet. The shutter vane will then tend to align itself in the direction of the resultant of these two fields. If conditions happen to be such that the field produced by the flow of current through the coil is as strong as that of the magnet, the vane will be deflected 45 degrees from its neutral position. Therefore, as the current through the coil increases or decreases, the vane turns to the left or right, accordingly, causing the width of the vane's shadow on the screen to increase or decrease correspondingly.

The coil of the shadowgraph unit is connected in series with the plate circuit of the r-f or i-f tubes under the influence of a-v-c in the same manner as shown previously for the milliammeter connection. When a station is being tuned-in, the a-v-c voltage increases as resonance is approached; this voltage being greatest,and the plate current of each controlled tube least, at resonance. This diminished plate current flowing through the coil reduces the coil's field so that the permanent magnet's field predominates and causes the vane to swing to a position more nearly at right angles to the screen. The shadow on the screen is therefore comparatively narrow. If a stronger signal is tuned-in,the minimum shadow width will be still narrower at resonance; hence, for any signal strength encountered, there is a minimum shadow width which indicates exact resonance.

Illustration (A) of Fig. 5 shows the narrow shadow obtained at resonance while (B) shows the wide shadow obtained when the receiver is detuned from a station.

NEON-TUBE TUNING INDICATORS

This type of tuning indicator consists of an elongated glass tube containing two electrodes,and is filled with neon gas and sealed. This device makes use of the fact that greater voltages applied to its terminals cause a longer (higher) column of colored light to appear in the tube. The height of this column of light is dependent upon the signal voltage in the r-f or i-f circuits of the receiver.

This action is somewhat analogous to the action of a thermometer, where more heat applied to the bulb of the thermometer causes the column of mercury to rise to a higher level. This type of indicator is also known as a TUNE-A-LITE or FLASH-O-GRAPH. With these fundamental facts in mind, let us now see how this action is brought about.

<u>PRINCIPLE OF THE NEON TUBE</u>: Upon connecting the electrodes of the neon tube across a d-c voltage of sufficient magnitude, as shown at (A) of Fig. 6,a colored glow of light will appear around the electrode which is connected to the negative terminal of the voltage source. This glow may be orange, red, green,or blue, depending upon what other chemicals are mixed with the neon to produce the color desired. In any case, this glow is produced in the following manner:

The neon gas inside of the tube consists of millions upon millions of molecules which, under ordinary conditions, are electrically neutral; that is, they are neither positively nor negatively charged. However, upon applying a relatively high d-c voltage across the elements within this tube, many of these molecules will be broken up into electrical charges -- that is, into the negative ions (electrons) and positive ions of which the gas molecules are composed. This process is called <u>ionization</u>.

The positively charged electrode attracts with tremendous force and speed any free negative electrons which may be floating around in

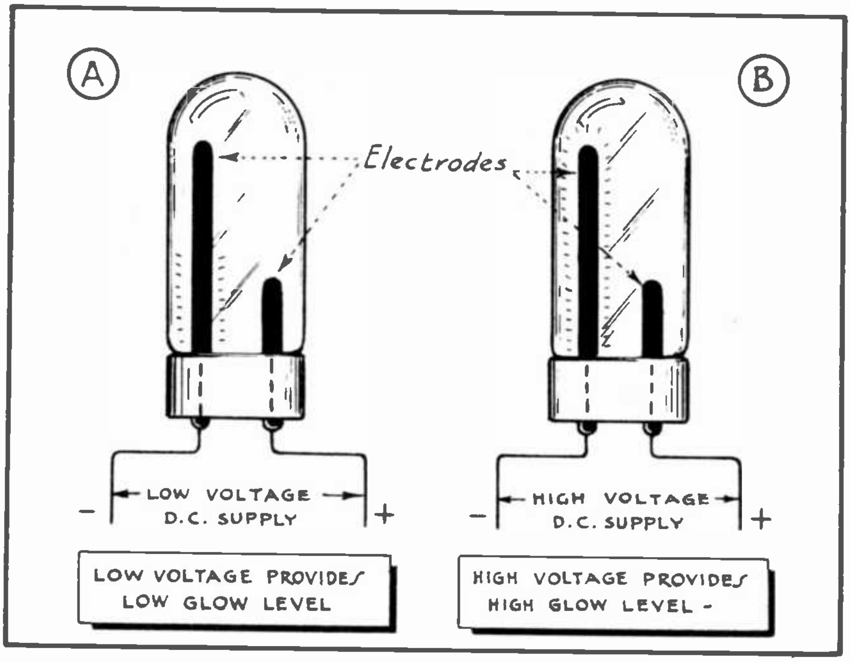

FIG. 6
PRINCIPLE OF THE FLASH-O-GRAPH

the gas. However, before one of these electrons can get very far, it collides with a neutral gas molecule that lies in its path and by collision liberates from it one or more electrons. During this frenzy of motion within the tube many of the free electrons re-combine with the positive ions to re-form the original gas, giving off light as they do so.

This action is most violent near the negative electrode, as this electrode repels the free negatively-charged electrons with such violence that the dissociation of neutral molecules and the re-combining of the electrons and positive ions is most pronounced in this region. Therefore, the glow (light) is concentrated around the negative electrode.

The greater the voltage applied across the electrodes, the more violent will be the action within the tube and the more intense will be the illumination obtained thereby. Since there is a natural tendency for the glow to confine itself around the negative electrode, a greater voltage will cause the glow to rise to a higher level along the elongated electrode, as illustrated at (B) in Fig. 6. Conversely, the application of a lesser voltage causes less of the negative electrode to be illuminated.

This same principle of obtaining light from neon gas is employed in some forms of electrical testing equipment and in the neon signs which are being used so extensively.

APPLICATION OF THE NEON TUBE AS A TUNING INDICATOR

Fig. 7 illustrates how the neon tube, just described, is connected in a receiver circuit to serve as a tuning indicator. Here you will observe that resistor R is connected in series with the plate circuit of all the r-f or i-f tubes. The short electrode of the tuning indicator is connected to the plate-end of this resistor and the long electrode to the B+ end of the same resistor, but through potentiometer R-1. The latter also serves as a bleeder between B+ and B-. The arm of this potentiometer is generally so set as to keep the long electrode of the neon tube at a potential of about 90 volts below B+.

From what has already been explained in this lesson, you will recall that when an r-f signal voltage is applied to the grid of an r-f or i-f amplifier tube, the plate current increases and decreases with the signal, but the average plate current remains constant. How-

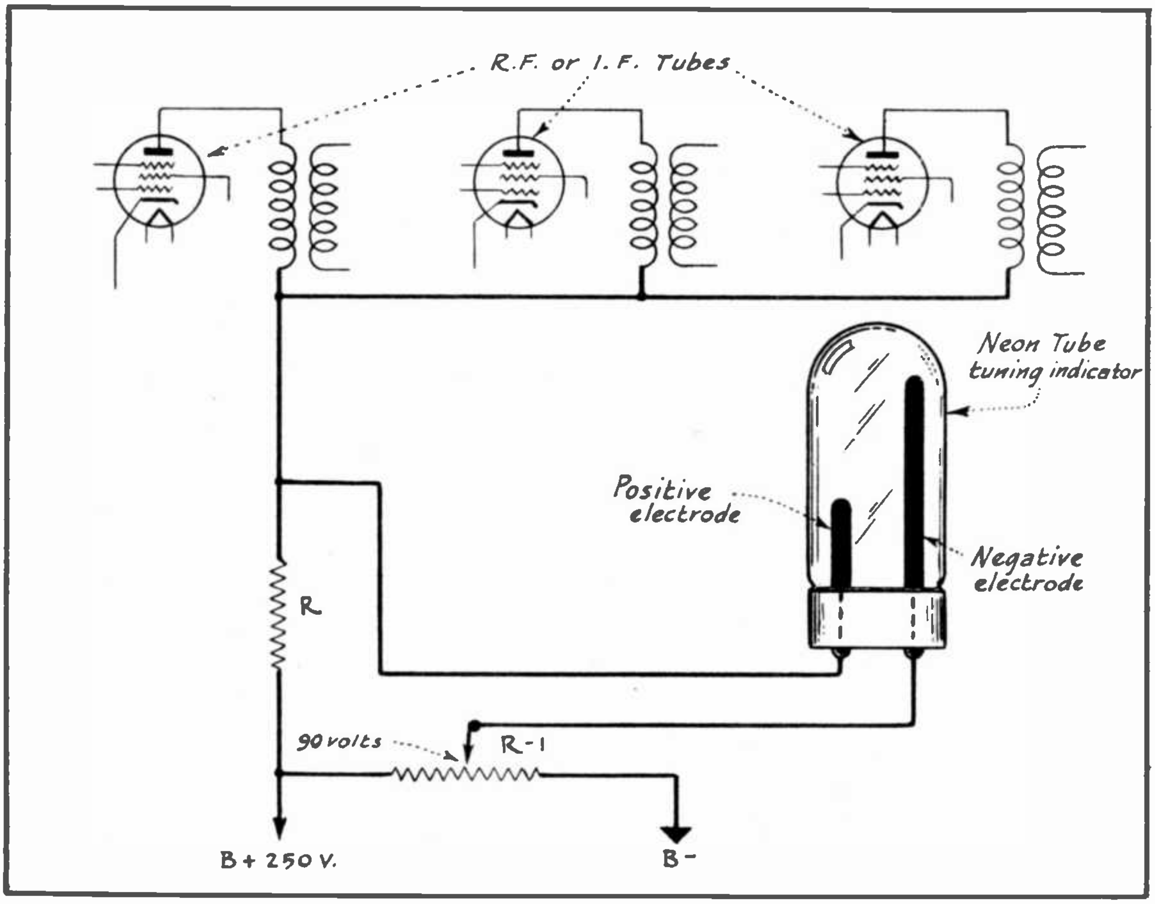

FIG. 7
APPLICATION OF THE FLASH-O-GRAPH

ever, when an r-f signal is fed to an a-v-c tube in a receiver, the a-v-c bias voltage, which is in turn affected, reduces the average plate current of the a-v-c controlled tubes and thus causes an increase in the actual plate voltage of the controlled tubes, due to a decrease in the voltage drop across any resistor that may be connected in the plate circuit of the tube or tubes. The neon tube resonance indicator makes use of this condition in the following manner:

When no signal is tuned in, the plate current of the three tubes (which may be either r-f or i-f amplifier tubes under a-v-c control) is high, and the voltage drop across R is also considerable, as shown at (A) in Fig. 8, where, for illustrative purposes, we have assumed the plate current of the a-v-c controlled tubes to be 10 ma. at no signal, and the voltage drop across R as 90 volts. This 90 volts will oppose the 90 volts developed across the arm of R-1 and B+; therefore, the net voltage across the electrodes of the neon tube is zero. Such being the case, no glow of light will appear in the tube at this time.

As a signal is being tuned in, and the point of resonance approached, the increasing signal strength will cause the plate currents of the a-v-c controlled tubes to decrease. This, in turn, causes the voltage drop across R to decrease. Let us assume, for example, that this voltage falls to 30 volts. The net voltage applied across the electrodes of the neon tube then increases to 90 minus 30, or 60 volts, as shown at (B) of Fig. 8. In other words, the long or so-called nega

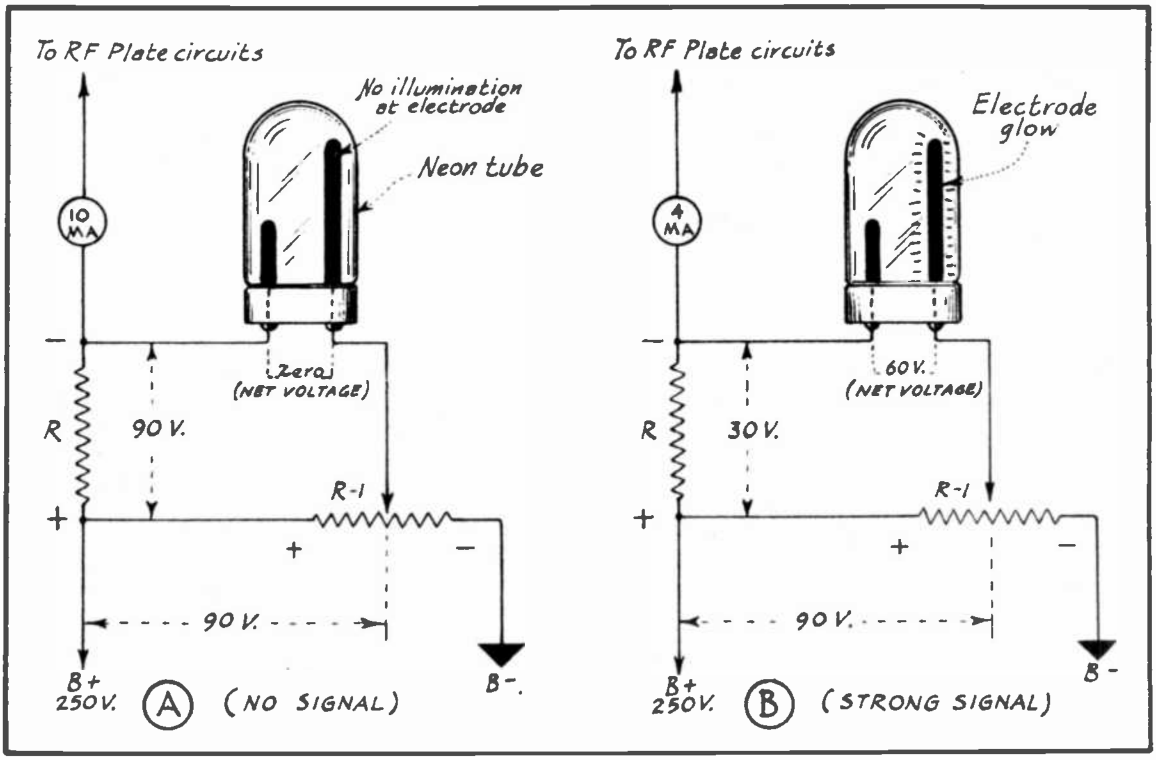

FIG. 8
EFFECT OF SIGNAL UPON THE FLASH-O-GRAPH

tive electrode of the neon tube is now 60 volts more negative than the short electrode.

A voltage of sufficient magnitude is now applied across the electrodes of the neon tube so as to cause the necessary amount of ionization to produce a glow of light around the long electrode. The voltage drop across R will be at a minimum value when the receiver is tuned to resonance with the signal being received. This will result in a maximum voltage across the terminals of the neon tube and a maximum height of the column of light in the neon tube. The receiver is therefore tuned until the column of light in the neon tube attains its greatest height.

PILOT LAMP RESONANCE INDICATOR

Some manufacturers utilize the regular dial lamp of the receiver for indicating when the radio has been tuned exactly to resonance with the incoming signal. This is made possible by a variation in the illumination of the dial lamp as stations are tuned in and out. The tuning circuits are in absolute resonance when the lamp is dim; the light becomes brighter as the point of resonance is passed.

While the action seems rather simple, the method for obtaining this effect is rather elaborate and somewhat complicated. In Fig. 9 is shown a typical circuit arrangement for the application of this system of tuning. From a close inspection of this circuit, you will observe that a saturable-core reactor (an iron-core choke coil with three legs and three windings) is incorporated in it. The basic idea in this case is to cause the changes in the d-c plate current of the a-v-c controlled tubes in the receiver to also control the flow of a-c through the dial lamp by means of the action of this saturable-core reactor.

As shown in the schematic diagram, the two coils, A_1 and A_2, have an equal number of turns and are mounted on the outer legs of the reactor core. They are connected in series with each other as well as with the dial lamp -- the latter obtaining its operating voltage from a secondary winding on the power transformer. These two coils are connected together so as to assist one another in producing an a-c magnetic flux around the outside legs of the core, as shown by the small arrows labeled as such. The center winding, D, is connected in series with the plate circuits of all the tubes which are controlled by the a-v-c system; the latter winding therefore carries the total d-c plate current of these tubes.

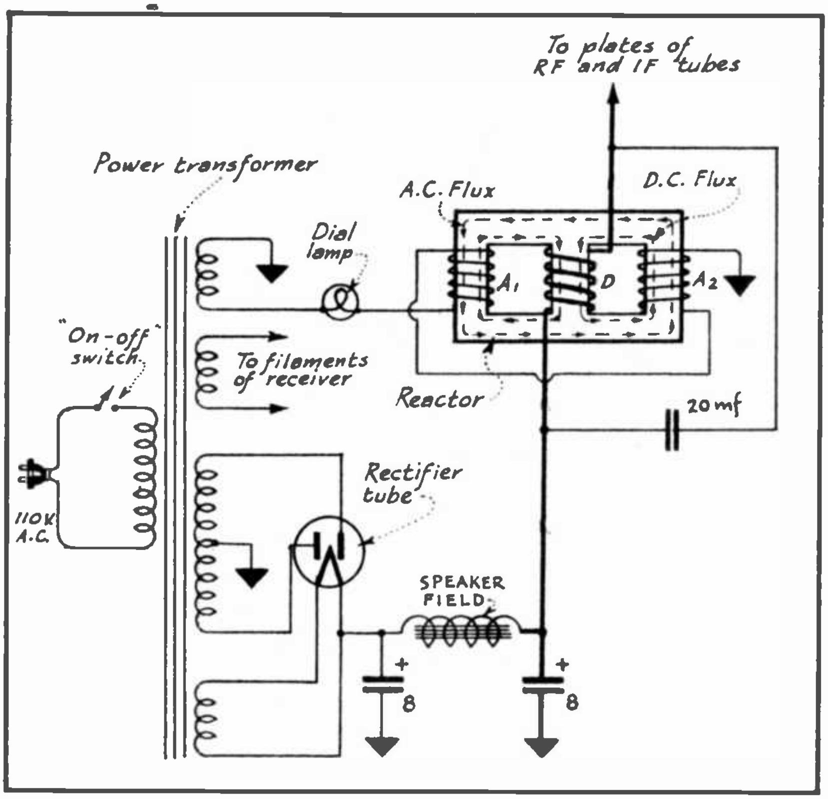

FIG. 9
CIRCUIT EMPLOYED WITH THE PILOT LAMP RESONANCE INDICATOR

When the receiver is not tuned to resonance with the signal of any station, a relatively high d-c plate current flows through winding D, since the a-v-c controlled tubes draw maximum plate current at this time. This current flowing through coil D sets up a d-c magnetic flux that follows the two paths which are labeled in the illustration as "d-c flux." The reactor is so designed that this d-c flux magnetizes the iron core beyond its saturation point. The a-c dial lamp current flowing thru coils A_1 and A_2 does not produce any appreciable change in magnetization of the iron, because of the iron being worked past its saturation point at this time. Consequently, as the opposition to the flow of a-c through these coils is now low, the full current flows through the dial lamp circuit, lighting the dial lamp at full brilliance.

When the receiver is tuned to a station, the negative bias placed on the a-v-c controlled tubes by virtue of the a-v-c action REDUCES the plate currents of these tubes. The more nearly the receiver is tuned to the incoming signal, the lower will be the plate current of these tubes. Then, since this current flows through the center coil D of the reactor, the d-c magnetic flux in the core diminishes in strength rapidly as the point of resonance is approached. This allows the core to operate below its magnetic saturation point, so that now the a-c dial lamp current flowing through coils A_1 and A_2 is able to produce cyclic variations of the magnetism in the core. This greatly increases the reactance and impedance (total opposition toward a-c) of these coils, thereby limiting the flow of dial-lamp current flowing through them and thus causes the lamp to operate at reduced brilliance. The nearer the receiver is tuned to resonance with the incoming signal, the less will be the illumination offered by the dial lamp. Thus, the dial lamp serves as a resonance indicator.

The 20 mf condenser is shunted across winding D so that these two units will function together as a filter, thereby preventing hum being induced into the B+ lead by the flow of a-c through windings A_1 and A_2.

CATHODE-RAY TUNING INDICATOR

The cathode-ray tube in a form known as the "magic eye," "tuning eye," "electron tuning indicator," etc., has gained widespread popularity. This is a special miniature combination triode and cathode-ray tube, similar in appearance to any other glass radio tube.

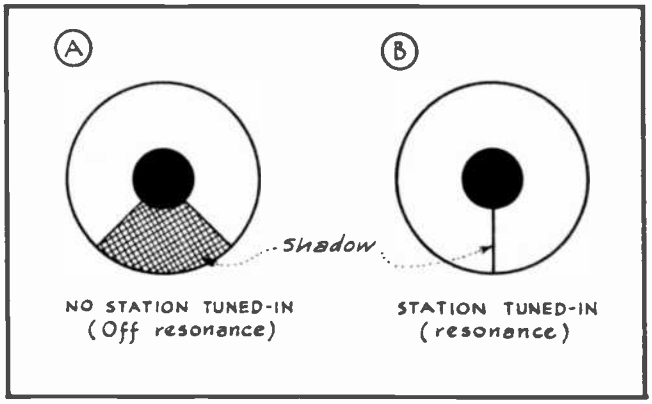

FIG. 10
CATHODE-RAY TUNING INDICATOR PATTERNS

The triode section serves for resonance indication by acting as a d-c amplifier. The electron-ray (cathode-ray) section causes a shaded area of narrow or wide proportions to appear upon fluorescent substance applied to a target, the width of this shaded area depending upon the value of the voltage fed to the input of the triode section. When not tuned to resonance with any station, the shadow area is comparatively large as shown at (A) of Fig. 10. The narrowest shadow obtained from a given signal indicates absolute resonance as at (B) of Fig. 10.

The construction of a typical cathode-ray tuning indicator tube is shown at (A) of Fig. 11, while (B) shows an enlarged view of the placement of the principal elements. The triode elements are located at the lower end of the tube, but the cathode extends upward thru a central opening in the target as does also a small extension of the plate. The latter is called the RAY CONTROL ELECTRODE. The target is coated with a fluorescent substance that glows with a green color when bombarded by a stream of electrons. Now, let us study the operating principles.

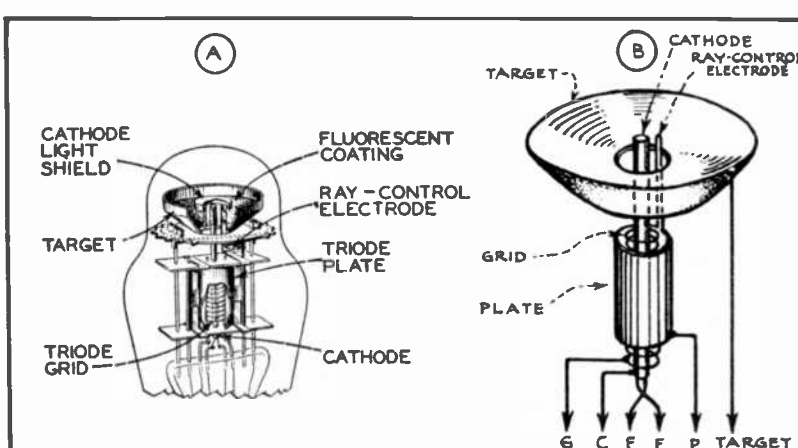

FIG. 11
STRUCTURAL DETAILS OF CATHODE-RAY TUNING INDICATOR TUBE

OPERATION OF THE TUBE: In Fig. 12 is shown the tube symbol and typical circuit connections for the application of such a tube. Here, you will observe that the target of the tube is connected directly to the positive side of the "B" power supply -- to a point of at least 90 volts potential. The plate is also connected to B+, but through a one megohm resistor. Thus, the positive potential of the plate and the ray-control electrode are lower in value than that of the target. The connection being such, it is apparent that the target will be maintained at a high positive potential of constant value, while the voltage effective at the plate and ray-control electrode varies in accordance with changes in the plate current. This can be explained in the following manner:

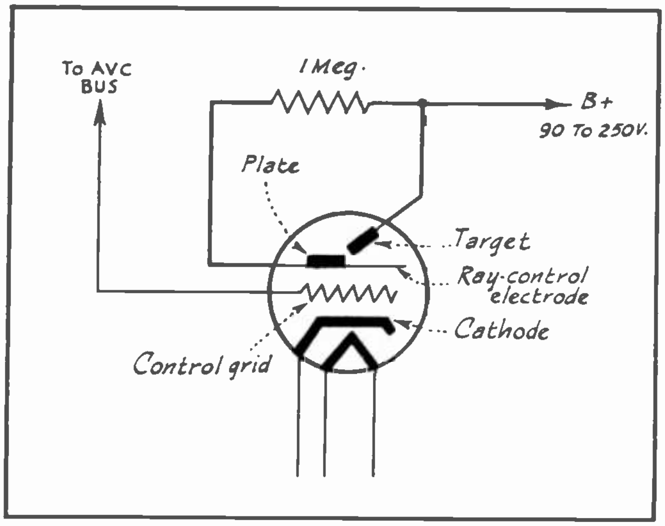

FIG. 12
SYMBOL OF THE CATHODE-RAY TUNING INDICATOR

When no voltage is applied to the grid, the plate current through this tube will be of a relatively high value, the voltage-drop across the one megohm resistor will be considerable and the ray-control electrode will therefore be less positive than the target; thus, it will actually be at a negative potential with respect to the target because the flow of current through the one-megohm resistor is in such a direction as to make the plate-end of this resistor negative with respect to the target-end. Under these conditions, electrons flowing toward the target are repelled by the electrostatic field of the ray-control electrode, and do not reach that portion of the target behind this electrode. Because the target does not glow where it is shielded from electrons, the control electrode causes a shadow to appear on the glowing target. The distribution of electrons at this time is illustrated at (A) of Fig. 13.

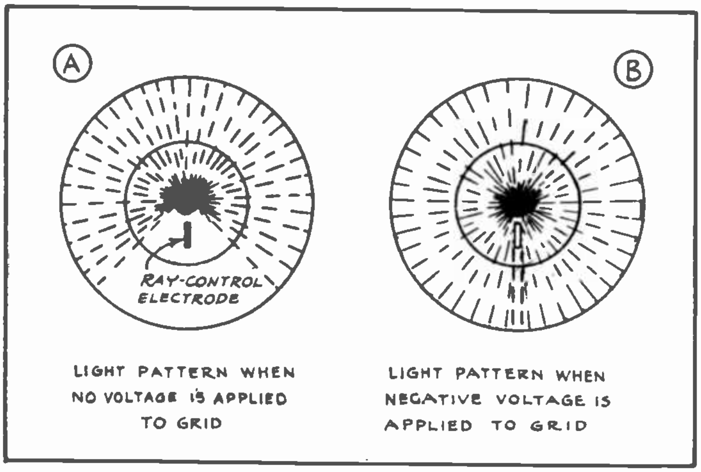

FIG. 13
HOW CHANGES IN POTENTIAL OF RAY-CONTROL ELECTRODE AFFECT THE TARGET

In this illustration, you are looking down upon the target-end of the tube; the dotted lines represent the flow of the electrons. Notice, particularly, how the ray-control electrode deflects many electrons from a straight-line path toward the target.

Now, let us suppose that a negative voltage is applied to the grid. Under such conditions, the plate current will decrease, and the voltage drop across the resistor will decrease. Therefore, a positive potential of greater magnitude than formerly will be applied to the ray-control electrode, and the ray-control electrode will as a consequence be less negative with respect to the target.

The effect of this condition is shown at (B) of Fig. 13. Here you will observe that the decrease in the potential-difference between the ray-control electrode and target causes this electrode to exert a lessened repelling force upon the electrons emitted by the cathode,and thus permits the electrons to follow a more straight-line path toward the target. This causes a larger area of the target to become illuminated, and thereby decreases the shadow-area.

The higher the negative voltage applied to the grid, the lower will be the plate current and the greater the area of target illumination.

APPLICATION OF THE TUBE: When using this tube as a tuning indicator in radio receivers, the grid is connected to the receiver's automatic volume control (a-v-c) circuit, which system applies a higher negative voltage to the grid when the receiver is tuned to absolute resonance with the station being received. Therefore, the target illumination will be greater at resonance. This method of connecting the tuning indicator differs from those so far described in this lesson -- the latter are connected in the plate circuits of the r-f and i-f tubes, whereas the cathode-ray indicator is connected to the a-v-c bus.

Fig. 14 shows a typical connection of a cathode-ray tube to an a-v-c distribution system. Here you will note the connections to be

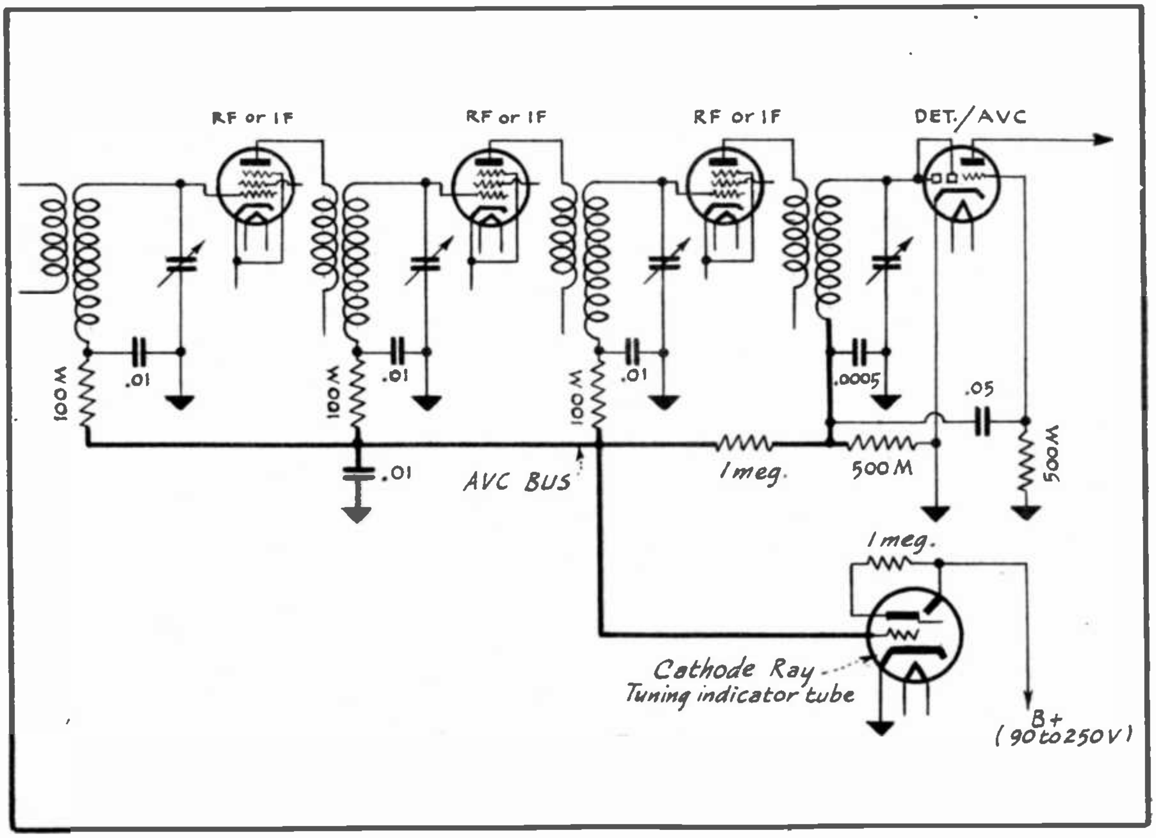

FIG. 14
APPLICATION OF CATHODE-RAY TUNING INDICATOR IN RECEIVER CIRCUIT

such that the area of the tube's luminous screen is determined by the amount of the negative bias voltage applied to either the r-f or i-f amplifier tubes by the a-v-c system. Hence, since the a-v-c voltage is at a maximum when the set is tuned to resonance with a station, the shadow-angle will be at a minimum at this time, as shown at (B) of Fig. 13.

CATHODE-RAY TUNING INDICATOR FOR RECEIVERS NOT EQUIPPED WITH A-V-C

All of the tuning indicators that we have discussed so far have been used in conjunction with receivers employing an a-v-c system and a diode type detector. However, the cathode-ray tube can also be used in receivers having neither an a-v-c system nor a diode detector. In other words, this arrangement can also be used in either t-r-f or superheterodyne receivers that employ a power detector. The circuit connections are then made as shown in Fig. 15.

The system operates as follows: The arm of potentiometer R-2 is set at the cathode-end of its resistance element. This places a positive voltage, equal to the no-signal bias of the detector, on the grid of the cathode-ray tube, opening the "eye" (producing a wide shadow). Rheostat R-1 in the cathode-ray tube circuit is next adjusted just to close the "eye" to a narrow line.

Now, when an r-f signal is tuned in, the plate current of the detector tube rises. This causes the voltage-drop across R-2 to increase, and the window pattern of the cathode-ray tube to open slightly. At the point of resonance, the pattern will have opened to a maximum; detuning the receiver causes it to close again. The cathode-ray tube thus acts as a visual tuning indicator, but in this case its pattern movement is reversed to that obtained by its previously explained applications. However, this reversed operation of the "eye," or shadow, is not especially objectionable -- we need only remember in this case that the greatest shadow indicates the point of resonance.

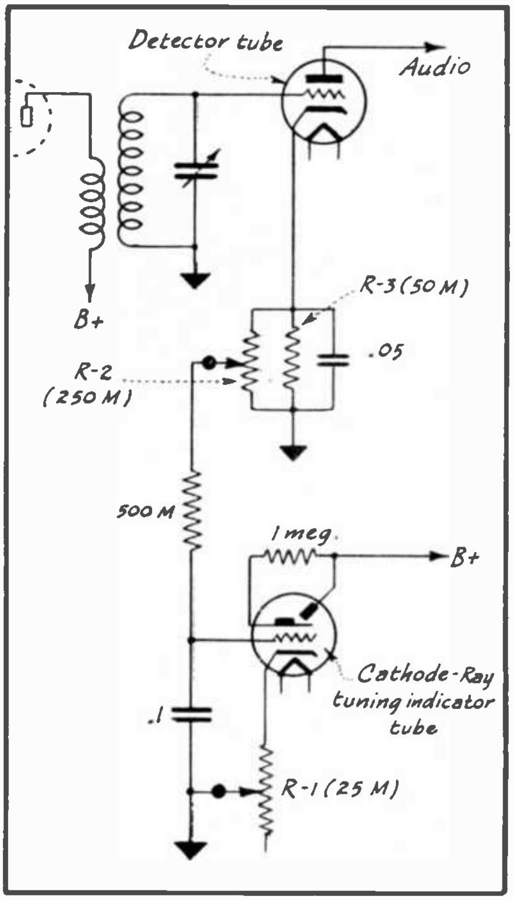

FIG. 15
APPLICATION OF CATHODE-RAY TUNING INDICATOR TO NON-A-V-C RECEIVERS

Should a very strong signal develop so much voltage across R-2 that the pattern opens fully and loses its indicating value thereby, it is then only necessary to move the arm of R-2 toward the grounded end of this potentiometer. Rheostat R-1 is then readjusted for a closed pattern, under no-signal conditions.

TWIN CATHODE-RAY TUNING INDICATOR TUBES

There are several variations in cathode-ray tuning indicator tubes -- one such variation is shown in Fig. 16. Here you will observe that the indicator tube has a filament, cathode and target, but no grid as do the more conventional cathode-ray tuning indicator tubes; and, instead of the usual single ray-control electrode, it has two such electrodes mounted on opposite sides of the cathode and connected to individual base pins.

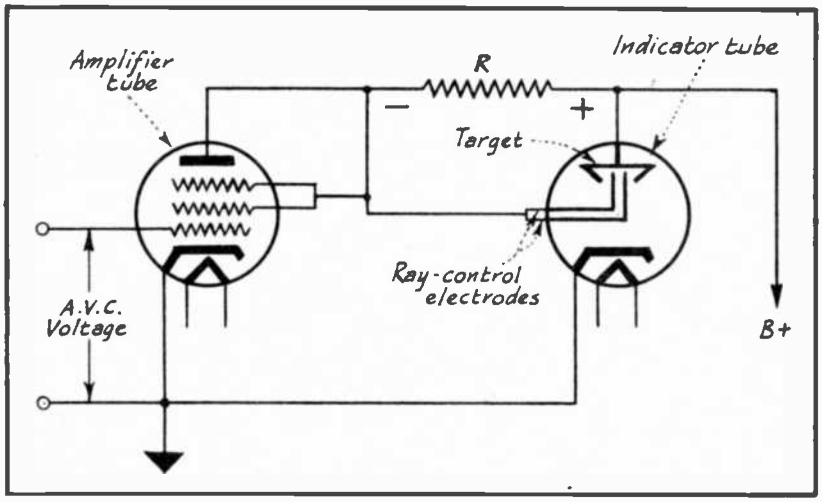

Fig. 16
How Synchronized Twin Patterns are obtained

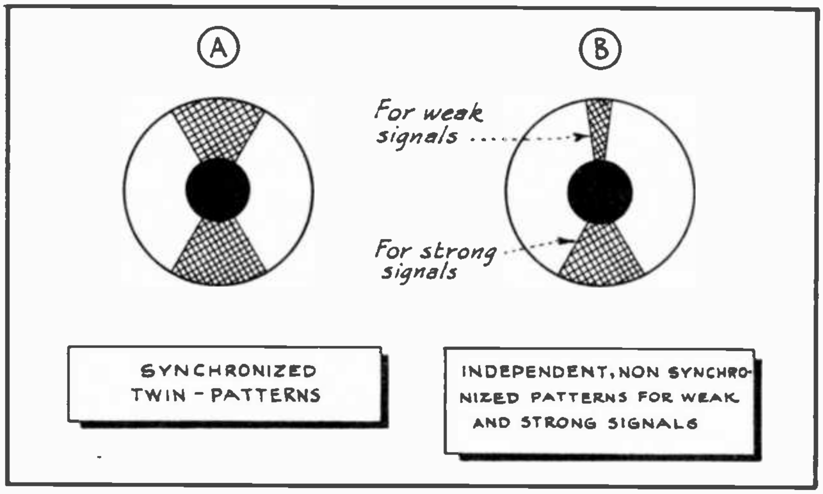

Fig. 17
Synchronized and Non-synchronized Twin Patterns

Because of the grid being eliminated in this case, a separate tube must be used as an amplifier for operating the "eye". Fig. 16 also shows how such an amplifier tube is used in conjunction with the indicator tube.

In this particular case, a pentode is being used as a triode amplifier by connecting together the screen grid, suppressor grid, and the plate. This circuit operates in the following manner:

Application of a-v-c voltage across the control grid circuit of the amplifier tube controls the plate current passed by this tube. This plate current must flow through resistor R which is connected in series with this tube's plate and B+. The volt-drop produced across R is applied between the target and ray-control electrodes of the indicator tube, causing the control electrodes to be negative with respect to the plate. Therefore, any change in the a-v-c voltage, as produced during the process of tuning, causes a corresponding change in the plate current passed by the amplifier tube and in the voltage-drop produced across R.

Any such change in the potential-difference between the target and control electrodes causes a change in the area of the indicator tube's illuminated pattern, in the same manner as already explained for the more conventional cathode-ray tuning indicator tube described earlier in this lesson. However, the placement of the control electrodes in the indicator tube used in Fig. 16 is such as to produce two patterns located diametrically opposite from each other as illustrated at (A) of Fig. 17, but which open and close in absolute synchronism (as one) with changes in a-v-c voltage.

Sometimes, the eye-opening of the cathode-ray tuning indicator tube is so wide when tuned to weak stations that the variations in the shadow-angle are not great enough to be observed accurately while tuning to such stations. In other cases, strong signals from nearby stations cause the shadow boundaries to overlap when the receiver is tuned to resonance. Both of these conditions are undesirable, as they make tuning by visual means somewhat difficult.

Proper design of the circuits will often permit a condition to be obtained that is an average of the two extremes mentioned in the previous paragraph,but even this is not always a satisfactory solution.

To overcome this disadvantage, the tuning indicator tube illustrated in Fig. 16 is sometimes used,but the two ray-control electrodes are then connected to the control circuit independently. By this means, a twin-pattern similar to that shown at (B) of Fig. 17 is obtained. Here, the smaller shadow-angle is used for tuning in weaker signals and the larger shadow-angle for tuning in stronger signals.

Using the indicator in a circuit as diagrammed in Fig. 18 makes this action possible. Here you will observe that resistor R-1 is connected in series with the screen grid of an r-f or i-f tube that is under control of the a-v-c system. Such being the case, the current flow thru R-1, and the voltage-drop across it, will vary while tuning -- the same as in any conventional a-v-c controlled circuit. In all cases, the screen-grid end of R-1 will be negative with respect to its B+ end.

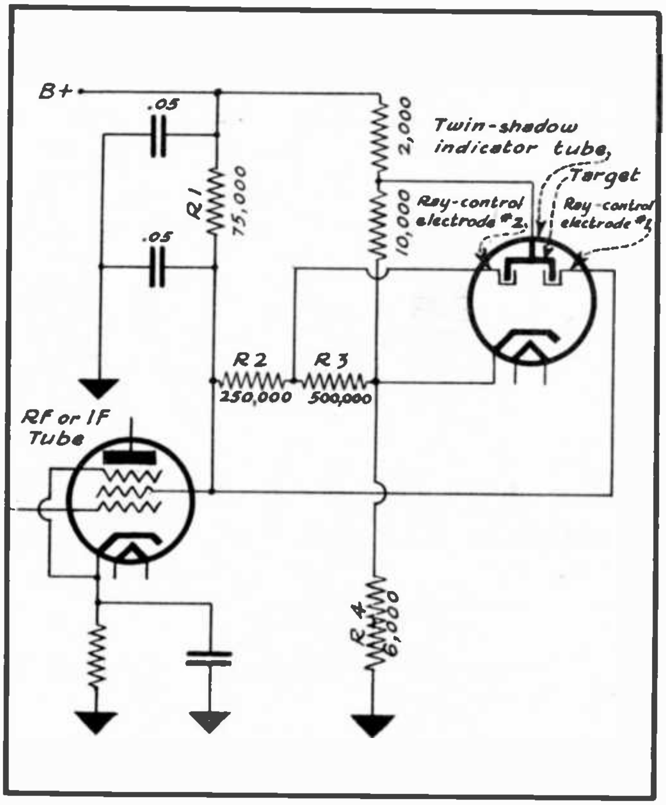

Fig. 18
How Non-synchronized Twin Patterns are obtained

Ray-control electrode No. 1 is connected directly to the negative-end of R-1, while the target is connected to the positive-end of R-1 through a 2000-ohm resistor. Thus, very nearly the total voltage-drop produced across R-1 will also be effective between the target and ray-control electrode No. 1, thereby making available considerable voltage for operating this section of the indicator tube, even on weak signals. Resistors R-2, R-3 and R-4 are connected in series with each other and thus serve as a bleeder circuit between the screen-grid end of R-1 and ground or B-. A small amount of current flows through this part of the circuit continually, and the resulting voltage drop thereby produced across R-2 causes ray-control electrode No. 2 to be less influenced by voltage changes across R-1. Therefore, only strong signals will affect this section of the tube. The full voltage across section No. 1 of the indicator tube will be adequate during the reception of strong signals to close this pattern entirely. Therefore, only section No. 2 will be used at this time.

The purpose of the two .05 mf condensers in Fig. 18 is to bypass to ground any r-f energy that may be present in the screen-grid circuit,thereby preventing it from entering the tuning indicator circuit.

Occasionally, you may find variations in the design and application of the cathode-ray tuning indicator; but, by having learned the basic principles presented in this lesson, you should experience no difficulty in analyzing the operation of similar systems.

EXAMINATION QUESTIONS

LESSON NO. 35

1. - How does the winding on the center leg of the saturable core reactor affect the pilot lamp resonance indicator?

2. - What causes the long electrode in a neon tube tuning indicator to glow?

3. - If a d-c milliammeter is connected in series with the common plate circuit lead of an i-f amplifier, controlled by a-v-c, will the meter indicate a greater or less current flow when the receiver is tuned to resonance with the signal being received?

4. - What causes the shadow-angle in the cathode-ray tuning indicator to decrease when the receiver is tuned to resonance with the signal being received?

5. - How do cathode-ray tuning indicators, capable of producing twin patterns, differ from the single-pattern indicator tubes?

6. - Why does the pattern, as produced by the tuning indicator in Fig. 15, open wide at resonance instead of closing under such conditions?

7. - If the ray-control electrode in a cathode-ray tuning indicator is made more negative, will the shadow-angle become wider or narrower?

8. - Describe briefly the operating principle of the shadowgraph tuning indicator.

9. - What causes the green glow in a cathode-ray tuning indicator tube?

10. - What advantage is gained by using a cathode-ray tuning indicator tube that furnishes non-synchronized twin-patterns?

Practical Technical Training In
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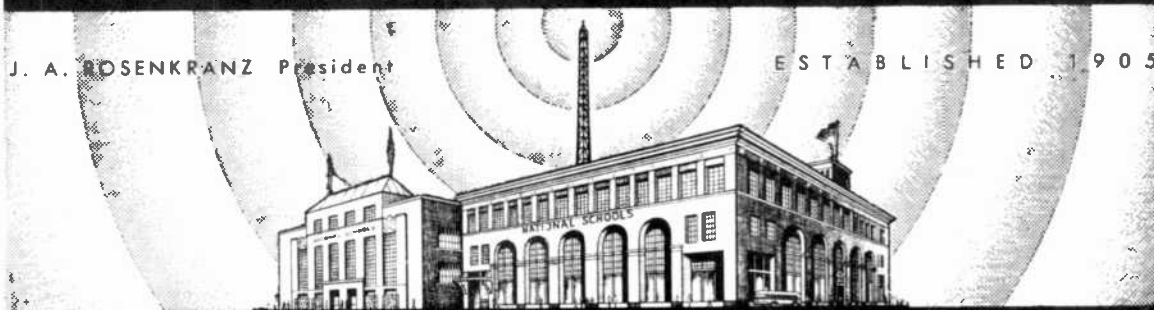

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LESSON NO. 36

FUNDAMENTALS OF ANTENNA THEORY

Today, one or more broadcast stations of appreciable power output are located in almost every fair-sized community; and present-day receivers are many times more sensitive than those used a few years ago. For these reasons, satisfactory reception of local stations can in most cases now be obtained by attaching a few feet of wire to the antenna post of the receiver and extending it along the molding of the room or under the rug.

Present conditions also make it feasible to equip modern receivers with self-contained (built-in) antennas -- made in the form of a

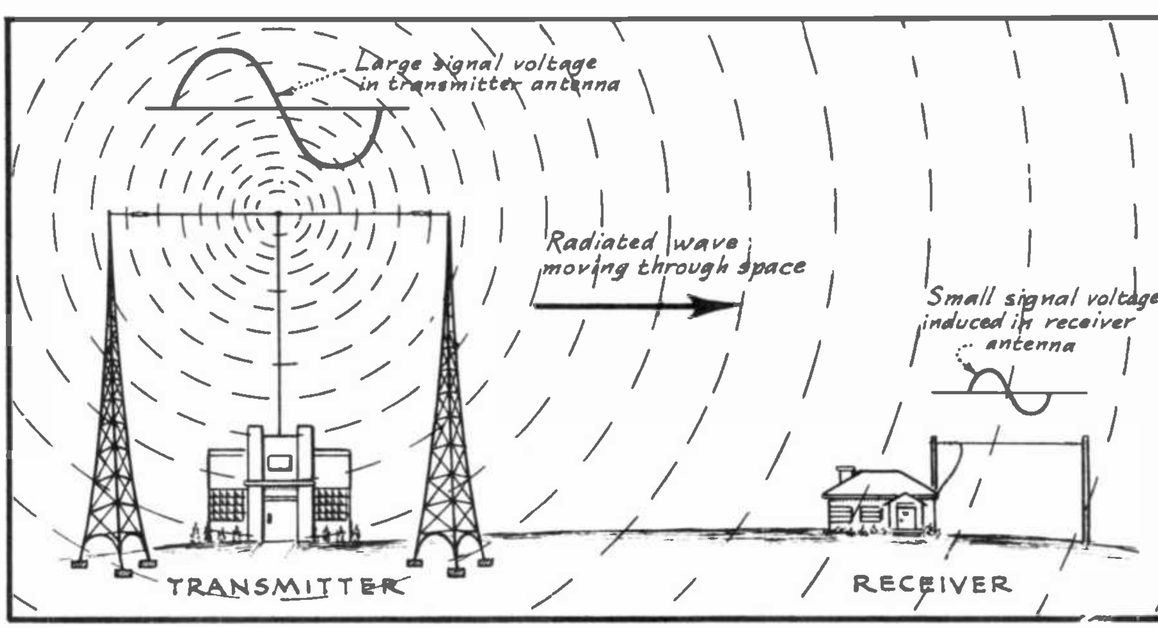

FIG. 1
HOW SIGNAL TRAVELS FROM TRANSMITTER TO RECEIVER

loop, as described in an earlier lesson. However, it is to be noted that although the short piece of wire and the loop antenna will both perform satisfactorily for the reception of standard broadcast signals radiated by local stations, they are, nevertheless, inadequate for long distance reception on this band. This is chiefly due to the fact that the ground wave radiated by such a station is of high intensity only within an area extending from 50 to 100 miles from the station.

A comparatively high signal voltage will be produced in practically any kind of antenna which is located within this radius, but as the distance increases beyond these limits, the signal voltage induced in the receiving antenna by the ground wave decreases rapidly. Thus, it becomes apparent that a well-designed, efficient outdoor antenna is still a necessity, even today, in order to bring in the more distant stations clearly.

Besides having the ability to deliver adequate signal voltages to the receiver, the design and construction of the antenna should also be such as to provide radio signals that are as free as possible from interference noise. The purpose of this lesson is to show you how both of these requirements can be met.

FUNDAMENTAL PRINCIPLE OF SIGNAL RADIATION

The power generated by the transmitter causes a radio-frequency current to flow through the transmitting antenna, which current produces an electromagnetic field that spreads outward into space to great distances, as illustrated in Fig.1. The intensity of this field varies in step with the frequency of the current which produces it -- so that a voltage of corresponding frequency, but of smaller magnitude, will be induced in a receiving antenna that intercepts it. This happens for the same reason that a voltage is induced in any conductor which intercepts a magnetic field that is in motion.

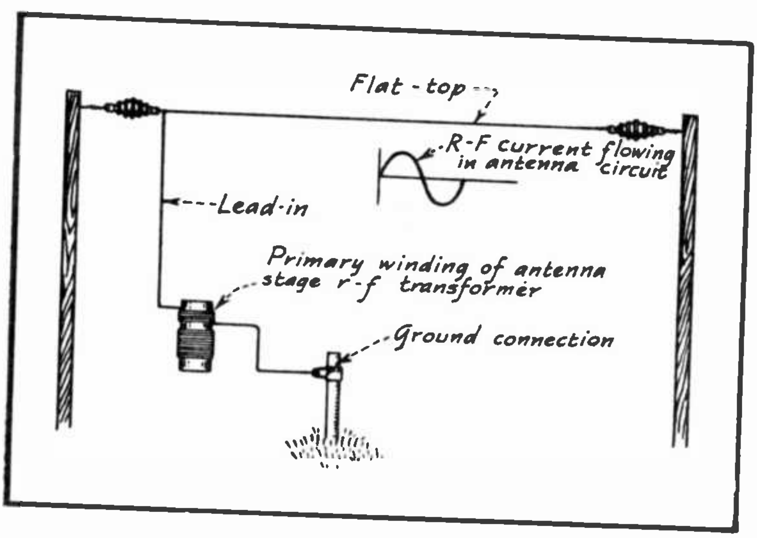

FIG. 2
RECEIVING ANTENNA CIRCUIT

The receiving antenna circuit in Fig.1 consists of an elevated horizontal wire, generally called the "flat-top," a lead-in wire, the antenna coil (primary winding of the antenna stage r-f transformer) and the ground connection, as shown in detail in Fig. 2. All of these parts, together, constitute a complete circuit for high-frequency (radio) currents. The induced current which flows through this circuit will be of the same frequency as that flowing in the transmitting antenna, because the intensity of the radiated field varies at this rate.

Thus, we can say that the receiving antenna is a device for providing a means whereby radio-frequency currents can be set up by the passing "field" of a transmitted signal and be delivered to the receiver for amplification and detection.

TYPES OF ANTENNAS

The point at which the antenna lead-in wire is connected to the horizontal portion of the antenna, or flat-top, provides a means for describing by name the type of antenna being considered. For instance, in Fig. 3 are shown three typical antenna systems. The one at (A) is known as the T-type antenna; those appearing at (B) and (C) are inverted-L types.

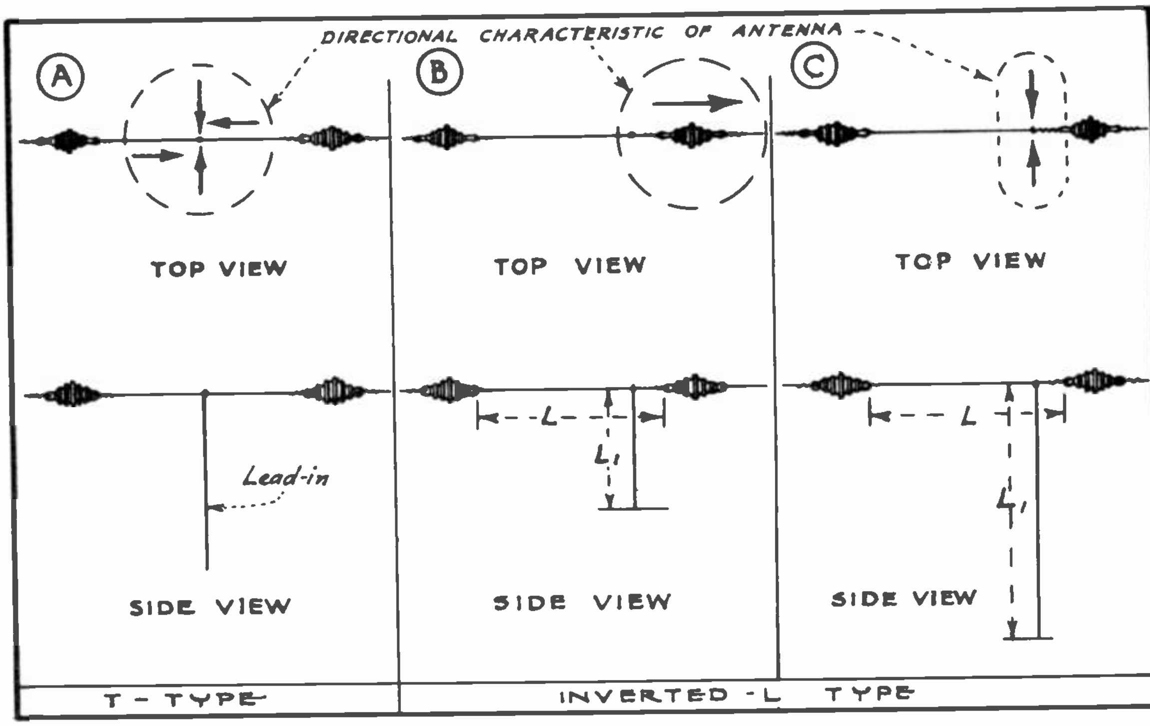

FIG. 3
THREE VARIATIONS OF THE MARCONI ANTENNA, AND THEIR DIRECTIONAL CHARACTERISTICS

As you can see, the T and inverted-L antennas differ only as to the point on the flat-top to which the lead-in is connected. In other words, the T-type has the lead-in connection in the center, or close to the center, while the L-antenna may have tnis connection made at either end.

If the lead-in is connected to the exact electrical center of the flat-top in a T-antenna, the induced voltage in the two portions toward either side of the center connection will be out of phase. That is, the voltage in one side will increase while that in the other side at the same time decreases by an equal amount; the opposition in polarity, cancelling the voltages in the flat-top, as illustrated graphically in Fig. 4. Thus, the lead-in provides the total signal voltage pick-up when such a connection is used, and the flat-top merely supports the lead-in.

All three antenna types shown in Fig. 3 have somewhat different directional characteristics. The T-type receives signals equally well from all directions, which characteristic makes it very desirable for certain installations. When erecting such an antenna, the lead-in should be made as long as possible. The flat-top can be very short, or can be broken up into as many portions as desired, since it contributes very little to signal pick-up.

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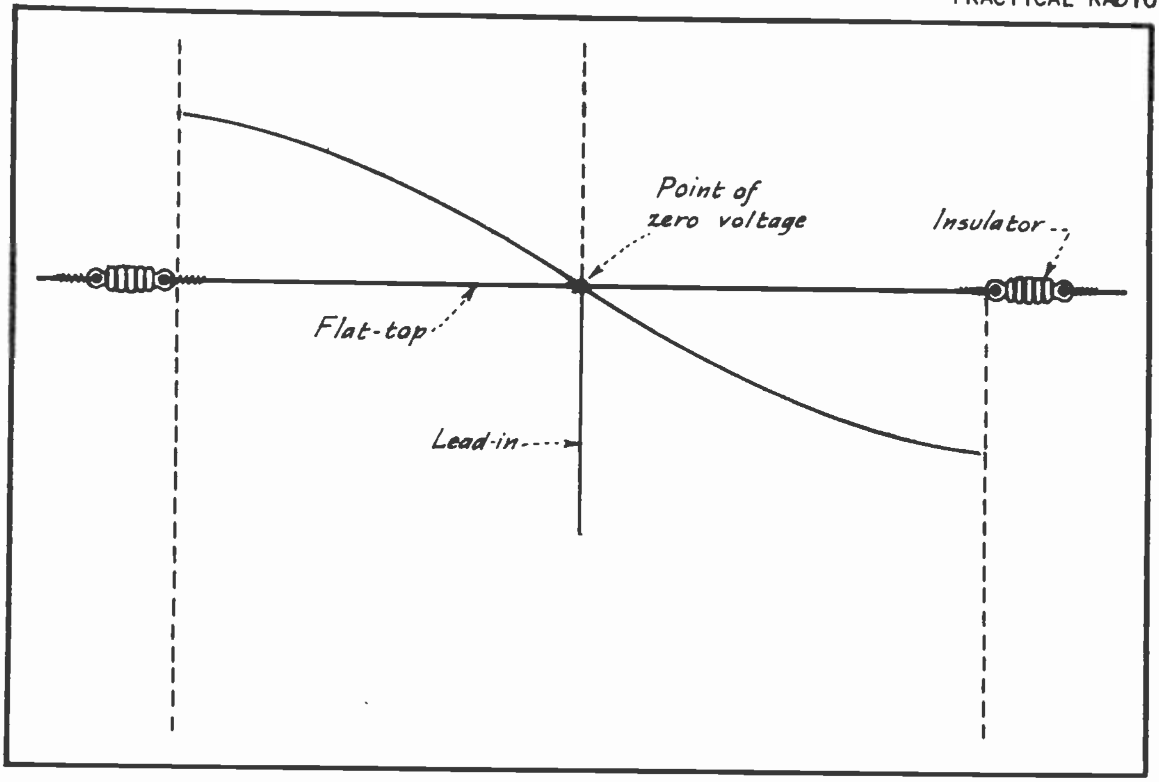

FIG. 4
FLAT-TOP OF T-ANTENNA PROVIDES NO PICK-UP
WHEN LEAD-IN IS CONNECTED TO EXACT CENTER

The inverted-L type antenna is used mostly for outdoor installations. As you will observe at (B) and (C) of Fig. 3, the directional characteristic of this antenna depends upon the length of the lead-in wire. At (B) the lead-in (L_1) is shorter than the flat-top (L), in which case signals will be received best when the wave travels along the length of the flat-top toward the lead-in end, or in the direction indicated by the arrow. When the lead-in wire is longer than the flat top, as at (C) of Fig. 3, the antenna will receive signals best when the wave approaches from two directions at right angles to the antenna flat-top.

The directional characteristic of an antenna is also dependent to a great extent upon its surroundings. Trees, metal roofs, towers, high buildings, etc., often alter the ability of the antenna to pick up signals from one or more directions. Therefore, these factors should be taken into account when erecting the antenna. The antenna should be arranged so that the increased reception of signals from one direction will compensate for a loss of signal energy due to absorption by some object that might be in the path of the wave approaching from this direction.

HERTZ AND MARCONI ANTENNAS

Any antenna which is connected to ground at one end is classed as a Marconi antenna, three simple types of which are shown in Fig. 5. The lead-in of all three of these antennas is connected to the primary of a coupling coil; the lower end of this coil is connected to ground.

Two types of Hertz antennas are shown in Fig. 6. There are many modifications of these two types, but in none of them will you find a

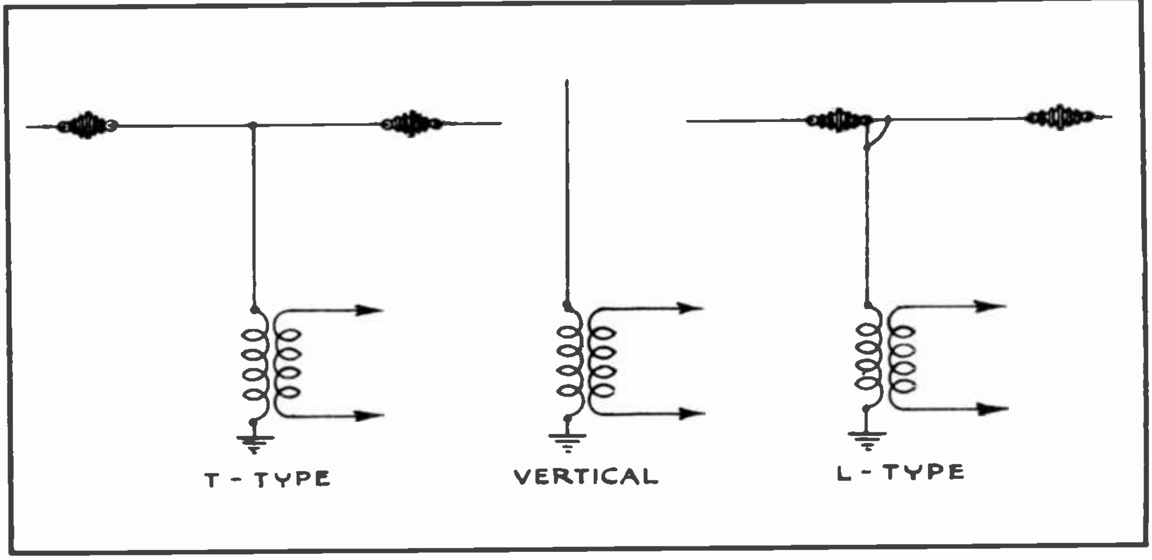

FIG. 5
TYPICAL MARCONI ANTENNAS

direct connection to ground used. The ground connection is the fundamental difference between the Marconi and the Hertz antenna; however, there is still another point of difference which distinguishes these two antennas even further -- and that is their application. These applications will be discussed later.

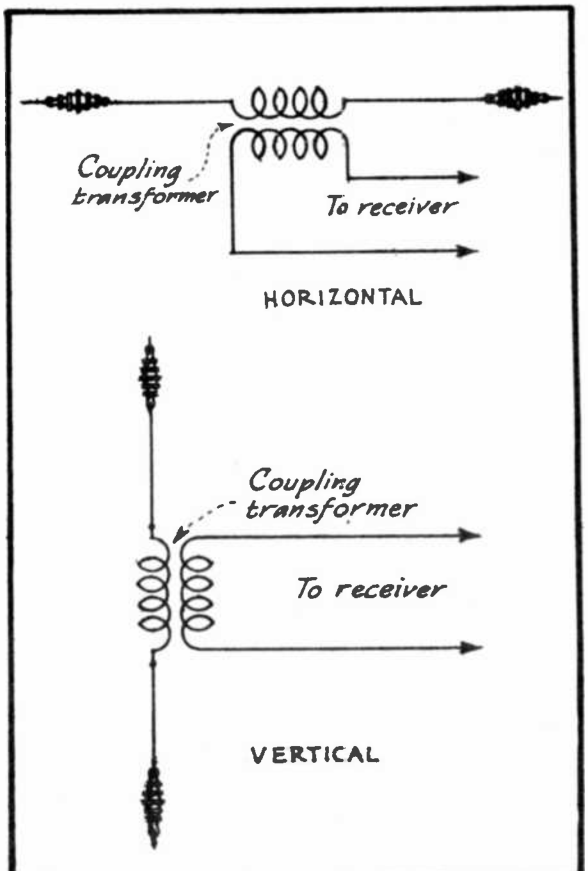

FIG. 6
HERTZ ANTENNAS

EQUIVALENT CIRCUIT OF AN ANTENNA

A wire which is suspended in space with no connection to ground has both inductance and capacity. This conductor may be the flat-top portion of an antenna -- since we can consider this part of the antenna as suspended and insulated in space.

The inductance and capacity of an antenna wire are distributed over the entire length of the conductor somewhat as shown at (A) of Fig. 7. The voltage which is induced in an antenna is similar in every respect to a voltage which would be applied by a generator of an equivalent output, connected in series with the antenna and ground, as at (A) of Fig. 7.

At (B) of Fig. 7 the distributed inductance and capacity of the antenna have been replaced by an equivalent inductance L_a and an equivalent capacity C_a. The electrical relationship of the antenna wire's resistance (R_a) to these values is also shown in this illustration, but it is of little significance for the purpose of this lesson.

The inductance of the r-f transformer's primary winding (L) and the distributed inductance of the antenna (L_a) can be lumped into a single inductance (L_t). If you will then examine the circuit at (C), you will find it to be a simple series circuit comprising inductance, capacity and resistance -- the ground connection being considered as the connecting link between one end of the circuit and the other.

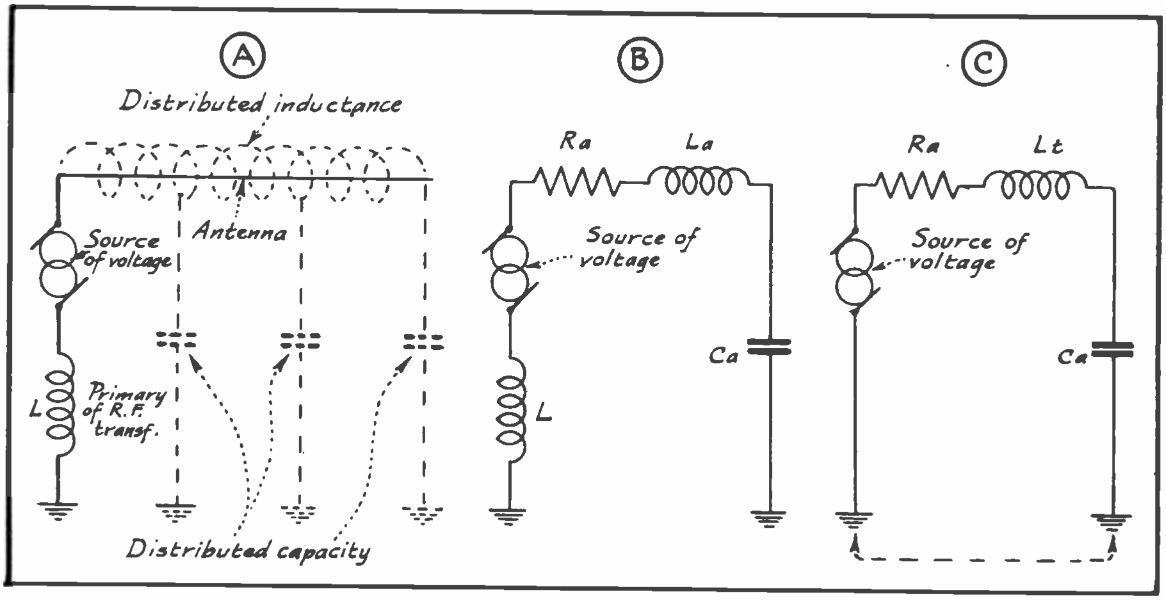

FIG. 7
EQUIVALENT CIRCUIT OF THE ANTENNA

From your study of radio tuning, you will remember that when a series circuit is tuned to resonance with a certain frequency, a large current of that frequency will flow through the circuit. This is exactly what happens in the antenna circuit, in that at or near the resonant frequency, it will be able to deliver maximum energy to the receiver. The width of the band of frequencies over which this increased transfer of energy can take place is determined to a great extent by the resistance of the antenna.

The constants of the ordinary outdoor antenna, designed for broadcast reception, are such as to resonate it to, or at least near, the broadcast band.

THE THEORY OF STANDING WAVES

Experience has shown that an antenna designed especially for the broadcast band may operate just as satisfactorily on certain shortwave bands. For instance, an antenna around 100 feet long may resonate fundamentally in the broadcast band, and yet will operate almost equally as well on the 49-meter and 19-meter bands. On the 31 and 25-meter bands, it may perform very poorly.

The reason for this seemingly erratic behavior of an antenna lies in the fact that any kind of a conductor, when suspended in space, will have standing waves of voltage and current distributed along its length. Several of these waves can be developed on the antenna, but we are interested only in those whose frequencies are in the bands we desire to receive.

As you have already learned from another lesson, the wavelength of an electromagnetic wave traveling in space is a measurement of the exact distance which one cycle of the moving wave will occupy. For example, the distance across one cycle of a wave having a frequency of 1,000,000 cycles per second is 300 meters.

Standing waves are set up on an antenna when the flat-top length is equal to one wavelength, one-half wavelength, or one-quarter wavelength of a certain electromagnetic field which is moving across it. Now, it must be understood that these standing waves are not waves in the same sense that alternate crests and troughs are produced in a water wave. Instead, they consist of voltage and current density distribution, which, if drawn graphically for a one-half wavelength antenna, would appear as illustrated in Fig. 8. Here it will be observed that the voltage value is minimum and the current value is maximum at the center of the antenna; conversely, the current value is minimum and the voltage value is maximum at the ends of the antenna.

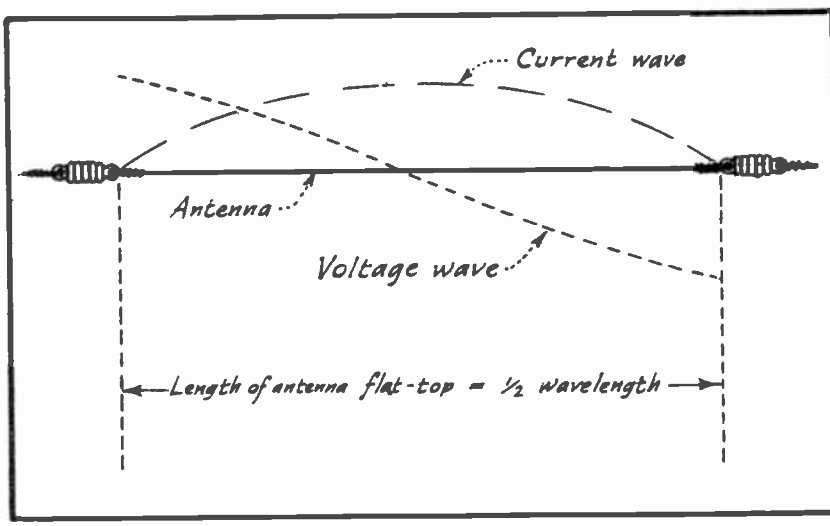

FIG. 8
STANDING WAVES ON ONE-HALF WAVELENGTH ANTENNA

Perhaps it is difficult to understand the foregoing assertions, but for the present just accept them as fundamental facts because standing waves will be explained more fully later in the course.

PERIODIC ANTENNA

A very beneficial result occurs when standing waves are set up on an antenna -- provided that they correspond to the wavelength of the signal which it is desired to receive. When the physical constants of the antenna and lead-in are such that either one-half wavelength or one-quarter wavelength of a standing wave are set up along its combined length, we have a condition for large energy transfer from the antenna to the input of the receiver. An antenna system which responds in this manner is called a periodic antenna.

A periodic antenna can thus be defined as one which has physical constants such that even multiples, or even fractional standing wavelengths of current and voltage, are developed along its length. This definition establishes the difference between a periodic and a resonant antenna, as in the latter type the inductance and capacity of the antenna combine to form a series resonant circuit.

If an antenna system should happen to be both periodic and resonant at a certain signal frequency, we would have a condition for maximum transfer of energy from the antenna to the receiver at that frequency. That is, a periodic condition of the antenna will establish points of large current density on the antenna and lead-in so that if the system is also resonant, the current will be able to reach a value limited only by the resistance of the antenna. By then connecting the primary of the antenna transformer to a point of maximum current density, a large voltage will be induced in the secondary.

APERIODIC ANTENNA

Periodic antennas are efficient only at frequencies at which the required fractional wavelengths of current and voltage appear along the length of the antenna. Thus, an antenna of this type is most useful when it is desired to receive strong signals from stations operating in comparatively narrow bands of frequencies.

In like manner, a resonant antenna is good for only one frequency, or for a narrow band of frequencies on either side of the resonant point. Thus, it is evident that if an antenna is to give at least fair results at <u>all</u> frequencies, the periodic conditions must be eliminated. That is, the antenna must be so constructed and erected that standing waves will not be developed along its length. An antenna of this type then becomes an <u>aperiodic antenna</u>.

Periodicity, or the development of distributed waves of voltage and current, cannot be eliminated entirely in an ordinary receiving type antenna due to the complexity of the arrangement required to produce an aperiodic condition. All that we can do then, from a practical standpoint, is to make the best use of existing conditions; or, to select the proper flat-top length, height and lead-in that will place the periodic points in the middle of desired frequency bands.

As we have already stated, an antenna for broadcast reception can very easily be made to resonate somewhere in the band, but for the same antenna to be periodic in the broadcast band, a flat-top length between 650 and 1600 feet would be required. An antenna flat-top of this length is, of course, impractical.

In the 19 and 49-meter bands, the length of the antenna may be very much shorter to be periodic. At these frequencies, the flat-top and lead-in, together, may have a total length of 60 and 160 feet, respectively. This explains the statement made earlier in the lesson, concerning the fact that an antenna 100 feet long, as used for broadcast reception,often works satisfactorily on the 19 and 49-meter bands.

In the broadcast band, the antenna will be aperiodic because it is so short in comparison to the length required, that standing waves corresponding to the broadcast frequencies will not be developed on it. However, a condition of resonance at the middle of the broadcast band will make this antenna quite efficient, because large currents will flow when voltages are induced in the antenna by passing electromagnetic fields.

THE ANTENNA AND ITS RELATION TO NOISE

The area covered by the ground wave is usually designated as the "dependable service area of the station." A receiving antenna, located outside of this area, will have a greater proportion of noise signal induced in it along with the desired station signal voltage. This condition becomes increasingly more noticeable at greater distances from the station.

Most of the noise induced in the ordinary antenna is due to man-made interference -- for strangely as it seems, man has managed to out do nature in producing radio interference. In the early days of radio, noisy reception was caused almost entirely by static interference, due to natural causes; but electrification of nearly every phase of modern living has increased the interference problem tremendously.

Every power supply line is a source of the most annoying and persistent kind of interference. Each of the many electrical devices included in every modern household is capable of producing interference that will affect every radio within blocks. Automobiles cause so much interference in the shortwave bands that a person living near a main thoroughfare cannot enjoy noise-free reception on any but the broadcast band. Even rural districts are fast becoming electrified, so that while being benefitted by the many conveniences which electric power can bring, they too will socn experience increased radio interference.

Interference can be attacked and eliminated at two points; either at its source, or at the receiver. The elimination of interference at its source is dealt with in great detail elsewhere in the course, as also is the prevention of interference noises entering the receiver through the power lines. In this lesson we are concerned only with the reduction of interference that may enter the receiver through the antenna system.

REDUCTION OF INTERFERENCE

Fig. 9 (A) shows how an indoor antenna is completely surrounded by noise (interference) fields which have their origin inside the house. Illustration (B) of Fig. 9 shows how a long outdoor antenna

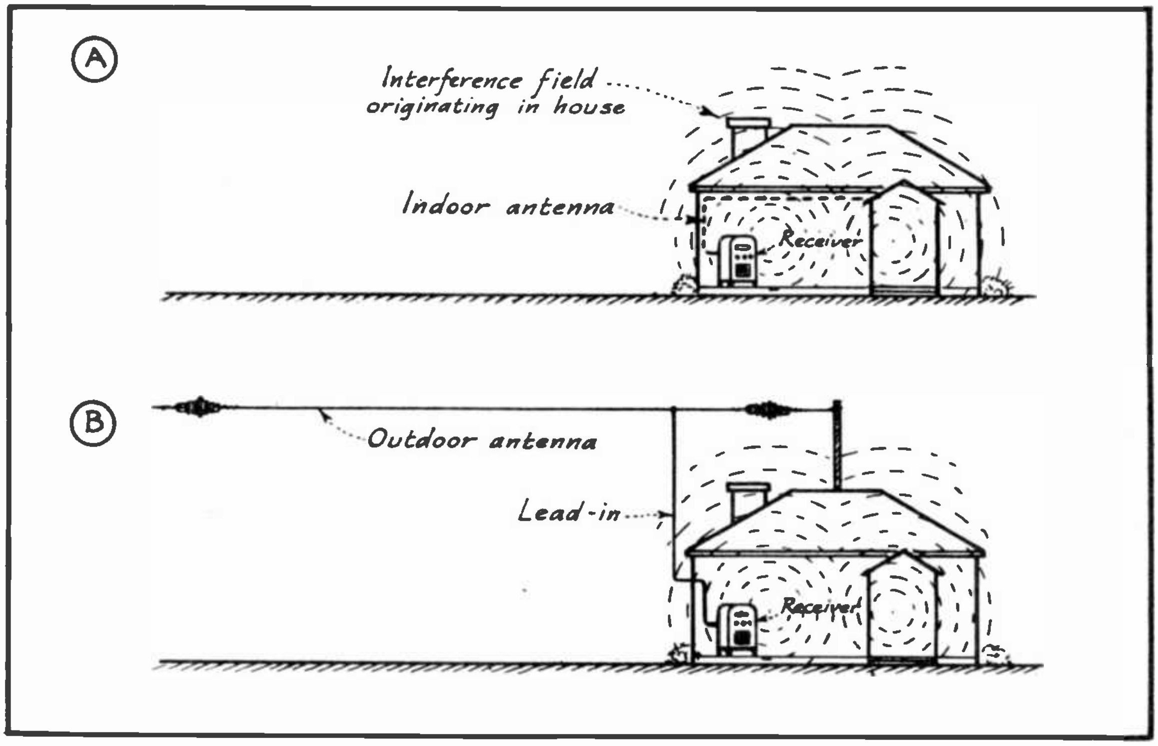

FIG. 9
HOW ELECTRICAL DISTURBANCES CAN PRODUCE EXCESSIVE NOISE IN A RECEIVER

may pick up a desired station signal, which is fairly free from man-made interference, but the lead-in is so located as to introduce considerable noise signal into the system. If the lead-in wire is as long as or longer than the antenna proper, it is probable that the combination of atmospheric static and local interference may be of sufficient intensity to completely "over-ride" the station signal, and thus cause noisy reception.

A SIMPLE NOISE-REDUCING ANTENNA

In Fig. 10 you are shown the most simple method of preventing the lead-in from picking up unwanted noise signals. Here, a grounded metal shield surrounds the lead-in, extending from the point where connection is made to the flat-top of the antenna, all the way to the receiver. This grounded shield isolates the lead-in wire from the local interference field and thereby reduces the noise-signal pick-up.

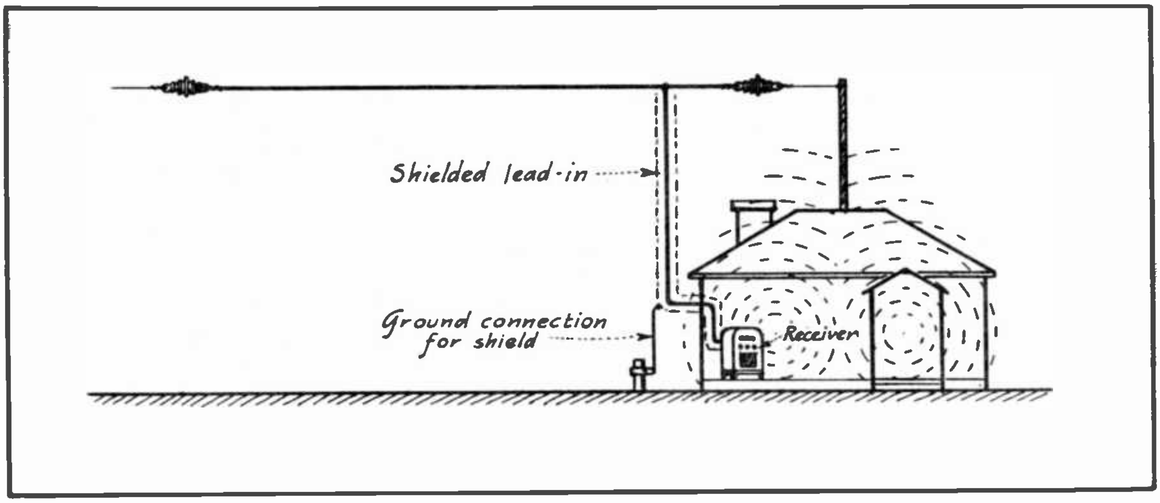

FIG. 10
SHIELDED LEAD-IN PREVENTS INTERFERENCE PICK-UP

This type of lead-in consists of the customary stranded copper conductor, surrounded by a layer of cotton which in turn is covered by a layer of rubber. Tinned copper or aluminum braid is applied over the rubber. The copper conductor carries the signal from the antenna to the receiver, whereas the metallic braid covering is connected to an effective ground.

CAPACITY EFFECT OF SHIELDED LEAD-IN: There is an old saying which states: "You never have a loss but that there is a small gain." The reverse of this is also very often true: That is, a gain is sometimes acquired at one point through a loss at some other point. This is exactly what occurs in an antenna system that employs a shielded lead-in.

Actually, the metal braid covering (the shield), and the central copper conductor, together constitute a capacity arrangement. The value of this capacity depends on the separation between the shield and the conductor, and on the length of the shielded portion. Usually, it is sufficient to bypass considerable signal energy to ground.

Besides isolating the lead-in conductor from interference fields and bypassing some of the signal energy to ground, the shield also prevents the lead-in from picking up any of the desired signal energy which would otherwise be added to that picked up by the flat-top of the system. However, the net results obtained from the shielded lead-in type of antenna are generally such that the improved signal-to-noise ratio outweighs the losses. Also, the location and method of installing the antenna can frequently be such as to compensate partially for these losses.

REDUCING SHIELDED LEAD-IN LOSSES

It has been proved that the loss in a shielded lead-in, due to the capacity effect between the conductor and shield, depends directly upon the signal voltage being handled by the conductor. In other words, if this voltage is kept down to a very low value, the bypassing of energy to ground is correspondingly reduced. It seems logical, therefore, that less loss of signal by this means will occur if the voltage at the point where we take energy from the antenna (the lead-in connection to the flat-top) is reduced, and again stepped up to its original value at the point where it is delivered to the receiver.

Fig. 11 shows one method of accomplishing this. Here, an auto-transformer is used as the coupling device at each end of the lead-in. The entire winding between the antenna flat-top and ground serves as the primary of the antenna coupling transformer. The turns of wire between the tap on the coil and ground serve as the secondary. The proportion of primary to secondary turns provides a step-down ratio of about 10 to 1.

The auto-transformer at the receiver end of the lead-in is a step-up type, the primary consisting of the few turns of wire included between the tap and ground, while the secondary comprises the complete winding. The step-up ratio of this auto-transformer is the inverse of the step-down ratio of the antenna coupling transformer, or 1 to 10. Thus, theoretically, we should have the same voltage input to the receiver as exists on the flat-top. However, there is still a consider-

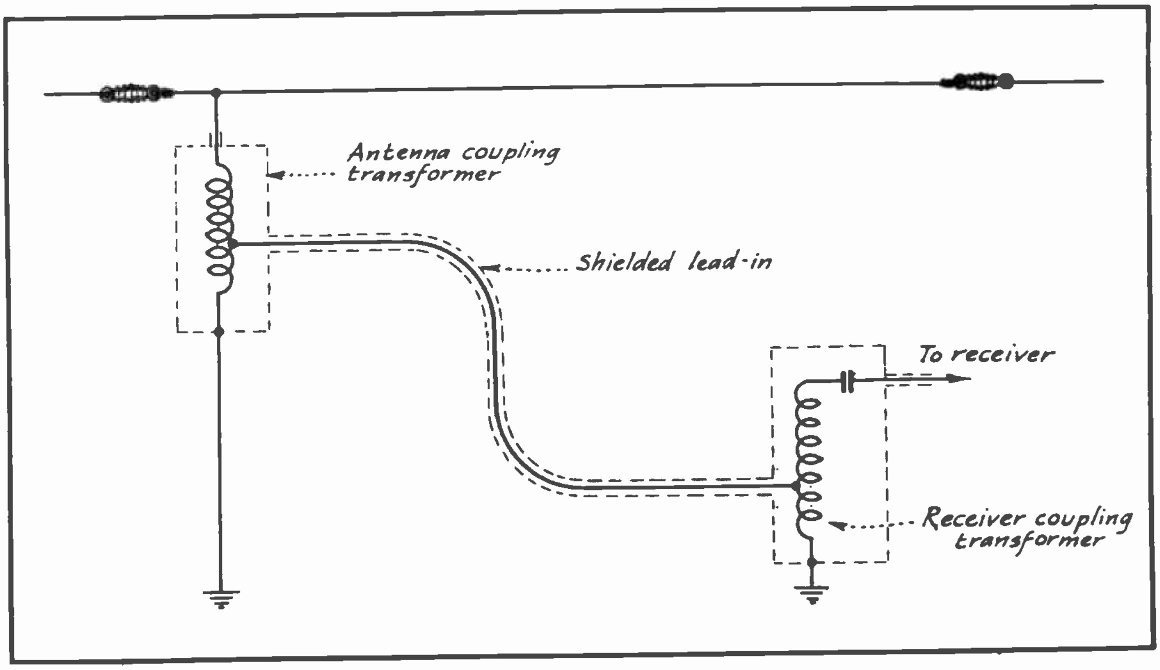

FIG. 11
SIMPLE NOISE-REDUCING ANTENNA WITH SHIELDED LEAD-IN AND AUTO-TRANSFORMER COUPLING

able loss in the shielded lead-in which prevents this type of antenna from being ideal.

THEORY OF THE MATCHED IMPEDANCE TRANSMISSION LINE

Fundamentally, a transmission line consists of two conductors, spaced some distance apart. The transmission line may be only a few feet or several hundreds of miles long. Sometimes, it is necessary to use only one conductor, ground forming the other -- as would be the case for an inverted-L antenna.

A simple type of transmission line is illustrated in Fig. 12 (A). This line consists of two conducting wires, spaced some distance apart, and of an indefinite length. An alternating voltage is applied across the terminals of the coupling transformer's primary winding, causing an a-c voltage to be induced in the secondary. The output end of the line is open, as no load is connected across terminals 1 and 2.

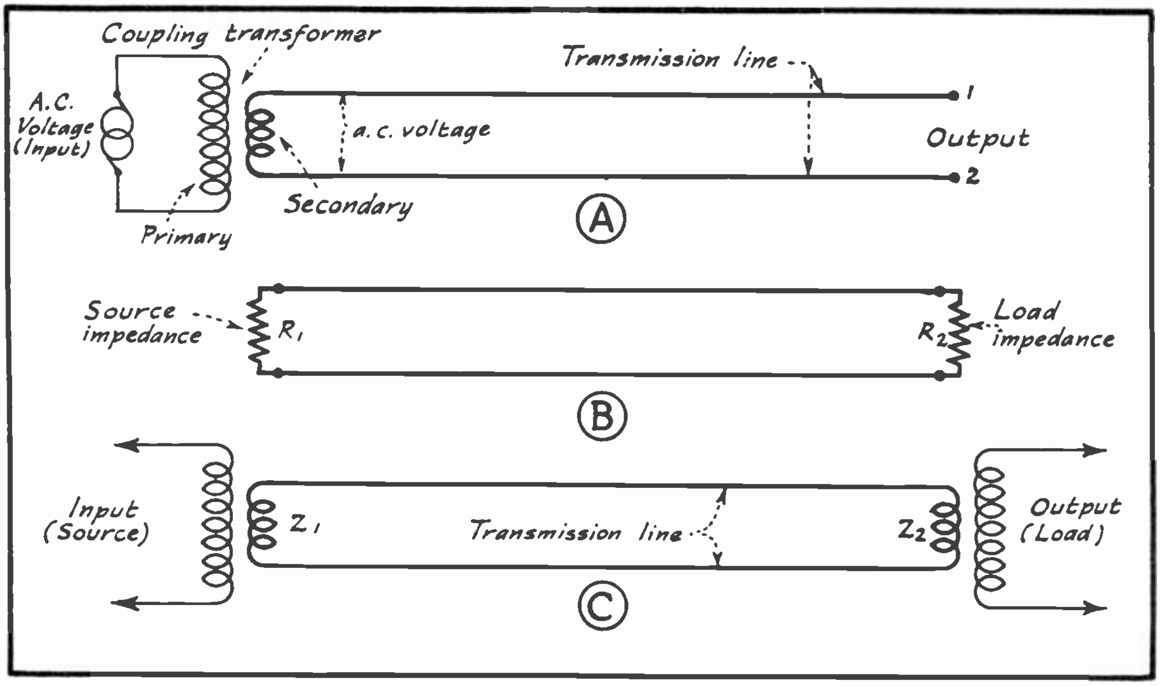

FIG. 12
MATCHING THE INPUT AND OUTPUT OF A TRANSMISSION LINE FOR MAXIMUM TRANSFER OF ENERGY

We have a similar occurrence when an a-c voltage is induced in an antenna wire by a signal wave, in which case standing waves of voltage and current are set up on each conductor, corresponding to the wavelength of the a-c source. These standing waves on the transmission line will be developed for all conditions except that where both the input and output ends of the line are terminated in values of impedance or resistance which are equal to the surge (characteristic) impedance of the line. (Note: The impedance of a circuit or electrical device is the total opposition offered toward a flow of alternating current by a combination of its resistance, inductance and capacitance. These properties are discussed in detail in later lessons, at which time the mathematical relations will be given.)

A fundamental law of electrical circuits states that the maximum amount of power will be transferred from the source to the load, when the load at the receiving end of any circuit is equal in value of resistance or impedance to the resistance or impedance of the source which is supplying power to the circuit. Applying this law to (B) of Fig. 12, it is apparent that R_1 must be equal to R_2 in order to obtain a maximum amount of energy transfer from R_1 to R_2. However, R_1 and R_2 must both be equal to the surge or characteristic impedance of the transmission line in order to prevent the formation of standing waves on the line.

Standing waves on a transmission line represent an expenditure of power from the line. That is, they may produce a condition wherein all the power supplied to the line will be stored in the waves of voltage and current, and none of it will be supplied to the load or receiving end of the line. Therefore, standing waves must be eliminated in order to establish proper conditions for obtaining maximum power in the load (R_2).

The characteristic impedance of a transmission line is dependent upon the size of wire used for the conductors, the spacing between the conductors, and the leakage of energy from one conductor to the other through insulators and supports. Later in the course, you will be given several formulas for determining the value of characteristic impedance, and the proper procedure for designing a transmission line.

Throughout the remainder of this lesson, the transmission line will be analyzed solely as a medium for transferring energy from the antenna flat-top to the receiver. Throughout this discussion, you should keep the following two rules in mind:

(1) The terminating (load) resistance or impedance of a transmission line must be equal to the resistance or impedance of the source. Referring to (C) of Fig. 12, a transmission line has one transformer at the input end and another at the output. According to the rule just given, the impedance of the input transformer's secondary (Z_1) must be equal to the impedance of the output transformer's primary (Z_2).

(2) The values of Z_1 and Z_2 must both be equal to the characteristic impedance of the transmission line. This is the assumed condition for the special types of antenna systems discussed in the following pages of this lesson.

MATCHED ANTENNA COUPLING TRANSFORMERS

To still further overcome the loss occurring in the shielded lead-in, special r-f coupling transformers have been developed. These transformers are designed to be used in conjunction with a shielded transmission line, two of these couplers being used -- one to couple the antenna to the transmission line, and the other to couple the transmission line to the receiver (see Fig. 13).

The system shown in Fig. 13 is similar in appearance to that of Fig. 11, yet it is quite different, electrically. The point of difference is that the lead-in of the matched coupling transformer system (Fig. 13) forms a matched impedance transmission line, whereas that in Fig. 11 does not.

We could use practically any impedance at the source (input) and termination of the transmission line, so long as the characteristic impedance of the line is made the same value.

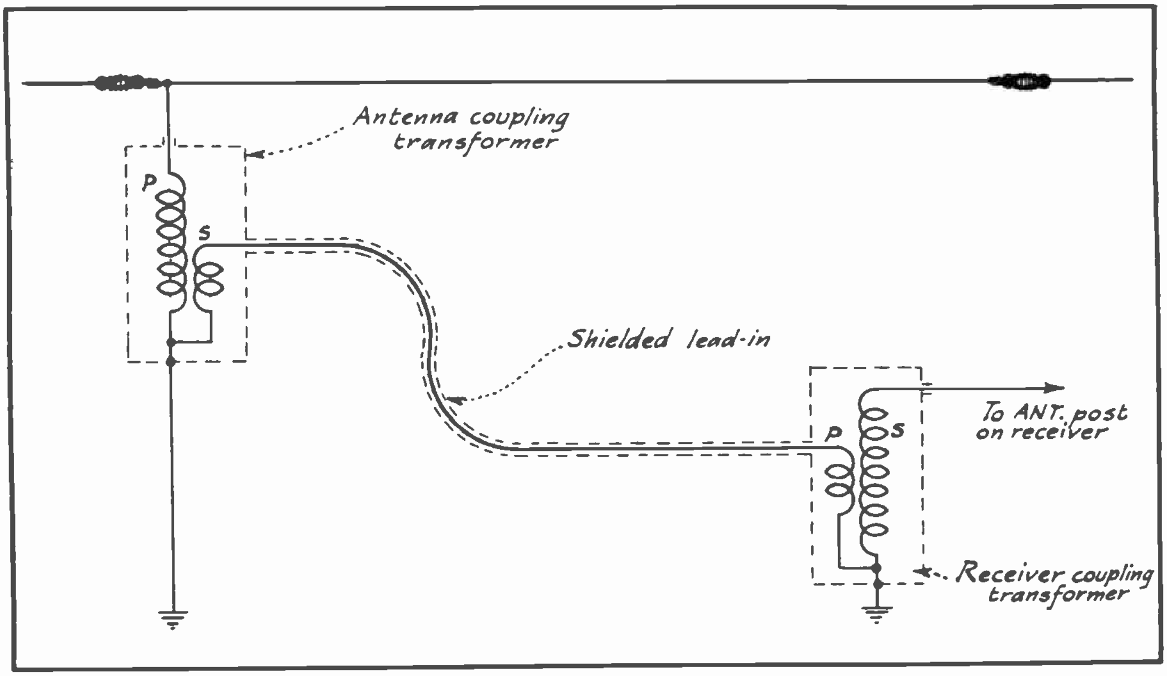

FIG. 13
ANTENNA SYSTEM EMPLOYING MATCHED COUPLING TRANSFORMERS AND A SHIELDED LEAD-IN

For the same reasons as given for the auto-transformer in Fig. 11, the antenna coupling transformer in Fig. 13 is of the step-down type while the set coupling transformer is of the step-up type. The primary of the antenna coupling transformer has a rather high impedance, which is desirable because a relatively high voltage will then be developed across it by the flow of current between the flat-top and ground. Due to transformer action, the current in the secondary is fairly large, but the voltage is small -- thus giving us a condition of low voltage and high current in the transmission line.

At the terminating, or receiver, end of the transmission line, we are concerned with two things. First of all, we must have a primary impedance which will match the secondary impedance of the antenna coupling transformer. Secondly, we must step up the voltage to its original antenna value. To accomplish this, we use a step-up transformer at this point -- the primary impedance of which is equal to the secondary impedance of the antenna coupler, and the turns ratio of which is equal to the inverse of the antenna coupler step-down ratio.

Both the antenna coupling transformer and the receiver coupling transformer must be carefully designed, because the slightest mismatch between them and the transmission line will cause considerable loss in the transmission line, and all the advantages of this system would then be lost.

DISADVANTAGES OF THE SHIELDED LEAD-IN TRANSMISSION LINE

The sole purpose of the shielded lead-in is to eliminate any noise which the lead-in might be inclined to pick up. The three types of shielded lead-in antennas which we have discussed up to this point, all accomplish their fundamental purpose, but still retain the following disadvantages:

In the case of the antenna illustrated in Fig. 10, the loss due to bypassing of the r-f energy, sometimes outweighs any gains in freedom from noise. The antenna in Fig. 11 compensates for some of the losses in the lead-in, but its efficiency is only slightly higher than that of Fig. 10.

The system illustrated in Fig. 13 is fairly efficient in comparison with the other two, but from 30% to 50% of the induced antenna voltage is usually lost in the transformers and lead-in. This loss can be tolerated if the interference signal voltage has been lowered to a point where it will have negligible effect on the receiver, as the reserve sensitivity of the receiver will more than make up for the loss in signal voltage brought about by the antenna lead-in.

Another disadvantage of the coupling transformer, shielded lead-in type of antenna, is that the maximum efficiency of this antenna is only realized over a comparatively narrow band of frequencies -- unless variable controls are added to the two impedance-matching transformers, which of course, is impractical. The system therefore does not perform equally well at all frequencies. However, the matching transformers can be designed and constructed to operate at maximum efficiency over a limited band of frequencies, such as the standard broadcast band. There are a number of very satisfactory kits of this type of antenna on the market.

THE TRANSPOSED LEAD-IN

Transposed conductors have been used by the electrical industry for many years. The most common example of this is the ordinary twisted lamp cord which you can buy in any electrical store. The chief reason for using twisted, or a transposed pair of conductors, is to reduce or eliminate any electromagnetic or electrostatic disturbance which may be produced around the conductors.

Fig. 14 illustrates graphically how a moving electromagnetic field, due to some electrical disturbance, can induce voltage in a transmission line. Illustration (A) represents a simple transmission line consisting of two parallel conductors, such as might be carrying energy from the flat-top of an antenna to a receiver. Since the interference field is moving from right to left as shown, a voltage will be induced in conductor #1 first, which in turn, will cause a current to flow through the line

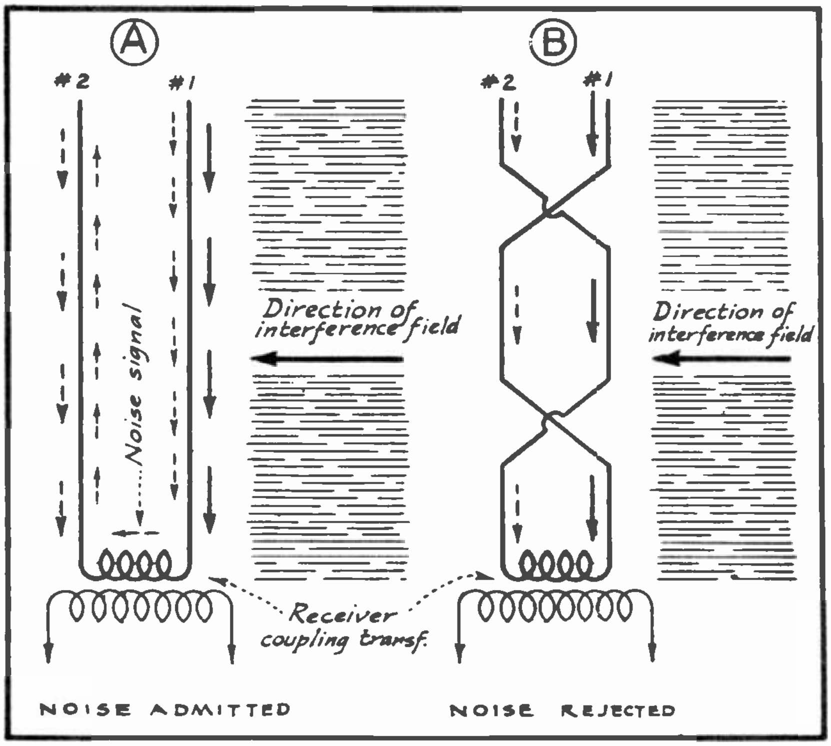

FIG. 14
PRINCIPLE OF TRANSPOSED LEAD-IN

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in the direction of the heavy, solid arrows. By the time the moving field has reached conductor #2 on its travel toward the left, its strength has been reduced somewhat due to the energy taken by conductor #1, and also because the intensity or strength of an electromagnetic field decreases quite rapidly as it moves farther away from its point of origin.

Therefore, when the field is intercepted by conductor #2, the voltage induced in this line will not be as great as that induced in conductor #1 (the broken, heavy arrows). Notice further that the direction of this current in conductor #2 opposes that in conductor #1 since the direction of the moving field is such as to cause the induced current to flow downward in both these conductors. Then, since the current flow in conductor #2 is opposing to and lower in value than that in conductor #1, the arithmetical difference of these two current values will flow from conductor #1 through the primary of the coupler coil and into conductor #2 (the small, dotted arrows). Thus, the interference field has been able to transmit some of its energy through the coupling coil, to the receiver.

Upon studying transmission line (B) in Fig. 14, you will observe a somewhat similar condition, except that the two conductors have been transposed or crossed over each other at intervals. By this means, alternate sections of both conductors #1 and #2 are placed closer to the point of origin of the interference field.

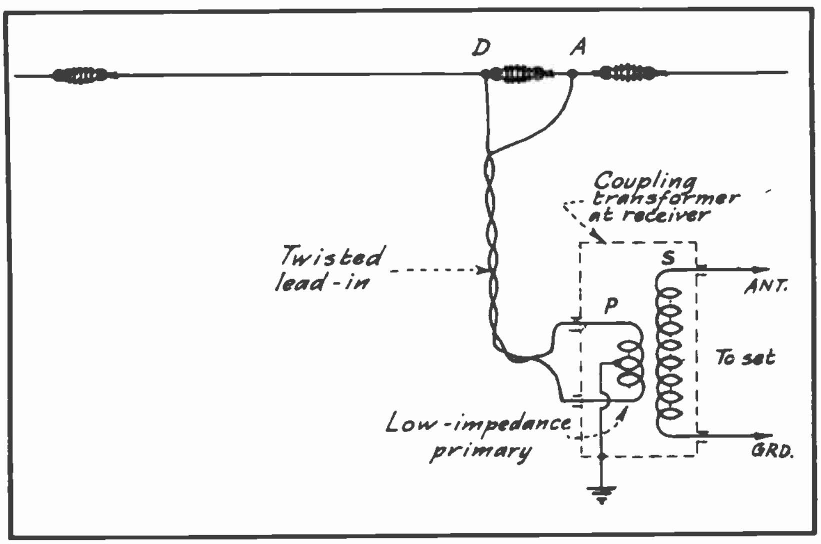

FIG. 15
TWISTED-PAIR LEAD-IN WITH AN INVERTED-L ANTENNA

For example, in the top section of the line, conductor #1 will have the greatest current induced in it, while conductor #2 carries the smaller current. In the next lower section, conditions are reversed; here, conductor #2 carries the greater current and conductor #1, the lesser. Because of this alternation in the amount of current flowing in the two conductors, we find that by the time the line reaches the primary of the receiver coupling transformer, the currents in the two conductors will be equal in value but opposite in polarity, and therefore will cancel out. Therefore, no current due to the interference field flows through the primary of the transformer, and consequently, no interference voltage will appear in the secondary.

So far in this discussion of the transposed lead-in, we have assumed the interference field to be acting upon the transmission line along the same plane as that of the line. For the other condition, where the field intercepts the transmission line conductors at right angles to the plane illustrated in Fig. 14, both conductors will be "cut" by the field simultaneously and the voltage induced in either a parallel-conductor line, or the transposed line, would be equal in each of the conductors. There would then be no difference in voltage in the conductors, and no interference current would flow through the primary of the coupling transformer.

INVERTED-L TYPE ANTENNA WITH TRANSPOSED LEAD-IN

Fig. 15 shows one type of inverted-L antenna, using a transposed or twisted-pair lead-in. In this case, the conductors comprising the lead-in (transmission line) are twisted together the same as ordinary lamp cord -- one wire being connected to the flat-top at point D and to one end of the coupling transformer's primary winding. The other transmission line conductor is connected to a short supporting length of wire at A and to the other primary terminal of the coupling transformer. Thus, only one wire actually carries the signal from the flat top of the antenna to the receiver. The other wire is used merely to cancel out any noise signal which may be picked up by the lead-in.

Considerable care must be used when installing an antenna of this type, as the length of the lead-in, the separation between the two conductors which form the lead-in, and the size of these conductors, all affect the impedance of the lead-in.

You have already seen that an antenna can have impedance because of its distributed inductance, capacity and resistance. In the antenna system appearing in Fig. 15, the flat-top itself forms the source or input impedance to the line, since there is no impedance matching device between the flat-top and the transmission line. The natural impedance of the transmission line and the impedance of the primary winding of the receiver coupling transformer combine to form the output impedance of the line.

The impedance of this transmission line is dependent directly upon the capacity existing between the two conductors of the line. This capacity, in turn, is dependent upon the separation of the two conductors, and by their length. Therefore, the length of the lead-in is the controlling factor of the impedance match.

In designing the lead-in to match a certain flat-top, the impedance of the flat-top and the lead-in must be determined in terms of a unit length of each. The length of the lead-in is then proportioned until the amount of capacity between the two conductors, in combination with the inductance and resistance of the line and primary of the coupling transformer, produces an impedance which is equal to that produced by the inductance, capacity and resistance of the antenna.

In commercial types of this antenna, the lead-in and coupling transformer have been carefully designed to match the flat-top supplied with the kit. Also, the correct method of installing the system will in such cases be specified by the manufacturer. If these installation instructions are not carried out faithfully, or if the supplied lengths of flat-top or lead-in are changed in any way, the impedance balance of the system will be destroyed, and satisfactory performance will not be obtained.

A similar type of twisted-conductor antenna transmission line is shown in Fig. 16. The main difference between this antenna and that shown in Fig. 15 is in the use of an impedance-matching transformer at each end of the line. This feature makes the length of the transmission line less critical, so that a little leeway can be allowed for the installation.

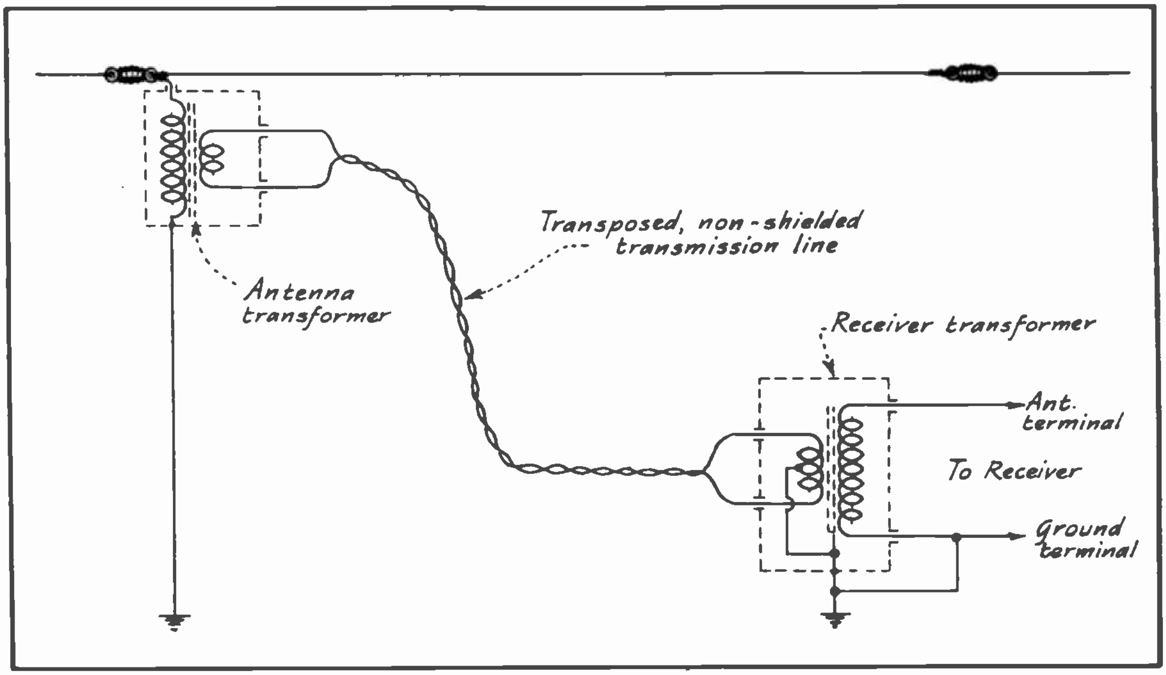

FIG. 16
MATCHED IMPEDANCE LEAD-IN WITH TRANSPOSED TRANSMISSION LINE

When erecting the various types of noise-reducing antenna systems described in this lesson, the same attention should be given to the structural requirements as already covered in an earlier lesson treating with antennas in general.

Wire, insulators, attaching devices, and other accessory equipment supplied with antenna kits are usually of good quality -- and the factory's instructions for erecting the system are generally sufficiently explanatory so that any radio technician can make the installation without difficulty. However, in addition to adhering to factory instructions as to set-up, also be sure that the antenna masts are firmly mounted and securely anchored, that ground connections (where necessary) are effectively made, that the transmission line is extended over its mounting surface in an approved manner, and that all other factors of good workmanship are given proper attention.

The radio serviceman should not attempt to construct impedance matching transformers nor should he attempt to build the rest of the antenna system around such transformers which he may have acquired separately from the other parts. Laboratory tested and precision-built noise-free antenna kits are priced so reasonably that it is more profitable to purchase one of these for the customer at wholesale prices, and then charge him for your services to install the system, plus a 40% profit on the kit.

We continue our discussion of antennas in the next lesson, wherein are described the most popular noise-free, all-wave types, multiple systems for large apartments and hotels, and other special types.

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EXAMINATION QUESTIONS

LESSON NO. 36

1. - Is local man-made interference more likely to be picked up by the flat-top or lead-in of an outdoor antenna?

2. - Explain how a transposed type lead-in aids in reducing noise pick-up.

3. - Explain briefly the operating principle of a noise-free antenna system comprising an inverted-L flat-top, a shielded transmission line and a coupling transformer at each end of the transmission line.

4. - What is the essential difference between a Hertz antenna and a Marconi antenna?

5. - How does a periodic antenna differ from an aperiodic antenna?

6. - What relation should exist between the source and load of a transmission line in order for maximum power to be transmitted through it?

7. - Why are some antennas equipped with a coupling transformer at each end of the shielded lead-in?

8. - What is meant by the equivalent circuit of an antenna?

9. - How does a shielded lead-in affect an antenna system?

10. - What is the object of using two conductors for the lead-in in Fig. 15, when only one of them carries the signal from the flat-top of the antenna to the receiver?

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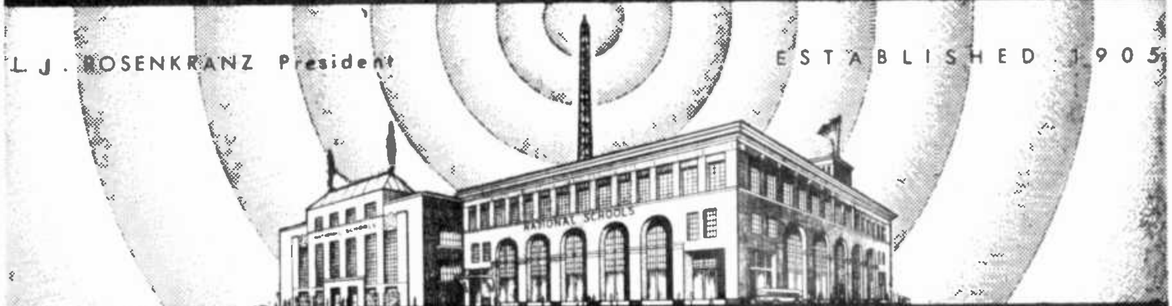

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LESSON NO. 37

COMPLEX ANTENNA SYSTEMS

Fading is one of the ills of shortwave reception that the average set-owner or radioman cannot hope to eliminate entirely, but excessive noise can be reduced, and very often eliminated, by the use of a modern antenna, supplementing built-in antennas. In this lesson, we will study the operating principles and the methods of installing a few of these modern commercial all-wave antenna systems.

Several different types of all-wave, noise-reducing antenna kits are shown in Fig. 1. All of these kits are designed and partially assembled so that any radioman can install them easily. As you can see in the illustration, most of the connections have already been made at the factory.

FIG. 1
COMMERCIAL ANTENNA KITS

DOUBLET ANTENNA

The majority of commercial all-wave, noise-reducing antennas have a two-section flat-top, and are therefore known as "doublets". The doublet is a modification of the horizontal Hertz antenna.

The transmission line can be either of the simple two-conductor parallel-wire type, or a transposed type. The parallel-wire type can be used only in a noise-free location -- in which case the doublet system would be no more advantageous than a single flat-top Marconi antenna. To be effective in a zone of considerable interference, the doublet must be used in conjunction with a transposed lead-in. The latter may consist of two conductors twisted together, or transposed at intervals by special insulating blocks as in Fig. 2.

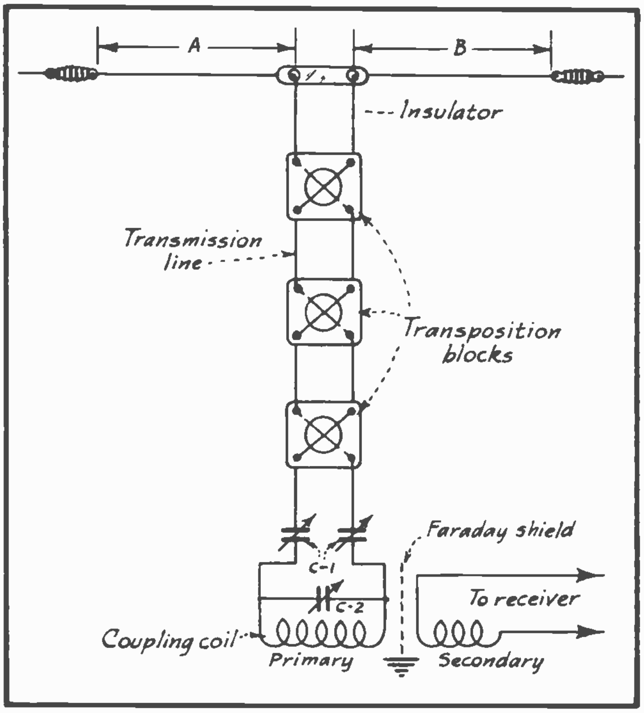

FIG. 2
DOUBLET ANTENNA

The doublet system shown in Fig. 2 is designed primarily for use on the shortwave bands. The two small condensers (C-1) are connected in series with the transmission line conductors, serving to tune the transmission line and the flat-top sections. By adjusting these condensers, the doublet can be resonated at a certain fundamental frequency, and will then automatically also be periodic at harmonics of this frequency.

Condenser C-2, which is shunted across the primary of the coupling transformer, varies the impedance of this winding to match the input impedance of the flat-top sections and the transmission line. Thus, maximum transfer of energy from the doublets to the receiver is obtained.

A Faraday shield, consisting of a sheet of parallel copper or aluminum wires insulated from each other except at one end, and usually grounded, is placed between the primary and secondary of the coupler coil for the purpose of reducing capacity between these two windings to zero. All energy transfer from the primary to the secondary must therefore occur by means of the primary's magnetic field. Since most of the noise signal would be transferred to the secondary by the capacity field between the primary and secondary, the Faraday shield helps to reduce the transfer of noise from the primary to the secondary winding.

A twisted-pair transmission line could not be used satisfactorily with the type of coupler system shown in Fig. 2. The reason for this is that large standing waves appear on the lead-in at the fundamental and harmonics of the signal being received -- and, since the wires used for a twisted-pair lead-in have considerable insulation, we would experience a large dielectric loss in the transmission line.

The two lengths (A) and (B) of the doublet are usually made 20 or 30 feet long. The length of the transmission line is not critical because the two series condensers, C-1, provide a means for varying its electrical length to the point of resonance.

DIRECTIONAL CHARACTERISTIC OF THE DOUBLET

When installing a doublet antenna, its directional characteristics must be taken into account. This type of antenna receives signal energy best from a direction that is at right angles to its length, as shown in Fig. 3. Large buildings, trees, or metal objects located near the antenna may alter its directional characteristics so that the conditions illustrated in Fig. 3 may not be realized. In general, however, the antenna should be installed so that the greatest number of the stations desired lie in the directivity pattern of the antenna.

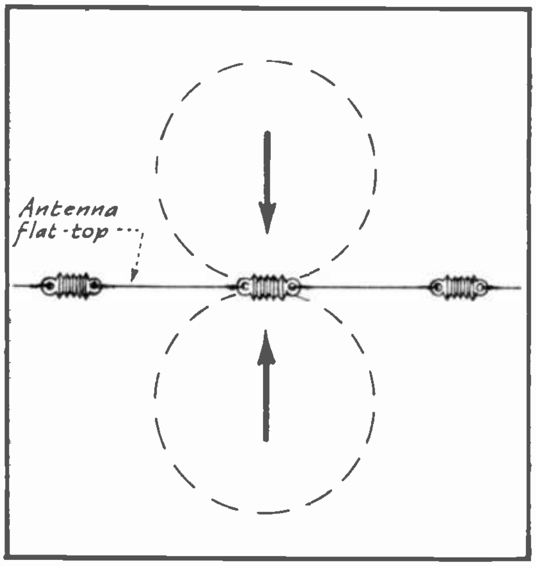

FIG. 3
DIRECTIONAL CHARACTERISTICS OF THE DOUBLET

DOUBLE-DOUBLET ANTENNA

The double-doublet antenna consists of two doublets arranged as shown in Fig. 4. The transmission line connections to the doublets at the cross-over insulator are so made that the system acts as an impedance matching transformer.

The two 16-1/2 foot sections, together, provide an antenna flat-top of 33 feet which forms a half-wave doublet, resonating at 14 megacycles. The two 29-foot sections, together, form a resonant half-wave flat-top having a fundamental of 7-1/2 megacycles, and the third harmonic of which is approximately 22 megacycles. Fig. 5 shows how the combination of these three periodic points on the flat-top provide an over-all response curve which covers a wide range of frequencies from 7 megacycles up to 22 megacycles.

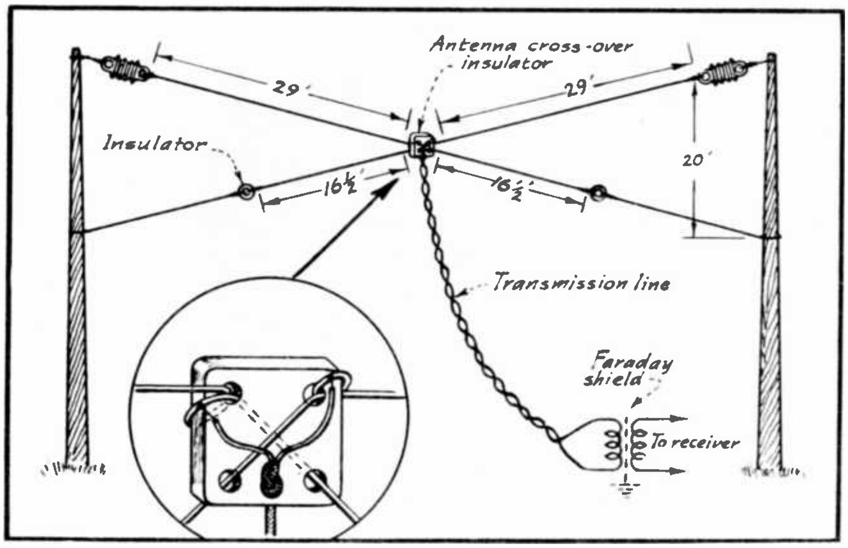

FIG. 4
DOUBLE-DOUBLET ANTENNA

A twisted-wire transmission line is used with this doublet system. The receiver coupling transformer is designed to accurately match the impedance of the antenna system at any of the three periodic points. A Faraday shield between the primary and secondary windings of the coupling transformer eliminates any capacitive

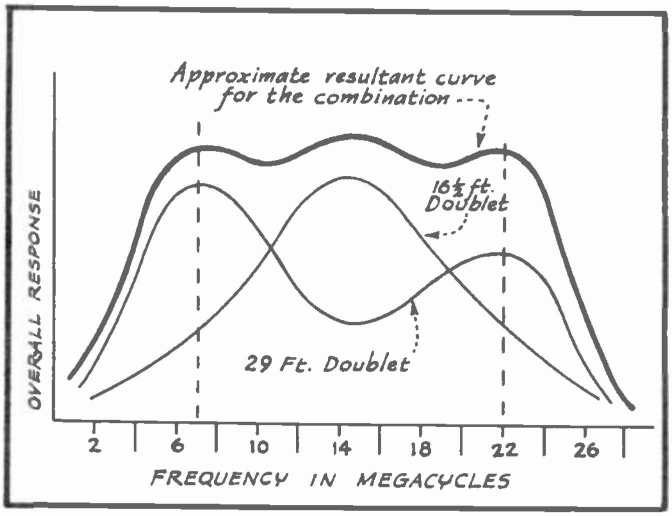

FIG. 5
RESPONSE CURVE OF THE DOUBLE-DOUBLET

coupling between these two windings, and so reduces the transfer of interference noise.

THE "SPIDERWEB" ANTENNA

The "spiderweb" antenna is simply an extension of the double doublet just described. As you will observe in Fig. 6, this antenna consists of three fundamental doublet sections -- all feeding into a common transmission line. Two additional small doublets are optional.

The range of the three fundamental doublets (A and B, C and D, E and F) extends from 49 meters (approximately 6 megacycles) to 16 meters (18.5 megacycles). By installing the other two small doublets (G and H, K and L), the range may be extended to 5 meters, or 60 megacycles.

The two doublet sections E and F, of 20' 5" each, form the 49-meter antenna system. If the required length of each of these sections were calculated, about 25 feet would be needed for a half-wave doublet. Therefore, to cause this part of the system to resonate at 49 meters, a small loading coil is connected at the junction point of these two doublet sections. This small winding is shown in Fig. 6 as being connected to the two 20' 5" doublet sections and to the transmission line. This loading coil, in combination with the two sections of the doublet, increases the electrical length of the flat-top so that it will resonate to the proper frequency.

The two doublet sections A and B form a resonant half-wave flat-top for 25 meters. In order to obtain the proper impedance match between this doublet and the transmission line, the upper portion of the transmission line is fanned out in a "V" and then connected to the two doublet sections at a distance of 4-1/2 feet toward either side of center. This "V" termination of the transmission line, in combination with the two 4-1/2 foot sections of the doublet, produces a reaction between standing waves which provides an impedance match between the doublet and the transmission line.

From 21.5 megacycles up to 60 megacycles, noise interference is practically negligible. The largest

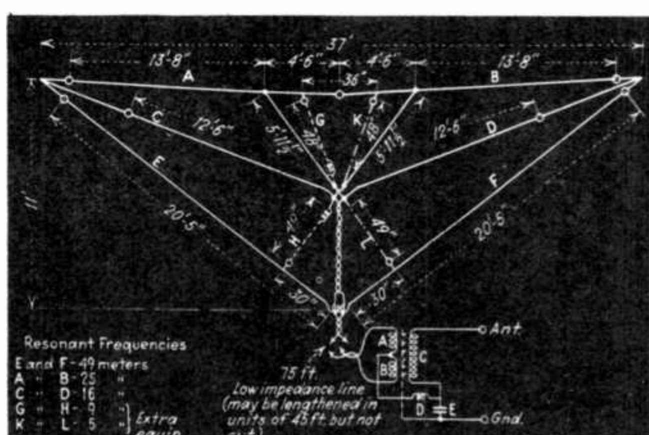

FIG. 6
"SPIDERWEB" ANTENNA

percentage of noise at these frequencies is produced by automobile ignition systems -- but, since automobile ignition interference is radiated only for rather short distances, most home receivers are relatively free from this type of interference. Therefore, the noise-reducing qualities of the lead-in system for the "spiderweb" antenna need be designed to be effective only at frequencies below 21.5 megacycles.

For reasons given in the preceding paragraph, the two optional doublets G-H and K-L act only as simple, vertical resonant collectors. One side of the transmission line is used to conduct the signal from each of these vertical collectors to the coupling transformer -- one-half of the latter's primary winding functioning for each of the collectors.

Since a static (Faraday) shield is used between the primary and secondary winding of the transformer, a small coupling coil (D) is connected to the center tap of the primary. This coil is coupled both capacitively and inductively to the secondary winding (C). Thus, maximum transfer of energy can take place for frequencies above 21 megacycles.

As you may have noticed, doublets G-H and K-L are of the same total length. In order to resonate G-H to 9 meters, two small loading coils are connected between the sections of this collector and their junction point with one side of the transmission line. These two loading coils extend the electrical length of the doublet G-H so that it resonates to 9 meters. Doublet K-L is of the proper length to resonate at 5 meters.

At frequencies below 21.5 megacycles, the two sections of doublets E-F, A-B, and C-D feed their respective sides of the transmission line. The impedance of each doublet is adjusted to match the impedance of the transmission line so that maximum transfer of energy occurs. The lead-in can thus function efficiently from a noise-reducing standpoint.

This same antenna can be employed for reception in the lower limits of the standard broadcast band. However, its efficiency is very much lower at broadcast frequencies, and no noise-reducing qualities are offered. The reason for this decrease in efficiency at these lower frequencies is that the antenna is converted from a doublet to a T-type at this time. The conversion is accomplished by means of a switch (not shown in the diagram).

The spiderweb antenna has several advantages over other types, the main one being that it is very efficient at frequencies ranging from 5 megacycles up to 60 megacycles. Another advantage is the small space required for mounting this antenna. (An antenna of this type requires a horizontal span of only 37 feet and a minimum vertical clearance of but 11 feet.)

The transmission line for this particular antenna may never be cut to a length less than 75 feet. If it is desired to lengthen it, units of 45 feet must be added. These dimensions for the transmission line cannot be altered without seriously affecting the efficiency of the antenna.

THE "V"-DOUBLET ANTENNA

This type of doublet antenna is both popular and efficient, but is critical as to construction and installation. The reason for its popularity lies in the fact that it is aperiodic, meaning that it will respond equally well over a wide range of frequencies. Thus, even though it may be designed fundamentally for a certain band of frequencies, it will operate almost as efficiently at frequencies which are removed considerably from the fundamental.

If such an antenna (shown in Fig. 7) is designed to operate on a fundamental frequency of 6 megacycles or 49 meters, its third harmonic or second periodic point will occur at around 18 megacycles. There is a span of 12 megacycles between these two points, but since the standing waves which normally appear on the two sections of the doublet are partially canceled out by the "V" connection of the transmission line to the antenna flat-top, the over-all response of the antenna does not drop to an inoperative value at a point midway between the fundamental and third harmonic.

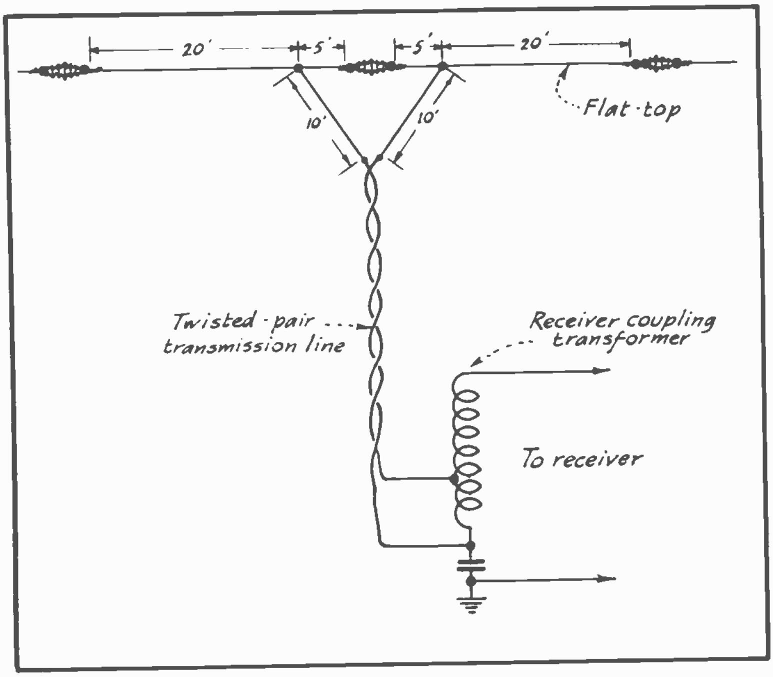

FIG. 7
DOUBLET ANTENNA WITH V-TYPE MATCHED TRANSMISSION LINE

Actually, the points of connection for the fanned-out sections of the transmission line to the doublet sections produce a slight resonant rise at the second harmonic of 6 megacycles (12 megacycles). This helps to maintain the over-all response at a point midway between the fundamental and the third harmonic, and thus keeps it fairly constant from about 3 megacycles all the way up to 25 megacycles.

However, the efficiency of this antenna is not as high as that of the double-doublet, nor that of the spiderweb antenna, because the partial cancellation of the standing waves on the horizontal sections tends to lower the amount of energy fed to the transmission line.

ALL-WAVE V-DOUBLET: Fig. 8 illustrates another type of "V" doublet antenna. Notice that three separate transformers are used to couple the antenna to the receiver. The primary winding of each of these transformers is tuned by the small variable condenser (C), which is shunted directly across the lead-in conductors. This provides a means for obtaining an accurate match of impedance between the coupling transformers and the "V"-matching section of the antenna.

The three transformers are fundamentally resonated at 6 megacycles, 12 megacycles, and 18 megacycles. This gives adequate coverage of the shortwave bands from about 4 megacycles up to 21 megacycles.

Besides those switch contacts which are connected to the terminals of the transformers, two additional sets of contacts (#4 and #5) are supplied on the switch. By tracing the connections of the latter, you will find that set #4 couples the doublet directly to the input of the receiver, with only the small capacity (C) being used to effect a match between the antenna and the receiver input. This connection to the antenna system covers a band extending from about 4 megacycles to 1.5 megacycles.

In position #5,the four-gang switch connects only one section of the doublet and lead-in to the receiver, and connects the other binding post to ground, thereby converting the antenna intc an inverted-L type. Under this condition, the antenna responds satisfactorily over the standard broadcast band.

All other positions of the switches connect one or the other of the three transformers between the antenna and the receiver in conventional "doublet manner" -- no ground connection being used.

TWO-CHANNEL NOISELESS ANTENNA SYSTEM

There are several modifications of the doublet antenna which can be used to provide all-wave coverage, or only two or three individual frequency ranges. One of these -- an off-center type doublet -- is shown in Fig. 9.

The flat-top of this antenna consists of two sections: One 60 feet long, and another which is proportioned to perform most efficiently at the middle of the 31-meter band.

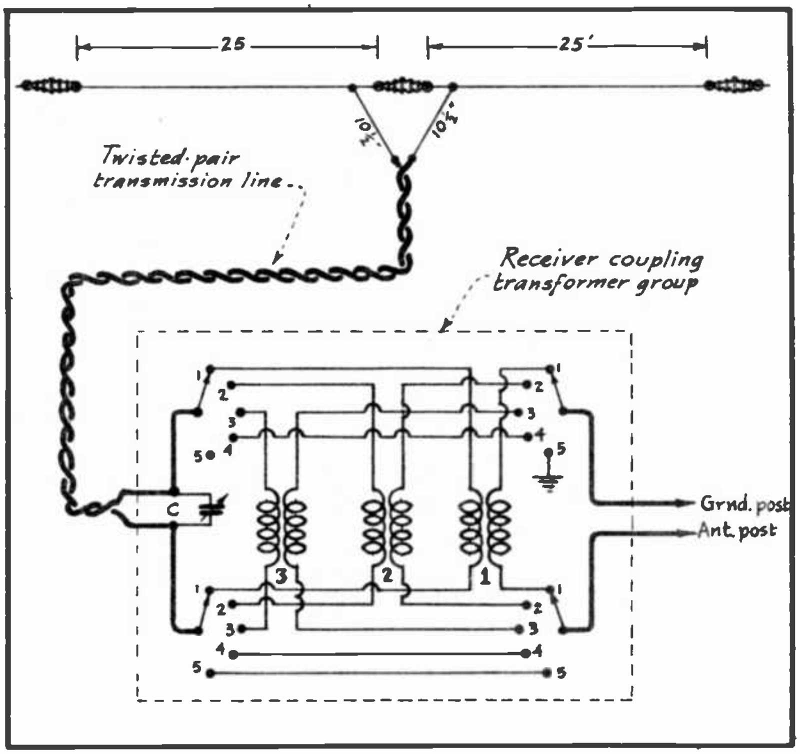

FIG. 8
ALL-WAVE V-DOUBLET AND COUPLING TRANSFORMERS

An antenna coupler transformer and a receiver coupling transformer are used to obtain maximum transfer of energy from the flat-top sections to the receiver. The windings of both these transformers are divided into two sections, powdered iron cores being used to make the transformers highly efficient.

A capacity (C) is connected across the dual primary winding of the antenna coupler. The purpose of this condenser is to shunt the energy collected by the antenna into the correct transformer section for most efficient transmission of the signal to the receiver coupler. Since the primary of the broadcast section of the antenna transformer has a very high reactance at shortwave frequencies, shortwave signals will be forced to take the path of lower impedance through capacity C, the primary of the shortwave antenna transformer section, and thence to ground. Actually, the combination of capacity C and the inductance of the shortwave transformer primary causes the circuit to be resonant at the frequency of the desired shortwave signals. The resonant point, thus produced, covers a fairly wide range of frequencies so that the shortwave response is fairly uniform over the band.

A similar condition occurs at broadcast frequencies. That is, capacity C, in combination with the inductance of the broadcast antenna primary, resonates the circuit to this band. The resultant impedance of the broadcast section of the transformer is thus very low in comparison with the reactance of the shortwave section; but, the ratio of discrimination in the two circuits is not as great as it would be when handling shortwave signals. Therefore, only a very small part of the signal energy might be shunted through the shortwave primary during the reception of standard broadcast programs; but, this small loss of energy is usually negligible even at the higher frequency end of the standard broadcast band. At the lower end of the band, the relative power of stations is somewhat greater, which makes up for any loss in the coupling transformers.

A simple two-conductor, shielded type of transmission line is used between the antenna coupler and the receiver coupling transformer. The shield of the transmission line forms a common connection between

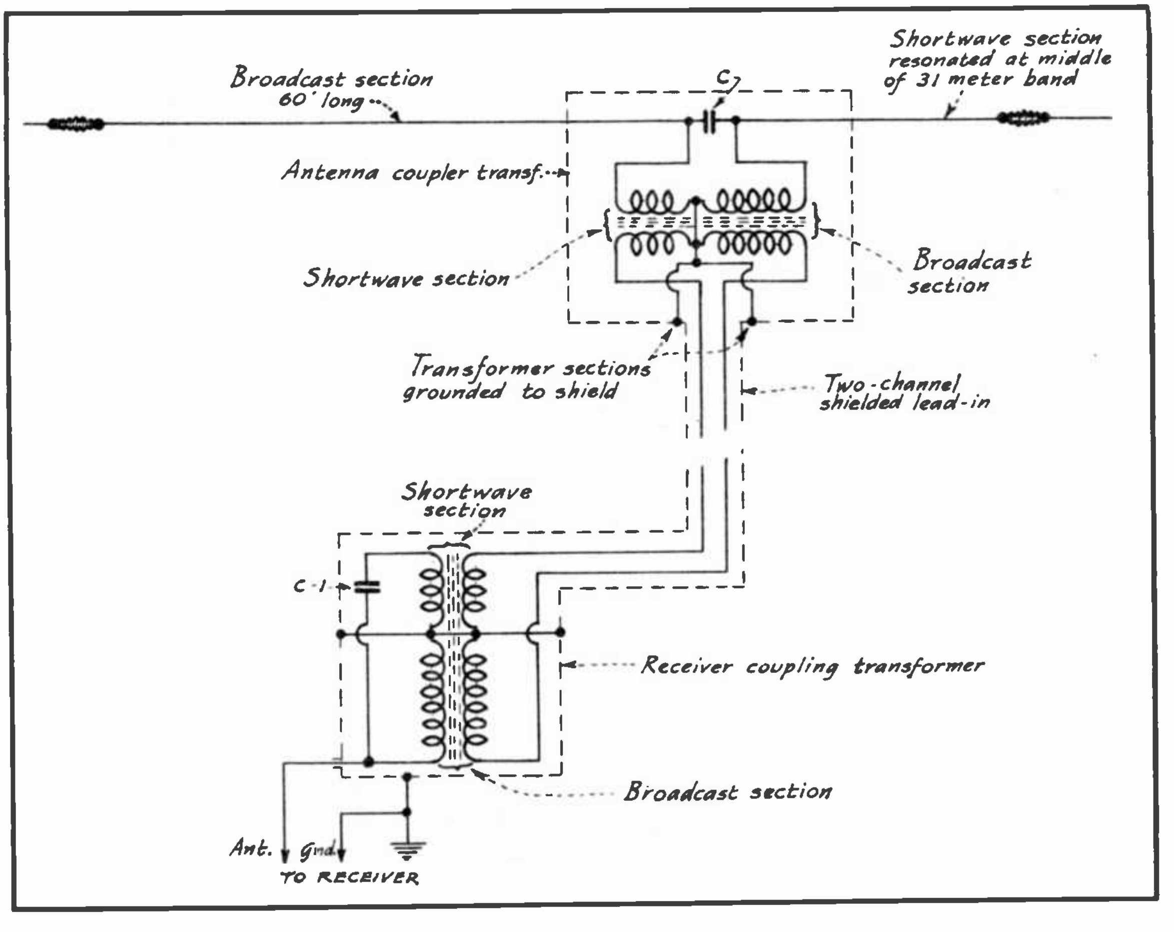

FIG. 9
TWO-CHANNEL NOISELESS ANTENNA SYSTEM

the shielding containers of the two coupling transformers; and,because of being grounded, it reduces or eliminates any noise pick-up by the lead-in system.

The conditions for transfer of energy from both sections of the receiver coupling transformer to the receiver are somewhat different from those of the antenna coupling transformer. At shortwave frequencies, the reactance of the broadcast section of the set—coupling transformer's secondary winding is very high. Consequently,the shortwave signals take the lower reactance path offered by condenser C-1 to the antenna terminal of the receiver,and hence to ground.

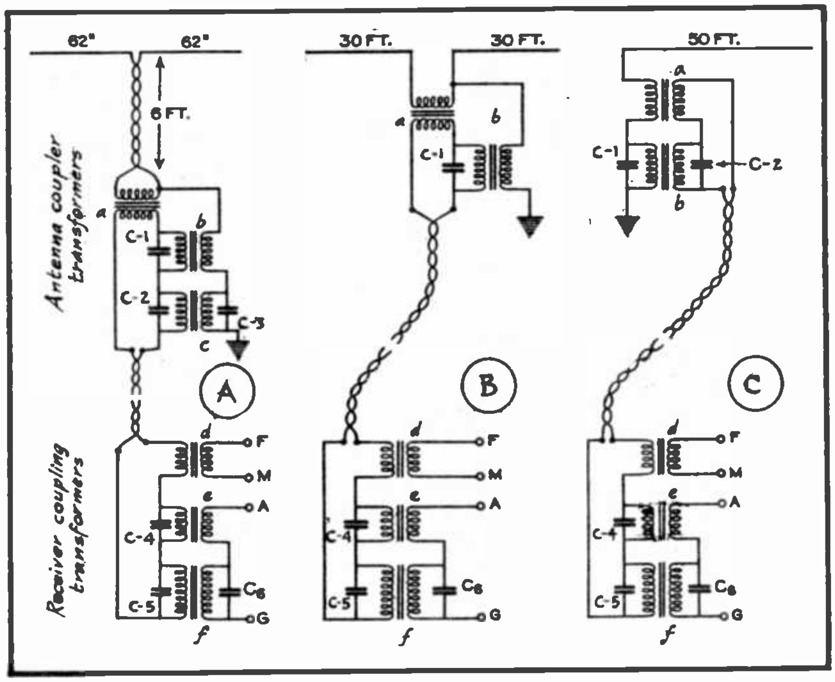

FIG. 10
ALL-WAVE NOISELESS ANTENNA SYSTEMS

The inductance of the shortwave secondary, in combination with the capacity of C-1, produces a rather high impedance at broadcast frequencies. Therefore, broadcast signals will be induced in the secondary winding of the transformer's broadcast section and pass directly to the antenna post of the receiver rather than through the high impedance of the shortwave secondary circuit.

The efficiency of this antenna system is very high, especially at broadcast frequencies and over the limited range of shortwave frequencies for which it is designed. At other frequencies, the response falls off very rapidly.

SPECIAL ANTENNAS FOR FREQUENCY MODULATION RECEIVERS

Since the advent of frequency modulation (F-M) and television, many receivers have been designed to incorporate special circuits and features which make them highly efficient for operation on the frequency bands employed for such transmissions. To keep abreast with these developments, antenna manufacturers have placed on the market several types of antenna systems which are specifically designed for such receivers.

Fig. 10 shows three antenna systems suitable for this purpose. All three use a similar receiver coupling transformer combination, but the antenna coupling arrangement is different in each case.

The operation of these complicated coupling systems is based on a multiple resonant effect which is produced when series and parallel elements are connected together. At certain frequencies the combination will be resonant (series resonance), while at other frequencies it will be anti-resonant (parallel resonance).

The antenna system at (A) is designed primarily for F-M and television reception, and consists of a doublet flat-top having two sections, each 62 inches long. A transposed, or twisted-pair lead-in section, 6 feet in length, connects the flat-top to the combination of antenna matching transformers. The remaining length of the transmission line, between the antenna matching transformers and the receiver coupler combination, is selected to provide the desired impedance of the line.

Upon examining the antenna coupler combination of transformers, we find the primary circuit to comprise the three primary windings of transformers "a", "b" and "c" -- all connected in series, and with the primary winding of "c" being shunted by condenser C-3. The secondary circuit consists of the three secondary windings connected in series, the secondaries of transformers "b" and "c" being shunted by capacities C-1 and C-2, respectively. At 60 megacycles, (5 meters), the impedance of primary "b" in series with the primary element of transformer "c" is so large that it can be neglected insofar as its effect on the operation of the coupling transformer "a" is concerned.

At this frequency, the 62-inch doublet operates as a half-wave Hertz antenna. Signal energy is coupled directly from the primary of transformer "a" into its secondary. The reactance of C-1 and C-2 at this frequency is negligible; the same is true of the two capacities C-4 and C-5. Therefore, the signal energy flows freely down the transmission line through C-1, C-2, the primary of transformer "d", C-4, C-5, and back to the secondary of transformer "a". Thus, the 60 megacycle F-M signal can be made available at the F-M terminals of transformer "d", for delivery to the frequency-modulation circuits of the receiver. It is also to be noted that the secondary of transformer "a", and the primary of "d", form an impedance match which allows for maximum transfer of energy at 60 megacycles.

As the frequency decreases below 60 megacycles, the combination of reactances in the primary circuits of both the antenna and receiver coupling transformers becomes quite complex. At certain frequencies both the primary combinations and secondary combinations become resonant; at which time maximum signal energy is transferred from the antenna to the receiver coupling transformers and thus to receiver terminals A and G (input to amplitude-modulation circuits).

Another factor to be considered is that as the frequency decreases, the doublet becomes more and more unbalanced, due to the fact that one side of the short section of transmission line between the flat-top and the antenna coupling transformer is more nearly grounded through the primaries of "b" and "c". At broadcast frequencies, this unbalance becomes almost 100% effective so that only one section of the doublet and one side of the 6-foot portion of the transmission line function as a collector of signal energy.

The operation of the system shown at (B) of Fig. 10 is very similar to that at (A), with the exception that the fundamental frequency response of system (B) is approximately 7 megacycles. However, the third harmonic of 7 megacycles (21 megacycles) would also develop maximum signal on the flat-top.

At 21 megacycles, the antenna coupling transformer would function almost to the exclusion of any effect which transformer "b" might have. This is because of the same reason as given for the antenna sys tem at (A) -- where we stated that the reactance of the primary of transformer "b" is so large at the highest frequency response of the flat-top that it has little effect on the signal energy in the primary of "a".

As the frequency approaches the fundamental periodic frequency of the doublet, the primary winding of transformer "b" acts as a shunt across one doublet section, unbalancing the system and allowing more

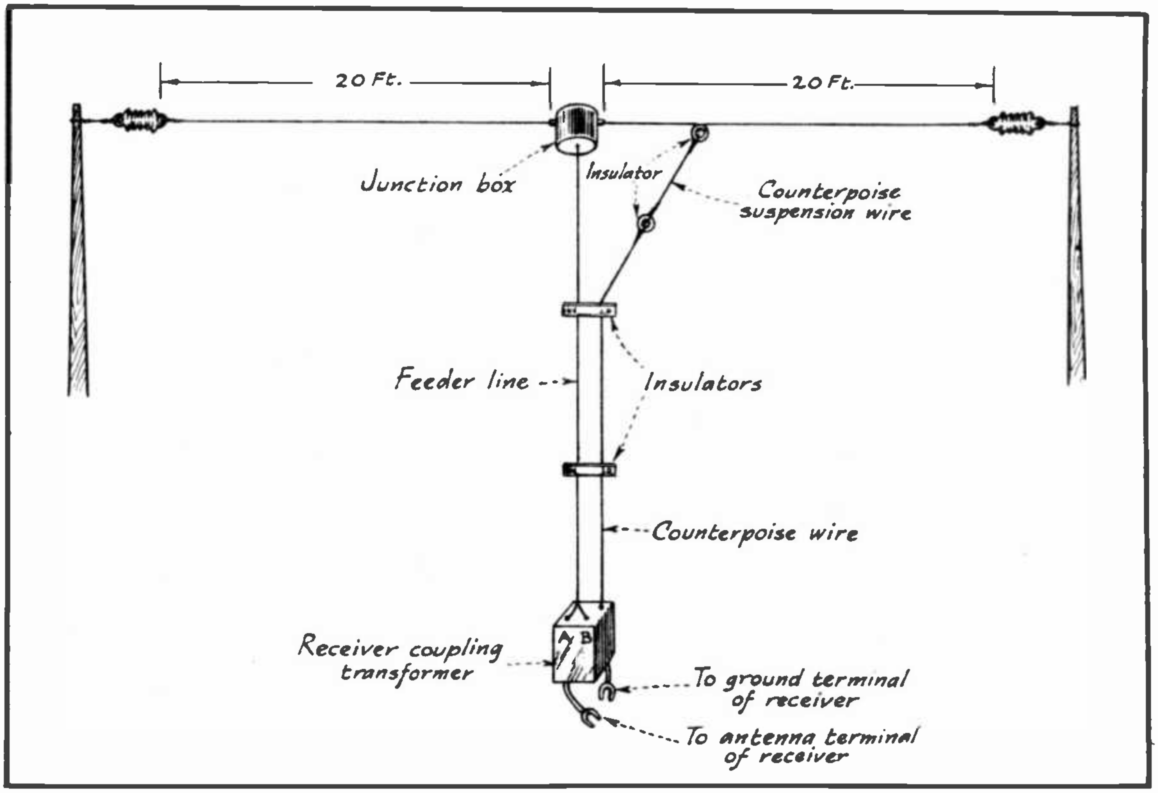

FIG. 11
COUNTERPOISE-DOUBLET ANTENNA

and more of the signal energy to flow to ground. This shunted energy, passing through the primary of transformer "b", produces a signal voltage in its secondary; which voltage causes a signal current to flow to the receiver coupling transformers.

Extremely high frequency signals provide their greatest transfer of energy through receiver coupling transformer "d". The reactances of transformers "e" and "f" combine to form resonant points such that "e" passes most of the intermediate frequencies, while "f" transfers most of the low-frequency energy.

This antenna system is not efficient at very high frequencies (around 60 megacycles), because the flat-top would then be operating at its ninth harmonic. As the harmonic response of an antenna flat-top increases, the signal energy decreases.

Diagram (C) of Fig. 10 illustrates an inverted-L type of antenna flat-top and a different antenna coupling arrangement. However, the same receiver coupling combination is used as for systems (A) and (B).

The operation of this system is almost the same as for an unbalanced condition of the two systems just discussed. At high frequencies, the reactance of the primary of transformer "b" is very high; therefore, practically all of the signal passes through condenser C-1 to ground. Thus, the signal energy is transferred to the secondary of transformer "a".

At lower frequencies, the reactance of C-1 increases while the reactance of the primary winding of transformer "b" decreases. Thus, more of the signal flows through the primary winding of "b", bringing about a corresponding increase of signal voltage in the secondary of "b". The two voltages induced in the secondaries of transformers "a" and "b" add together to provide a stronger signal.

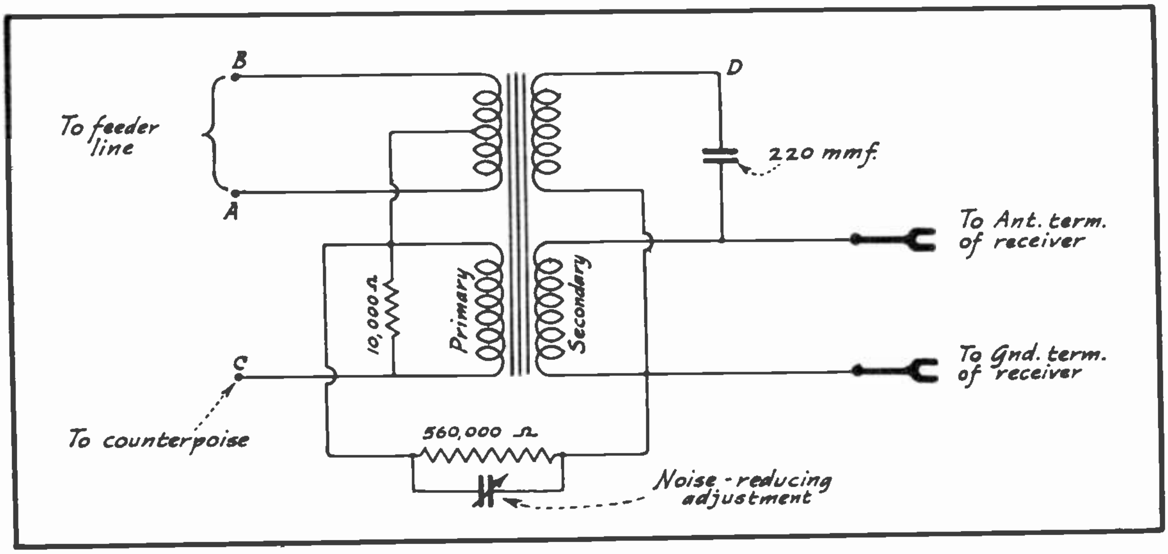

FIG. 12
DIAGRAM OF RECEIVER COUPLING TRANSFORMER

The installation of this antenna is much more simple than either of the other two shown in Fig. 10. However, like antenna (B), its efficiency is low at extremely high frequencies.

ANTI-NOISE "COUNTERPOISE" DOUBLET ANTENNA

The different parts used, and method of installing this system, are shown in Fig. 11. A detailed schematic diagram of the connections to the windings of the receiver coupling transformer appears in Fig. 12. This system is especially suitable in locations where noise interference is extremely troublesome.

As will be observed in Fig. 11, a simple doublet flat-top, with 20-foot sections, is employed. This doublet is connected through a junction box to a feeder line, the latter terminating in a special receiver coupling transformer.

In addition to these usual components, the system utilizes a separate vertical lead-in wire, called the "counterpoise". The counterpoise must be so located and arranged that its total length is ten feet more than half the length of the transmission line; for example, if the transmission line is 40 feet long, the counterpoise should be 20 + 10, or 30 feet long. Likewise, the counterpoise must be located so that it picks up considerable noise signal -- the idea being to feed a large noise signal into the receiver coupling transformer and then reversing its phase relation so that it cancels any noise picked up by the antenna flat-top and transmission line.

Referring to the diagram in Fig. 12, notice that the center tap of the line transformer primary is connected to one side of the counterpoise primary. A small adjustable condenser, shunted by a 560,000 ohm resistor, is connected between this common connection point and ground. This condenser provides the noise-reducing adjustment.

The noise signal appearing at the center of the line primary is approximately in phase with (in step with) the station signal appearing across the ends of this winding. However, when we apply an alternating voltage across a capacity, the voltage developed across the capacity, because of its reactance, is approximately 180 degrees out of phase (out of step) with the applied voltage. (That is, the reactive voltage increases as the applied voltage decreases, and vice versa.) This is exactly what occurs in the circuit of Fig. 12, in which case the out-of-phase noise voltage can be adjusted until it exactly equals and cancels at the line transformer, the in-phase noise voltage developed in the antenna system.

Noise reduction in this system is effective from the highest to the lowest frequencies for which the antenna system is designed. At broadcast frequencies, the counterpoise acts as the signal collector, which is the reason for the secondary winding opposite the counterpoise primary.

At the higher shortwave frequencies, the signal energy is transferred to the upper secondary in Fig. 12, and appears between point D and Ground. The signal then reacts through the 220 mmf condenser, and is applied across the antenna and ground terminals of the receiver.

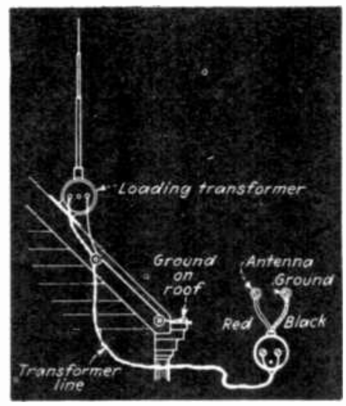

FIG. 13
ROD TYPE ANTENNA

The purpose of the resistor connected across the counterpoise primary winding, and that in shunt with the adjustable condenser, is to broaden the response of these circuits so that there will be no discrimination against signals in the counterpoise circuit.

THE VERTICAL ROD ("FISH POLE") ANTENNA

A description of antenna systems would not be complete without mentioning the vertical type illustrated in Fig. 13. This is a noise-reducing system by virtue of the antenna matching transformers, twisted transmission line, and receiver coupling transformer.

The vertical rod (collector) is usually telescopic in design, similar to those used for automobile radios, and the extended length of which may be anywhere from 9 to 15 feet. The antenna matching transformer is located at the base of the vertical rod, and is so designed as to act as a loading coil for the collector -- thus extending its electrical length.

Both the antenna matching transformer and the receiver coupling transformer, of the particular system illustrated in Fig. 13, are designed to operate at maximum efficiency over a frequency range extending from 500 kc to 22 megacycles.

MULTIPLE OR MASTER ANTENNA SYSTEMS

It is quite simple to install an antenna in a private dwelling, particularly in suburban or rural areas. But, for city dwellers, who live in apartment houses or hotels, installing an antenna may become quite a problem. Obviously, if each set-owner in a large apartment house or hotel were allowed to erect his individual antenna, the roof of the building would no doubt soon be covered by such a maze of poles and wires as to resemble a barb-wire entanglement on "no-man's land."

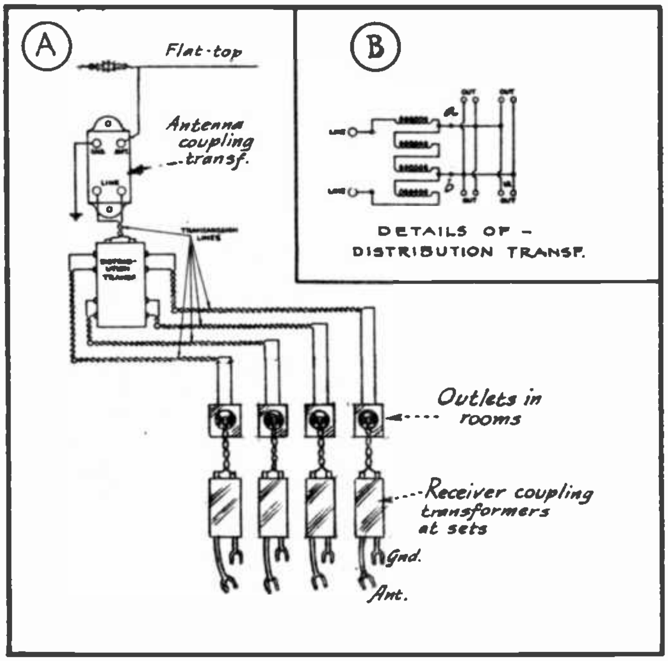

FIG. 14
FOUR-UNIT DISTRIBUTION SYSTEM

The latter is a very dangerous and unsatisfactory condition both for the tenants and for the apartment or hotel owner. For this reason, many cities have already passed legislation which prevents the erection of more than two or three antennas to a prescribed roof area. (This may vary in different localities.)

Under such circumstances, set-owners often resort to antenna substitutes, such as trick gadgets that connect the receiver to one side of the power line system, to the telephone line, to the steam radiator, etc. Every one of these "trick connectors" is a potential source of danger to the set-owner and his family because of the fire hazard and exposure to electric shock. In addition to this danger, such connections often transmit the worst kind of intereference noise to the receiver.

Even a modern receiver with a built-in antenna does not always solve this problem, because large buildings often contain appreciable amounts of steel in their structure. The latter may act as an effective shield and thereby prevent radio waves of sufficient strength from reaching the antenna. The only satisfactory solution to this problem, therefore, resolves itself into applying some method whereby a single, modern noiseless antenna can be utilized to supply signal energy to any number of receivers. In the remaining pages of this lesson several such systems are described.

FOUR-UNIT DISTRIBUTION SYSTEM

The arrangement shown in Fig. 14 will allow up to four receivers to be operated simultaneously from a common antenna. The antenna flat-top is of an inverted-L design, and can be of any length between 20 and 120 feet. As you will see at (A) of Fig. 14, an antenna coupling transformer feeds the signal received from the flat-top into a twisted wire transmission line which is terminated in a distribution transformer. Twisted-wire transmission lines of any length required are extended to the outlets in the four rooms where the receivers are located. A receiver coupling transformer transfers the signal from the outlet to the receiver.

From an inspection of the schematic diagram appearing at (B) in Fig. 14, which shows the connections of the distribution transformer, you can see that it is an auto-transformer. Actually, only one set of output terminals ("a" and "b") is supplied on the distribution transformer to which two sets of parallel-connected distributing leads are connected. Thus, four sets of terminals are available for connecting the receivers to the system.

The receiver coupling transformer may be a single-winding (auto transformer) type similar to those already shown, or it may be of the conventional two-winding design. In either case, the total combination of windings is such as to produce an impedance-matched system.

This type of distribution system would be suited to a four-family flat.

A 50-UNIT DISTRIBUTION SYSTEM

For large apartment houses, or for apartment hotels, a more extensive distribution system would be necessary.

The antenna system illustrated in Fig. 15 is designed to accommodate 50 receivers. For best results, the antenna flat-top should be about 100 feet long; however, any length from 20 to 120 feet will provide satisfactory reception. When installing a system as this, it is important that the flat-top be located fairly high above any surrounding objects, and in an area that is comparatively free from noise interference fields. As is shown in Fig. 15, that portion of the transmission line between the antenna transformer and the point where the line enters the building, is left unshielded.

From the point where the transmission line enters the building, to the various receiver stations,a single shielded wire is used -- the

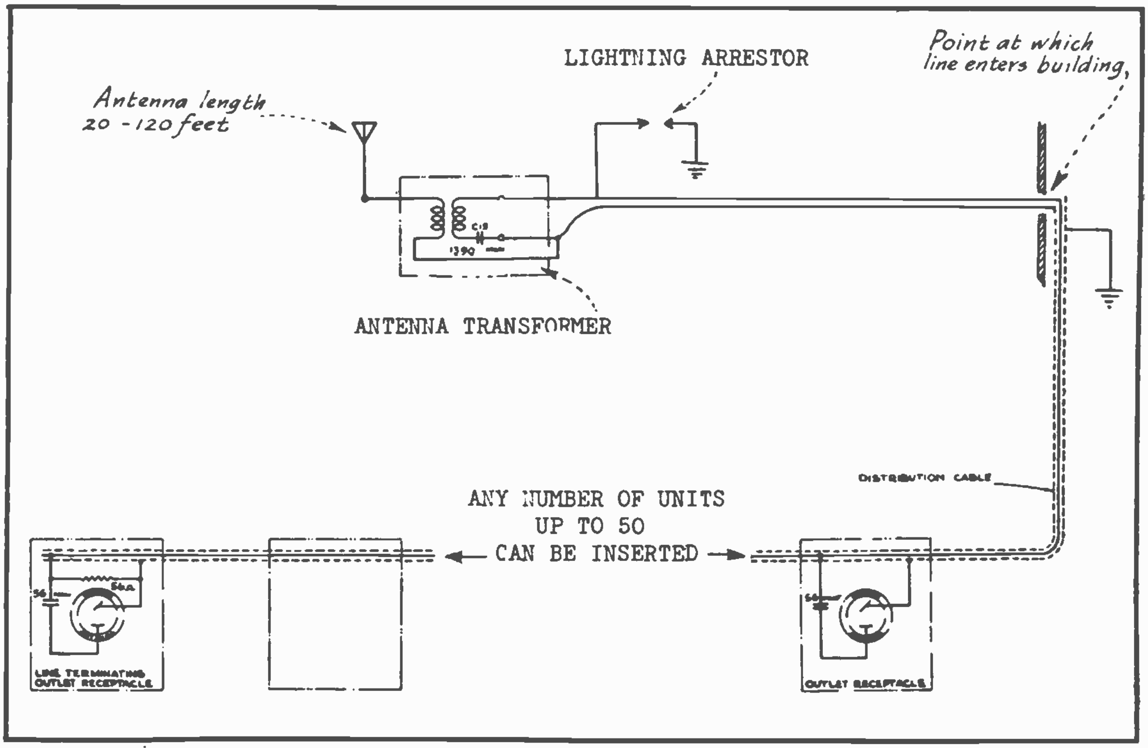

FIG. 15
FIFTY-UNIT DISTRIBUTION SYSTEM

N

grounded shield serving as one side of the distribution circuit. For the particular system illustrated, not more than 500 feet of this shielded cable can be used for distributing the signal to the various apartments.

A special receptacle is installed at each point where a receiver is to be connected to the distribution line. This receptacle is constructed in the form of a plug-in socket in which only a special antenna-ground plug will fit. Thus precluding the possibility of someone plugging in an electrical appliance that might short the distribution line and thereby render it unserviceable during such time as the appliance may be left connected.

Signal energy is transferred from the distribution line to a receiver through the small 56-mmf condenser contained in each outlet receptacle. When a receiver is plugged into the receptacle, this small capacity is in series with the primary winding of the receiver's antenna coil and the line. Since this system is designed fundamentally for broadcast reception, it is quite improbable that the 56-mmf condenser in series with the primary of an antenna coil may become resonant to any frequency in the broadcast band,and thus in effect short the transmission line.

The outlet receptacle which is connected to the end of the transmission line must contain a shunt resistance of 56 ohms. This resistance forms the terminating impedance of the transmission line. If no terminating impedance were used at the end of the line, standing waves would probably be formed. The latter condition would result in certain points along the line offering no transfer of signal energy at all to the outlet connected at that point, while other points would provide a maximum transfer of signal.

500-UNIT DISTRIBUTION SYSTEM

Where it is necessary to couple several hundred receivers to a single antenna system -- such as would be the case in a large hotel -- an amplifier must be used between the antenna and the distribution line so that the input signal to the line will be of sufficient value to carry over as much as 2000 feet of line without suffering too great an attenuation due to the large number of receivers that may be connected across the line at any one time.

In order to obtain constant amplification over the entire range of broadcast frequencies, the band is divided into three channels and fed to three separate amplifier tubes. Fig. 16 shows this arrangement and also the distribution system. As you will note, the distribution line and outlet receptacles used for this system are similar to those of the 50-unit system previously described.

A similar type of antenna installation is employed with the 500-unit distribution system as for the 50-unit system (see Fig. 15 and also details in Fig. 17). The flat-top is a simple inverted-L type, feeding into an antenna matching transformer. A twisted-wire transmission line feeds energy from the antenna transformer to the amplifier-matching transformer, the internal connections of these transformers being as shown in Fig. 16.

The amplifier-matching transformer, labeled T-1 in Fig. 16, is enclosed by broken lines to show that it is shielded separate from the other amplifier components. The primary circuits of the input transformers to each of the amplifier tubes are all connected in parallel across the two output leads of the amplifier matching transformer. Two wave-traps are also coupled to the windings of the latter, and are

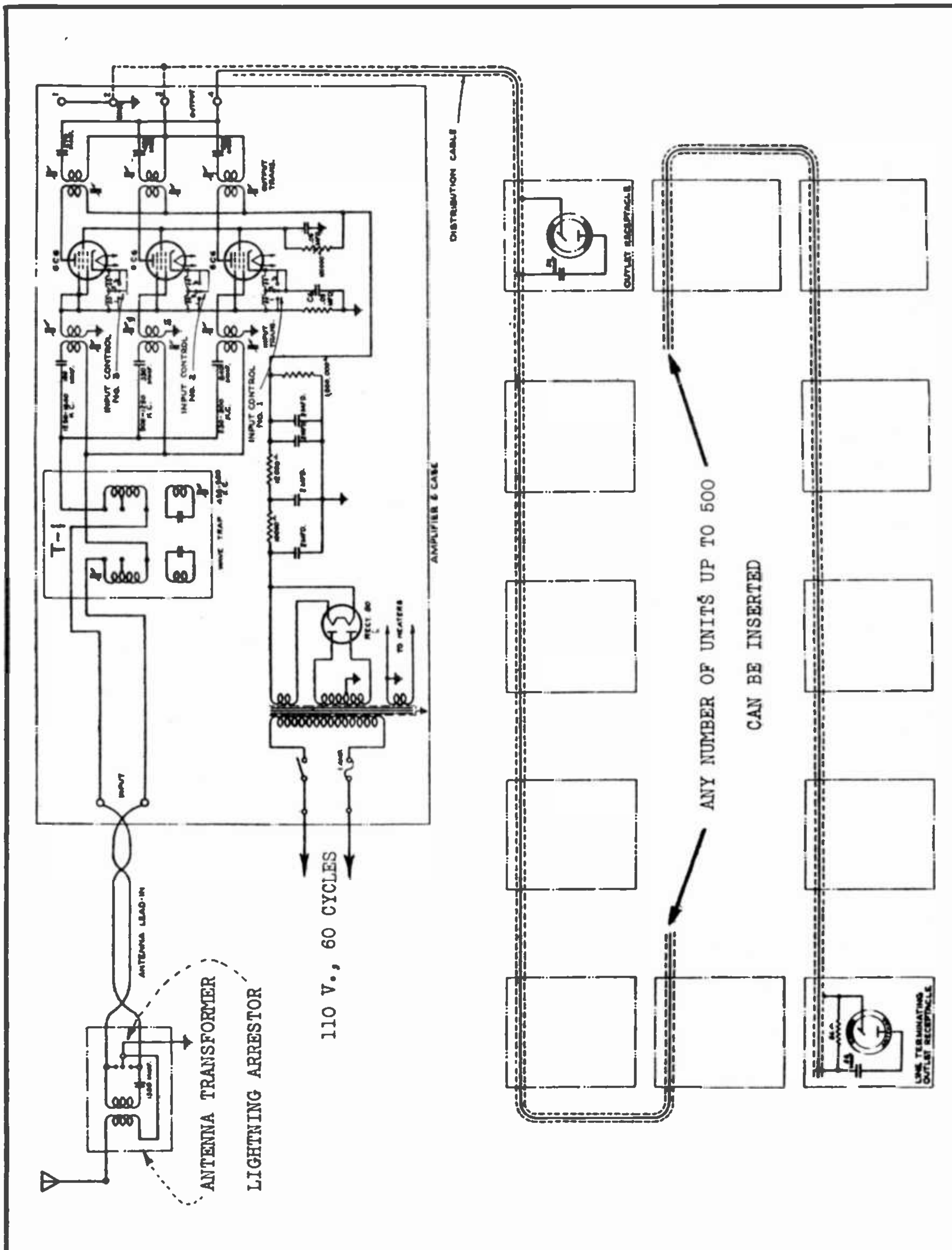

Fig. 16
500-unit Distribution System

tuned to about 465 kc -- the standard i-f frequency. Because of these wave-traps, no interfering signal of this frequency can reach the amplifiers and thus be passed on to any of the receivers which are connected to the distribution line.

The amplifier-matching transformers, wave-traps, and input circuits of the amplifier are all permeability tuned. That is,powdered iron cores are so arranged that they can be moved in or out of the windings, so as to change their inductance value. This results in maximum gain in each of the amplifier circuits, and reduces losses in the tuned circuits.

A rather novel method of input control is used for each of the three amplifier tubes so as to maintain the gain at a reasonably high level, and to prevent any impedance mismatch in the amplifier-matching transformer circuits. This control is designated in Fig. 16 as Input Control #1,#2, and #3. As you will notice,this control consists of a switching system in the cathode circuit of each of the 6C6 amplifier tubes, so arranged that all or only portions of a small tapped inductance may be connected in the circuit -- depending on the position of the switch. The reason for this circuit component can be explained as follows:

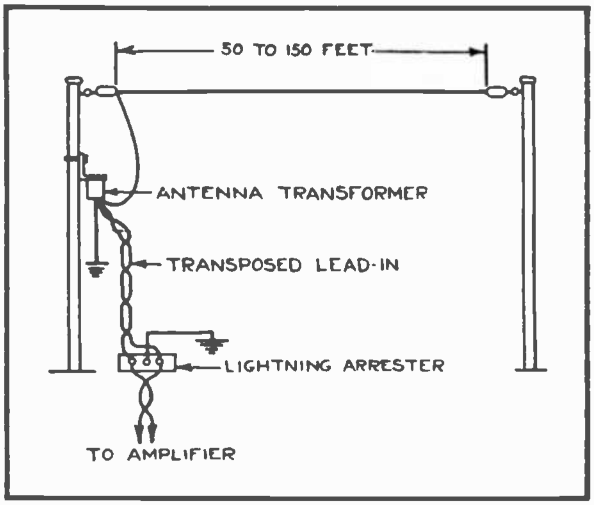

FIG. 17
ANTENNA INSTALLATION FOR THE 50-UNIT SYSTEM

As a vacuum tube circuit approaches the point of oscillation, the tube's gain rises to several hundred times its normal value (depending, of course, on the type of tube). So long as the tube circuit does not commence to oscillate,this increased gain is very useful.

Now, by connecting the small inductance in the cathode circuit of each 6C6 tube, a small amount of feedback voltage is introduced into the control grid circuit of each tube. This results in regeneration and a consequent gain in amplification -- any increase or decrease in regeneration being controlled by the amount of inductance in the cathode circuits. Since this is a controllable factor in Fig. 16, the gain of the amplifier can thus be controlled in each channel.

The upper terminals of the output transformer in each amplifier channel are connected together to the distribution cable conductor. The lower terminals of these transformers are all connected to the shield and to ground. Thus, the secondary windings are all effectively connected in parallel. These paralleled windings form the input (source) impedance for the distribution cable.

As in the case of the 50-unit system, the outlet receptacle which is connected to the end of the distribution line must have a terminating resistance of 56 ohms.

MULTIPLE ALL-WAVE DISTRIBUTION SYSTEM

All of the multiple-outlet distribution systems described thus far have been designed for operation on the standard broadcast band only. In Fig. 18, however, is shown a highly perfected arrangement that will supply shortwave, as well as broadcast reception, to as many as 500 receivers.

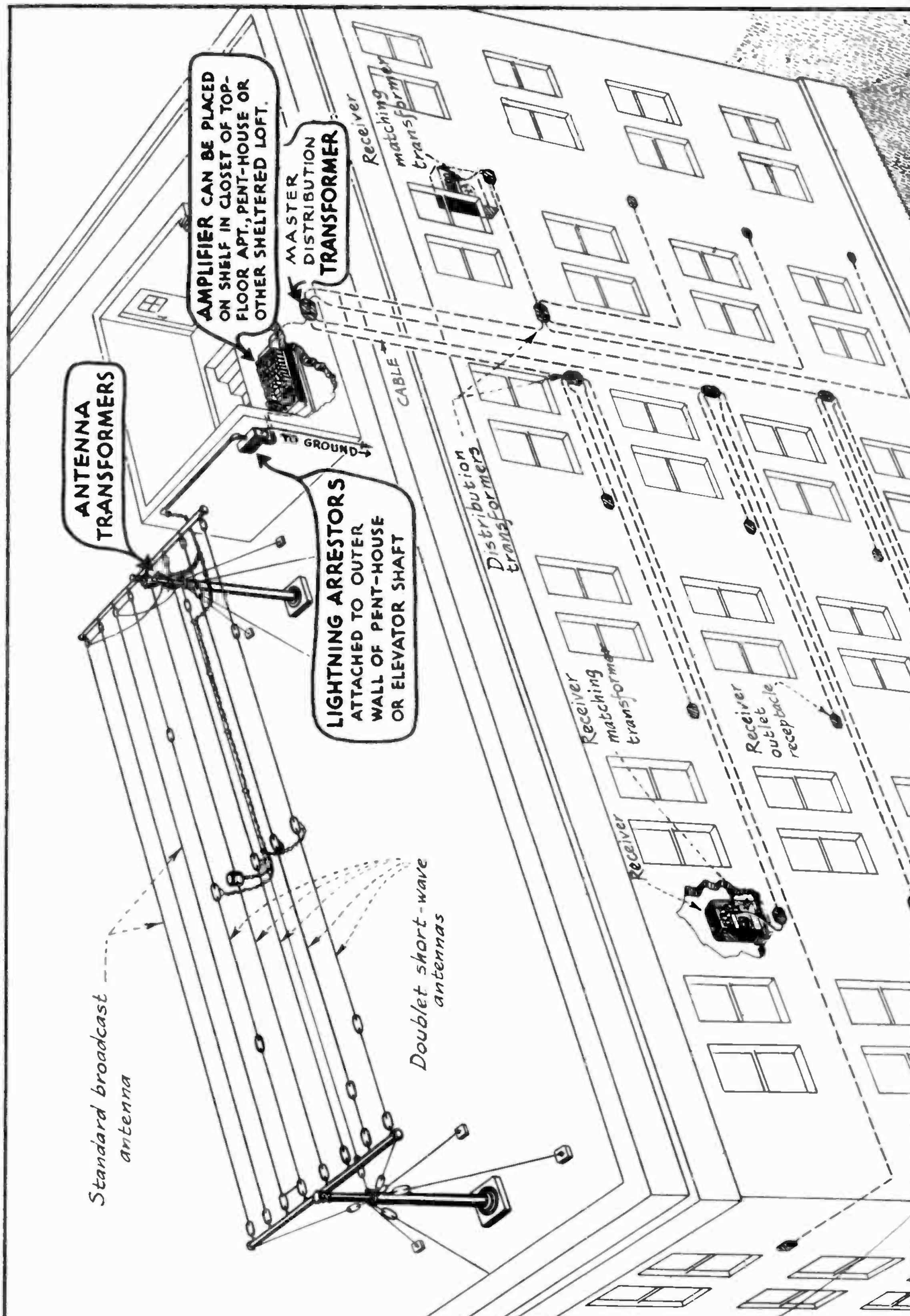

Fig. 18
Installation Features of All-wave 500-unit Distribution System

In this case, seven different antenna flat-tops are used to pick up the desired signals. Five of these are shortwave doublets; two for broadcast reception. Antenna transformers are used with the two standard broadcast and the low-frequency shortwave antennas. The remaining four shortwave doublets are connected directly to a common transmission line. Matching transformers are employed at the end of the transmission line to couple the signal energy to a complex amplifier.

The standard broadcast and shortwave bands are divided into ten different channels for amplification. A separate amplifier is used for each of these channels, making a total of ten amplifier circuits.

The combined output of these ten amplifier channels is fed into a common master distribution transformer, from which branch-lines run to several other distributing transformers. The latter feed the various individual lines to which the outlet receptacles are connected.

The outlet receptacles for this distribution system differ from those used in systems previously described, in that a matching transformer must be used for each receiver which is connected to the line. This is the transformer shown on the back of the two radios in Fig. 18. These matching transformers must be used because separate lines are employed to feed the signal to each receiver outlet.

EXAMINATION QUESTIONS

LESSON NO. 37

1. - How does the counterpoise function to cancel noise signal picked up by the transmission line of the "counterpoise" doublet antenna?

2. - What is the purpose of the loading coils employed in the "spiderweb" antenna system?

3. - Describe a simple doublet antenna.

4. - Why must a 56-ohm resistor be connected across the terminating point of the distribution line of either the 50-unit or the 500-unit system?

5. - How does a double-doublet antenna maintain uniform response?

6. - Describe briefly an antenna which is suitable for frequency modulation receivers.

7. - Will a doublet antenna provide noise-free reception when only a two-conductor parallel-wire transmission line is used? Explain the reason for your answer.

8. - What is the reason for using ten separate amplifier channels in the all-wave multiple receiver system of Fig. 18?

9. - Describe the two-channel noiseless antenna and explain how the antenna coupling transformer operates.

10. - Is the efficiency of a "V"-type matched transmission line antenna higher or lower than that of an equivalent double-doublet system?

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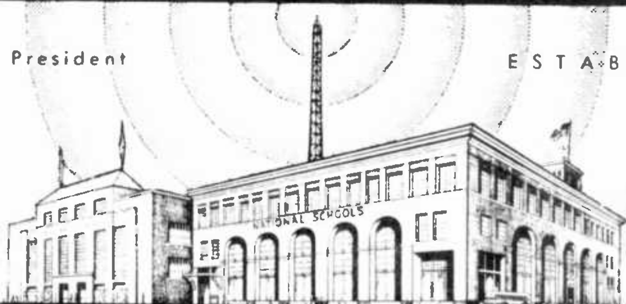

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LESSON NO. 38

VOLTAGE DISTRIBUTION IN RECEIVERS

IN A-C RECEIVERS THE A-C LINE VOLTAGE IS "STEPPED UP" BY A POWER TRANSFORMER, CONVERTED TO A D-C SUPPLY BY MEANS OF A RECTIFIER, AND REMAINING PULSATIONS ARE THEN SMOOTHED OUT BY THE FILTER SYSTEM. FINALLY, THE FILTERED D-C IS PASSED THRU A RESISTANCE NETWORK FROM WHERE IT IS DISTRIBUTED AT THE PROPER VOLTAGE TO THE VARIOUS CIRCUITS OF THE RECEIVER.

YOU ARE ALREADY FAMILIAR WITH THIS SYSTEM AND WITH THE PARTS WHICH WE WILL AGAIN DISCUSS IN THIS LESSON. AT THIS TIME, HOWEVER, WE WILL TREAT THE SUBJECT OF D-C VOLTAGE DISTRIBUTION FROM A DIFFERENT ANGLE; AND IN THE FIRST SECTION OF THIS LESSON, YOU WILL BE SHOWN HOW TO DESIGN VOLTAGE DISTRIBUTION SYSTEMS. WITH THIS KNOWLEDGE, YOU WILL BE ABLE TO DETERMINE THE VARIOUS SIZES OF RESISTORS USED FOR THIS PURPOSE, THEIR WATT RATING, ETC.

LET US ASSUME THAT A RADIO RECEIVER HAS JUST BEEN BUILT IN ACCORDANCE WITH THE CIRCUITS SHOWN IN FIG. 2, AND IT IS NECESSARY TO PROVIDE A RESISTANCE SYSTEM THAT WILL SATISFACTORILY SUPPLY THIS RECEIVER

FIG. 1
A SECTION OF NATIONAL'S
BROADCAST TRANSMITTER

WITH THE PROPER "B", "C" AND SCREEN-GRID VOLTAGES. FOR THE PRESENT, WE ARE NOT CONCERNED WITH THE FILAMENT CIRCUIT.

DETERMINING THE TUBE LOAD

OUR FIRST STEP IS TO DETERMINE THE VOLTAGES AND CURRENTS REQUIRED BY THE DIFFERENT TUBES, AND BY REFERRING TO FIG. 2 AND THE OPERATING CHARACTERISTICS OF THE TUBES USED, WE HAVE THE FOLLOWING DATA AT HAND.

EACH OF THE TYPE 6D6 R.F. TUBES REQUIRES A PLATE VOLTAGE OF 250, A SCREEN VOLTAGE OF 100 VOLTS AND A MINIMUM BIAS VOLTAGE OF -3. UNDER THESE CONDITIONS, THE PLATE CURRENT DRAWN BY EACH OF THESE TUBES WILL BE 8.2 MA., AND THE SCREEN CURRENT APPROXIMATELY 2 MA. FOR EACH TUBE.

THE TYPE 42 POWER AMPLIFIER TUBE REQUIRES A PLATE VOLTAGE OF 250, A SCREEN GRID VOLTAGE OF 250, AND A GRID BIAS OF -16.5 VOLTS. THIS TUBE WILL THEN DRAW A PLATE CURRENT OF 34 MA., AND A SCREEN CURRENT OF 6.5 MA.

WE WILL ASSUME THAT THE 6C6 DETECTOR TUBE IN THIS CASE REQUIRES A PLATE SUPPLY VOLTAGE OF 250 VOLTS, A GRID BIAS OF -4.3 VOLTS, AND A SCREEN GRID VOLTAGE OF 75. WHEN SO OPERATED, ABOUT 0.33 MA. OF PLATE CURRENT WILL FLOW, AND APPROXIMATELY 0.1 MA. OF SCREEN GRID CURRENT.

IT IS TO BE NOTED THAT WHEN SPECIFYING VALUES FOR TUBES OPERATED AS RESISTANCE-COUPLED POWER DETECTORS, SUCH AS EMPLOYED IN THE CIRCUIT OF FIG. 2, THE TUBE MANUFACTURERS MAKE IT A GENERAL PRACTICE TO SPECIFY

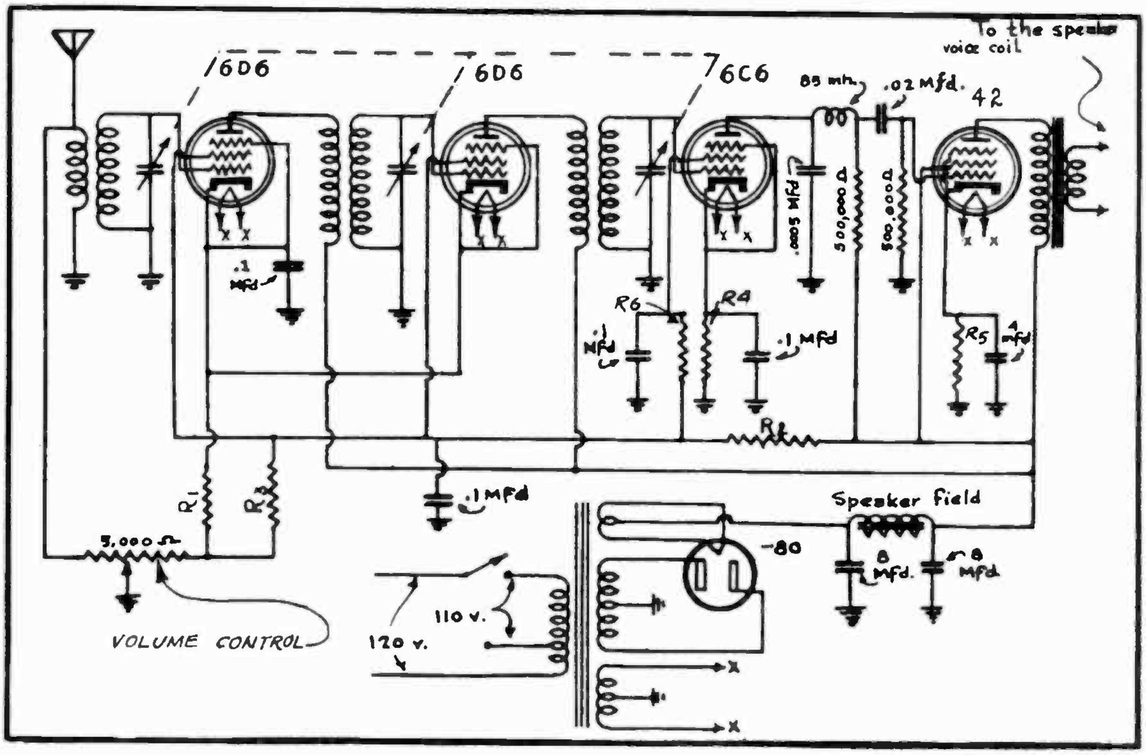

FIG. 2
FIVE-TUBE RADIO RECEIVER CIRCUITS.

THE B VOLTAGE SOURCE NECESSARY FOR THE DETECTOR'S PLATE SUPPLY, TOGETHER WITH THE REQUIRED PLATE CIRCUIT RESISTOR VALUE FOR BEST OPERATION, RATHER THAN SPECIFYING THE ACTUAL PLATE VOLTAGE AS MEASURED AT THE TUBE SOCKET. FOR THE 6C6 A PLATE CIRCUIT RESISTOR OF 0.5 MEGOHM IS SPECIFIED.

ALSO, BEAR IT IN MIND THAT SOMETIMES THE OPERATING VALUES FOR THE SAME TYPE OF TUBE VARY SOMEWHAT IN THE DIFFERENT MAKES, BUT IN ANY EVENT, THE DESIGN PROCEDURE SUGGESTED IN THIS LESSON SHOULD BE CARRIED OUT.

THE R.F. LOAD

THE NEXT STEP IS TO DETERMINE THE COMBINED CURRENT THAT THE TWO R.F. STAGES WILL REQUIRE FROM THE B SUPPLY. TO SIMPLIFY THIS ANALYSIS, THE BASIC DIAGRAM OF FIG. 3 IS PRESENTED. THE RESISTORS HERE SHOWN ARE INDEXED AS R_1 AND R_2, TO CORRESPOND WITH THE SAME RESISTORS SHOWN IN FIG. 2.

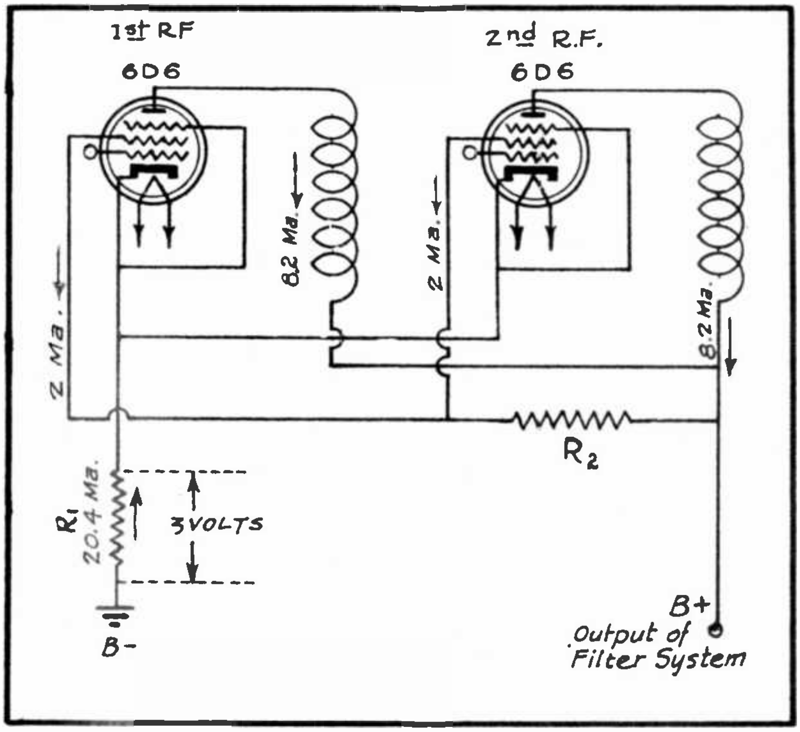

FIG. 3
SIMPLIFIED R.F. LOAD CIRCUIT.

UPON STUDYING FIG. 3 CLOSELY YOU WILL SEE THAT THIS CIRCUIT IS SUCH THAT THE COMBINED PLATE AND SCREEN CURRENTS OF BOTH THE R.F. TUBES WILL FLOW THRU R_1. SINCE THE PLATE CURRENT THRU EACH TUBE IS 8.2 MA., AND THE SCREEN CURRENT 2 MA., THE TOTAL CURRENT FLOWING THRU EACH OF THESE TUBES WILL BE 8.2 + 2 = 10.2 MA. THIS TOTAL B CURRENT PER TUBE IS SOMETIMES CALLED THE "CATHODE CURRENT", BECAUSE ALL OF IT MUST FLOW THROUGH THE CATHODE IN ORDER TO COMPLETE THE CIRCUIT.

THE CIRCUIT CONNECTION OF RESISTOR R_1 IS SUCH THAT THE CATHODE CURRENT OF BOTH OF THE R.F. TUBES MUST FLOW THRU IT, AND THEREFORE IT WILL CARRY A CURRENT OF 2 x 10.2 = 20.4 MA.

CALCULATING THE R.F. BIAS RESISTOR

BY AGAIN REFERRING TO FIG. 2, YOU WILL OBSERVE THAT IN THE ACTUAL CIRCUIT, THE GROUND OR B- CONNECTION FOR R_1 IS COMPLETED THRU THE ARM TERMINAL OF THE 5000 OHM POTENTIOMETER THAT IS USED AS THE VOLUME CON-

TROL. WHEN THE ARM OF THE POTENTIOMETER SHOWN IN FIG. 2 IS MOVED TO THE EXTREME RIGHT IT WILL GROUND THE LOWER END OF R_1. WHEN SUCH IS THE CASE,THE MINIMUM PERMISSIBLE RESISTANCE IS INCLUDED IN THE CATHODE CIRCUIT OF THE R.F. AMPLIFIER, RESULTING IN MINIMUM BIAS VOLTAGE AND MAXIMUM VOLUME. (THE 6D6 TUBES HAVE A VARIABLE-MU CHARACTERISTIC THAT IS HERE USED TO ASSIST THE CONTROL OF VOLUME).

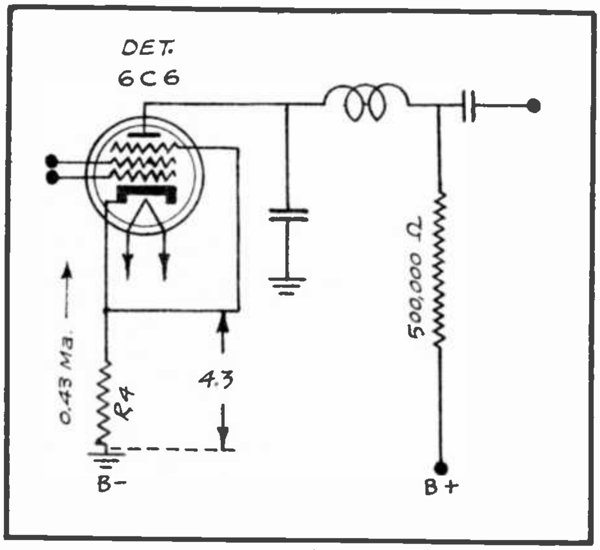

FIG. 4
CALCULATING DETECTOR BIAS RESISTOR.

WITH THE VOLUME CONTROL IN THIS POSITION, THE CATHODE CIRCUIT BECOMES EQUIVALENT TO THAT ILLUSTRATED IN FIG. 3, WHERE FOR THE SAKE OF SIMPLICITY THE VOLUME CONTROL HAS BEEN OMITTED. AT THIS TIME IT IS THE DUTY OF R_1 TO FURNISH THE MINIMUM BIAS OF -3 VOLTS AS PREVIOUSLY SPECIFIED IN THIS LESSON.

THE REQUIRED RESISTANCE RATING FOR R_1 IS DETERMINED BY APPLICATION OF OHM'S LAW IN THE FOLLOWING MANNER: $R = \frac{E}{I} = \frac{3}{.0204} =$ 147 OHMS (APPROXIMATELY). NOTICE THAT WHEN APPLYING OHM'S LAW, THE CURRENT VALUE 20.4 MA.MUST FIRST BE CONVERTED TO ITS EQUIVALENT 0.0204 AMP.

RESISTORS OF SUCH ODD RATINGS AS 147 OHMS ARE NOT COMMERCIALLY AVAILABLE UNLESS THEY ARE SPECIALLY CONSTRUCTED. THEREFORE, IF A STANDARD RESISTOR IS TO BE USED FOR THIS PURPOSE, WE MUST SELECT THE NEAREST STANDARD COMMERCIAL VALUE, WHICH IS 150 OHMS. FROM A PRACTICAL STANDPOINT, THIS SLIGHT DIFFERENCE FROM THE CALCULATED VALUE CAN BE NEGLECTED, AS IT WILL NOT RESULT IN ANY NOTICEABLE EFFECT UPON THE PERFORMANCE OF THE SET. IN FACT, EVEN A VALUE AS HIGH AS 200 OHMS WOULD NOT BE ENTIRELY IMPRACTICAL, IF NECESSARY TO USE IT.

THRU THE USE OF THE VOLUME CONTROL, THE EFFECTIVE BIAS RESISTANCE AND BIAS VOLTAGE CAN BE INCREASED, AND THE VOLUME CORRESPONDINGLY REDUCED.

THE DETECTOR BIAS RESISTOR

THE ESSENTIAL PARTS OF THE CIRCUIT CONCERNED IN THE CALCULATION OF THE VALUE OF THE DETECTOR'S BIAS RESISTOR ARE SHOWN IN FIG. 4. THE BIAS RESISTOR R_4 WILL PASS A CURRENT OF 0.33+ 0.1 = 0.43 MA. THEREFORE, SINCE

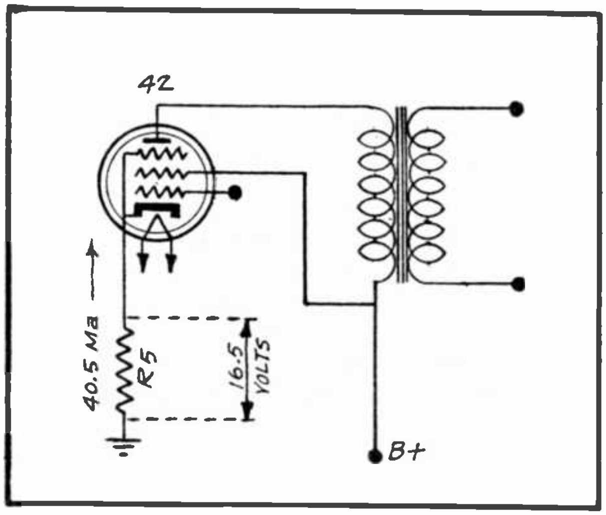

FIG. 5
CALCULATING POWER STAGE BIAS RESISTOR.

A BIAS VOLTAGE OF -4.3 VOLTS IS REQUIRED, THE NECESSARY VALUE FOR R_4 IS $R = \frac{E}{I} = \frac{4.3}{.00043} = 10{,}000$ OHMS. THIS RATING IS COMMERCIALLY AVAILABLE.

POWER STAGE BIAS RESISTOR

FIG. 5 ILLUSTRATES THE BASIC PARTS AND VALUES CONCERNED IN CALCULATING THE RATING OF THE BIAS RESISTOR OF THE TYPE 42 POWER TUBE. SINCE THE PLATE CURRENT DRAWN BY THIS TUBE IS 34 MA., AND THE SCREEN CURRENT 6.5 MA., THE TOTAL CURRENT FLOWING THRU THE BIAS RESISTOR R_5, IS 34 + 6.5 = 40.5 MA. THEREFORE, TO PRODUCE THE NECESSARY BIAS VOLTAGE OF -16.5, THIS RESISTOR MUST HAVE A VALUE OF $R = \frac{E}{I} = \frac{16.5}{0.0405} = 407$ OHMS, AND A STANDARD RESISTOR OF 400 OHMS WILL PROVE SATISFACTORY.

EFFECTIVE PLATE VOLTAGE

AN IMPORTANT POINT TO REMEMBER IS THAT THE B VOLTAGE SUPPLIED TO THE PLATE CIRCUIT OF ANY TUBE IS NOT NECESSARILY OF THE SAME VALUE AS THE PLATE VOLTAGE EFFECTIVE AT THE TUBE. FOR EXAMPLE, FIG. 6 SHOWS AN AUDIO AMPLIFIER STAGE WHEREIN THE TUBE IS OPERATING WITH A BIAS OF -10 VOLTS.

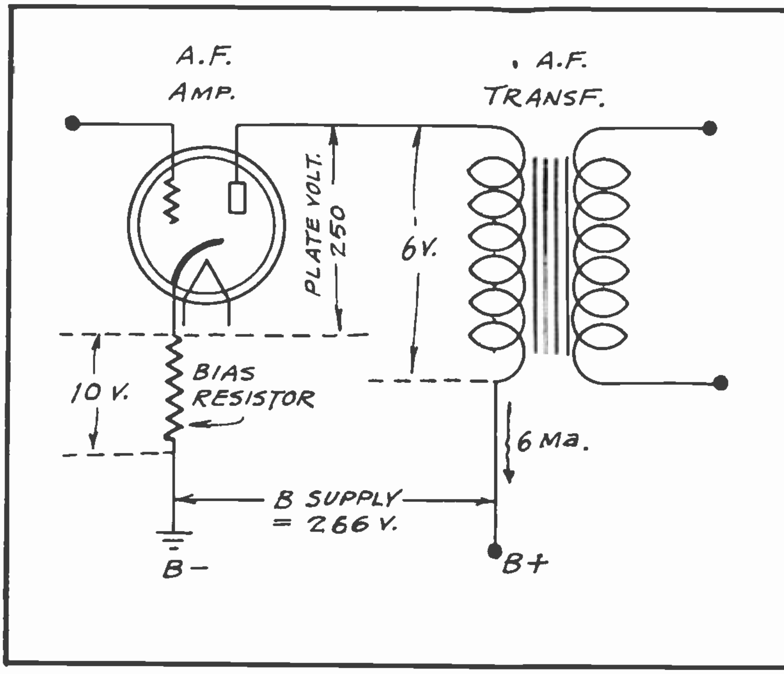

FIG. 6
VOLTAGE DROPS IN THE CIRCUIT.

ALSO NOTE THAT IN THIS SAME TUBE'S PLATE CIRCUIT IS INCLUDED THE PRIMARY WINDING OF AN AUDIO TRANSFORMER, THE RESISTANCE OF WHICH IS 1000 OHMS. THE B SUPPLY VOLTAGE ACROSS THE B+ AND B- TERMINALS IS 266 VOLTS, AND A PLATE CURRENT OF 6 MA. FLOWS THRU THE CIRCUIT.

THE FLOW OF 6 MA. OF PLATE CURRENT THRU THE 1000 OHMS OF RESISTANCE OFFERED BY THE A.F. TRANSFORMER'S PRIMARY ACCOUNTS FOR A VOLTAGE DROP OF 6 VOLTS ACROSS THE EXTREMITIES OF THIS WINDING. ($E = I \times R = 0.006 \times 1000 = 6$ VOLTS).

THE SUM OF THE VOLTAGE DROPS ACROSS THIS TRANSFORMER WINDING AND THE BIAS RESISTOR IS 6 + 10 = 16 VOLTS. THEREFORE, THE ACTUAL OR EFFECTIVE PLATE VOLTAGE, MEASURED BETWEEN THE TUBE'S PLATE AND CATHODE, IS 266—16, OR 250 VOLTS.

THIS EXAMPLE THUS SHOWS WHY, IN PRACTICE, THE PLATE VOLTAGE IS AL-

WAYS LESS THAN THE B SUPPLY VOLTAGE.

CALCULATING THE SCREEN GRID CIRCUIT RESISTORS

FIG. 7 ILLUSTRATES THE BASIC CIRCUIT FOR WORKING OUT THE VALUES FOR THE VARIOUS RESISTANCE THAT ARE INCLUDED IN THE SCREEN GRID CIRCUITS OF THIS RECEIVER.

THE HIGHEST B VOLTAGE REQUIRED BY ANY OF THE TUBES WILL BE DEMANDED BY THE 42, WHICH REQUIRES A PLATE VOLTAGE OF 250 AND A BIAS OF -16.5 VOLTS.

IN ADDITION, THE PRIMARY WINDING OF THE OUTPUT TRANSFORMER, HAVING A RESISTANCE OF 500 OHMS, IS CONNECTED IN THIS TUBE'S PLATE CIRCUIT. WITH A PLATE CURRENT OF 34 MA. FLOWING THROUGH THIS WINDING, THE VOLTAGE DROP ACROSS IT WILL BE 17 VOLTS $(E = I \times R = 0.034 \times 500 = 17)$. THE TOTAL B SUPPLY VOLTAGE REQUIRED BY THIS TUBE, AND MEASURED ACROSS THE OUTPUT TERMINALS OF THE POWER SUPPLY FILTER SYSTEM, THUS BECOMES 250 + 16.5 + 17 = 283.5 VOLTS.

TO PROTECT THE FILTER CONDENSERS AGAINST BREAK-DOWN DURING THE RECEIVER TUBES' WARMING-UP PERIOD, MEANS MUST BE PROVIDED FOR CIRCULATION OF A BLEEDER CURRENT. IN THE CIRCUITS OF FIG. 2 AND 7, THIS IS ACCOMPLISHED BY R_2 AND R_3 IN COMBINATION, PROVIDING A PERMANENTLY CLOSED CIRCUIT ACROSS THE FILTER OUTPUT.

THE AMOUNT OF BLEEDER CURRENT IS LEFT TO THE DESIGNER'S JUDGEMENT,

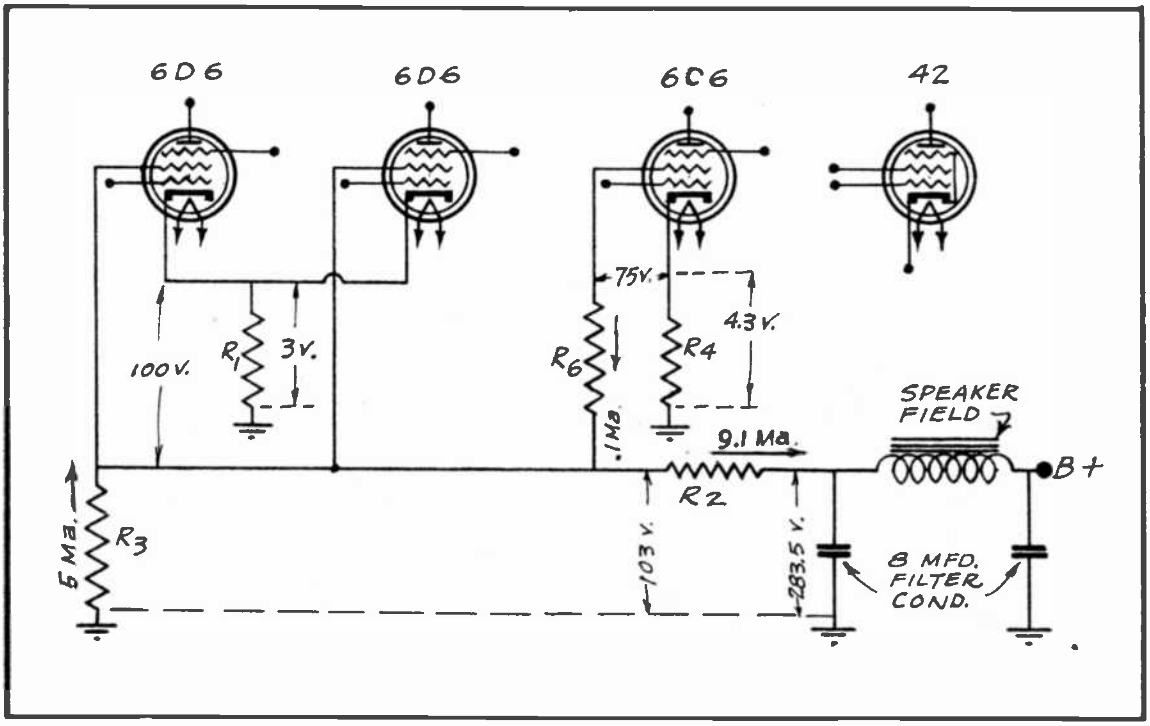

FIG. 7
CALCULATING SCREEN RESISTOR VALUES.

BUT TOO MUCH BLEEDER CURRENT INCREASES THE TOTAL LOAD UPON THE RECTIFIER, AND THE VOLTAGE DROP ACROSS THE FILTER SYSTEM IS ALSO INCREASED. ON THE OTHER HAND, TOO LITTLE BLEEDER CURRENT WILL MAKE THE SYSTEM LESS STABLE IN OPERATION, SO WE TRY TO ARRIVE AT A HAPPY MEDIUM BY ALLOWING FROM 3 TO 10 MA. FOR OUR PARTICULAR EXAMPLE WE SHALL SELECT A BLEEDER CURRENT OF 5 MA.

THE TOTAL CURRENT FLOW THROUGH R_2 WILL BE EQUAL TO THE SUM OF THE BLEEDER CURRENT AND THE SCREEN CURRENT DRAWN BY THE R.F. AND DETECTOR TUBES. FROM THE DATA ALREADY FURNISHED IN THIS LESSON, THE TOTAL CURRENT FLOW THROUGH R_2 IS THEREFORE $5 + 2 + 2 + 0.1 = 9.1$ MA.

A VOLTAGE OF 100 IS REQUIRED BY THE SCREEN GRIDS OF THE 6D6 TUBES, AND SINCE THIS SCREEN VOLTAGE MUST EXIST ACROSS THE SCREEN GRID AND CATHODE TERMINALS OF THESE TUBES (WHICH OPERATE WITH A BIAS VOLTAGE OF -3 VOLTS)THE SCREEN GRID SUPPLY VOLTAGE AT THE SCREEN GRID END OF THE CIRCUIT (OUTPUT) OF R_2)MUST BE 100 + 3 OR 103 VOLTS. THIS ME/NS THAT A VOLTAGE DROP OF 283.5 - 103, OR ABOUT 180, MUST BE FURNISHED BY R_2. THE VALUE OF R_2 MUST THEREFORE BE APPROXIMATELY 20,000 OHMS ($R = \frac{E}{I} = \frac{180}{0.0091} = 19{,}780$).

SINCE THIS SAME 103 VOLTS IS APPLIED ACROSS THE EXTREMITIES OF R_3, AND THE CURRENT CARRIED BY THIS RESISTOR IS 5 MA., THE VALUE OF R_3 MUST ALSO BE 20,000 OHMS ($R = \frac{E}{I} = \frac{103}{0.005} = 20{,}600$).

THE VOLTAGE REQUIRED AT THE SCREEN GRID END OF R_6 IS $75 + 4.3 = 79.3$ VOLTS. THEREFORE, THE VOLTAGE DROP ACROSS R_6 MUST BE $103 - 79.3 =$

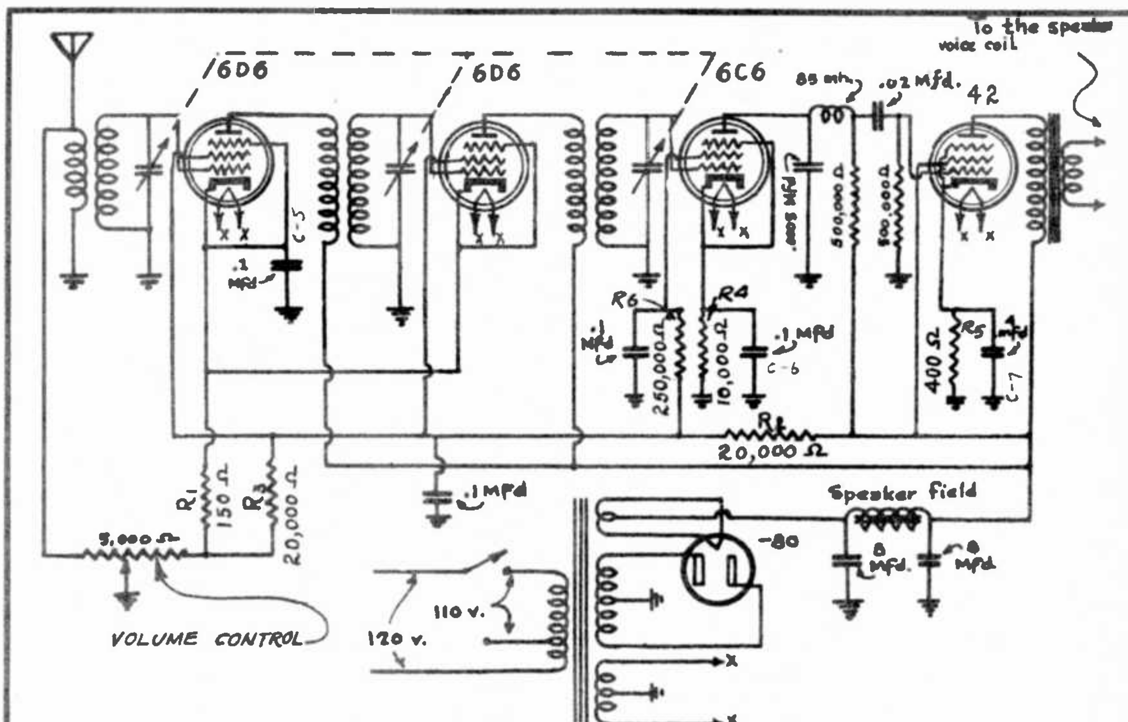

FIG. 8
COMPLETE CIRCUITS WITH RESISTOR VALUES DESIGNATED.

23.7 volts, and since this resistance passes 0.1 ma., the resistance value required for R_6 is 237,000 ohms ($R = \frac{E}{I} = \frac{23.7}{0.0001} = 237,000$. We would employ the nearest standard rating available, or 250,000 ohms.

VARIATIONS IN PLATE VOLTAGE

Another important point to notice in the circuit of Fig. 2 is that the plate circuits of the R.F. and detector tubes are connected to the 283.5 volt point of the system. In reality, and according to our calculations, the plate circuits of the R.F. tubes should be connected to a point of 250 + 3 or 253 volts, and the detector plate circuit to a point of 250 volts. To make this possible, additional resistance would have to be included in these plate circuits, together with an additional by-pass condenser, but this would necessitate an additional expense to make a correction of only about 30 volts, in a circuit operating at between 250 and 300 volts.

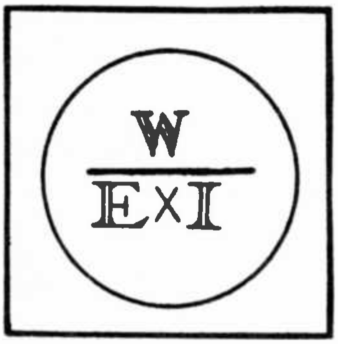

Fig. 9
Reminder Formula.

The tube operating characteristics, as furnished by the tube manufacturers, are sufficiently flexible so that this variation of about 12% from the calculated value will have no noticeable effect upon the sensitivity and fidelity performance of the receiver, as far as the human ear is concerned. Therefore, it is practical to connect all of the plate circuits of this receiver to the same 283.5 volt point.

The circuit is again shown in its complete form in Fig. 8, with the values of all resistors indicated. The 500,000 ohm detector plate circuit resistor and the 500,000 ohm grid leak for the type 42 tube do not enter into our calculations at this time, because they are not regarded as a part of the voltage distribution system.

ELECTRIC POWER

We still are not through with figuring on this voltage-divider for the receiver, because even though its resistance values are correct, this does not mean that the resistor will "stand-up" under the strain of service. Whenever a current flows through a resistance the result is not only a voltage drop, but also a certain amount of POWER will be dissipated in the form of heat. We measure this power in WATTS.

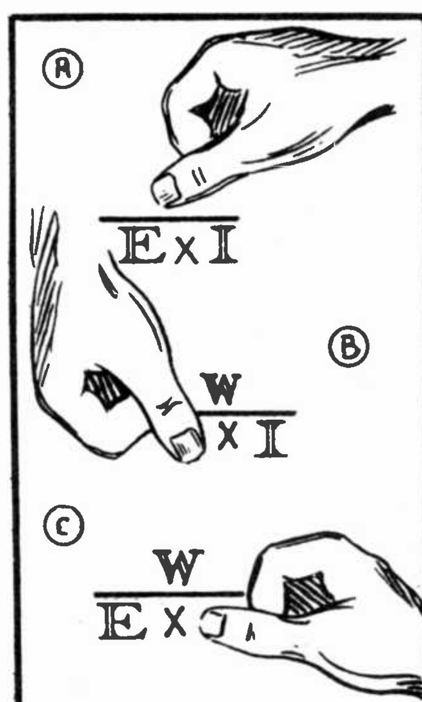

Fig. 10
Three Forms Of
Watt's Law.

THE WATT IS THE UNIT OF ELECTRIC POWER, AND REPRESENTS THE WORK DONE BY A CURRENT FLOW OF ONE AMPERE WHICH IS BEING FORCED TO FLOW BY AN ELECTRIC PRESSURE OF ONE VOLT. TO FIND THE NUMBER OF WATTS IN A CIRCUIT IT IS ONLY NECESSARY TO MULTIPLY THE NUMBER OF AMPERES FLOWING IN THAT CIRCUIT BY THE NUMBER OF VOLTS IMPRESSED ACROSS THE CIRCUIT. THIS RELATION BETWEEN WATTS, AMPERES, AND VOLTS IS KNOWN AS "WATT'S LAW" AND THE EXPRESSION SHOWN IN FIG. 9 OFFERS AN EASY METHOD FOR REMEMBERING THIS IMPORTANT RELATION. IN THIS CASE, W STANDS FOR WATTS, E FOR VOLTS, AND I FOR AMPERES.

IN USING OHM'S LAW YOU ARE ALREADY FAMILIAR WITH THE FACT THAT IF WE KNOW ANY TWO VALUES OF THE FORMULA, THE THIRD CAN BE DETERMINED VERY READILY. THE SAME IS TRUE IN RESPECT TO WATT'S LAW. FOR EXAMPLE, BY USING THE EXPRESSION AS GIVEN IN FIG. 9, YOU CAN SIMPLY COVER UP THE VALUE YOU WISH TO DETERMINE, AND THE REMAINING PORTION OF THE FORMULA WILL TELL YOU HOW TO FIND IT.

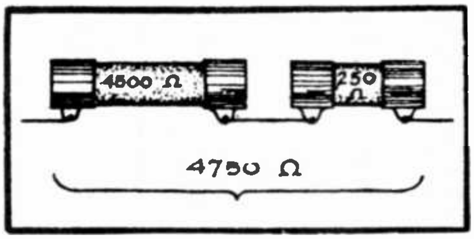

FIG. 11
"BUILDING UP" A RESISTOR TO PROPER VALUE.

TO ILLUSTRATE THIS MORE CLEARLY, WE CALL YOUR ATTENTION TO FIG. 10. TO FIND THE WATTS IN A CIRCUIT, SIMPLY COVER THE W AS SHOWN AT (A), AND THE REMAINING PORTION TELLS US TO MULTIPLY THE VOLTS BY THE AMPERES. TO FIND THE VOLTS, COVER THE E AS SHOWN AT (B), AND THE BALANCE OF THE EXPRESSION TELLS US TO DIVIDE THE WATTS BY THE AMPERES. FINALLY, AT (C) COVERING UP THE I, WE CAN FIND THE AMPERES BY DIVIDING THE WATTS BY THE VOLTS.

REMEMBER THEN, THAT WATTS EQUAL VOLTS MULTIPLIED BY AMPS ($W = E \times I$). VOLTS EQUALS WATTS DIVIDED BY AMPERES ($E = \frac{W}{I}$), AND AMPERES EQUALS WATTS DIVIDED BY VOLTS ($I = \frac{W}{E}$).

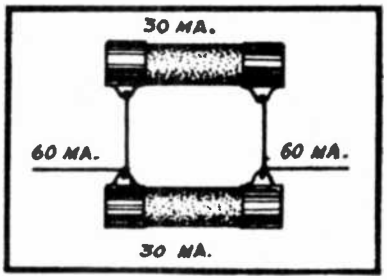

FIG. 12
PARALLELLED RESISTORS.

YOU MAY ENCOUNTER A PROBLEM IN WHICH THE CURRENT OR VOLTAGE IN THE CIRCUIT IS UNKNOWN, AND SOME VALUE IN WATT'S LAW IS TO BE FOUND. IN SUCH CASE, TWO OTHER HANDY RELATIONS ARE AT YOUR DISPOSAL: $W = I^2 \times R$, AND (2) $W = \frac{E^2}{R}$.

IN THE FIRST EXAMPLE, (1) THE WATTS MAY BE FOUND BY MULTIPLYING THE CURRENT BY ITSELF (SQUARING IT) AND THEN MULTIPLYING BY THE RESISTANCE. THIS FORMULA IS USEFUL WHEN VOLTAGE AND WATTS ARE BOTH UNKNOWN. IN THE SECOND EXAMPLE (2), THE WATTS OR POWER CAN BE FOUND BY MULTIPLYING THE VOLTAGE BY ITSELF (SQUARING IT) AND THEN DIVIDING THIS VALUE BY THE RESISTANCE. THIS RELATION IS VERY VALUABLE WHEN WATTS AND CURRENT ARE BOTH UNKNOWN.

IN RADIO WORK WE FREQUENTLY HANDLE SUCH SMALL AMOUNTS OF ELECTRIC POWER THAT THE WATT IS TOO LARGE A UNIT, AND FOR SUCH PURPOSES THE MILLIWATT IS GENERALLY USED. ONE MILLIWATT IS EQUIVALENT TO $\frac{1}{1000}$ OF

ONE WATT, BUT SOMETIMES EVEN THIS UNIT IS RATHER LARGE, SO A STILL SMALLER UNIT OF POWER IS NEEDED. THIS VERY SMALL UNIT IS THE MICROWATT, AND IS EQUIVALENT TO $\frac{1}{1,000,000}$ WATT (THE ONE-MILLIONTH PART OF 1 WATT).

ON THE OTHER HAND, IN TRANSMISSION WORK, WHERE LARGE AMOUNTS OF POWER ARE HANDLED, IT IS CONVENIENT TO USE A LARGE UNIT, LARGER THAN THE WATT, AND FOR SUCH PURPOSES WE USE THE KILOWATT. ONE KILOWATT (KW) IS EQUAL TO 1000 WATTS.

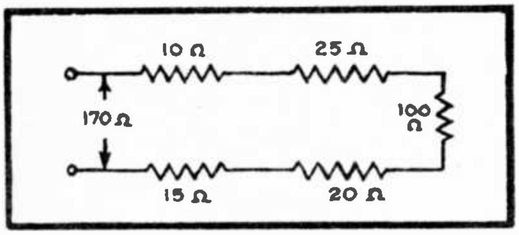

FIG. 13
SERIES-CONNECTED RESISTORS.

WATT RATING OF RESISTORS

ALL RESISTORS ARE RATED ACCORDING TO THE WATTS THAT THEY WILL DISSIPATE, OR EVEN ACCORDING TO BOTH WATTS AND CURRENT. IN OTHER WORDS, IF YOU NEED A 1000-OHM RESISTOR, YOU CAN GET ONE WITH A RATING OF 1/2 WATT, 1 WATT, 10 WATTS, AND MANY OTHER RATINGS, YET ALL OF THEM HAVING THE SAME RESISTANCE VALUE.

SHOULD YOU, BY CHANCE, PUT A RESISTOR RATED 5000 OHMS AND 1 WATT IN A CIRCUIT WHERE THE CURRENT THRU THIS RESISTOR AND THE VOLTAGE ACROSS IT WILL REQUIRE IT TO DISSIPATE 20 WATTS, THE RESISTOR WILL BURN OUT, AND WILL HAVE TO BE REPLACED WITH ANOTHER OF A HIGHER WATT RATING. CHOOSING THE PROPER RESISTORS IS AN IMPORTANT PART OF THE RADIO TECHNICIAN'S WORK, AND CAN BY NO MEANS BE SLIGHTED IF HE PLANS ON HAVING SATISFIED CUSTOMERS.

NOW THAT YOU ARE FAMILIAR WITH THE ELECTRICAL UNIT OF POWER (THE WATT) AND ITS RELATION TO RESISTOR RATINGS, LET US CONTINUE BY DETERMINING THE NECESSARY WATT RATINGS FOR THE VARIOUS RESISTANCE RATINGS CONSIDERED IN THE CIRCUIT OF FIG. 8. IN EACH CASE THE WATT RATING IS EQUAL TO THE CURRENT FLOWING THRU THE RESISTOR, MULTIPLIED BY THE VOLTAGE DROP ACROSS IT, AND THESE WATT RATINGS WORK OUT TO THE VALUES SHOWN IN TABLE I.

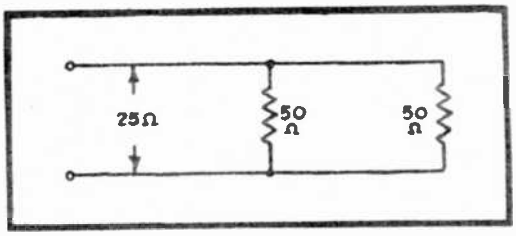

FIG. 14
TWO RESISTORS IN PARALLEL.

HIGHER WATT RATING REQUIRED THAN THOSE CALCULATED

THE WATT VALUES AS THUS FAR CALCULATED ARE NOT SUITABLE FOR USE, BECAUSE THE COMMERCIAL RATINGS GIVEN RESISTORS ARE THOSE UNDER WHICH THE RESISTOR REACHES A TEMPERATURE OF NEARLY 500° F., IN AN AIR SPACE OF ONE CUBIC FOOT SURROUNDING THE RESISTOR, AND WITH AN AIR TEMPERATURE OF 68° F. A RESISTOR AT 500° F WOULD BE UNSAFE IN A RECEIVER, SO WE MUST USE A RESISTOR WITH A WATT RATING OF FROM TWO TO FOUR TIMES THAT DETERMINED BY THE FOREGOING CALCULATIONS. FURTHERMORE, WE MUST ALLOW A SUFFICIENT MARGIN OF SAFETY, SO THAT THE RESISTORS WILL HOLD UP UNDER THE MOST ABNORMAL CONDITIONS THAT MAY OCCUR IN SERVICE.

IT SHOULD ALSO BE NOTED THAT THE RESISTANCE OF A RESISTOR VARIES

TABLE I							
WATT-RATING CALCULATIONS							
WATT RATING OF R_1	=	E x I	=	3 x 0.0204	=	0.0612	WATT
" " " R_2	=	E x I	=	180 x 0.0091	=	1.638	"
" " " R_3	=	E x I	=	103 x 0.005	=	0.515	"
" " " R_4	=	E x I	=	4.3 x 0.00043	=	0.0018	"
" " " R_5	=	E x I	=	16.5 x 0.0405	=	0.668	"
" " " R_6	=	E x I	=	23.7 x 0.0001	=	0.0024	"

WITH A CHANGE IN ITS TEMPERATURE; THIS MEANS THAT A HOT RESISTOR WILL PRODUCE A DIFFERENT VOLTAGE DROP THAN WHEN IT IS COLD OR JUST WARM.

TO GIVE THE RESISTORS A "FIGHTING CHANCE" AGAINST HIGH TEMPERATURES AND THE CONDITION JUST MENTIONED, WE MUST CHOOSE THEM WITH A WATT RATING SUFFICIENTLY HIGH. TO ALLOW THE RESISTORS IN THE VOLTAGE DISTRIBUTION SYSTEM UNDER DISCUSSION TO OPERATE AT ONE-QUARTER THEIR WATT RATING, LET US LOOK BACK AT OUR FIGURES, AND DETERMINE THE WATT RATINGS REQUIRED FOR THE VARIOUS SECTIONS OF THE SYSTEM, SO THAT WE WILL INSURE THEM AGAINST "BURN OUTS". THESE VALUES, CORRECTED TO TWO TIMES THE CALCULATED VALUES, APPEAR IN TABLE II, TOGETHER WITH NEAREST STANDARD WATT RATING AVAILABLE.

SERIES AND PARALLEL RESISTOR COMBINATIONS

AT THIS POINT IT IS WELL TO MENTION THAT IN CASE THAT A RESISTOR OF A CERTAIN RESISTANCE AND WATT RATING IS NOT AVAILABLE, TWO OR MORE RESISTORS OF VARIOUS RESISTANCE VALUES MAY BE CONNECTED IN A SERIES COMBINATION, THUS PROVIDING THE REQUIRED RESISTANCE VALUE. THE WATT RATING OF EACH OF THESE, HOWEVER, MUST COME UP TO THE REQUIREMENTS.

TO ILLUSTRATE THIS POINT, LET US SUPPOSE THAT YOU NEED A 4750-OHM RESISTOR WITH A 20 WATT RATING. IF THIS SIZE IS NOT AVAILABLE, THEN A 4500-OHM, 20-WATT RESISTOR AND A 250-OHM, 20-WATT RESISTOR MAY BE CONNECTED IN SERIES AS SHOWN IN FIG. 11.

ON THE OTHER HAND, IF YOU HAVE TROUBLE IN GETTING THE PROPER WATT RATING, BUT HAVE QUITE AN ASSORTMENT OF RESISTANCE VALUES TO CHOOSE

TABLE II						
CORRECTED WATT RATINGS						
CORRECTED RATING					STANDARD RATING	
R_1 = 0.0612 x 2	=	0.12	WATT	(APPROX.)	1/4	WATT
R_2 = 1.638 x 2	=	3.25	"	"	3	"
R_3 = 0.515 x 2	=	1.03	"	"	1	"
R_4 = 0.0018 x 2	=	0.0036	"	"	1/4	"
R_5 = 0.668 x 2	=	1.336	"	"	2	"
R_6 = 0.0024 x 2	=	0.0048	"	"	1/4	"

FROM, YOU CAN WORK OUT A SOLUTION AS PICTURED IN FIG. 12. HERE THE RESISTOR IS EXPECTED TO CARRY 60 MA., BUT IT IS ASSUMED THAT THE RESISTORS AVAILABLE HAVE A SAFE CARRYING CAPACITY OF ONLY 30 MA.

TWO OF THESE RESISTORS CAN BE CONNECTED IN PARALLEL, TO PERMIT THE 60 MA. TO BE PASSED SAFELY, EACH CARRYING HALF OF THE CURRENT OR 30 MA. WHEN CONNECTING TWO SUCH RESISTORS IN PARALLEL, EACH MUST HAVE DOUBLE THE RESISTANCE REQUIRED. THAT IS, IF A TOTAL RESISTANCE OF 1000 OHMS IS NEEDED, THEN EACH OF THESE PARALLELED RESISTORS MUST HAVE A RESISTANCE VALUE OF 2000 OHMS.

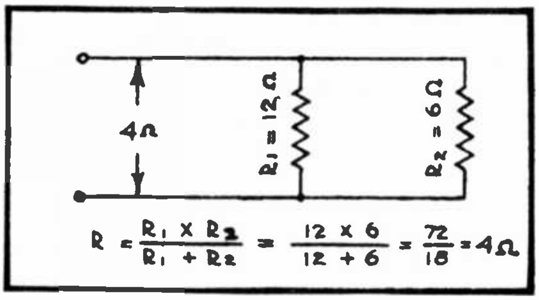

FIG. 15
TWO UNEQUAL PARALLEL-CONNECTED RESISTORS.

SERIES RESISTOR COMBINATIONS

YOU HAVE ALREADY LEARNED THAT THE TOTAL RESISTANCE OF A SERIES-CONNECTED RESISTOR GROUP IS EQUAL TO THE SUM OF THE INDIVIDUAL RESISTANCES CONNECTED IN THE GROUP. FOR INSTANCE, IN FIG. 13 FIVE RESISTORS, HAVING VALUES OF 10 OHMS, 25 OHMS, 100 OHMS, 20 OHMS AND 15 OHMS, RESPECTIVELY, ARE ALL CONNECTED IN SERIES. THE TOTAL RESISTANCE OF THIS CIRCUIT THEN BECOMES EQUAL TO 10 + 25 + 100 + 20 + 15, OR A TOTAL OF 170 OHMS.

PARALLEL RESISTOR COMBINATIONS

WHEN RESISTORS ARE CONNECTED IN PARALLEL THE RESULT IS ENTIRELY DIFFERENT. WE SHALL START THIS INSPECTION OF PARALLEL RESISTOR COMBINATIONS WITH THE MOST SIMPLE FORM, NAMELY TWO RESISTORS OF THE SAME RESISTANCE VALUE CONNECTED IN PARALLEL, AS PICTURED IN FIG. 14.

WHENEVER TWO RESISTORS OF THE SAME VALUE ARE CONNECTED IN PARALLEL, THE TOTAL RESISTANCE OF THE COMBINATION IS JUST ONE-HALF THAT OF EACH OF THE TWO RESISTORS. FOR EXAMPLE, WITH THE RESISTORS INDICATED IN FIG. 14, WHERE EACH HAS A VALUE OF 50 OHMS, THE COMBINED RESISTANCE OF THE TWO WILL BE ONE-HALF OF 50 OHMS, OR 25 OHMS.

IN CASE THAT TWO RESISTORS OF DIFFERENT VALUES ARE CONNECTED IN PARALLEL, AS IN FIG. 15, THE TOTAL RESISTANCE OF THE COMBINATION IS CALCULATED BY DIVIDING THE PRODUCT OF THE TWO RESISTOR VALUES BY THE SUM OF THE SAME VALUES. THIS CAN BE EXPRESSED AS A FORMULA IN THE FOLLOWING MANNER: $R = \frac{R_1 \times R_2}{R_1 + R_2}$ WHEREIN R = THE TOTAL OR COMBINED RESISTANCE, AND R_1 AND R_2 ARE THE INDIVIDUAL RESISTOR VALUES.

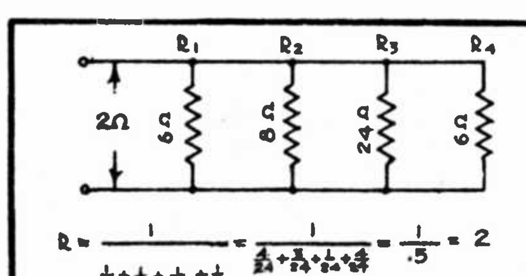

FIG. 16
A PARALLEL RESISTOR COMBINATION.

IN THE CIRCUIT OF FIG. 15, WHERE R_1 = 12 OHMS AND R_2 = 6 OHMS, WE CAN SUBSTITUTE THESE VALUES IN THE FORM-

ULA: $R = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{12 \times 6}{12 + 6} = \frac{72}{18} = 4$ OHMS, WHICH IS THE TOTAL OR COMBINED RESISTANCE OF THIS CIRCUIT.

WHENEVER MORE THAN TWO RESISTORS ARE CONNECTED IN PARALLEL, SUCH AS THE RESISTOR COMBINATION INDICATED IN FIG. 16, THE TOTAL RESISTANCE OF THE COMBINATION IS CALCULATED IN TERMS OF CONDUCTANCE. THE CONDUCTANCE OF ANY RESISTANCE IS EQUAL TO THE RECIPROCAL OF THE RESISTANCE VALUE. FOR INSTANCE, THE CONDUCTANCE OF 25 OHMS IS $\frac{1}{25}$; THE CONDUCTANCE OF 30 OHMS IS $\frac{1}{30}$, ETC.

THE UNIT OF CONDUCTANCE IS MHO, OR THE WORD "OHM" SPELLED BACKWARD.

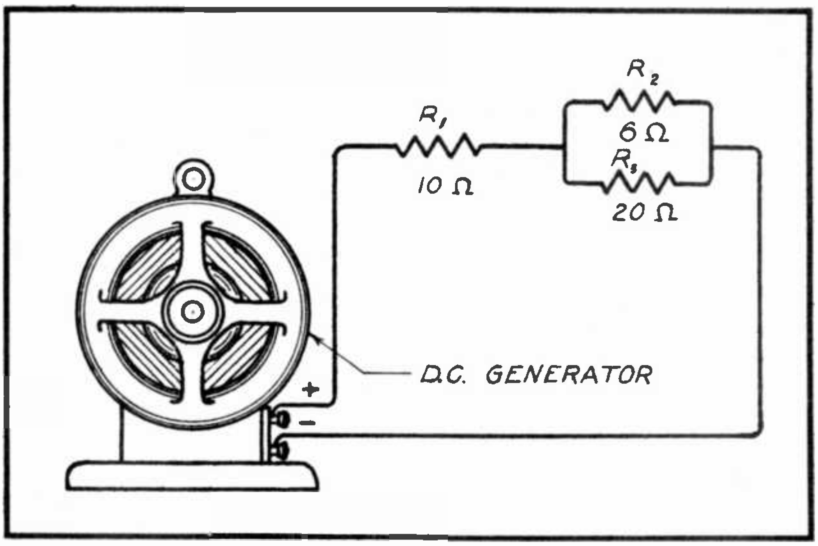

FIG. 17
THE COMBINATION CIRCUIT.

THE RULE FOR CALCULATING THE TOTAL OR COMBINED RESISTANCE OF A COMBINATION OF ANY NUMBER OF PARALLEL RESISTORS IS AS FOLLOWS: "THE CONDUCTANCE OF THE ENTIRE PARALLEL CIRCUIT IS EQUAL TO THE SUM OF THE CONDUCTANCES OF THE INDIVIDUAL BRANCHES". EXPRESSED AS A FORMULA THIS WOULD BE $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$ ETC.

APPLYING THIS FORMULA TO THE CIRCUIT INDICATED IN FIG. 16, WE HAVE: $\frac{1}{R} = \frac{1}{6} + \frac{1}{8} + \frac{1}{24} + \frac{1}{6} = \frac{4}{24} + \frac{3}{24} + \frac{1}{24} + \frac{4}{24} = \frac{12}{24} = \frac{1}{2}$. THEN, IF $\frac{1}{R} = \frac{1}{2}$, OR THE CONDUCTANCE OF THE TOTAL RESISTANCE IS EQUAL TO $\frac{1}{2}$, WE CAN CHANGE THIS CONDUCTANCE VALUE TO OHMS OR RESISTANCE BY INVERTING IT, SO THAT IT BECOMES 2 OHMS. IN OTHER WORDS, THE TOTAL OR COMBINED RESISTANCE OF THE CIRCUIT IN FIG. 16 IS 2 OHMS.

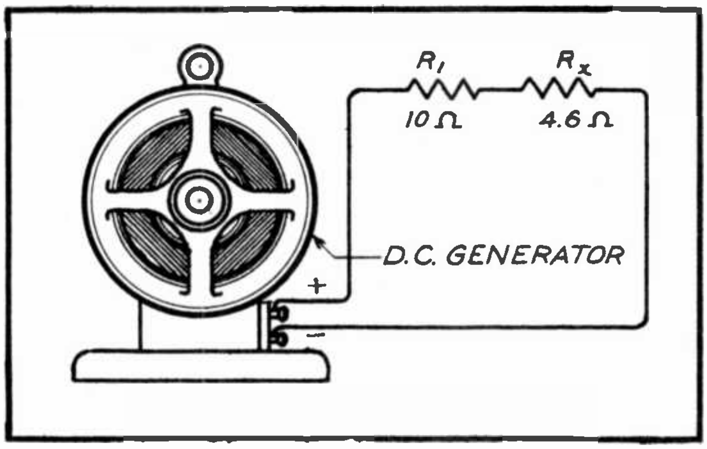

FIG. 18
THE EQUIVALENT CIRCUIT.

SERIES-PARALLEL CIRCUITS

IN FIG. 17 YOU ARE SHOWN A TYPICAL SERIES-PARALLEL COMBINATION OF RESISTAN-

CES. HERE THE RESISTANCES R_2 AND R_3 ARE CONNECTED IN PARALLEL, WHILE RESISTANCE R_1 IS CONNECTED IN SERIES WITH THE GENERATOR AND THE TWO PARALLELED RESISTORS.

THE MOST SIMPLE PROCEDURE FOR SOLVING A PROBLEM OF THIS TYPE IS FIRST TO REDUCE THE TWO PARALLEL RESISTANCES TO A SINGLE EQUIVALENT RESISTANCE. THAT IS TO SAY, IN THE CIRCUIT OF FIG. 18 THE COMBINED RESISTANCE OF R_2 AND R_3 IS FOUND AS FOLLOWS:

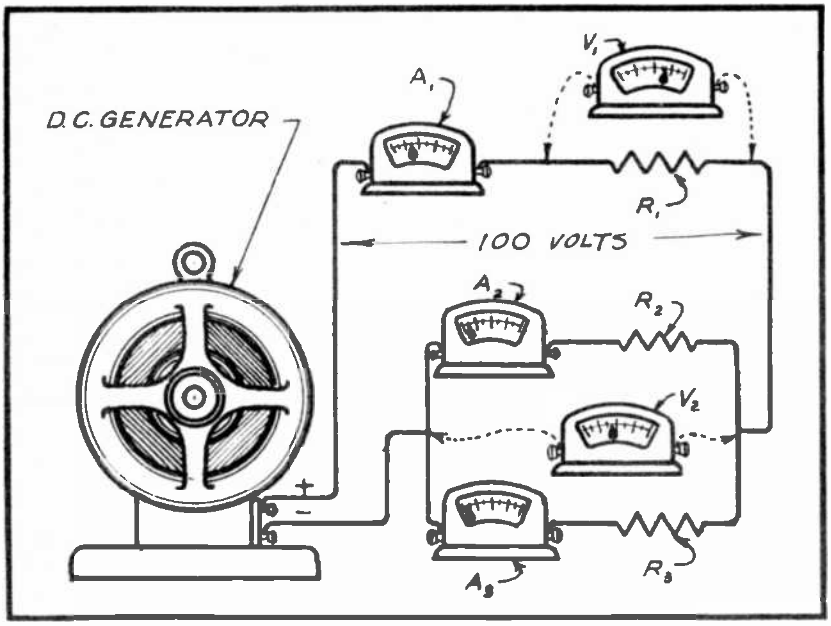

FIG. 19
CURRENT AND VOLTAGE DISTRIBUTION.

$$R = \frac{R_2 \times R_3}{R_2 + R_3} = \frac{6 \times 20}{6 + 20} = \frac{120}{26} = 4.6 \text{ OHMS.}$$

BY GIVING THIS COMBINED RESISTANCE OF R_2 AND R_3 THE IDENTIFYING SYMBOL R_x, WE CAN SUBSTITUTE IT FOR R_2 AND R_3, AND CONNECT IT IN SERIES WITH R_1 AS DONE IN THE EQUIVALENT CIRCUIT SHOWN IN FIG. 18. THE TOTAL RESISTANCE OF THE CIRCUIT IN FIG. 18 IS EQUAL TO 10 OHMS PLUS 4.6 OHMS, OR 14.6 OHMS, WHICH IS ALSO EQUAL TO THE COMBINED RESISTANCE OF THE CIRCUIT ILLUSTRATED IN FIG. 17.

THE CIRCUIT OF FIG. 17 CAN BE STILL FURTHER ANALYZED IN THE FOLLOWING MANNER: KNOWING THE TOTAL RESISTANCE OF THE CIRCUIT TO BE 14.6 OHMS, AND ASSUMING THE GENERATOR TO PRODUCE AN E.M.F. OF 100 VOLTS, WE CAN DETERMINE THE TOTAL CURRENT FLOW THROUGH THE CIRCUIT BY APPLYING OHM'S LAW IN THE FORM $I = E/R = \frac{100}{14.6} =$ 6.85 AMPS. THIS CURRENT FLOW WILL BE INDICATED BY AMMETER A_1 IN FIG. 19, WHERE WE HAVE THE SAME CIRCUIT AS IN FIG. 17 BUT WITH AMMETERS AND VOLTMETERS INSTALLED AT SUITABLE POINTS.

IT IS OBVIOUS THAT THIS CURRENT OF 6.85 AMPS MUST FLOW THRU R_1,

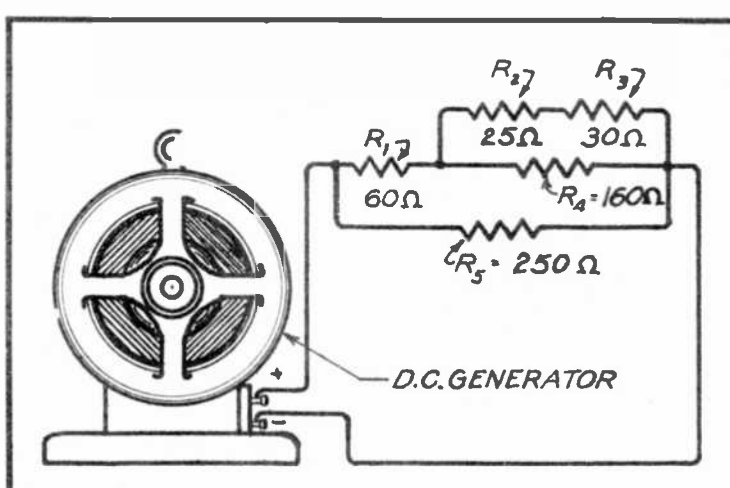

FIG. 20
THE COMPLEX CIRCUIT.

AND THEREFORE THE VOLTAGE DROP ACROSS R_1, AS INDICATED BY VOLTMETER V_1, WILL BE $E = I \times R_1 = 6.85 \times 10 = 68.5$ VOLTS.

ASSUMING THAT THE GENERATOR VOLTAGE IS 100 VOLTS, THE VOLTAGE-DROP ACROSS THE EXTREMITIES OF R_2 AND R_3, AS INDICATED BY VOLTMETER V_2, WILL BE EQUAL TO 100 MINUS 68.5, OR 31.5 VOLTS. THE CURRENT FLOW THRU R_2, AS SHOWN BY AMMETER A_2, WILL THEN BE $I = E/R_2 = \frac{31.5}{6} = 5.25$ AMPS.

SIMILARLY, THE CURRENT FLOW THROUGH R_3, AS INDICATED BY AMMETER A_3, WILL BE $I = \frac{E}{R_3} = \frac{31.5}{20} = 1.575$ AMPS.

ANALYSIS OF COMPLEX NETWORKS

IN FIG. 20 IS INDICATED A RESISTANCE NETWORK OF A RATHER COMPLEX TYPE. TO DETERMINE THE COMBINED RESISTANCE OF SUCH AN ARRANGEMENT, EACH SECTION OF THE CIRCUIT IS REDUCED TO ITS EQUIVALENT IN A MORE SIMPLE FORM.

THE SUCCESSIVE STEPS IN THE ANALYSIS OF THIS CIRCUIT ARE SHOWN IN FIG. 21. NOTICE AT A THAT SERIES RESISTANCES R_2 AND R_3 HAVE BEEN REDUCED TO AN EQUIVALENT RESISTANCE R_a OF $(25 + 30) = 55$ OHMS. AT B THE PARALLELED RESISTANCES R_a AND R_4 HAVE BEEN REDUCED TO AN EQUIVALENT RESISTANCE R_6, HAVING A VALUE OF 40.9 OHMS, AS DETERMINED BY THE

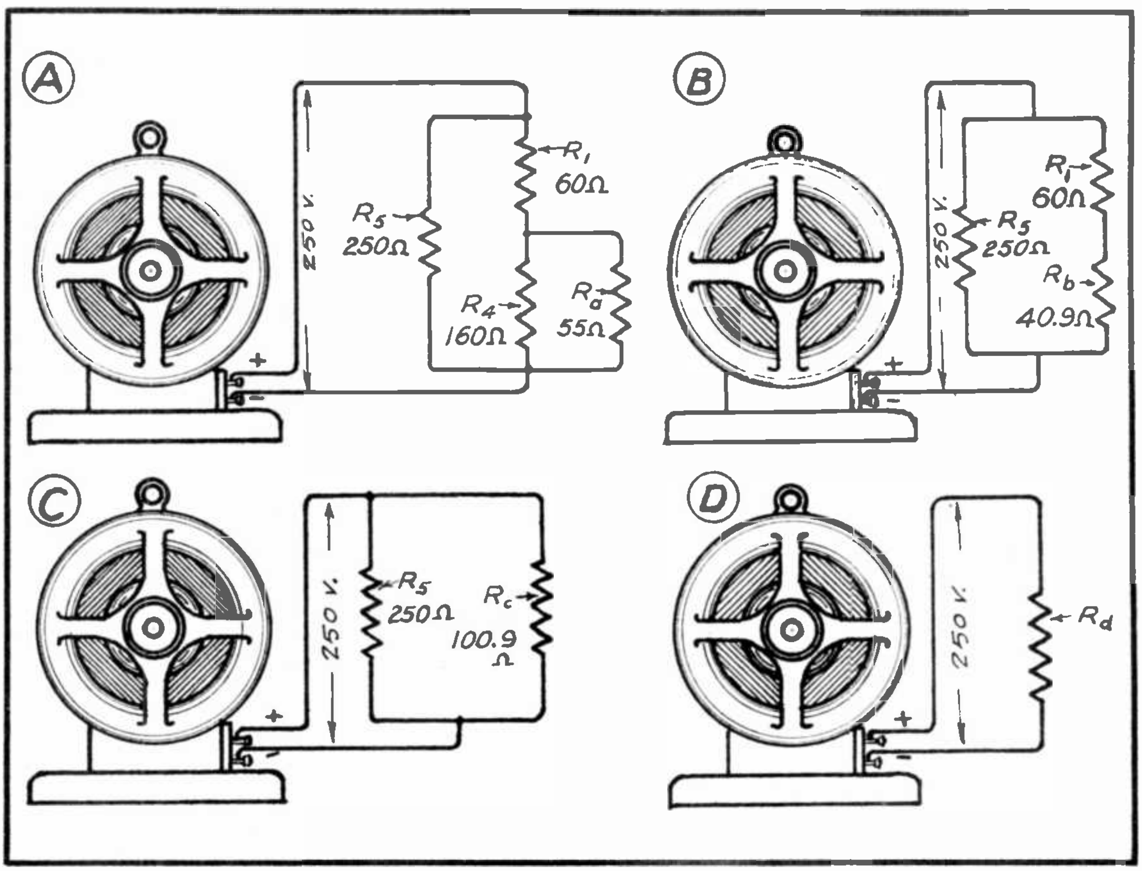

FIG. 21
THE CIRCUIT ANALYSIS.

CALCULATION $R_b = \frac{R_a \times R_4}{R_a + R_4} = \frac{55 \times 160}{55 + 160} = \frac{8800}{215} = 40.9$ OHMS. AT C THE SERIES RESISTANCES R_1 AND R_b HAVE BEEN REDUCED TO AN EQUIVALENT RESISTANCE R_c, AS FOLLOWS: $R_1 + R_6 = 60 + 40.9 = 100.9$ OHMS. FINALLY, AT D THE TWO PARALLELED RESISTANCES R_c AND R_5 HAVE BEEN REDUCED TO A SINGLE EQUIVALENT RESISTANCE R_d, WHOSE VALUE IS 71.88 OHMS, ACCORDING TO THE FOLLOWING CALCULATION: $R_d = \frac{R_c \times R_5}{R_c + R_5} = \frac{100.9 \times 250}{100.9 + 250} = \frac{25,225}{350.9} = 71.88$ OHMS. THUS, THE COMBINED RESISTANCE OF THE CIRCUIT ILLUSTRATED IN FIG. 20 AMOUNTS TO 71.88 OHMS.

TO CALCULATE THE CURRENT FLOWING THRU THE VARIOUS SECTIONS OF THIS CIRCUIT, AS WELL AS THE VOLTAGE-DROP ACROSS THE VARIOUS SECTIONS, START WITH D OF FIG. 21 AND WORK BACK TOWARD A OF THE SAME ILLUSTRATION. THAT IS TO SAY, IF THE GENERATOR E.M.F. IS 250 VOLTS, THE TOTAL CURRENT FLOW THRU THE CIRCUIT WOULD BE $I = \frac{E}{R_d} = \frac{250}{71.88} = 3.48$ AMPS. (APPROXIMATELY).

THE VOLTAGE-DROP ACROSS BOTH R_5 AND R_c, ACCORDING TO C OF FIG. 21, IS 250 VOLTS, AND THE CURRENT FLOW THRU R_5 IS $I = \frac{E}{R_5} = \frac{250}{250} = 1$ AMPERE. THE CURRENT FLOW THRU R_c IS $I = \frac{E}{R_c} = \frac{250}{100.9} = 2.47$ AMP.

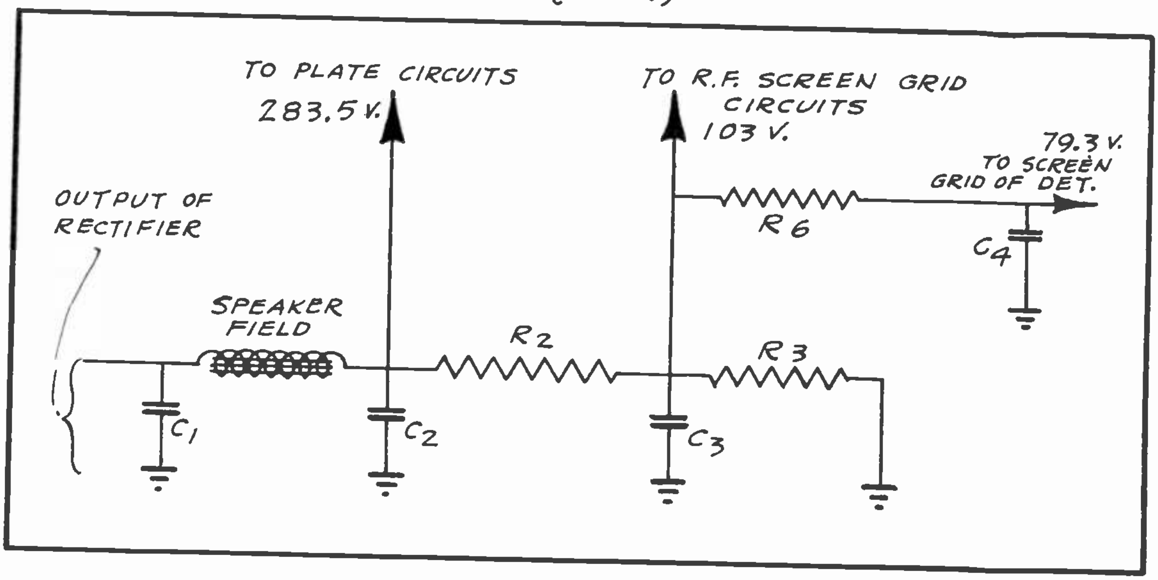

FIG. 22
THE RESISTANCE NETWORK.

ACCORDING TO B AND C OF FIG. 21, THE CURRENT FLOW THRU BOTH R_1 AND R_b OF CIRCUIT B AMOUNTS TO 2.47 AMPS, SINCE THE VALUE OF $R_c = R_1 + R_b$. THIS BEING TRUE, THE VOLTAGE-DROP DEVELOPED ACROSS R_1 IS EQUAL TO $E = I \times R = 2.47 \times 60 = 148.20$ VOLTS. THE VOLTAGE-DROP ACROSS R_b IS EQUAL TO $250 - 148.2 = 101.8$ VOLTS. THIS SAME VOLTAGE IS ALSO APPLIED ACROSS THE EXTREMITIES OF THE PARALLEL RESISTANCES R_a AND R_4. THE CURRENT FLOW THROUGH R_a WILL THEN BE $I = \frac{E}{R_a} = \frac{101.8}{55} = 1.85$ AMPS, AND THE CURRENT FLOW

THROUGH R_4 WILL BE $I = \frac{E}{R_4} = \frac{101.8}{160} = .636$ AMP.

THE ANALYSIS AS GIVEN FOR FIGS. 17 TO 21 INCLUSIVE CAN BE APPLIED IN THE SAME MANNER, WHETHER THE VOLTAGE SUPPLY BE FURNISHED BY A D.C. GENERATOR AS SHOWN, BY A BATTERY, OR BY THE OUTPUT OF A B SUPPLY'S FILTER CIRCUIT.

SELECTION OF BY-PASS CONDENSERS

ANOTHER IMPORTANT POINT TO BE CONSIDERED IS THE SELECTION OF THE BY-PASS CONDENSERS FOR THE VOLTAGE DISTRIBUTION SYSTEM WHICH WE HAVE JUST DESIGNED. TO ASSIST YOU IN THIS MATTER, THE MAJOR PART OF THE VOLTAGE DISTRIBUTION SYSTEM IS INDICATED IN DETAIL IN FIG. 22, INCLUDING ITS CONDENSERS.

FOR THE PRESENT, WE ARE NOT PARTICULARLY INTERESTED IN THE CAPACITY VALUES OF THESE CONDENSERS, AS THIS PROBLEM IS TREATED IN DETAIL IN A LATER LESSON.

OUR CHIEF CONCERN AT THIS TIME IS TO SELECT THESE CONDENSERS FROM THE STANDPOINT OF THEIR RATING IN D.C. WORKING VOLTAGE, TO PREVENT THEIR BREAKING DOWN FROM EXCESS VOLTAGE.

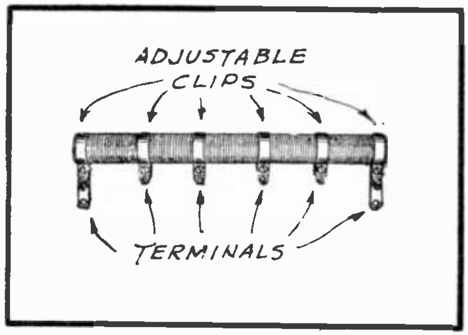

FIG. 23
TYPICAL VOLTAGE DIVIDER.

CONDENSERS C_1 AND C_2 ARE, OF COURSE, A PART OF THE B POWER FILTER SYSTEM, AND HAVE AN E.M.F. OF APPROXIMATELY 300 VOLTS APPLIED ACROSS THEM DURING NORMAL OPERATION OF THE RECEIVER. HOWEVER, WHEN THE POWER SWITCH IS OPERATED TO SWITCH THE RECEIVER ON OR OFF, MOMENTARY SURGE VOLTAGES RESULT, AND SUCH SURGES MAY REACH VALUES AS HIGH AS 400 VOLTS. IT IS THEREFORE CUSTOMARY TO USE CONDENSERS RATED AT A "PEAK D.C. WORKING VOLTAGE" OF APPROXIMATELY 500 FOR THIS PURPOSE.

UNDER NORMAL CONDITIONS CONDENSER C_3 HAS 103 VOLTS APPLIED ACROSS ITS EXTREMITIES, AND THEREFORE A STANDARD D.C. WORKING VOLTAGE RATING OF 200 VOLTS WILL GIVE AN AMPLE MARGIN OF SAFETY FOR THIS UNIT.

CONDENSER C_4 IS SUBJECTED TO 79.3 VOLTS, AND ALTHOUGH A RATING OF ABOUT 150 VOLTS WOULD BE SUFFICIENT, IT IS PRACTICAL TO USE THE NEAREST COMMON STANDARD RATING OF 200 VOLTS.

IN FIG. 8, CONDENSERS C_5, C_6, AND C_7 ARE USED TO BY-PASS THE BIAS RESISTORS R_1, R_4, AND R_5, RESPECTIVELY. THE VOLTAGE APPLIED ACROSS THEM IS THEREFORE RELATIVELY LOW IN VALUE. IN OTHER WORDS, C_5 IS SUBJECTED TO 3 VOLTS, C_6 TO 4.3 VOLTS, AND C_7 TO 16.5 VOLTS. IT CAN READILY BE SEEN THAT FOR THESE CONDENSERS, ANY D.C. WORKING VOLTAGE EXCEEDING APPROXIMATELY 25 VOLTS WOULD BE SUFFICIENT.

IN COMMERCIAL RECEIVERS YOU WILL USUALLY FIND THESE CATHODE RE-

SISTOR BY-PASS CONDENSERS RATED CONSIDERABLY HIGHER (AS TO THE D.C. WORKING VOLTAGE) THAN IS TECHNICALLY NECESSARY, FOR THE REASON THAT CONDENSERS WITH RATINGS OF 200 AND 400 VOLTS ARE MANUFACTURED IN THE GREATEST NUMBER FOR GENERAL "ALL-AROUND" PURPOSE, AND THEREFORE ARE JUST AS LOW IN COST AS NON-STANDARD CONDENSERS OF LOWER VOLTAGE RATINGS.

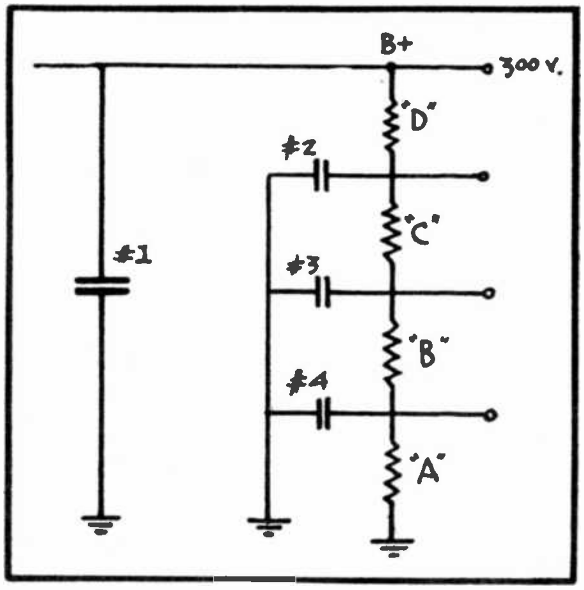

FIG. 24
VOLTAGE DIVIDER SYSTEM.

VOLTAGE DIVIDERS

VOLTAGE-DIVIDER SYSTEMS OF THE TYPE ILLUSTRATED IN FIGS. 23 AND 24 CAN BE CALCULATED IN THE SAME MANNER AS ALREADY EXPLAINED FOR A COMBINATION OF INDIVIDUAL RESISTORS. FOR INSTANCE, IN THE SYSTEM SHOWN IN FIG. 24, SIMPLY STUDY THE RECEIVER CIRCUITS CURRENT REQUIREMENTS AND THEN DETERMINE THE CURRENT FLOW THROUGH THE VARIOUS RESISTANCE SECTIONS A, B, C, AND D. THIS DONE, DETERMINE THE REQUIRED VOLTAGE-DROP ACROSS EACH RESISTOR SECTION, AND WITH THIS DATA DETERMINED, CALCULATE THE RESISTANCE VALUE OF EACH SECTION.

IT IS THE MORE COMMON PRACTICE TO USE INDIVIDUAL RESISTORS RATHER THAN VOLTAGE DIVIDERS IN THE LATE MODEL RECEIVERS, AS BY SO DOING REPLACEMENTS CAN BE MADE AT A LATER TIME WITH GREATER EASE -- ALSO, LESS CHASSIS SPACE IS REQUIRED FOR THEIR MOUNTING. FURTHERMORE, THIS ARRANGEMENT PERMITS THE USE OF RESISTORS OF COMPARATIVELY LOW WATT RATING, BECAUSE ANY SINGLE RESISTOR DOES NOT NECESSARILY CARRY CURRENT FOR SO MANY DIFFERENT CIRCUITS. THIS FEATURE MATERIALLY REDUCES THE RESISTOR COST.

WITH THE NEXT LESSON, YOU ARE GOING TO COMMENCE YOUR ADVANCED STUDIES OF ALTERNATING CURRENT CIRCUITS. SO FAR, ALL OF THE LESSONS TREATING WITH A.C. HAVE BEEN OF A RATHER SIMPLE NATURE BUT FROM NOW ON, YOU ARE GOING TO LEARN MANY OF THE MORE IMPORTANT TECHNICAL LAWS GOVERNING SUCH CIRCUITS, AS WELL AS THE FORMULAS AND CALCULATIONS RELATED THERETO. YOU ARE GOING TO FIND THESE COMING STUDIES ESPECIALLY INTERESTING AND INSTRUCTIVE.

LESSON NO. 38

1. - IF FOR A CERTAIN TUBE A GRID BIAS OF 10 VOLTS IS REQUIRED, AND 5 MA. OF PLATE CURRENT FLOWS THRU THE TUBE, WHAT WILL BE THE PROPER VALUE FOR THE BIAS RESISTOR?

2. - IF THREE SCREEN GRID TUBES EACH PASS 8 MA., INCLUDING BOTH THE PLATE CURRENT AND SCREEN CURRENT, AND ALL THREE TUBES USE A COMMON BIAS RESISTOR ACROSS WHICH 3 VOLTS MUST BE DEVELOPED, WHAT WILL BE THE CORRECT VALUE OF BIAS RESISTOR TO USE?

3. - IF THROUGH A CERTAIN SECTION OF A VOLTAGE DIVIDER SYSTEM, A BLEEDER CURRENT OF 10 MA. IS FLOWING, IN ADDITION TO 5 MA. OF PLATE CURRENT FOR A TUBE, AND A VOLTAGE DROP OF 75 VOLTS IS TO BE DEVELOPED ACROSS THIS RESISTOR SECTION, WHAT WILL BE THE REQUIRED RESISTANCE VALUE OF THIS SECTION?

4. - A CERTAIN 2000 OHM RESISTOR CARRIES A CURRENT OF 65 MA. HOW MUCH WATTAGE WILL BE PRODUCED?

5. - WHY IS IT ADVISABLE TO SELECT RESISTORS OF GREATER WATT RATING THAN ACTUALLY REQUIRED ACCORDING TO WATT'S LAW?

6. - A 200 OHM AND A 400 OHM RESISTOR ARE CONNECTED IN PARALLEL. WHAT IS THE TOTAL RESISTANCE OF THIS COMBINATION?

7. - FOUR RESISTORS HAVING VALUES OF 10; 30; 15 AND 60 OHMS ARE ALL CONNECTED IN PARALLEL. WHAT IS THE TOTAL RESISTANCE OF THIS COMBINATION?

8. - WHY IS IT SO IMPORTANT TO CONSIDER THE D.C. WORKING VOLTAGE OF BYPASS CONDENSERS?

9. - A CERTAIN TUBE DRAWS A PLATE CURRENT OF 5 MA. WITH AN APPLIED PLATE VOLTAGE OF 150 VOLTS AND A GRID BIAS OF 9 VOLTS. AN A.F. CHOKE HAVING A D.C. RESISTANCE OF 1000 OHMS IS CONNECTED IN ITS PLATE CIRCUIT. WHAT "B" VOLTAGE MUST BE FURNISHED THIS CIRCUIT SO THAT THE EFFECTIVE PLATE VOLTAGE MAY BE 150 VOLTS?

10. - EXPLAIN THE GENERAL PROCEDURE WHICH YOU WOULD FOLLOW TO DESIGN A RESISTANCE NETWORK FOR VOLTAGE DISTRIBUTION IN A CONVENTIONAL RECEIVER.

DEAR STUDENT—

Practical Training means the acquisition of Technical information and facts, and the learning how to apply them in a useful manner.

In order to acquire knowledge we must use our brain. Our brain, like our body, only grows and develops when properly used.

When we stop using any part of our body it starves and dies. When we fail to use our brain cells they decay and die of starvation.

Let's learn how to use intelligently our natural abilities, talents, and gifts, and apply them efficiently to our task at hand.

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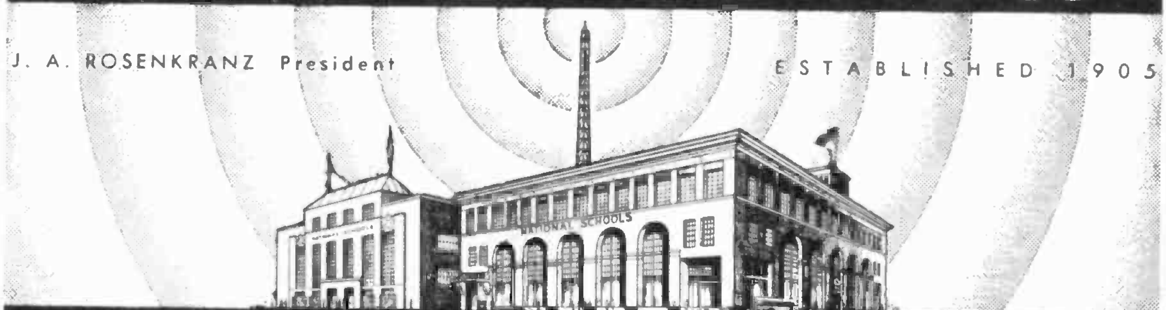

NATIONAL SCHOOLS ★ LOS ANGELES 37, CALIF.

LESSON NO. 39

THE ESSENTIALS OF A. C. CIRCUITS

Complete training is required in order for a man to attain success in Radio. This is the chief reason why salaries are relatively high in this field, and also why you will have to face less competition than in those industries where thorough training is not so essential.

It is our sincere desire to help you qualify for one of the better class of jobs that the Radio industry has to offer. Therefore, we are making sure that you receive complete instruction on technical subjects pertaining to Radio as well as on the practical phases of the science. This complete, all-embracing type of training will elevate you above the average radio serviceman, so that you will be capable of directing the work of others rather than being the one who is required to put another's ideas into action.

FIG. 1
MODERN BROADCAST A. C. POWER PANEL

As you were told before, you are at this time entering a very important part of your training, where you will learn the fundamental principles upon which the designing of radio equipment is based. As part of this work, you will learn how to determine the number of turns to wind on an R. F. transformer so that it will tune with a certain condenser over any desired wave band; you will learn how to design and construct amplifiers, power transformers, fil-

TER SYSTEMS ETC. AND THIS KIND OF KNOWLEDGE IS GOING TO MAKE YOU A VALUABLE MAN -- THE TYPE OF MAN WHO IS IN DEMAND.

THERE ARE A FEW IMPORTANT BASIC FACTS WITH WHICH YOU MUST FIRST BECOME FAMILIAR BEFORE CONTINUING WITH THIS ADVANCED WORK AND WE SHALL COMMENCE IMMEDIATELY IN GETTING THESE FACTS FIRMLY IMBEDDED IN YOUR MIND. FOR THE PRESENT, WE ARE GOING TO DEAL WITH A.C. CIRCUITS ENTIRELY AND WITH MANY OF THE POINTS TO BE CONSIDERED, YOU ARE TO A CERTAIN EXTENT ALREADY FAMILIAR BUT YOU ARE GOING TO LEARN MANY NEW AND INTERESTING ELECTRICAL TERMS WHICH AS YET ARE PROBABLY UNKNOWN TO YOU.

IN ORDER FOR YOU TO BE ABLE TO GRASP EACH IMPORTANT POINT AS WE CONTINUE WITH THIS DISCUSSION, IT IS NECESSARY THAT YOU BE THOROUGHLY FAMILIAR WITH THE TERM "DEGREE". THEREFORE, WE SHALL CLEAR YOU UP ON THIS MATTER IMMEDIATELY.

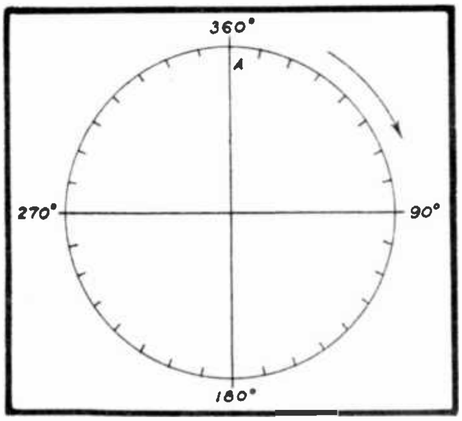

FIG. 2
The Circle.

THE DEGREE

NOW IN FIG. 2, YOU WILL FIND A CIRCLE, WHICH HAS BEEN DIVIDED INTO MANY EQUAL PARTS. THE DISTANCE AROUND THIS CIRCLE OR THE CIRCLE'S BORDER LINE, IF YOU WANT TO CONSIDER IT AS SUCH, IS CALLED THE CIRCUMFERENCE OF THE CIRCLE. SHOULD YOU DIVIDE THE CIRCUMFERENCE OF THIS CIRCLE, OR THE CIRCUMFERENCE OF ANY SIZE CIRCLE FOR THAT MATTER, INTO 360 EQUAL PARTS, THEN EACH OF THESE 360 EQUAL PARTS WOULD BE CALLED A "DEGREE".

BY PLACING THE POINT OF YOUR PENCIL ON THE CIRCUMFERENCE OF THIS CIRCLE AT "A" IN FIG. 2 AND TRACING THE CIRCUMFERENCE WITH IT IN THE DIRECTION INDICATED BY THE ARROW, THEN BY THE TIME YOUR PENCIL POINT TRAVELLED ONE QUARTER OF THE DISTANCE AROUND THE CIRCLE'S CIRCUMFERENCE, IT WOULD HAVE TRAVELLED A DISTANCE OF 90°. THE DISTANCE FROM POINT "A" TO ANOTHER POINT HALF-WAY AROUND THE CIRCUMFERENCE WOULD COMPLETE A DISTANCE OF 180°. TRAVELING FROM POINT "A" TO ANOTHER POINT 3/4 OF THE WAY AROUND THE CIRCUMFERENCE WOULD CALL FOR A TRAVERSED DISTANCE OF 270° AND TO MAKE A ROUND TRIP FROM POINT "A" AND BACK TO POINT "A" WOULD REQUIRE YOUR PENCIL TO TRAVEL A DISTANCE OF 360° ETC.

REMEMBER NOW. - IN ANY CIRCLE, IRRESPECTIVE OF ITS SIZE, THERE ARE 360° AND 1/4 OF THE DISTANCE AROUND ITS CIRCUMFERENCE IS EQUAL TO 90°; 1/2 THE DISTANCE AROUND THE CIRCUMFERENCE IS EQUAL TO 180°; 3/4 THE DISTANCE AROUND IS EQUAL TO 270°; ALL OF THE WAY AROUND IS EQUAL TO 360°: 1/8 OF THE WAY AROUND IS EQUAL TO 45° ETC. THE SMALL "ZERO" TO THE UPPER RIGHT OF THE NUMBER DENOTES DEGREES.

REPRESENTING DEGREES ALONG A STRAIGHT LINE

NOW SUPPOSE THAT WE SHOULD TAKE OUR CIRCLE OF FIG. 2 AND LAY OFF THE CIRCUMFERENCIAL DISTANCE AS A STRAIGHT LINE. THE VARIOUS DEGREES COULD THEN BE ILLUSTRATED ALONG THIS STRAIGHT LINE AS SHOWN YOU IN FIG. 3. IN OTHER WORDS, THE LENGTH OF THIS STRAIGHT LINE IS EQUAL TO THE CIRCUMFERENCE OR DISTANCE AROUND THE CIRCLE. THE VARIOUS DEGREE MARKS CAN THEN BE REPRESENTED ALONG THIS LINE AS SHOWN AND HAVE EXACTLY THE SAME MEANING

AS THOUGH PICTURED ON THE CIRCLE. YOU WILL FIND THIS PRACTICE CARRIED OUT A GREAT DEAL IN TECHNICAL ARTICLES ETC. AND IT IS ADVISABLE THAT YOU BECOME THOROUGHLY FAMILIAR WITH THIS SYSTEM OF REPRESENTING DEGREES. IN FACT, WE ARE ALREADY GOING TO PUT IT TO PRACTICAL USE IN THIS LESSON.

GENERATING AN A.C. VOLTAGE

SINCE WE ARE GOING TO DEAL WITH ALTERNATING CURRENT CIRCUITS IN THIS LESSON, IT IS ADVISABLE THAT BEFORE GOING ANY FARTHER, YOU FIRST BECOME FAMILIAR WITH THE METHOD WHEREBY A.C. VOLTAGES ARE PRODUCED BY MEANS OF A GENERATOR.

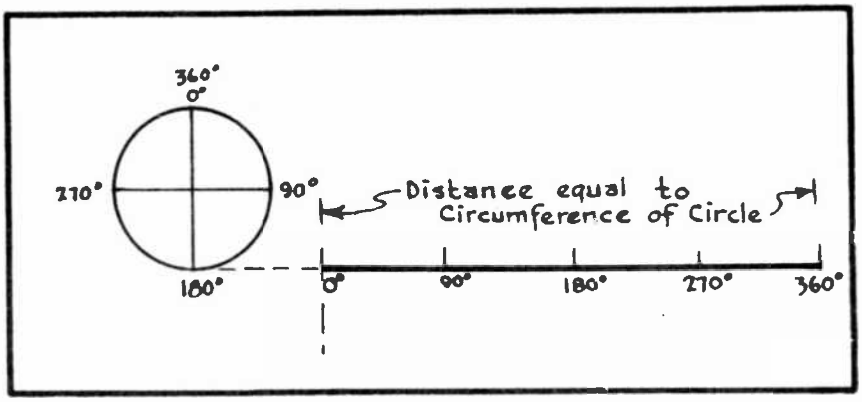

FIG. 3
Representing Degrees Along A Straight Line.

THE FIRST IMPORTANT POINT FOR YOU TO REMEMBER REGARDING THIS MATTER IS THAT ALL GENERATORS DEVELOPE A VOLTAGE OR E.M.F.(ELECTROMOTIVE FORCE), THROUGH THE ACT OF A CONDUCTOR, CUTTING MAGNETIC LINES OF FORCE. THIS IMPORTANT PRINCIPLE IS ILLUSTRATED IN FIG.4 AND THE FOLLOWING EXPLANATION WILL AID YOU IN SEEING JUST HOW THIS IS ACCOMPLISHED.

UPON CAREFUL INSPECTION OF FIG. 4, YOU WILL OBSERVE THAT HERE WE HAVE A COPPER WIRE LOCATED BETWEEN A NORTH AND SOUTH POLE OF TWO MAGNETS, SO THAT IT IS COMPLETELY SURROUNDED BY THE MAGNETIC FIELD OR LINES OF FORCE, WHICH ARE PRODUCED BY THE MAGNETS. NOW THEN, IF WE SHOULD BY SOME MECHANICAL MEANS FORCE THIS WIRE TO MOVE THROUGH THIS MAGNETIC FIELD IN AN UPWARD DIRECTION, AS INDICATED BY THE ARROW, IT IS OBVIOUS THAT THE WIRE WILL AT THIS TIME BE CUTTING LINES OF FORCE.

THIS ACTION CAUSES A VOLTAGE TO BE DEVELOPED OR GENERATED ACROSS THE ENDS OF THE COPPER WIRE AND IF THE CIRCUIT OF THIS WIRE IS COMPLETED BY CONNECTING ITS ENDS TOGETHER, THIS GENERATED VOLTAGE WILL BE CAPABLE OF FORCING AN ELECTRIC CURRENT TO FLOW THROUGH THE COPPER WIRE. IN OTHER WORDS, THIS VOLTAGE IS GENERATED IN THE COPPER WIRE THROUGH THE ACT OF INDUCTION AND BECAUSE OF THIS FACT, WE REFER TO THE WIRE CUTTING THE LINES OF FORCE AS BEING THE INDUCTOR.

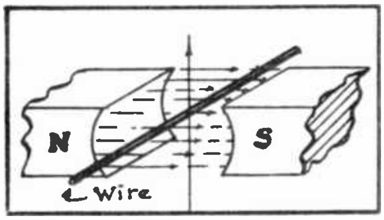

FIG.4
Cutting Lines of Force.

SHOULD THE INDUCTOR IN FIG.4 AGAIN BE MOVED THROUGH THIS SAME MAGNETIC FIELD BUT IN A DOWNWARD DIRECTION, YOU WOULD FIND THAT A VOLTAGE WOULD ONCE MORE BE GENERATED, ONLY THAT AT THIS TIME, THE POLARITY OF THE INDUCED VOLTAGE WOULD BE REVERSED. THE RESULT WOULD BE THAT IF THE CIRCUIT SHOULD BE COMPLETED BY CONNECTING THE ENDS OF THE WIRE TOGETHER, THIS PRESENT INDUCED VOLTAGE WOULD CAUSE A CURRENT TO FLOW THROUGH IT IN A DIRECTION OPPOSITE TO THAT AS

YOU FOUND IT WHEN MOVING THE INDUCTOR UPWARDS.

IN OTHER WORDS, IT IS APPARENT THAT BY MOVING A CONDUCTOR, WHICH HAS A COMPLETE CIRCUIT, RAPIDLY UP AND DOWN WITHIN A MAGNETIC FIELD, AN ALTERNATING CURRENT WILL BE GENERATED. THIS IS YOUR FUNDAMENTAL OR BASIC GENERATOR PRINCIPLE AND IT IS APPLIED IN PRACTICE AS ILLUSTRATED IN FIG. 5.

THE A.C. GENERATOR

IN FIG. 5, YOU WILL NOTE THAT OUR INDUCTOR TAKES THE SHAPE OF A LOOP, INSTEAD OF A STRAIGHT WIRE AND A BRASS OR COPPER RING IS FASTENED TO EACH END OF THE LOOP AT "A" AND "B" AND WE CALL THESE RINGS COLLECTOR RINGS OR SLIP RINGS. A STATIONARY CARBON BRUSH MAKES A WIPING CONTACT WITH EACH OF THE COLLECTOR RINGS, SO THAT EVEN THOUGH THE COLLECTOR RINGS SHOULD REVOLVE, THE BRUSHES WILL EACH MAINTAIN A SLIDING CONTACT WITH ITS INDIVIDUAL COLLECTOR RING. THESE TWO BRUSHES ARE THEN CONNECTED ACROSS AN EXTERNAL CIRCUIT OR LOAD, WHICH IN THE CASE OF FIG.5 HAPPENS TO BE A LAMP.

NOW THEN, WITH THE WIRE LOOP IN THE POSITION SHOWN AT THE LEFT OF FIG.5, YOU WILL OBSERVE THAT THE SIDE OF THE LOOP MARKED 1 AND 2 IS NEXT TO THE NORTH POLE PIECE (N) AND SIDE 3 AND 4 OF THE LOOP IS UNDER THE INFLUENCE OF THE SOUTH POLE PIECE (S). WITH THIS CONDITION FIRMLY FIXED IN YOUR MIND, LET US NEXT SEE WHAT HAPPENS AS THE LOOP IS ROTATED IN A CLOCKWISE DIRECTION OR AS INDICATED BY THE ARROW OF ROTATION.

DURING THIS MOVEMENT OF THE LOOP, IT IS CLEAR THAT SIDE 1 AND 2 OF THE LOOP WILL BE CUTTING THE FIELD'S LINES OF FORCE IN AN UPWARD DIRECTION, WHILE SIDE 3 AND 4 IS AT THIS SAME TIME CUTTING THE LINES OF FORCE IN A DOWNWARD DIRECTION. THE RESULT IS THAT THE VOLTAGE INDUCED BY THIS CUTTING OF THE LINES OF FORCE WILL CAUSE A CURRENT TO FLOW THROUGH THE LOOP AND OUTER CIRCUIT IN THE DIRECTION AS INDICATED. NOTICE ESPECIALLY THAT THE GENERATED CURRENT IS AT THIS TIME FLOWING OVER THE EXTERNAL CIRCUIT FROM BRUSH "A" TOWARDS BRUSH "B".

AFTER THE WIRE LOOP HAS BEEN ROTATED ONE-HALF REVOLUTION OR 180°, IT WILL COME TO THE POSITION AS PICTURED AT THE RIGHT OF FIG. 5. AT THIS TIME, YOU WILL NOTE THAT SIDE 1 AND 2 IS NOW CUTTING LINES OF FORCE IN A DOWNWARD DIRECTION, WHILE SIDE 3 AND 4 IS CUTTING THEM IN AN UPWARD DIR-

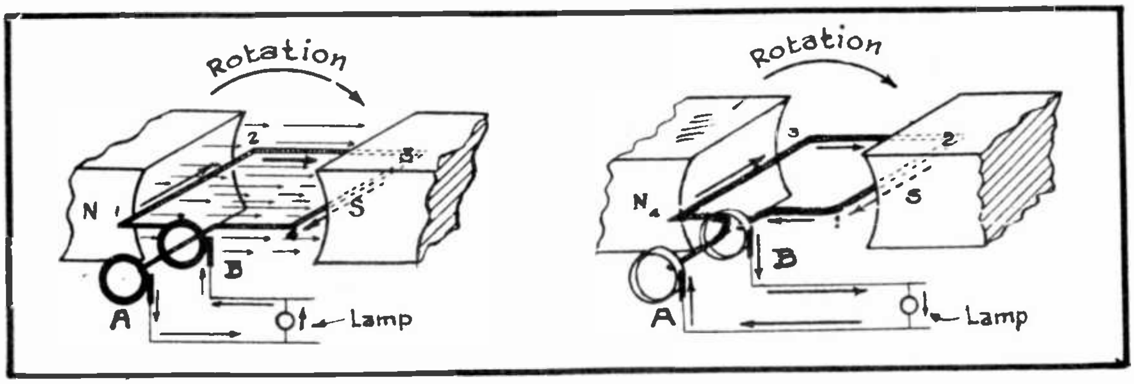

FIG. 5
Generating Alternating Current.

ECTION. IN OTHER WORDS, THE TWO SIDES OF THE LOOP ARE NOW EACH CUTTING LINES OF FORCE IN A DIRECTION OPPOSITE TO WHAT THEY DID WHILE IN THE POSITION PREVIOUSLY DESCRIBED AND THIS MEANS THAT NOW THE INDUCED VOLTAGE CAUSES CURRENT TO FLOW THROUGH THE LOOP IN AN OPPOSITE DIRECTION.

BY CAREFULLY COMPARING THE RIGHT AND LEFT ILLUSTRATIONS OF FIG. 5, YOU WILL NOTICE THAT AT THE RIGHT, THE GENERATED CURRENT IS FLOWING OVER THE EXTERNAL CIRCUIT FROM "B" TOWARDS "A" -- EXACTLY OPPOSITE TO ITS DIRECTION OF FLOW AS FOUND IN THE UNIT AT THE LEFT OF FIG. 5. IN OTHERWORDS, ALTERNATING CURRENT IS BEING GENERATED BY THIS SIMPLE DEVICE AND THE FLOW OF CURRENT WILL REVERSE ITSELF AS EACH HALF-REVOLUTION OR 180° OF THE LOOP'S TRAVEL IS COMPLETED.

IN ACTUAL PRACTICE, INSTEAD OF ONLY A SINGLE WIRE LOOP BEING REVOLVED IN THE MAGNETIC FIELD, MANY LOOPS, EACH CONSISTING OF A GREAT MANY TURNS, ARE ALL PLACED ON AN IRON CORE OR ROTOR WHICH IS PROVIDED WITH A SHAFT THROUGH ITS CENTER. THIS ENTIRE UNIT IS CALLED AN ARMATURE AND IT REVOLVES AS A BODY, SUPPORTED IN BEARINGS.

THE MECHANICAL FORCE WITH WHICH TO ROTATE THE GENERATOR ARMATURE MAY BE SUPPLIED BY AN ELECTRIC MOTOR, A GASOLINE, DIESEL OR STEAM ENGINE, BY A WATER TURBINE ETC.

NOW LET US CONTINUE AND INVESTIGATE SOME MORE IMPORTANT AND INTERESTING FACTS CONCERNING ALTERNATING CURRENTS.

THE REVOLVING ARMATURE

AT THE LEFT OF FIG. 6, WE HAVE A SIMPLE TWO-POLE A.C. GENERATOR, SHOWING ONLY A SINGLE ROTATING CONDUCTOR OR ARMATURE WIRE FOR THE SAKE OF SIMPLICITY. THIS CONDUCTOR IS GOING TO BE ROTATED THROUGH THE MAGNETIC FIELD OF THE GENERATOR IN A CLOCKWISE DIRECTION AS INDICATED BY THE SMALL ARROW HEADS.

AT THE RIGHT OF FIG. 6, WE HAVE LAID OUT AS A STRAIGHT LINE, THE

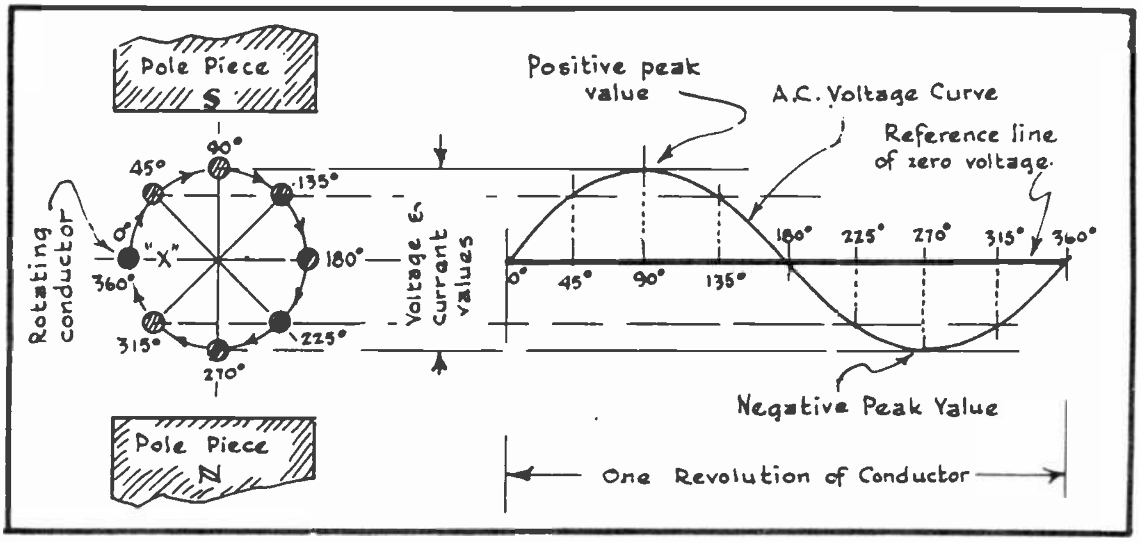

FIG. 6
Producing the "Sine Curve".

CIRCUMFERENCIAL DISTANCE TO BE TRAVELLED BY THIS CONDUCTOR, MARKING EACH 45° FROM 0° TO 360°. THE COMPLETE LENGTH OF THIS HORIZONTAL LINE WILL REPRESENT 1 REVOLUTION OF THE CONDUCTOR AS STATED ON THE DRAWING AND THIS LINE IS GOING TO REPRESENT THE REFERENCE LINE OF ZERO VOLTAGE ON THIS GRAPH.

THE SINE CURVE

NOW THEN, YOU ALREADY KNOW THAT THE LINES OF FORCE, WHICH ARE PRODUCED BY THE POLE PIECES OF THE GENERATOR, FLOW STRAIGHT ACROSS THE ARMATURE FROM THE NORTH POLE TO THE SOUTH POLE. THEREFORE, WHEN OUR ROTATING CONDUCTOR IS AT POINT "X", WHICH IS OUR STARTING OR 0° POINT, IT WILL BE MOVING PARALLEL TO THE LINES OF FORCE. CONSEQUENTLY, IT WILL NOT BE CUTTING ANY LINES OF FORCE AT THIS TIME AND FOR THIS REASON, THE GENERATED VOLTAGE AND CURRENT WILL BE ZERO. THAT IS TO SAY, NO GENERATION IS OCCURRING AT THIS INSTANT.

HOWEVER, AS THE ROTATING CONDUCTOR MOVES FROM POINT "X" TO THE 45° POINT OF ITS TRAVEL, IT WILL COMMENCE CUTTING LINES OF FORCE AND THEREFORE A VOLTAGE IS BEING GENERATED AND IT INCREASES IN VALUE RAPIDLY AS THE ROTATING CONDUCTOR COMMENCES TO CUT MORE LINES OF FORCE AT NEARLY RIGHT ANGLES. WE CAN SHOW THIS VOLTAGE INCREASE GRAPHICALLY BY MEANS OF THE CURVE AT THE RIGHT OF FIG. 6.

THE SHAPE OF THIS CURVE IS OBTAINED BY MEANS OF PROJECTION. THAT IS WE DRAW A HORIZONTAL DOTTED LINE FROM THE 45° POSITION OF THE ROTATING CONDUCTOR SO AS TO INTERSECT THE VERTICAL LINE WHICH IS DRAWN THROUGH THE 45° MARK ON THE REFERENCE LINE AT THE RIGHT. THE SLOPE OF THE FIRST PORTION OF THE CURVE MUST THEN BE SUCH AS TO EXTEND FROM THE 0° POINT OF THE REFERENCE LINE THROUGH THE POINT WHERE THE TWO LINES CROSS AT THE 45° POSITION OF THE REFERENCE LINE.

AS THE CONDUCTOR IS ROTATED FARTHER, OR FROM THE 45° MARK TO THE 90° POSITION, IT WILL CUT STILL MORE LINES OF FORCE AND STILL MORE NEARLY AT RIGHT ANGLES SO THAT THE GENERATED VOLTAGE CONTINUES TO INCREASE. FINALLY, AT THE 90° POSITION, THE MAXIMUM NUMBER OF LINES OF FORCE ARE BEING CUT AT RIGHT ANGLES AND THEREFORE, THE GENERATED VOLTAGE IS AT THIS TIME AT ITS PEAK OR MAXIMUM VALUE. THEN BY PROJECTING THE 90° POSITION OF THE CONDUCTOR OVER TO THE VERTICAL LINE, WHICH IS DRAWN THROUGH THE 90° POINT OF OUR GRAPH, WE DETERMINE THE HIGHEST OR PEAK POSITION FOR THE VOLTAGE CURVE.

DURING THE TIME THAT THE CONDUCTOR TRAVELS FROM ITS 90° POINT TO THE 180° POSITION, IT WILL BEGIN CUTTING LESS LINES OF FORCE AT A MORE NEARLY PARALLEL PLANE UNTIL THE 180° POSITION IS FINALLY REACHED. THIS MEANS THAT THE GENERATED VOLTAGE WILL BE DECREASING AT THIS TIME, SO THAT THE VOLTAGE CURVE GRADUALLY APPROACHES THE REFERENCE LINE OF ZERO VOLTAGE. THEN AS THE CONDUCTOR PASSES THROUGH ITS 180° POSITION, NO VOLTAGE AT ALL IS BEING GENERATED DUE TO THE FACT THAT THE CONDUCTOR IS MOVING PARALLEL TO LINES OF FORCE. CONSEQUENTLY, OUR VOLTAGE CURVE DROPS TO A ZERO VALUE AT THE 180° MARK.

FROM THE 180° TO THE 270° POSITION, THE REVOLVING CONDUCTOR WILL AGAIN COMMENCE CUTTING MORE AND MORE LINES OF FORCE AT AN INCREASING ANGLE BUT AT THIS TIME, THE LINES OF FORCE ARE BEING CUT IN AN OPPOSITE DIRECTION THAN BEFORE. FOR THIS REASON, THE POLARITY OF THE VOLTAGE IS NOW REVERSED

AND THE VOLTAGE INCREASE IS THEREFORE AT THIS TIME REPRESENTED BY THAT PORTION OF THE CURVE WHICH IS DRAWN BELOW THE REFERENCE LINE OF ZERO VOLTAGE. AT THE 270° POINT, OF COURSE, THE CONDUCTOR IS CUTTING A MAXIMUM NUMBER OF LINES OF FORCE AT RIGHT ANGLES, SO THAT WE HAVE OUR MAXIMUM OR NEGATIVE PEAK VOLTAGE AT THIS INSTANT.

AS THE CONDUCTOR GRADUALLY APPROACHES POSITION "X" AGAIN, SO AS TO COMPLETE 360° OF TRAVEL OR ONE COMPLETE REVOLUTION, THE GENERATED VOLTAGE BECOMES LESS UNTIL AT "X" OR THE 360° MARK, IT FINALLY REACHES A ZERO VALUE. THIS EXPLAINS WHY THE VOLTAGE CURVE AGAIN STRIKES THE REFERENCE LINE OF ZERO VOLTAGE AT THE 360° MARK.

IN THIS CASE, THE CURRENT UNDERGOES THE SAME CHANGES IN RELATIVE VALUE AS DOES THE VOLTAGE AND FOR THIS REASON, THE SAME CURVE CAN REPRESENT EITHER THE VOLTAGE OR CURRENT VARIATION IN THIS PARTICULAR EXAMPLE. AS YOU WILL NOTE FROM THE RESULTING VOLTAGE CURVE, ONE A.C. CYCLE WILL BE COMPLETED DURING THE SINGLE REVOLUTION OF THIS CONDUCTOR AND AS THE ROTATION OF THE CONDUCTOR CONTINUES, WE WILL HAVE AN ENTIRE SERIES OF CYCLES.

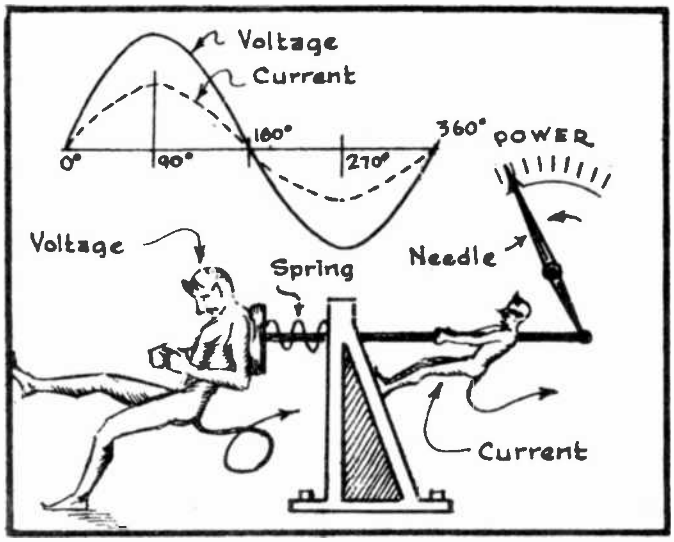

FIG. 7
Voltage and Current "in Phase".

THIS SAME CURVE OF FIG. 6 IS ALSO FREQUENTLY SPOKEN OF AS THE SINE CURVE AND SO NOW IF YOU SHOULD HEAR OR READ OF ANY OF THESE TERMS, YOU WILL KNOW JUST EXACTLY WHAT IS MEANT BY THEM.

THE DIFFERENT A.C. VALUES

AS YOU WILL OBSERVE FROM OUR VOLTAGE CURVE IN FIG. 6, THE VALUE OF THE VOLTAGE AND CURRENT IS CONTINUALLY VARYING DURING THE CYCLE AND AS A RESULT, A DIFFERENT VALUE IS OBTAINED AT EACH SUCCESSIVE INSTANT. FOR THIS REASON, WE SPEAK OF THREE DIFFERENT KINDS OF VALUES WHEN REFERRING TO ALTERNATING VOLTAGE OR CURRENT. THESE THREE VALUES ARE KNOWN AS THE PEAK VALUE, INSTANTANEOUS VALUE AND THE EFFECTIVE VALUE. FOR GENERAL PRACTICAL WORK, HOWEVER, ONLY THE PEAK AND EFFECTIVE VALUES ARE OF IMPORTANCE.

THE PEAK VALUES ARE CLEARLY ILLUSTRATED FOR YOU IN FIG. 6 AND OF COURSE THESE VALUES ARE JUST WHAT THEIR NAME INDICATES. THAT IS, THE PEAK VOLTAGE OR CURRENT IS THE MAXIMUM VOLTAGE OR CURRENT WHICH IS GENERATED AT SOME INSTANT OF THE CYCLE.

WHEN WE SPEAK OF A.C. CIRCUITS AS OPERATING AT A VOLTAGE OF 220 VOLTS, WE ARE REFERRING TO THE EFFECTIVE VOLTAGE VALUE AND NOT TO THE PEAK VALUE. THE TERM "EFFECTIVE VOLTAGE" IS ALWAYS UNDERSTOOD TO BE MEANT UNLESS WE ACTUALLY SPECIFY "PEAK VOLTAGE". THE PEAK VOLTAGE OF A 220 VOLT circuit is really equal to approximately 311.17 volts because the effective voltage is approximately equal to .707 of the maximum or peak voltage. In like manner, if the peak voltage is 155.16 volts, then the effective voltage is equal to approximately 110 volts and we would speak of the system as being a 110 volt circuit. An A.C. voltmeter registers the EFFECTIVE voltage and not the peak voltage.

The EFFECTIVE CURRENT of an A.C. circuit is the current which has the same heating effect as a direct current of so many amperes. The effective value of the current in an A.C. circuit is equal to approximately .707 times the maximum current of the cycle. In other words, if the maximum current at some instant of the cycle is 50 amperes, then the effective current is equal to .707 X 50 or 35.35 amperes.

The EFFECTIVE VOLTAGE then can also be considered as the alternating voltage required to force a current thru a circuit having the same heating value as the current which is produced by a DIRECT VOLTAGE of this SAME VALUE. The effective values are also frequently spoken of as the "root mean square value," which is generally abreviated as R.M.S. You will come across this term quite often in radio literature and so now you will already know what it means and will have no reason to wonder about it if you should find it used somewhere.

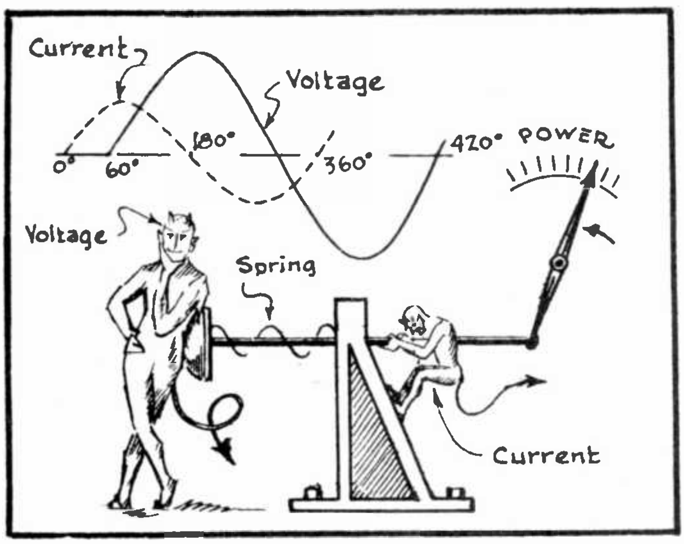

FIG. 8

Voltage and Current "out of Phase"

Remember now, -- to determine the effective voltage in terms of the peak voltage, simply multiply the peak voltage by .707. For instance, if the peak voltage is 435 volts, then the effective voltage will be equal to 435 X .707 or 307.545 volts. The same rule applies to current, for in this case, the effective current is equal to the peak current multiplied by .707. That is to say, if the peak current is 55 amperes, the effective current will be equal to 55 X .707 or 38.885 amperes.

On the other hand, to determine peak values in terms of effective values, multiply the effective value by the constant 1.41. In other words, if the effective voltage is known to be 300 volts, then the peak voltage will be equal to 300 X 1.41 or 423 volts. In like manner, if the effective current is 30 amperes, then the peak current will be equal to 30 X 1.41 or 42.3 amperes.

These rules as here given, however, apply only to circuits in which the alternating voltages and currents are of a true sine-wave form.

The INSTANTANEOUS values of the current or voltage in an A.C. cir-

CUIT ARE THE VALUES AT SOME PARTICULAR INSTANT OF THE CYCLE. THAT IS, THE VALUE AT THE 35° POINT OF THE CYCLE, AT THE 42° POINT ETC., BUT FOR PRACTICAL RADIO PURPOSES, YOU WILL HAVE NO USE FOR INSTANTANEOUS VALUES OF EITHER THE VOLTAGE OR CURRENT. HOWEVER, IN A LATER LESSON YOU WILL BE SHOWN HOW TO CALCULATE PROBLEMS INVOLVING INSTANTANEOUS VALUES.

THE MEANING OF "PHASE"

NOW THERE IS ANOTHER ELECTRICAL EXPRESSION WHICH YOU WILL FIND USED A GREAT DEAL RELATIVE TO A.C. CIRCUITS IN RADIO AND THIS IS THE TERM "PHASE". NO DOUBT, FIG. 7 AND FIG. 8 WILL AID YOU CONSIDERABLY IN GRASPING THE MEANING OF THIS POPULAR TERM.

IN FIG. 7, FOR INSTANCE, WE HAVE AN EXAMPLE ILLUSTRATING THE FACT THAT THE VOLTAGE AND CURRENT IN AN A.C. CIRCUIT ARE "IN PHASE". HERE WE ARE PICTURING VOLTAGE AS THE LARGE AND MORE POWERFUL DEMON WHILE THE CURRENT IS THE SMALLER BUT ACTIVE HARD WORKING LITTLE FELLOW. BOTH ARE APPLYING THEIR UTMOST EFFORTS SIMULTANEOUSLY TOWARDS COMPRESSING THE SPRING, THEREBY CAUSING THE INDICATING NEEDLE TO SWING A CONSIDERABLE DISTANCE ACROSS THE SCALE. IN OTHER WORDS, THE VOLTAGE AND CURRENT ARE BOTH IN STEP WITH EACHOTHER, WORKING IN CLOSE "TEAM WORK."

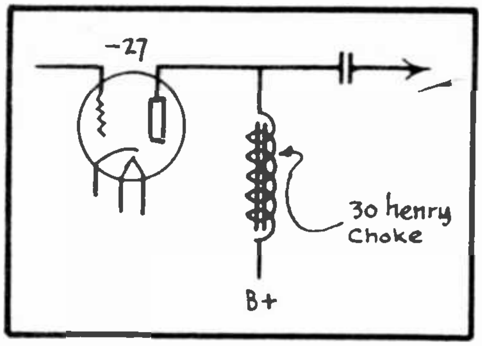

FIG. 9

Calculating Inductive Reactance.

NOW THEN, IF WE SHOULD SHOW BOTH THE VOLTAGE AND CURRENT SINE CURVES SIMULTANEOUSLY AT THIS TIME, THEY WOULD APPEAR AS ILLUSTRATED AT THE UPPER LEFT OF FIG. 7. AS YOU WILL NOTE, THE PEAK VALUES OF BOTH THE VOLTAGE AND CURRENT OCCUR AT THE SAME INSTANT AND THEY BOTH DROP TO A ZERO VALUE AT THE SAME INSTANT. THIS RELATION BETWEEN THE VOLTAGE AND CURRENT ALWAYS EXISTS WHENEVER THE VOLTAGE AND THE CURRENT ARE IN PHASE.

WHENEVER AN A.C. CIRCUIT CONTAINS RESISTANCE ALONE AND NEITHER INDUCTANCE OR CAPACITY, THEN THE VOLTAGE AND CURRENT ARE ALWAYS IN PHASE AS HERE SHOWN.

NOW IN FIG. 8, WE HAVE PICTURED A DIFFERENT CONDITION, FOR HERE VOLTAGE IS "LAYING DOWN ON THE JOB" AND DOESN'T REALLY COMMENCE WORKING AS HARD AS IT SHOULD UNTIL THE CURRENT HAS ALREADY COMMENCED TO BUILD UP. THE RESULT IS, THAT THE CURRENT REACHES ITS PEAK VALUE BEFORE THE VOLTAGE REACHES ITS PEAK VALUE. IN OTHER WORDS, THE VOLTAGE LAGS BEHIND THE CURRENT OR THE CURRENT LEADS THE VOLTAGE AND SO NATURALLY SINCE THE CURRENT AND VOLTAGE ARE NOW OUT OF STEP WITH EACHOTHER, WE USE THE ELECTRICAL EXPRESSION BY SAYING THAT THEY ARE "OUT OF PHASE".

AS YOU SHALL SEE A LITTLE LATER, THERE ARE ALSO TIMES WHERE THE VOLTAGE LEADS THE CURRENT IN AN A.C. CIRCUIT BUT IRRESPECTIVE OF WHICH OF THE TWO VALUES IS LEADING THE OTHER, THEY ARE OUT OF PHASE UNLESS INCREASING AND DECREASING IN VALUE SIMULTANEOUSLY. NOW THAT YOU UNDERSTAND WHAT IS MEANT BY THESE TWO ELECTRICAL TERMS "IN PHASE" AND "OUT OF PHASE", LET US NEXT INVESTIGATE THE MATTER OF INDUCTANCE A LITTLE MORE THOROUGHLY.

INDUCTIVE REACTANCE

IN ALL OF YOUR PRELIMINARY STUDIES, YOU LEARNED THAT AN INDUCTANCE OR COIL OFFERED AN OPPOSITION TO THE FLOW OF ALTERNATING CURRENT DUE TO THE SELF INDUCTION IN THE WINDING. YOU ALSO LEARNED THAT THE OPPOSITION OFFERED BY AN INDUCTANCE INCREASES WITH AN INCREASE IN FREQUENCY BUT NOW LET US CONSIDER THIS EFFECT IN GREATER DETAIL. TO BEGIN WITH, IT IS UNDERSTOOD THAT A STRAIGHT WIRE OFFERS A RESISTIVE EFFECT TO BOTH D.C. AND A.C. CURRENTS AND THE CONDUCTOR'S RESISTANCE IS DETERMINED BY THE MATERIAL, LENGTH, AREA AND TEMPERATURE OF THE CONDUCTOR. FURTHERMORE, YOU KNOW THAT THE CONDUCTOR'S RESISTANCE IS MEASURED IN OHMS.

SINCE A COIL OR INDUCTANCE OFFERS AN OPPOSITION TO THE FLOW OF AN A.C. CURRENT ON ACCOUNT OF ITS MAGNETIC QUALITIES, IT IS NO MORE BUT REASONABLE THAT WE ALSO MEASURE THIS TYPE OF OPPOSITION IN OHMS, BECAUSE THE EFFECT OF A GIVEN E.M.F. OF SELF INDUCTION IN IMPEDING OR RETARDING THE FLOW OF CURRENT IS EQUIVALENT TO A CERTAIN NUMBER OF OHMS RESISTANCE WHICH WOULD HAVE EXACTLY THE SAME EFFECT. NOW THE REAL ELECTRICAL NAME FOR THIS EFFECT OF SELF-INDUCTION TO OPPOSING THE FLOW OF ALTERNATING CURRENT IS CALLED INDUCTIVE REACTANCE. SO REMEMBER NOW, INDUCTIVE REACTANCE IS SIMPLY THE OPPOSITION OFFERED BY A COIL OR WINDING TO THE FLOW OF A.C. OR PULSATING D.C. CURRENTS DUE TO SELF-INDUCTION IN THE WINDING.

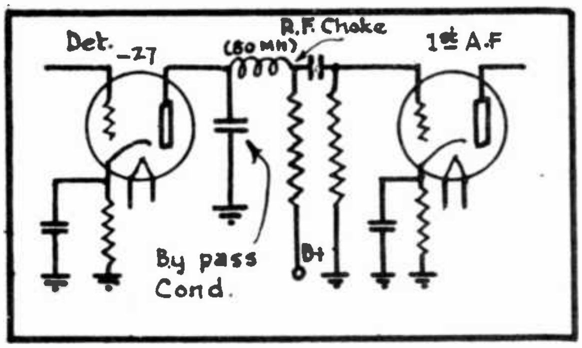

FIG. 10

Inductive Reactance of R. F. Choke.

CALCULATING INDUCTIVE REACTANCE

WE HAVE A SIMPLE FORMULA AVAILABLE FOR OUR USE, WHICH ENABLES US TO CALCULATE QUITE READILY THE INDUCTIVE REACTANCE OF ANY INDUCTANCE. TO DETERMINE THE INDUCTIVE REACTANCE OF ANY COIL, SIMPLY MULTIPLY TOGETHER 2 X 3.1416 X FREQUENCY IN CYCLES PER SECOND X THE INDUCTANCE OF THE COIL IN HENRIES. EXPRESSED AS A FORMULA WE HAVE $X_L = 2\pi f L$ WHERE X_L IS THE STANDARD SYMBOL FOR INDUCTIVE REACTANCE, π IS THE CONSTANT 3.1416, "f" IS THE FREQUENCY EXPRESSED IN CYCLES PER SECOND AND L IS THE SYMBOL FOR INDUCTANCE IN HENRIES.

SOMETIMES YOU WILL ALSO COME ACROSS THIS FORMULA WRITTEN IN THE FORM $X_L = 6.28 f L$. IN THIS CASE, THE APPROXIMATE VALUE OF π OR 3.14 HAS ALREADY BEEN DOUBLED OR MULTIPLIED BY 2 SO AS TO GIVE THE CONSTANT 6.28 IN THE LATTER FORM. OTHERWISE, BOTH FORMULAE ARE IDENTICAL AND YOU CAN USE EITHER. THE LATTER OR $X_L = 6.28 f L$ IS MOST USED FOR PRACTICAL PURPOSES BECAUSE IT REQUIRES LESS COMPUTATION AND IS SUFFICIENTLY ACCURATE EVEN THOUGH THE LAST TWO DECIMAL PLACES HAVE BEEN DROPPED FROM THE VALUE OF π.

IN FIG. 9, WE HAVE A PRACTICAL EXAMPLE FOR DETERMINING THE INDUCTIVE REACTANCE OF AN INDUCTANCE. IN THIS CASE, A 30 HENRY CHOKE OR IMPEDANCE COIL IS CONNECTED IN THE PLATE CIRCUIT OF A TYPE -27 TUBE. LET US NOW DETERMINE THE INDUCTIVE REACTANCE OF THIS CHOKE AT THE TIME THAT AUDIO

CURRENT VARIATIONS OF A 100 CYCLE FREQUENCY FLOW THROUGH IT.

OUR FORMULA FOR THIS CALCULATION IS OF COURSE $X_L = 6.28 f L$, SO OUR FIRST STEP IS TO SUBSTITUTE OUR VALUES INTO THE FORMULA. SINCE THE FREQUENCY, WITH WHICH WE ARE DEALING AT THIS PARTICULAR TIME, IS 100 CYCLES AND THE INDUCTANCE OF THE CHOKE IS 30 HENRIES, WE SIMPLY INSERT THESE VALUES FOR "f" AND "L" IN THE FORMULA. WE THEN HAVE THE EXPRESSION THAT $X_L = 6.28 \times 100 \times 30$ AND HENCE BY MULTIPLYING TOGETHER 6.28 BY 100 BY 30, WE FIND THAT THE INDUCTIVE REACTANCE FOR THIS 30 HENRY CHOKE AT 100 CYCLES IS 18,840 OHMS. AS YOU WILL NOTE, THIS CHOKE WILL OFFER A CONSIDERABLE LOAD IN THE PLATE CIRCUIT OF THIS TUBE AT 100 CYCLES IN SPITE OF THE FACT THAT THE D.C. OR OHMIC RESISTANCE OF THE WIRE MAKING UP THE CHOKE IS RELATIVELY LOW.

FOR THE SAKE OF EXPLANATION, LET US SEE WHAT HAPPENS WHEN THE FREQUENCY OF THE CURRENT PASSING THROUGH THIS SAME CHOKE IS INCREASED. FOR EXAMPLE, WE WILL ASSUME THAT AN AUDIO FREQUENCY OF 2000 CYCLES IS ACTING UPON IT AT ONE INSTANT. AT THIS TIME, WE HAVE TO SUBSTITUTE THE VALUE OF 2000 FOR "f" IN OUR FORMULA AND THE EXPRESSION THEN BECOMES $X_L = 6.28 \times 2000 \times 30$. WORKING OUT THIS CALCULATION, WE FIND THE INDUCTIVE REACTANCE FOR THIS CHOKE AT 2000 CYCLES TO BE 376,800 OHMS. THIS SHOWS YOU THAT THE INDUCTIVE REACTANCE INCREASES VERY RAPIDLY AS THE OPERATING FREQUENCY IS INCREASED.

QUITE OFTEN IN YOUR RADIO WORK, YOU WILL HAVE TO DEAL WITH COILS ETC; WHOSE INDUCTANCE IS SO SMALL THAT THE UNIT "MILLIHENRY" OR "MICROHENRY" IS USED, SUCH AS IN THE CASE OF R.F. CHOKES AND R.F. TRANSFORMER WINDINGS. IN THIS INSTANCE, YOU WILL HAVE TO BE CAREFUL WHEN CALCULATING THE COIL'S INDUCTIVE REACTANCE WITH OUR FORMULA, FOR THE VALUE OF THE INDUCTANCE WILL FIRST HAVE TO BE CHANGED TO HENRIES. THAT IS, IF THE COIL'S INDUCTANCE IS GIVEN AS 80 MILLIHENRIES, THIS IS, EQUIVALENT TO .080 HENRIES. IF THE INDUCTANCE IS GIVEN AS 100 MICROHENRIES, THEN THIS IS EQUIVALENT TO .0001 HENRIES ETC.

TO BE SURE THAT YOU UNDERSTAND HOW TO TACKLE A PROBLEM WHERE VALUES MUST FIRST BE CHANGED TO DIFFERENT UNITS, LET US WORK OUT THE PROBLEM ILLUSTRATED IN FIG. 10. HERE WE HAVE AN 80 MILLIHENRY CHOKE CONNECTED IN THE PLATE CIRCUIT OF A TYPE -27 DETECTOR TUBE. NOW LET US DETERMINE THE INDUCTIVE REACTANCE OR THE OPPOSITION OFFERED BY THIS CHOKE TO A RADIO FREQUENCY OF 500 KC.

OUR FIRST STEP IS TO CHANGE THE VALUE OF THE CHOKE FROM 80 MILLIHENRIES TO ITS EQUIVALENT OF .080 HENRIES. THE RADIO FREQUENCY OF 500 KC. MUST NEXT BE CHANGED TO ITS EQUIVALENT OF 500,000 CYCLES. THIS DONE, WE ARE NOW READY TO SUBSTITUTE THESE NEW VALUES INTO OUR FORMULA OF INDUCTIVE REACTANCE. THAT IS, $X_L = 6.28 f L$ OR $X_L = 6.28 \times 500{,}000 \times .080 = 251{,}200$ OHMS.

AS YOU WILL NOTE FROM THE RESULTS OF THIS CALCULATION, AN ORDINARY R.F. CHOKE OFFERS A GREAT DEAL OF OPPOSITION OR INDUCTIVE REACTANCE TO RADIO FREQUENCIES.

ANOTHER GROUP OF HANDY FORMULAS FOR EASY DETERMINATION OF THE INDUCTIVE REACTANCE OF A GIVEN INDUCTANCE ARE AS FOLLOWS:

IF THE FREQUENCY IS GIVEN IN CYCLES AND THE INDUCTANCE IN HENRIES,

THEN THE REACTANCE IN OHMS = $\frac{\text{CYCLES} \times \text{HENRIES} \times 1000}{159}$. THAT IS, MULTIPLY TOGETHER THE FREQUENCY IN CYCLES, INDUCTANCE IN HENRIES AND MULTIPLY THIS PRODUCT BY 1000. FINALLY, DIVIDE THIS RESULT BY 159 AND THE ANSWER WILL BE THE REACTANCE IN OHMS.

IF THE FREQUENCY IS GIVEN IN KILOCYCLES AND THE INDUCTANCE IN MILLIHENRIES, THEN THE INDUCTIVE REACTANCE IN OHMS IS EXPRESSED AS FOLLOWS: $\frac{\text{KILOCYCLES} \times \text{MILLIHENRIES} \times 1000}{159}$. THESE ARE ONLY APPROXIMATE FORMLAE BUT OFFER SUFFICIENTLY ACCURATE RESULTS FOR ORDINARY PRACTICAL PURPOSES.

IN THIS LESSON, YOU HAVE RECEIVED CONSIDERABLE INFORMATION OF IMPORTANCE RELATIVE TO A.C. CIRCUITS AND YOU ARE URGED TO STUDY THIS LESSON VERY CAREFULLY. WE SHALL CONTINUE OUR INVESTIGATION OF MANY MORE INTERESTING PHENOMENA CONCERNING ALTERNATING CURRENTS IN THE FOLLOWING LESSONS. THEN WHEN YOU HAVE MASTERED THE COMING LESSONS, YOU ARE GOING TO ENTER THE MOST FASCINATING PORTION OF YOUR RADIO TRAINING, NAMELY THAT OF DESIGNING AND CONSTRUCTING RADIO EQUIPMENT SUCH AS R.F. COILS, POWER TRANSFORMERS, COMPLETE POWER PACKS ETC.

Examination Questions

1. - EXPLAIN HOW A GENERATOR PRODUCES AN ALTERNATING VOLTAGE.

2. - DESCRIBE THE "SINE CURVE".

3. - WHAT DO WE MEAN BY THE TERMS PEAK VALUE, INSTANTANEOUS VALUE, AND EFFECTIVE VALUE?

4. - IF THE PEAK VOLTAGE OF A CERTAIN A.C. CIRCUIT IS 600 VOLTS, WHAT IS THE EFFECTIVE VOLTAGE?

5. - IF THE EFFECTIVE VOLTAGE OF A CERTAIN A.C. CIRCUIT IS 256 VOLTS, WHAT IS THE PEAK VOLTAGE?

6. - WHAT DO WE MEAN BY THE EXPRESSIONS "IN PHASE" AND "OUT OF PHASE" WITH RESPECT TO A.C. CIRCUITS?

7. - WHAT IS MEANT BY THE TERM INDUCTIVE REACTANCE?

8. - A CERTAIN A.F. CHOKE HAS AN INDUCTANCE OF 30 HENRIES. WHAT WILL BE ITS INDUCTIVE REACTANCE TOWARDS A.F. CURRENTS HAVING A FREQUENCY OF 1500 CYCLES PER SECOND?

9. - WHAT INDUCTIVE REACTANCE WILL AN 85 MILLIHENRY R.F. CHOKE OFFER TOWARDS RADIO FREQUENCY CURRENTS OF 600 KC?

10. - WHENEVER AN A.C. CIRCUIT CONTAINS RESISTANCE ALONE AND NO INDUCTANCE OR CAPACITY, WILL THE VOLTAGE AND CURRENT BE IN PHASE OR OUT OF PHASE?

Practical Technical Training In
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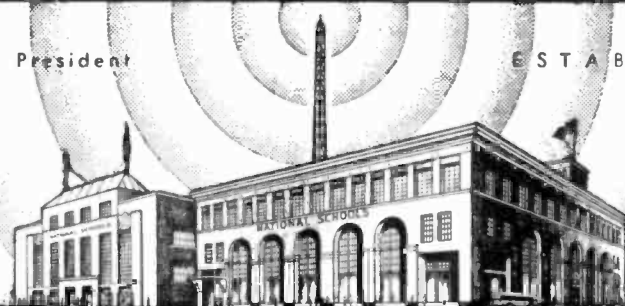

NATIONAL SCHOOLS ★ LOS ANGELES 37, CALIF.

LESSON NO. 40

INDUCTANCE-CONDENSER CALCULATIONS IN A. C. CIRCUITS --- IMPEDANCE

By means of thorough radio training, you can become an expert radio service engineer, a radio dealer, a tester for a radio manufacturing concern, a designer, etc. This, of course, means greater possibilities for employment in the radio field. Each branch of the industry offers you many opportunities with good salaries.

FIG. 1
TESTING RADIO EQUIPMENT

Set yourself a goal and keep this goal in mind constantly, so that you will be inspired to study diligently in order to attain the success that is bound to come. Remember, that each lesson is a stepping stone which brings you closer and closer to that good radio job.

Now, let us continue with the second portion of our study, which concerns the essentials of A. C. circuits.

PHASE RELATION IN INDUCTIVE CIRCUITS

First, we shall investigate the matter of phase relation in a circuit containing inductance alone and no resistance or capacity. Of course, such a condition is really impossible in a practical sense but, nevertheless, an understanding of it will aid you in more readily understanding the phase relation in inductive circuits than if we should already consider a complex con-

DITION AS REALLY EXISTS IN ACTUAL PRACTICE.

THE VOLTAGE AND CURRENT FOR A PURE INDUCTIVE CIRCUIT ARE SHOWN TOGETHER IN FIG. 2. HERE YOU WILL NOTE THAT THE VOLTAGE COMMENCES TO INCREASE RAPIDLY BEFORE THE CURRENT ACTUALLY STARTS TO FLOW THROUGH THE CIRCUIT. THIS PECULIAR EFFECT IS DUE TO THE COUNTER ELECTROMOTIVE FORCE DEVELOPED BY THE INDUCTANCE AS A VOLTAGE IS FIRST APPLIED ACROSS IT. THE VOLTAGE, YOU WILL NOTE IN FIG. 2, REACHES ITS PEAK VALUE AT 90° AND AT THIS SAME INSTANT, THE CURRENT JUST STARTS ITS INCREASE IN VALUE. IN OTHER WORDS, THE CURRENT LAGS BEHIND THE VOLTAGE BY 90°, OR THE VOLTAGE LEADS THE CURRENT BY 90°. CONTINUALLY, THE CURRENT REACHES ITS PEAK VALUE WHEN THE VOLTAGE IS ZERO AND THE VOLTAGE REACHES ITS PEAK VALUE WHEN THE CURRENT IS AT ZERO. THUS WE CONCLUDE, THAT IN CIRCUITS CONTAINING INDUCTANCE ALONE, THE VOLTAGE AND CURRENT ARE 90° OUT OF PHASE, WITH THE VOLTAGE LEADING THE CURRENT.

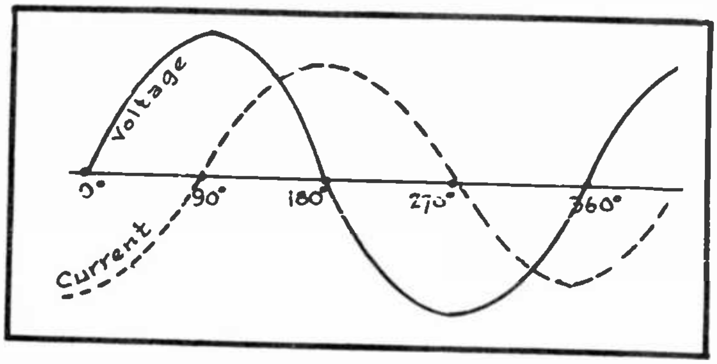

FIG. 2
Voltage Leads Current in Inductive Circuits.

SERIES CONNECTED INDUCTANCES

NOW LET US CONSIDER THE EFFECT WHICH IS PRODUCED WHEN INDUCTANCES ARE CONNECTED IN SERIES. THIS IS ILLUSTRATED FOR YOU IN FIG. 3 AND IT IS INTERESTING TO NOTE THAT WE TREAT SERIES CONNECTED INDUCTANCES THE SAME AS SERIES CONNECTED RESISTORS. THAT IS, AT THE TOP OF FIG. 3, WE HAVE A 300 OHM, 200 OHM AND 400 OHM RESISTOR CONNECTED IN SERIES. THE TOTAL RESISTANCE OF THIS COMBINATION THUS BECOMES EQUAL TO THEIR SUM (300 + 200 + 400 OR 900 OHMS.)

WHEN INDUCTANCES ARE CONNECTED IN SERIES, WE FIGURE THE TOTAL INDUCTANCE THE SAME WAY. THAT IS, IN THE CASE OF FIG.3, THE 300 MICROHENRY (THE SYMBOL "μh" DENOTES "MICROHENRY"), 200 MICHROHENRY AND 400 MICHROHENRY COILS ARE CONNECTED TOGETHER IN SERIES. THE TOTAL INDUCTANCE OF THE COMBINATION THUS BECOMES 300 + 200 + 400 OR 900 MICHROHENRIES. IN LIKE MANNER, THE TOTAL INDUCTIVE REACTANCE OF THESE THREE COILS TOWARDS THE FLOW OF AN A.C. CURRENT OF GIVEN FREQUENCY WOULD BE EQUAL TO THE SUM OF THE REACTANCES OF THE THREE COILS.

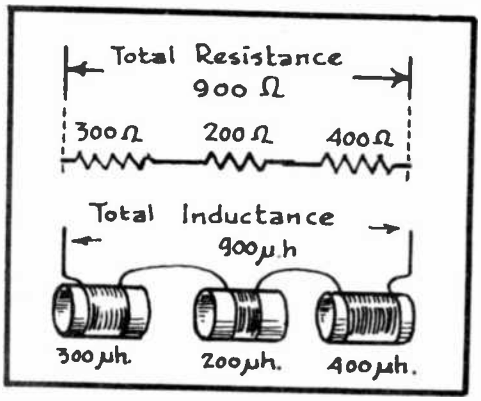

FIG. 3
Inductances Connected In Series.

PARALLEL CONNECTED INDUCTANCES

IN FIG.4, WE HAVE PICTURED THE CONDITION WHERE THREE COILS, OR INDUCTANCES ARE CONNECTED IN PARALLEL AND IN THIS CASE, THE COMPUTATION FOR THE TOTAL OR COMBINED INDUCTANCE CAN BE COMPARED TO THAT OF CALCULATING THE COMBINED RESISTANCE OF A PARALLEL CONNECTED GROUP OF RESISTORS. FOR

EXAMPLE, AT THE TOP OF FIG. 4, WE HAVE A 300, 200 AND 400 OHM RESISTOR CONNECTED IN PARALLEL AND AS YOU LEARNED IN A PREVIOUS LESSON, THE RECIPROCAL OF THE COMBINED RESISTANCE OF THIS COMBINATION IS FOUND BY ADDING THE RECIPROCALS OF THE INDIVIDUAL RESISTORS. THAT IS, $\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}$ OR $\frac{1}{R}=\frac{1}{300}+\frac{1}{200}+\frac{1}{400}$ OR $1/R=\frac{4}{1200}+\frac{6}{1200}+\frac{3}{1200}$ OR $R=92.3$ OHMS.

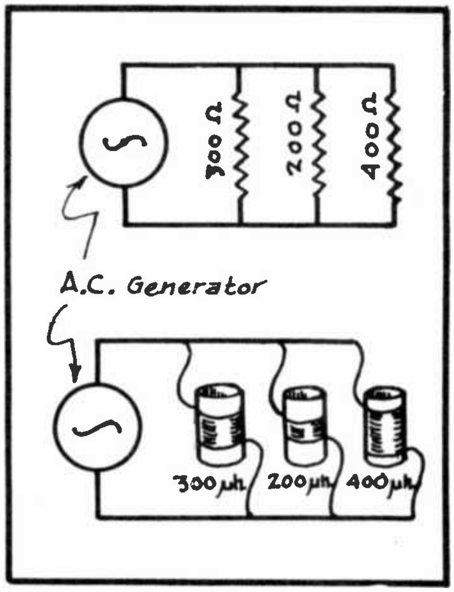

FIG. 4
Inductances Connected In Parallel.

IN LIKE MANNER, THE RECIPROCAL OF THE TOTAL INDUCTANCE OF A GROUP OF PARALLEL CONNECTED INDUCTANCES, BECOMES EQUAL TO THE SUM OF THE RECIPROCALS OF THE INDIVIDUAL INDUCTANCES. FOR EXAMPLE, IN THE CASE OF FIG. 4, $\frac{1}{L}=\frac{1}{L_1}+\frac{1}{L_2}+\frac{1}{L_3}$ WHERE L REPRESENTS INDUCTANCE. CONTINUING, WE HAVE THAT $\frac{1}{L}=\frac{1}{300}+\frac{1}{200}+\frac{1}{400}$ OR $\frac{1}{L}=\frac{4}{1200}+\frac{6}{1200}+\frac{3}{1200}$, WHENCE L OR THE COMBINED INDUCTANCE BECOMES 92.3 MICROHENRIES. IT THUS ALSO FOLLOWS THAT THE TOTAL INDUCTIVE REACTANCE OF THESE THREE COILS TOWARDS THE FLOW OF AN A.C. CURRENT OF GIVEN FREQUENCY WOULD BE FIGURED WITH THE AID OF RECIPROCALS. IN OTHER WORDS, IF THREE PARALLEL CONNECTED COILS AT A GIVEN FREQUENCY RESPECTIVELY HAVE AN INDUCTIVE REACTANCE OF 2000 OHMS, 1500 OHMS AND 3000 OHMS, THE THREE TOGETHER WOULD HAVE A COMBINED REACTANCE OF 666.66 OHMS ($\frac{1}{X_L}=\frac{1}{2000}+\frac{1}{1500}+\frac{1}{3000}$ OR $X_L=666.66$ OHMS).

CAPACITIVE REACTANCE

NOW LET US TURN OUR ATTENTION TO A DIFFERENT TYPE OF REACTANCE. THIS TIME, IT IS GOING TO BE CAPACITIVE REACTANCE AND THIS IS THE REAL NAME FOR THE OPPOSING EFFECT THAT A CONDENSER OFFERS TO THE FLOW OF AN ALTERNATING CURRENT. YOU ARE ALREADY SOMEWHAT FAMILIAR WITH THIS INTERESTING PHENOMENA BUT AT THIS TIME, WE ARE GOING TO CONSIDER IT IN A MORE ADVANCED FORM.

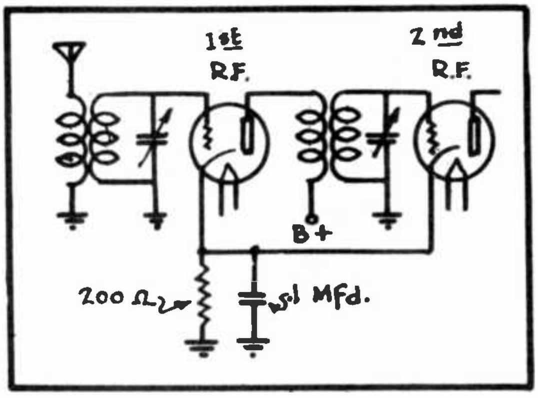

FIG. 5
Calculating Capacitive Reactance.

TO BEGIN WITH, CAPACITIVE REACTANCE IS ALSO MEASURED IN OHMS, THE SAME AS RESISTANCE AND INDUCTIVE REACTANCE. THE METHOD OF CALCULATING THE CAPACITIVE REACTANCE, HOWEVER, IS SOMEWHAT DIFFERENT, AND WE MAKE USE OF THE FOLLOWING FORMULA: $X_c=\frac{1}{2\pi fC}$ OR $X_c=\frac{1}{6.28 fC}$ WHERE X_c IS THE SYMBOL FOR CAPACITIVE REACTANCE, "2π" IS THE CONSTANT 6.28 (APPROXIMATE) "f" IS THE FREQUENCY IN CYCLES PER SECOND AND "C" IS THE CAPACITY OF THE GIVEN CONDENSER EXPRESSED IN FARADS.

A PRACTICAL CAPACITIVE REACTANCE PROBLEM

LET US WORK OUT A PRACTICAL PROBLEM INCLUDING CAPACITIVE REACTANCE AND SEE JUST WHERE WE STAND. IN FIG. 5 YOU ARE SHOWN TWO R.F. AMPLIFYING STAGES WHICH HAVE A 200-OHM GRID-BIAS RESISTOR INSTALLED IN THEIR COMMON CATHODE CIRCUIT. THIS 200-OHM RESISTOR IS BYPASSED BY A .1 MFD CONDENSER.

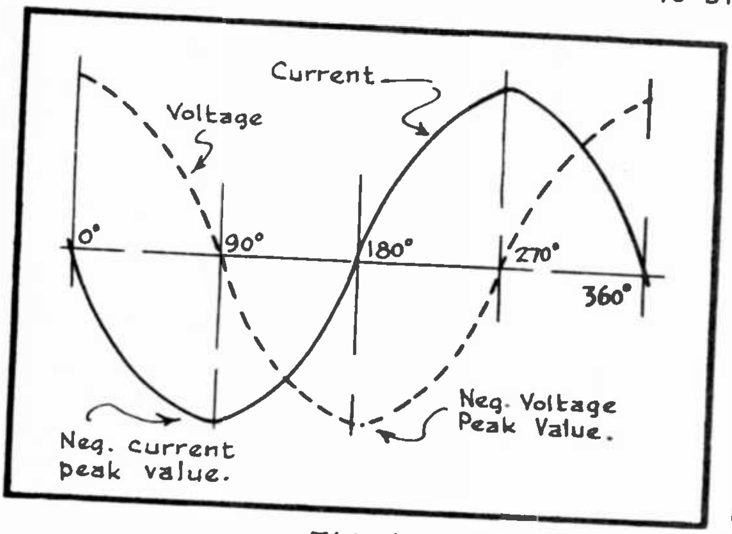

FIG. 6
Current Leads the Voltage in a Capacitive Circuit.

AS YOU ALREADY KNOW, THE PURPOSE OF THIS BYPASS CONDENSER IS TO PASS THE RADIO FREQUENCIES TO GROUND SO THAT THEY WON'T PASS THROUGH THIS RESISTOR, BUT NOW LET US SEE HOW THIS CONDITION IS GOING TO WORK OUT MATHEMATICALLY.

SINCE WE ALREADY KNOW THAT A CONDENSER OFFERS LESS OPPOSITION OR LESS REACTANCE TO ALTERNATING CURRENTS AS THE FREQUENCY INCREASES, LET US CHOOSE A LOW RADIO BROADCAST FREQUENCY AND SEE WHAT IS GOING TO HAPPEN. WE SHALL ASSUME AN R.F. OF 550 KC. THE CAPACITIVE REACTANCE OF THIS .1 MFD CONDENSER TO A RADIO FREQUENCY OF 550 KC IS EXPRESSED BY THE FORMULA AS:

$$X_C = \frac{1}{6.28 \times 550{,}000 \times .0000001}$$

(NOTE THAT 550,000 CYCLES = 550 KC AND .0000001 FARAD = .1 MFD.) THIS FORMULA WORKS OUT AS $X_C = \frac{1}{.3454}$ OR THE CAPACITIVE REACTANCE OF THE .1 MFD CONDENSER AT 550 KC IS 2.89 OR APPROXIMATELY 3 OHMS.

THE BIAS RESISTOR OFFERS APPROXIMATELY 200 OHMS OF RESISTANCE IRRESPECTIVE OF THE FREQUENCY, AND SINCE WE FOUND THAT THE .1 MFD BYPASS CONDENSER ONLY HAS A CAPACITIVE REACTANCE OF APPROXIMATELY 3 OHMS AT 550 KC, IT IS OBVIOUS THAT CURRENTS OF THIS FREQUENCY WILL MOST NATURALLY PASS THROUGH THE CONDENSER IN PREFERENCE TO THE RESISTOR BECAUSE THE OPPOSITION OFFERED BY THE RESISTOR TO THESE CURRENTS IS NEARLY 70 TIMES AS GREAT AS THAT OFFERED BY THE CONDENSER.

AS THE FREQUENCY BEING HANDLED BECOMES GREATER, THE CAPACITIVE REACTANCE BECOMES LESS AT A RAPID RATE, SO THAT THE EFFECT OF THE BYPASS CONDENSER BECOMES STILL MORE PRONOUNCED. FOR EXAMPLE, AT 1500 KC THE REACTANCE OF THE BYPASS CONDENSER IN FIG. 5 BECOMES AS FOLLOWS:

$$X_C = \frac{1}{6.28 \times 1{,}500{,}000 \times .0000001}$$

OR X_C = 1.06 OR 1 OHM (APPROX.). IN OTHER WORDS, AT A FREQUENCY OF 1500 KC, THE BIAS RESISTOR OF-

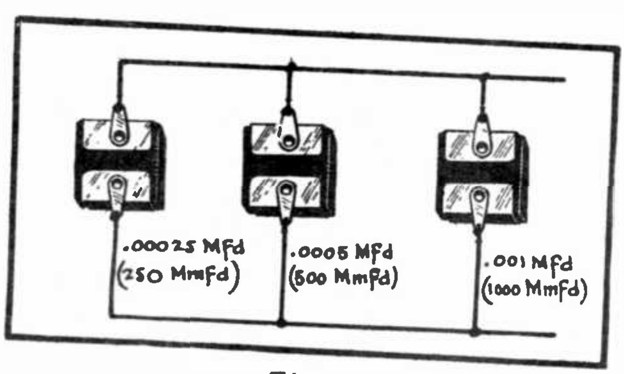

FIG. 7
Capacity Increased by Parallel Connection.

FERS ABOUT 200 TIMES AS MUCH OPPOSITION TO THESE HIGH FREQUENCIES AS DOES THE CONDENSER AND SO THESE CURRENTS HAVE A STILL GREATER TENDENCY TO PASS THROUGH THE CONDENSER IN PREFERANCE TO PASSING THROUGH THE 200 OHM RESISTOR.

THIS PRACTICAL PROBLEM IN ITSELF SHOWS YOU JUST EXACTLY WHAT A BY-PASS CONDENSER ACCOMPLISHES, THEREBY EMPHASIZING ITS IMPORTANCE STILL MORE.

ANOTHER FORMULA WHICH YOU CAN USE IN ORDER TO DETERMINE THE CAPACITIVE REACTANCE OF A GIVEN CONDENSER AT A SPECIFIED FREQUENCY IS AS FOLLOWS:

$$\text{CAPACITIVE REACTANCE IN OHMS} = \frac{159,155}{\text{FREQUENCY IN CYCLES} \times \text{CAPACITY IN MFD.}}$$

THIS FORMULA CHECKS CLOSELY WITH THE ONE GIVEN YOU PREVIOUSLY. FOR EXAMPLE, WHEN USED TO CALCULATE THE CAPACITIVE REACTANCE OF THE BY-PASS CONDENSER IN FIG. 5 AT 550 KC., THIS SECOND FORMULA WORKS OUT AS: $X_c = \frac{159,155}{550,000 \times .1} = 2.89$ OHMS OR APPROXIMATELY 3 OHMS, THE SAME AS OBTAINED FROM THE PREVIOUS COMPUTATION.

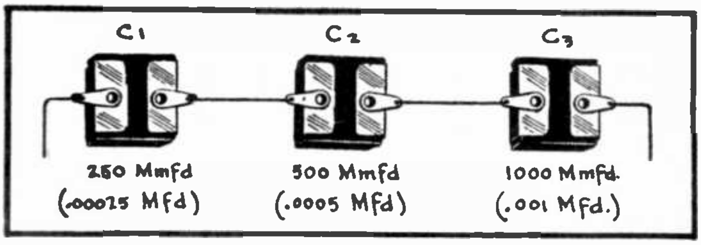

FIG. 8

Capacity Reduced by Series Connection.

THE PHASE RELATION IN CAPACITIVE CIRCUITS

NOW THAT YOU ARE FAMILIAR WITH CAPACITIVE REACTANCE, LET US NEXT INVESTIGATE THE MATTER OF THE PHASE RELATION IN AN ELECTRICAL CIRCUIT CONTAINING CAPACITY ONLY. IN THIS CASE, THE VOLTAGE AND CURRENT CURVES WOULD APPEAR AS ILLUSTRATED IN FIG. 6. NOTICE IN THIS GRAPH HOW DURING THIS ONE CYCLE, THE CURRENT REACHES ITS MAXIMUM OR PEAK VALUE 90° BEFORE THE VOLTAGE REACHES ITS PEAK VALUE. IN OTHER WORDS, IN A PURELY CAPACITIVE CIRCUIT, THE VOLTAGE AND CURRENT ARE 90° OUT OF PHASE BUT THE CURRENT LEADS THE VOLTAGE IN THIS CASE. THIS IS JUST THE REVERSE OF WHAT TAKES PLACE IN A PURE INDUCTIVE CIRCUIT.

WITH THIS POINT SETTLED, WE WILL PROCEED WITH THE MATTER CONCERNING SERIES AND PARALLEL CONDENSER CONNECTIONS, DISCUSSING THE PARALLEL ARRANGEMENT FIRST.

CONDENSERS CONNECTED IN PARALLEL

IN FIG. 7, YOU WILL SEE AN ILLUSTRATION WHERE THREE FIXED CONDENSERS OF DIFFERENT VALUES ARE CONNECTED IN PARALLEL. THESE CONDENSERS HAVE THE RESPECTIVE VALUES OF .00025 MFD. (250 MMFD.); .0005 MFD. (500 MMFD.) AND .001 MFD. (1000 MMFD.).

THE COMBINED CAPACITY OF A PARALLEL CAPACITY COMBINATION IS EQUAL TO THE SUM OF THE INDIVIDUAL CAPACITIES. THAT IS, IN THE CASE OF FIG. 7, THE COMBINED CAPACITY OF THE GROUP IS EQUAL TO 250+500+1000 MMFD. OR 1750 MMFD. IN TERMS OF MICROFARADS, THIS TOTAL CAPACITY WOULD AMOUNT TO .00025+.0005+.001 OR .00175 MFDS. NOTICE THAT THE COMBINED CAPACITY

INCREASES AS THE NUMBER OR VALUE OF THE PARALLEL CAPACITIES IS INCREASED.

NOW, IN FIG. 8, WE SEE THESE SAME THREE CONDENSERS CONNECTED IN SERIES. TO DETERMINE THE TOTAL CAPACITY OF THIS COMBINATION, WE USE THE FORMULA: $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$, WHERE C = THE TOTAL CAPACITY, AND C_1, C_2 AND C_3, THE VARIOUS INDIVIDUAL CAPACITIES. THUS, IN THE CASE OF FIG. 8, THE CAPACITY OF THE COMBINATION BECOMES:

$\frac{1}{C} = \frac{1}{250} + \frac{1}{500} + \frac{1}{1000}$ OR $\frac{1}{C} = \frac{4}{1000} + \frac{2}{1000} + \frac{1}{1000} = \frac{7}{1000}$. SINCE $\frac{1}{C} = \frac{7}{1000}$, WE ALSO HAVE 7C = 1000 OR C = 142.857 MMFD OR APPROXIMATELY 143 MMFD. IN TERMS OF MICROFARADS, THIS VALUE WOULD BE EQUIVALENT TO .000143 MFD.

FROM THE FOREGOING CALCULATIONS, YOU HAVE DEFINITE PROOF THAT AS CAPACITIES ARE CONNECTED IN SERIES, THE TOTAL CAPACITY BECOMES LESS. IT IS INTERESTING TO NOTE THAT WHEN DEALING WITH SERIES AND PARALLEL CAPACITIES, WE HAVE EXACTLY THE OPPOSITE EFFECT TO THAT WHEN DEALING WITH RESISTORS IN THESE SAME COMBINATIONS.

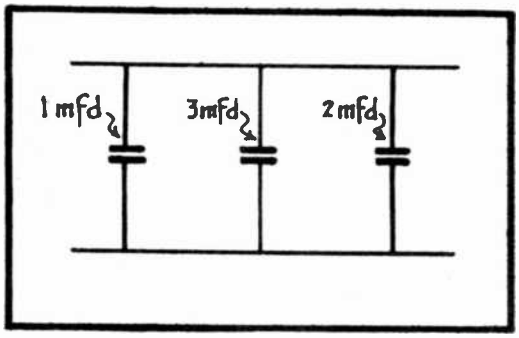

FIG. 9
Group of Parallel Connected Condensers.

CAPACITIVE REACTANCE IN PARALLEL CAPACITIVE CIRCUITS

FIRST, LET US LOOK AT FIG. 9. HERE WE HAVE THREE CONDENSERS CONNECTED IN PARALLEL AND THEIR VALUES ARE RESPECTIVELY, 1 MFD, 3 MFD, AND 2 MFD. FROM WHAT YOU LEARNED IN YOUR PREVIOUR LESSON, YOU WILL REALIZE IMMEDIATELY THAT THE CAPACITY OF THIS ENTIRE PARALLEL ARRANGEMENT BECOMES EQUAL TO 1 MFD + 3 MFD + 2 MFD, OR 6 MICROFARADS.

THE REACTANCE OF THIS EFFECTIVE 6-MFD CAPACITY TO A RADIO FREQUENCY OF 1600 KILOCYCLES CAN BE DETERMINED BY THE FORMULA:

$$X_C = \frac{159,155}{\text{FREQUENCY IN CYCLES} \times \text{CAPACITY IN MFD}} \text{ OR } X_C = \frac{159,155}{1,600,000 \times 6} = .016 \text{ OHM (APPROX.)}$$

YOU CAN GET THIS SAME RESULT BY FIRST DETERMINING THE CAPACITIVE REACTANCE OF EACH OF THE INDIVIDUAL CONDENSERS TOWARD THIS FREQUENCY. THESE SEPARATE REACTANCES CAN THEN BE ADDED TOGETHER BY RECIPROCALS THE SAME AS THOUGH THEY WERE PARALLELED RESISTORS, BUT THIS METHOD OF SOLVING THE PROBLEM IS MUCH MORE COMPLICATED THAN THE SIMPLER METHOD JUST GIVEN YOU.

THE MAIN THING TO REMEMBER IS THAT THE CAPACITIVE REACTANCE OF THE GROUP OF PARALLEL CONDENSERS IN FIG. 9 TO ANY GIVEN FREQUENCY IS LESS THAN THE REACTANCE OFFERED BY ANY ONE OF THE INDIVIDUAL CONDENSERS TO THIS SAME FREQUENCY.

CAPACITIVE REACTANCE WITH SERIES CAPACITIES

NOW, LET US PROCEED WITH THE CASE WHERE WE HAVE TO DEAL WITH THE CAPACITIVE REACTANCE OF A SERIES CONNECTED GROUP OF CONDENSERS. IN FIG. 10, FOR EXAMPLE, WE HAVE THREE CONDENSERS CONNECTED IN SERIES AND THEIR RESPECTIVE VALUES ARE AGAIN 1 MFD, 3 MFD, AND 2 MFD.

THE COMBINED CAPACITY OF THIS CIRCUIT WILL BE FOUND WITH THE AID OF THE FORMULA: $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$, OR

$\frac{1}{C} = \frac{1}{1} + \frac{1}{3} + \frac{1}{2}$ WHENCE $\frac{1}{C} = \frac{6}{6} + \frac{2}{6} + \frac{3}{6}$ OR $\frac{1}{C} = \frac{11}{6}$, OR C = .545 MFD. THUS, THE CAPACITIVE REACTANCE OF THIS SERIES COMBINATION TO 1600 KC WILL BE:

$$X_C = \frac{159,155}{1,600,000 \times .545} \text{ OR } X_C = \frac{159,155}{872,000} = .182 \text{ OHM.}$$

YOU COULD GET THE SAME RESULT BY DETERMINING THE CAPACITIVE REACTANCE FOR EACH OF THESE THREE CONDENSERS SEPARATELY AND THEN ADDING THE RESULTS TOGETHER SO AS TO FIND THE TOTAL REACTANCE OF THIS COMBINATION. BUT HERE AGAIN, THIS PROCESS WOULD BE LONGER THAN THE METHOD OF SOLVING THIS PROBLEM AS EXPLAINED ABOVE.

THE IMPORTANT THING TO REMEMBER ABOUT THIS TYPE OF CIRCUIT IS THAT THE CAPACITIVE REACTANCE BECOMES GREATER AS THE NUMBER OF SERIES CONNECTED CAPACITIES IS INCREASED.

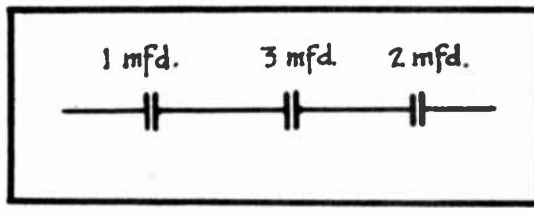

FIG. 10
Group of Series Connected Condensers.

IMPEDANCE

SO FAR, WE HAVE CONSIDERED CIRCUITS CONTAINING SOLELY CAPACITY OR INDUCTANCE. IN PRACTICE, HOWEVER, WE GENERALLY HAVE TO DEAL WITH A COMBINATION OF CAPACITY AND RESISTANCE, OF INDUCTANCE AND RESISTANCE OR EVEN WITH COMBINATIONS CONTAINING ALL THREE OF THESE CONDITIONS. THAT IS, INDUCTANCE, CAPACITY AND RESISTANCE.

TO BEGIN WITH, LET US LOOK AT FIG. 11, WHERE WE HAVE A COIL OR INDUCTANCE CONNECTED IN SERIES WITH A RESISTANCE. IN FACT, THIS RESISTANCE CAN EVEN BE CONSIDERED AS BEING THE OHMIC RESISTANCE OF THE WIRE MAKING UP THE COIL, FOR IT IS IMPOSSIBLE TO CONSTRUCT A COIL WHICH HAS INDUCTANCE ONLY WITHOUT ANY RESISTANCE.

IN THIS ILLUSTRATION, WE WILL HAVE TO CONSIDER THE OPPOSITION OFFERED TO THE CURRENT FLOW BY BOTH THE INDUCTANCE AND THE RESISTANCE, AND THE COMBINED EFFECT OF ALL THE REACTANCE AND ALL OF THE RESISTANCE IN A CIRCUIT IS CALLED THE IMPEDANCE, AND THE IMPEDANCE IS REPRESENTED BY THE LETTER "Z". IN ORDER TO DETERMINE THE TOTAL OPPOSITION OR THE IMPEDANCE OF THE CIRCUIT IN FIG. 11 TOWARD THE 60-CYCLE A.C. CURRENT, WE USE THE FORMULA: $Z = \sqrt{R^2 + X_L^2}$. THAT IS, THE IMPEDANCE IS EQUAL TO THE SQUARE ROOT OF THE RESISTANCE SQUARED, PLUS THE INDUCTIVE REACTANCE OF THE COIL AT 60 CYCLES SQUARED.

IN OTHER WORDS, THE INDUCTIVE REACTANCE OF THIS COIL TO A 60-CYCLE CURRENT WILL BE: $X_L = 2\pi fL$ OR $X_L = 6.28 \times 60 \times 15 = 5652$ OHMS. THE IMPEDANCE WILL THEN BE: $Z = \sqrt{2000^2 + 5652^2} = \sqrt{4,000,000 + 31,945,104} = \sqrt{35,945,104} = 5995$, OR APPROXIMATELY 6000 OHMS.

THE IMPEDANCE TRIANGLE FOR INDUCTANCE AND RESISTANCE

IMPEDANCE PROBLEMS INVOLVING INDUCTANCE AND RESISTANCE CAN ALSO BE

WORKED OUT BY MEANS OF THE IMPEDANCE TRIANGLE. THIS IS A VERY SIMPLE METHOD AS YOU SHALL PRESENTLY SEE. IN FIG. 12, FOR EXAMPLE, WE HAVE A RESISTANCE-INDUCTANCE COMBINATION IN WHICH THE RESISTANCE HAS A VALUE OF 10 OHMS AND THE INDUCTANCE AT THE FREQUENCY BEING HANDLED HAS A REACTANCE OF 12 OHMS.

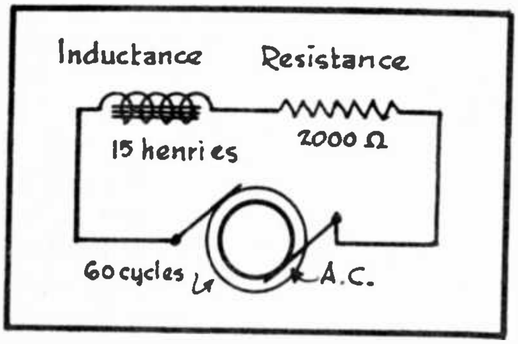

FIG. 11
Circuit With Inductance and Resistance.

TO FIND THE IMPEDANCE OF THIS CIRCUIT BY MEANS OF THE IMPEDANCE TRIANGLE, PROCEED AS ILLUSTRATED IN FIG. 13. THAT IS, FIRST DRAW A HORIZONTAL LINE. THIS LINE REPRESENTS RESISTANCE AND SINCE THE VALUE OF THE RESISTANCE IN OUR PRESENT PROBLEM IS 10 OHMS, DRAW THIS LINE 10 UNITS LONG. THE UNIT USED IS A MATTER OF CHOICE AND MAY BE 1/8", 1/4", 1/2", 1" OR ANY OTHER SUITABLE UNIT. IN THE CASE OF FIG. 13, 1/8" WAS CHOSEN AS THE UNIT AND CONSEQUENTLY THE RESISTANCE LINE IS 10/8" OR 1 1/4" LONG. THIS FORMS THE BASE FOR THE IMPEDANCE TRIANGLE. THE NEXT STEP IS TO DRAW THE INDUCTIVE REACTANCE LINE. THIS IS A VERTICAL LINE DRAWN AT RIGHT ANGLES TO THE END OF THE RESISTANCE LINE AND SINCE THE INDUCTIVE REACTANCE IN OUR PRESENT PROBLEM IS 12 OHMS, THIS LINE SHOULD BE DRAWN 12 UNITS LONG. (THE SAME UNIT MUST BE USED AS THAT USED FOR THE RESISTANCE LINE.)

THIS DONE, THE NEXT STEP IS TO CONNECT TOGETHER THE ENDS OF THESE TWO LINES BY A THIRD LINE WHICH IS DESIGNATED AS THE IMPEDANCE LINE IN FIG. 13. NOW MEASURE THIS LINE AND SEE HOW MANY UNITS IT CONTAINS AND THE RESULT WILL BE THE IMPEDANCE OF THE CIRCUIT IN OHMS. IN THE CASE OF THE PROBLEM GIVEN IN FIG. 12, THE IMPEDANCE LINE IN FIG. 13 WILL BE FOUND TO BE APPROXIMATELY $15\frac{1}{2}$ UNITS LONG. HENCE THE IMPEDANCE OF THIS CIRCUIT TO THE FREQUENCY BEING CONSIDERED IS ABOUT $15\frac{1}{2}$ OHMS.

IT IS INTERESTING TO NOTE HOW CLOSE IMPEDANCE VALUES AS DETERMINED BY THE IMPEDANCE TRIANGLE METHOD APPROACH THE CALCULATED IMPEDANCE VALUE. FOR EXAMPLE, SINCE $Z=\sqrt{R^2+X_L^2}$, WE FIND THAT BY SUBSTITUTING INTO IT THE RESISTANCE AND INDUCTIVE REACTANCE VALUES GIVEN IN FIG. 12, WE HAVE $Z=\sqrt{10^2+12^2}=\sqrt{100+144}=\sqrt{244}=15.62$ OHMS.

AS YOU WILL NOTICE THIS VALUE IS NOT SO VERY FAR OFF FROM THE MORE APPROXIMATE METHOD AS EMPLOYED IN FIG. 13.

IMPEDANCE OFFERED BY A RESISTANCE-CAPACITY COMBINATION

NOW LET US CONSIDER A CIRCUIT CONTAINING CAPACITY AND RESISTANCE. THIS IS ILLUSTRATED FOR YOU IN FIG. 14 AND THE VALUES ARE 20 OHMS FOR THE RESISTOR AND 1 MFD. FOR THE CONDENSER. OUR PROBLEM IS TO FIND THE TOTAL OPPOSITION OR IMPEDANCE OFFERED BY THIS CIRCUIT TO A CURRENT AT 600 CYCLES. IN THIS CASE, WE USE THE FORM

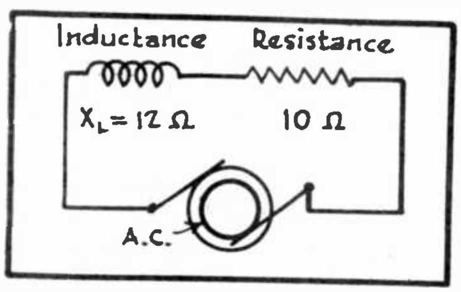

FIG. 12
Another Impedance Problem.

ULA $Z = \sqrt{R^2 + X_C^2}$. THAT IS, THE IMPEDANCE IS EQUAL TO THE SQUARE ROOT OF THE RESISTANCE SQUARED, PLUS THE CAPACITIVE REACTANCE SQUARED.

THE CAPACITIVE REACTANCE OF THE 1 MFD CONDENSER TO THE 600-CYCLE CURRENT AS DETERMINED BY THE FORMULA:

$$X_C = \frac{159{,}155}{\text{FREQ. IN CYCLES} \times \text{CAPACITY IN MFD}}$$

IS $X_C = \frac{159{,}155}{600 \times 1} = \frac{159{,}155}{600} = 265.26$ OHMS

THE IMPEDANCE WILL THUS BE EQUAL TO $\sqrt{20^2 + 265.26^2} = \sqrt{70{,}762.8}$, OR APPROXIMATELY 266 OHMS.

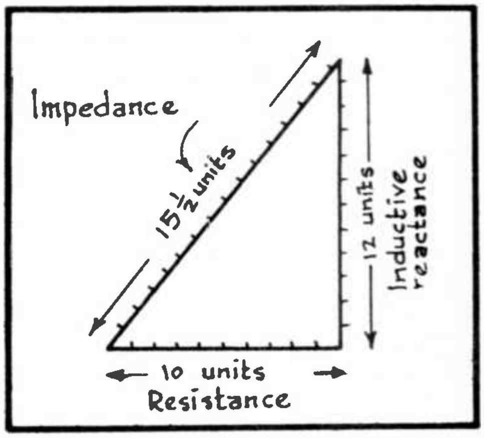

FIG. 13
Impedance Triangle for Inductance and Resistance.

IT IS ALSO POSSIBLE TO WORK OUT IMPEDANCE PROBLEMS INVOLVING RESISTANCE AND CAPACITIVE REACTANCE BY MEANS OF THE IMPEDANCE TRIANGLE. FOR EXAMPLE, AT THE TOP OF FIG. 15, WE HAVE AN A.C. CIRCUIT CONTAINING A 15-OHM RESISTANCE AND THE REACTANCE OF THE CONDENSER AT THE FREQUENCY BEING HANDLED IS 6 OHMS.

IN THE LOWER PORTION OF FIG. 15, WE ARE REPRESENTING THE RELATION BETWEEN THIS RESISTANCE AND CAPACITIVE REACTANCE IN THE FORM OF THE IMPEDANCE TRIANGLE. SUCH A TRIANGLE IS ALSO FREQUENTLY SPOKEN OF AS THE VECTOR RELATION OF RESISTANCE AND CAPACITIVE REACTANCE.

NOTE IN FIG. 15 THAT THE HORIZONTAL RESISTANCE LINE OF THE TRIANGLE IS DRAWN 15 UNITS LONG, SO AS TO REPRESENT 15 OHMS. THE CAPACITIVE REACTANCE LINE IS 6 UNITS LONG SO AS TO REPRESENT 6 OHMS OF CAPACITIVE REACTANCE, BUT THIS LINE EXTENDS DOWNWARD AT RIGHT ANGLES TO THE EXTREMITY OF THE RESISTANCE LINE, OR IN A DIRECTION OPPOSITE TO THAT OF THE INDUCTIVE REACTANCE LINE WHICH WAS SHOWN YOU IN A PREVIOUS PROBLEM.

THE TWO EXTREMITIES OF THE RESISTANCE AND CAPACITIVE REACTANCE LINES ARE THEN CONNECTED TOGETHER BY THE THIRD LINE OF THE TRIANGLE AND, UPON MEASUREMENT WITH A RULE, IT WILL BE FOUND THAT THIS LINE IS 16 UNITS LONG. HENCE, THE IMPEDANCE OF THIS CIRCUIT IS 16 OHMS.

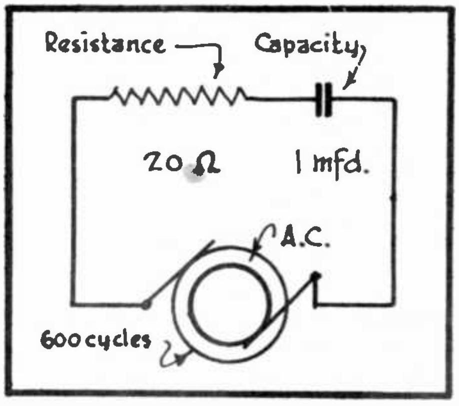

FIG. 14
Circuit With Capacity and Resistance.

PROBLEMS INVOLVING RESISTANCE, CAPACITY, AND INDUCTANCE

NOW, LET US CONSIDER THE CASE WHERE WE HAVE A CIRCUIT CONTAINING RESISTANCE, INDUCTANCE AND CAPACITY. HERE THE IMPEDANCE WILL BE EXPRESSED BY THE FORMULA $Z = \sqrt{R^2 + X^2}$, IN WHICH "X" IS THE NET REACTANCE OR THE ARITHMETICAL DIFFERENCE BETWEEN THE INDUCTIVE REACTANCE AND THE CAPACITIVE REACTANCE.

TO ILLUSTRATE THIS IMPORTANT POINT, LET US LOOK AT FIG. 16, WHERE WE HAVE A CIRCUIT IN WHICH A 10-HENRY CHOKE IS CONNECTED

IN SERIES WITH A 50 MFD. CONDENSER. THE WIRE OF THIS SAME CHOKE IS OF SUCH CROSS-SECTION AND LENGTH AS TO OFFER A RESISTANCE OF 5 OHMS. THIS 5 OHMS OF RESISTANCE CAN BE CONSIDERED AS A RESISTANCE INSERTED IN SERIES WITH THE CIRCUIT AS HERE PICTURED.

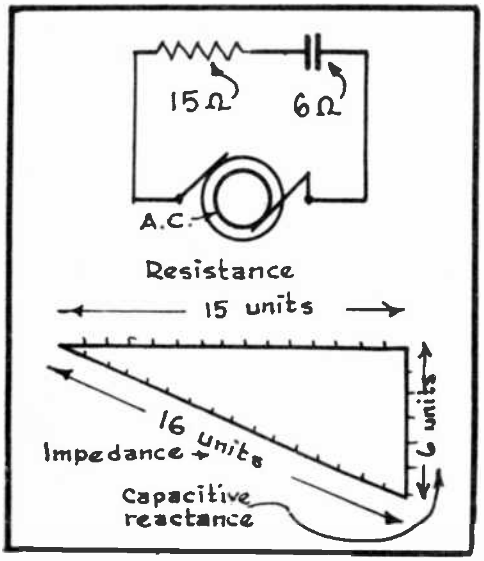

FIG. 15
Impedance Triangle for Resistance and Capacity.

OUR FIRST STEP IN DETERMINING THE IMPEDANCE OF THIS CIRCUIT TO A 1000 CYCLE CURRENT IS TO FIRST CALCULATE THE INDUCTIVE AND CAPACITIVE REACTANCE TO THIS FREQUENCY. TO FIND THE INDUCTIVE REACTANCE, USE THE FORMULA $X_L = 2\pi f L$ WHENCE $X_L = 6.28 \times 1000 \times 10 = 62,800$ OHMS.

THE CAPACITIVE REACTANCE OF THE 50 MFD. CONDENSER TOWARD THE 1000 CYCLE CURRENT WILL BE FOUND WITH THE FORMULA $X_c = \frac{1}{2\pi f C} = \frac{1}{6.28 \times 1000 \times .00005} = \frac{1}{.314} = 3.2$ OHMS.

THE NET OR EFFECTIVE REACTANCE OF THE CIRCUIT THENCE BECOMES 62,800-3.2 OR 62796.8 OHMS. THE IMPEDANCE FORMULA WILL THEN BE EXPRESSED AS $Z = \sqrt{R^2 + X^2}$ OR $Z = \sqrt{5^2 + 62796.8^2}$ OR Z = 62796 OHMS.

IN THIS PARTICULAR PROBLEM, WE SUBTRACTED THE CAPACITIVE REACTANCE FROM THE INDUCTIVE REACTANCE IN ORDER TO DETERMINE THE NET REACTANCE. HOWEVER, IN SUCH CASES WHERE THE CAPACITIVE REACTANCE IS GREATER THAN THE INDUCTIVE REACTANCE, THEN THE INDUCTIVE REACTANCE IS SUBTRACTED FROM THE CAPACITIVE REACTANCE IN ORDER TO DETERMINE THE NET REACTANCE. THE REST OF THE CALCULATIONS, HOWEVER, WOULD BE CARRIED OUT IN THE SAME MANNER AS ALREADY SHOWN YOU.

IN THIS PROBLEM, A VERY INTERESTING CONDITION OCCURS AND THAT IS THAT THE IMPEDANCE OF THE CIRCUIT UNDER CONSIDERATION IS PRACTICALLY EQUAL TO THAT OF THE INDUCTIVE REACTANCE ALONE. THE REASON FOR THIS IS THAT THE INDUCTIVE REACTANCE IS SO VERY LARGE IN RELATION TO THE PURE RESISTANCE AND CAPACITIVE REACTANCE THAT THE CIRCUIT AS A WHOLE ACTUALLY ASSUMES THE CHARACTERISTICS OF A PURE INDUCTIVE CIRCUIT.

IN PRACTICE, WHERE SUCH CONDITION OCCUR THAT THE INDUCTIVE REACTANCE IS SO VERY LARGE IN RESPECT TO THE PURE RESISTANCE, ONE GENERALLY ASSUMES THE NET REACTANCE AS OFFERING THE TOTAL OPPOSITION TO CURRENT FLOW AND THE PURE RESISTANCE IS CONSIDERED AS NEGLIGIBLE.

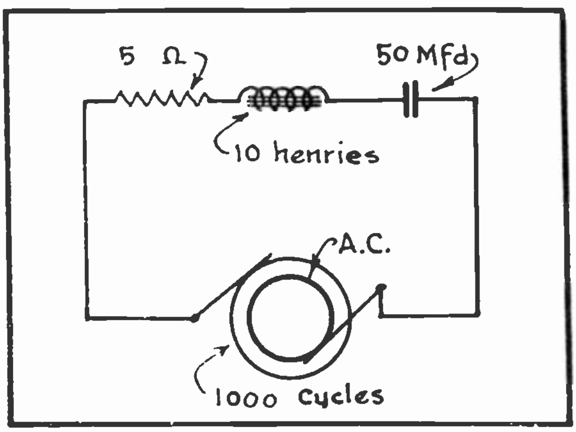

FIG. 16
A Circuit With Resistance, Inductance and Capacity.

REMEMBER, HOWEVER, THAT WHEN AN APPRECIABLE PURE RESISTANCE IS PRESENT IN THE CIRCUIT, IT WILL AFFECT THE IMPEDANCE OF SUCH A CIRCUIT MATERIALLY AND MUST THEREFORE, BE ACCOUNTED FOR IN THE FORMULA FOR THE CALCULATION OF THE CIRCUIT'S TOTAL IMPEDANCE.

SIMILAR CONDITIONS AS THIS ALSO ARISE WHEN THE CAPACITIVE REACTANCE OF A CIRCUIT IS VERY LARGE IN PROPORTION TO ITS PURE RESISTANCE. IN THIS CASE, THE IMPEDANCE OF THE CIRCUIT WILL ASSUME THE CHARACTERISTICS OF A PURE CAPACITIVE CIRCUIT AND THE PURE RESISTANCE CAN BE CONSIDERED AS NEGLIGIBLE.

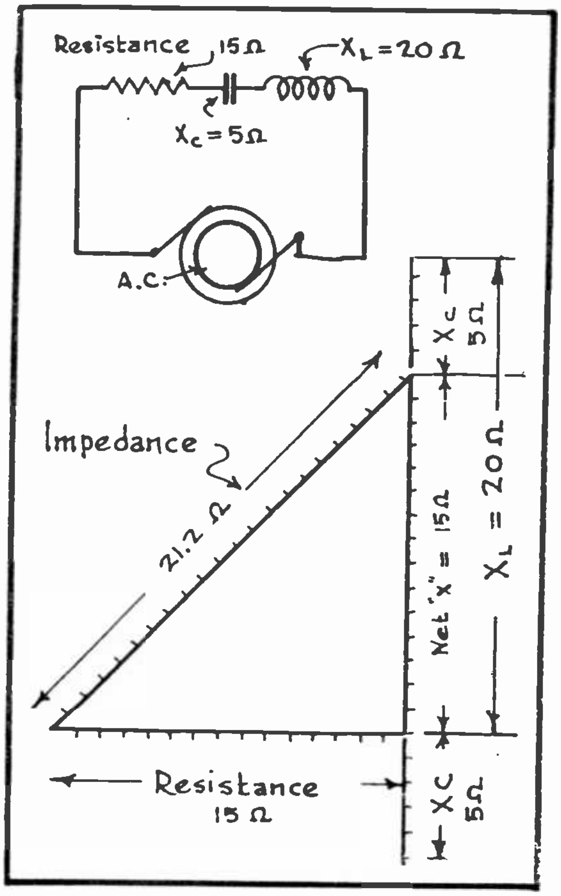

FIG. 17
Vector Relation of Resistance, Capacitive Reactance and Inductive Reactance.

PROBLEMS OF THIS NATURE CAN ALSO BE REPRESENTED BY A VECTOR DIAGRAM AND SOLVED THEREBY. FOR EXAMPLE, IN FIG. 17, YOU WILL SEE A CIRCUIT COMPOSED OF INDUCTANCE, CAPACITY AND RESISTANCE. THE VECTOR RELATION FOR THIS PROBLEM IS ALSO SHOWN IN FIG. 17.

IN THIS PARTICULAR CASE, THE RESISTANCE HAS A VALUE OF 15 OHMS, AND THE INDUCTIVE REACTANCE IS 20 OHMS. OBSERVE IN THE LOWER PORTION OF FIG. 17 THAT THE HORIZONTAL RESISTANCE LINE IS DRAWN 15 UNITS LONG. THE VERTICAL OR INDUCTIVE REACTANCE LINE EXTENDS UPWARD FROM THE RESISTANCE LINE FOR 20 UNITS, THEREBY REPRESENTING THE VALUE OF 20 OHMS.

THE CAPACITIVE REACTANCE LINE, WHICH REPRESENTS 5 OHMS, IS DRAWN STRAIGHT DOWNWARDS FROM THE RESISTANCE LINE FOR A DISTANCE OF 5 UNITS. UPON SUBTRACTING THE X_C–5 OHM LINE FROM THE 20 OHM INDUCTIVE REACTANCE LINE, WE HAVE LEFT THE NET REACTANCE LINE WHICH IS ONLY 15 UNITS LONG. THIS REPRESENTS A NET REACTANCE OF 15 OHMS.

NOW BY CONNECTING TOGETHER THE END OF THE RESISTANCE LINE WITH THE 15TH MARK OF THE NET REACTANCE LINE, WE OBTAIN THE IMPEDANCE. UPON MEASUREMENT WITH A RULE, THIS IMPEDANCE LINE WILL BE FOUND TO BE 21.2 UNITS LONG, THUS SHOWING THAT THE IMPEDANCE FOR THIS CIRCUIT IS APPROXIMATELY 21 OHMS.

YOU ARE GRADUALLY DEVELOPING A GOOD UNDERSTANDING OF A.C. CIRCUITS AND IN THE FOLLOWING LESSON, YOU ARE GOING TO EXPAND THIS KNOWLEDGE STILL MORE BY LEARNING THE MATHEMATICAL LAWS WHICH GOVERN RESONANT CIRCUITS AND MANY OTHER INTERESTING FEATURES OF IMPORTANCE.

EXAMINATION QUESTIONS

LESSON NO. 40

"When a man really finds himself at the top of the ladder of success, he is never alone. No man can climb to genuine success without taking others along with him."

1. – Explain the phase relation which exists between the voltage and current in a pure inductive circuit.

2. – Explain the phase relation which exists between the voltage and current in a pure capacitive circuit.

3. – If inductances of 30, 25 and 15 henries respectively are all connected in series, what will be the total inductance of this combination?

4. – If inductances of 100; 200 and 50 microhenries respectively are all connected in parallel, what will be the total inductance of this combination?

5. – What capacitive reactance will a condenser of .25 mfd. offer towards an R.F. signal current of 600 Kc.?

6. – If three condensers having a capacity rating of 2; 4 and 8 mfd. respectively are all connected in parallel, what reactance will this combination offer towards a 60 cycle current?

7. – Explain what is meant by the term IMPEDANCE?

8. – If an inductance of 15 henries is connected in series with a resistance of 2000 ohms, what impedance will this circuit offer towards a 120 cycle current?

9. – If a condenser of 10 mfd. capacity rating is connected in series with a resistance of 500 ohms and an inductance of 20 henries, what impedance will this circuit offer towards a 50-cycle current?

10. – Illustrate how the impedance may be determined by means of the "impedance triangle" if the D.C. resistance of a certain circuit is 10 ohms and its inductive reactance 15 ohms.

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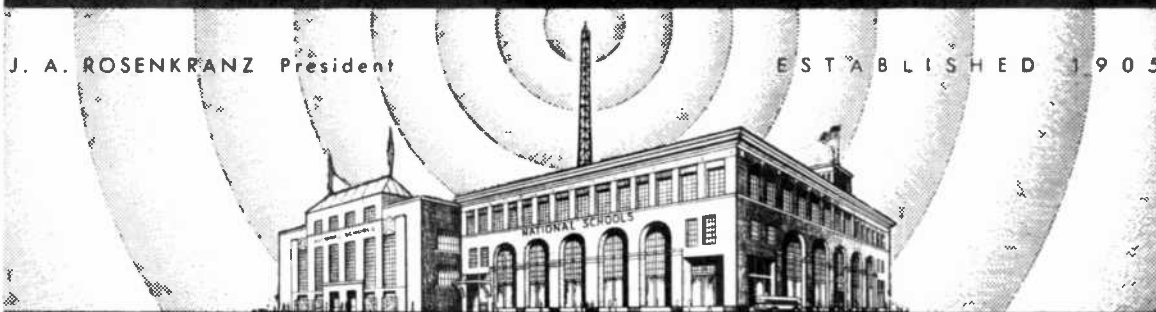

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LESSON NO. 41

OHM'S LAW FOR A.C. CIRCUITS
RESONANCE

In this lesson, we are going to continue our discussion on A.C. circuits by studying, first, the relation between partial voltages and the combined voltage of circuits involving impedance. In Fig. 1, for example, we have a circuit containing three resistors which are connected in series in an A. C. circuit. The ammeter indicates a current flow of 6 amperes, which reading represents the effective current flow in the circuit.

Since this same 6 amperes must flow through all of these resistors, we find, according to Ohm's Law, that the voltage drop across the 4-ohm resistor is equal to 4 X 6 or 24 volts (E = I X R). The drop across the 9-ohm resistor is 6 X 9 or 54 volts, and the drop across the 6-ohm resistor is 6 X 6 or 36 volts. The total voltage, which is impressed across the entire group of resistors, thus equals 24 + 54 + 36 or 114 volts. These are the effective voltage values of the A. C. circuit.

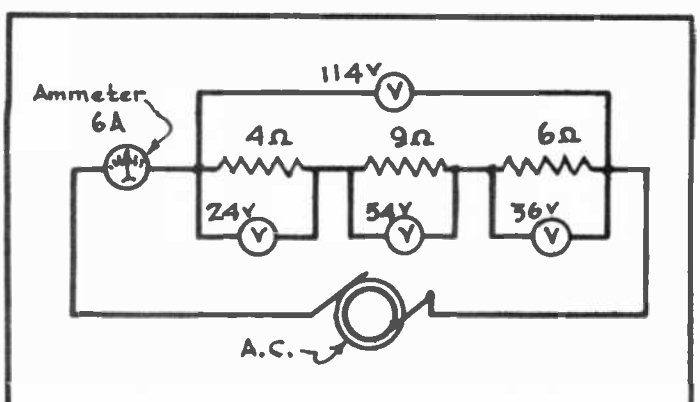


Fig. 1
Voltage Distribution in a Pure Resistance Circuit

With this point well in mind, let us next consider Fig. 2. Here, we have another A. C. circuit; but this time a resistor, a condenser and an inductance are connected in series. Keep this circuit firmly fixed in your mind, as what you are now going to be told about it is very important.

Ohm's Law can be applied just as well to condensers and inductances as it can to resistors, only that in the case of conden-

SERS AND INDUCTANCES THE REACTANCE TAKES THE PLACE OF THE RESISTANCE. WE THUS FIND IN FIG. 2 THAT THE VOLT-DROP ACROSS THE 4 OHM RESISTOR IS EQUAL TO 4 X 6 OR 24 VOLTS. THE VOLT DROP ACROSS THE CONDENSER WILL BE EQUAL TO THE CURRENT IN AMPERES TIMES THE CAPACITIVE REACTANCE OF THIS CONDENSER AT THE FREQUENCY BEING HANDLED. IN OTHER WORDS, THE VOLTAGE DROP ACROSS THIS CONDENSER WILL BE 9 X 6 OR 54 VOLTS. THEN IN LIKE MANNER, THE VOLTAGE DROP ACROSS THE INDUCTANCE WILL BE EQUAL TO THE CURRENT TIMES THE INDUCTIVE REACTANCE OF THIS COIL AT THE FREQUENCY OF THE EXISTING CURRENT FLOW. THAT IS, THE VOLTAGE DROP ACROSS THIS INDUCTANCE IS 6 X 6 OR 36 VOLTS.

NOW THEN, HERE IS THE MOST IMPORTANT THING FOR YOU TO REMEMBER. THE VOLTAGE ACROSS THIS ENTIRE SERIES GROUP OF FIG. 2 WILL NOT BE 24+54+36 OR 114 VOLTS BECAUSE IN THE CASE OF FIG. 2, WE HAVE IMPEDANCE TO CONSIDER. THE IMPEDANCE OF THIS CIRCUIT OF FIG.2 IS NOT 4+9+6 OR 19 OHMS AS IN THE CASE OF A PURE RESISTANCE CIRCUIT. BUT TO FIND THE IMPEDANCE OF THE CIRCUIT IN FIG. 2, WE MUST USE THE FORMULA $Z=\sqrt{R^2+X^2}$ WHERE R = THE 4 OHMS OF RESISTANCE AND "X" THE NET REACTANCE OF THE CIRCUIT. IN THE CASE OF FIG.2, THE NET REACTANCE OF THE CIRCUIT IS 9 -6 OR 3 OHMS. THAT IS, THE CAPACITIVE REACTANCE MINUS THE INDUCTIVE REACTANCE. THE IMPEDANCE WOULD THUS BECOME EQUAL TO $\sqrt{4^2+3^2}=\sqrt{16+9}=\sqrt{25}$ OR 5 OHMS.

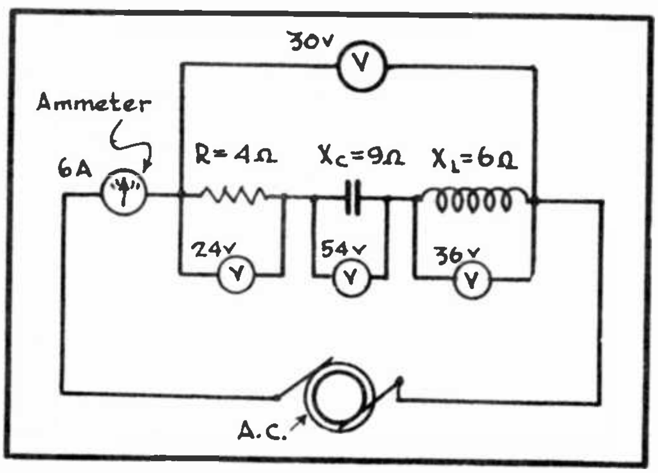


FIG. 2
Voltage Distribution in a Combination Circuit.

IT THUS FOLLOWS THAT THE EFFECTIVE VOLT DROP ACROSS THE SERIES COMBINATION IN FIG. 2 IS EQUAL TO THE CURRENT FLOW TIMES THE IMPEDANCE OR 6 X 5 = 30 VOLTS. SO YOU SEE, THIS VOLT DROP IS LESS THAN ONE MIGHT SUPPOSE UPON FIRST THOUGHT.

OHM'S LAW FOR A.C. CIRCUITS

REMEMBER NOW THAT THE OHM'S LAW RELATION ALSO HOLDS GOOD IN A.C. CIRCUITS JUST AS MUCH AS IT DOES IN THE D.C. CIRCUITS, ONLY THAT IN THE CASE OF A.C., EFFECTIVE VOLTS = EFFECTIVE CURRENT X IMPEDANCE. IMPEDANCE = $\frac{\text{EFFECTIVE VOLTS}}{\text{EFFECTIVE CURRENT}}$ OR EFFECTIVE CURRENT = $\frac{\text{EFFECTIVE VOLTS}}{\text{IMPEDANCE}}$.

IN ALL CASES, THE EFFECTIVE VALUES, ARE THOSE AS INDICATED BY AN A.C. TYPE METER AND OF COURSE THE EFFECTIVE CURRENT MUST BE EXPRESSED IN AMPERES AND NOT IN MILLIAMPERES ETC.

TO BE SURE THAT YOU UNDERSTAND THE APPLICATION OF OHM'S LAW TO A.C. CIRCUITS, LET US WORK OUT A FEW SIMPLE PRACTICAL PROBLEMS. LET US ASSUME, FOR EXAMPLE, THAT WE HAVE A 30 HENRY CHOKE, CONNECTED IN SERIES WITH A 1000 OHM RESISTOR. HOW MUCH VOLTAGE WOULD BE REQUIRED TO FORCE 10 MILLIAMPERES THROUGH THIS CIRCUIT?

To figure this problem, we could picture it as shown you in Fig. 3. The inductive reactance of this choke to the 120 cycle current is found with the formula $X_L = 6.28 f L = 6.28 \times 120 \times 30 = 22{,}608$ ohms. The impedance of this circuit to 120 cycles is found with the formula as follows: $Z = \sqrt{R^2 + X_L^2} = \sqrt{1000^2 + 22608^2} = \sqrt{512{,}121{,}664} = 22630$ ohms. Then according to Ohm's Law, the effective voltage required to force 10 milliamperes through the impedance of 22630 ohms, will be obtained by multiplying the impedance by the effective current. Hence $22630 \times .010 = 226.3$ volts, which is the effective voltage required.

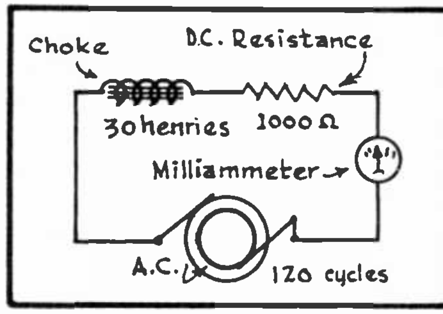


FIG. 3
Figuring Voltage.

For this same circuit of Fig. 3, if the impedance is known to be 22630 ohms and 300 volts is applied across the circuit, then the current which will flow can be calculated by dividing the effective volts (300) by the impedance. Hence $\frac{300}{22630} = .013$ amperes or 13 milliamperes.

Then again, in the case of Fig. 3, if the effective voltage applied across the ends of the circuit is known to be 200 volts and the milliammeter registers a current flow of 15 milliamperes, then the impedance of the circuit can be found by dividing the voltmeter reading by the milliammeter reading. That is, the impedance $= \frac{200}{.015} = 13333$ ohms.

You would handle any other circuit in like manner whether it be made up of a capacity and resistance, capacity and inductance or all three of these characteristics. In all cases, you must consider the impedance of the circuit when applying Ohm's Law to the combined circuit.

RESONANCE

You have already been made familiar with the condition of resonance in receiver circuits. At this time, however, you are going to obtain a still better understanding of this important radio principle.

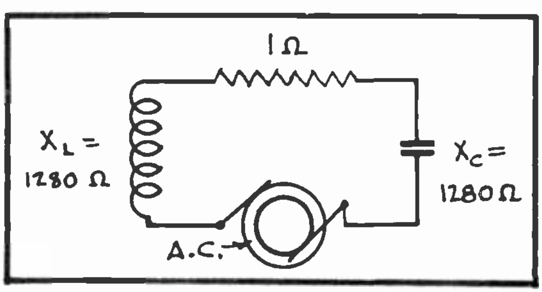


FIG. 4
Series Resonance.

A little earlier in this lesson, you were told that the impedance of a circuit containing resistance, inductance and capacity could be calculated with the formula as follows: $Z = \sqrt{R^2 + X^2}$, in which "X" is the net reactance of the circuit or the arithmetical difference between the capacitive reactance and inductive reactance of the circuit. Consequently, this same formula could be written as $Z = \sqrt{R^2 + (X_C - X_L)^2}$. Now by looking at this latter formula, its is perfectly obvious that if the circuit conditions are such that the inductive reactance at some given frequency is EXACTLY EQUAL to the capacitive reactance at this same frequency. Then the arithmetical difference between them or the net reactance, in other words, would be equal to zero (0).

This being the case, it is clear that the impedance of the circuit under these conditions would be equal to its D.C. resistance. This would be the least possible opposition, which a circuit could offer an A.C. current flow and this is the condition of RESONANCE. That is to say, at resonance, the total opposition to the current flow is simply equal to the circuit's D.C. resistance, or ohmic resistance, and therefore, the MAXIMUM CURRENT can flow through it.

So that you will gain a still clearer understanding of the resonance condition, let us look carefully at Fig. 4. Here we have a coil and condenser connected in series across an A.C. source of E.M.F. and we shall consider this circuit as having a resistance of 1 ohm, which we have pictured separately in Fig. 4. Now then, note carefully that the inductive reactance of the coil toward the frequency being handled is 1280 ohms and the condenser offers a capacitive reactance of 1280 ohms. The impedance of the circuit at this time is $Z = \sqrt{R^2 + (X_C - X_L)^2} = \sqrt{R^2 + (0)^2} = \sqrt{R^2} = \sqrt{1^2} = 1$ ohm. Thus you will see that at resonance, the only opposition offered the current flow is the ohmic resistance of the circuit. Naturally, this circuit is now equivalent to a pure resistance circuit and therefore, there will be no phase difference between the voltage and current which are present in the circuit at this time.

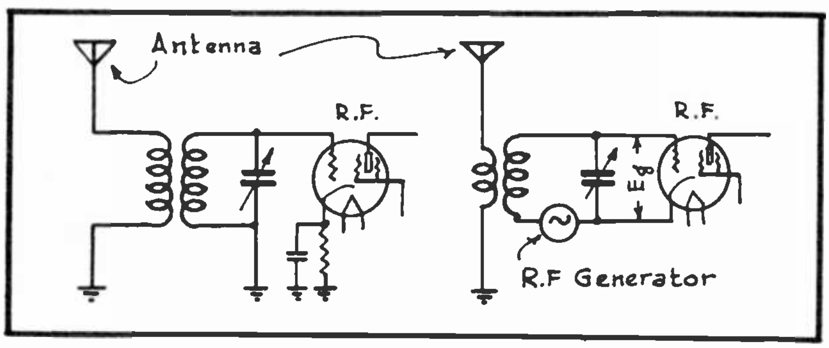


FIG. 5

Example of a Series Resonance Circuit.

Should the frequency of the current flow through this circuit remain constant, then you would find that if either the inductive or capacitive values should be changed, then these opposite reactances would no longer neutralize eachother to give a net reactance value of zero and therefore, the circuit would no longer be resonant to the given frequency. This, of course, is the whole principle of tuning, for in radio receivers, we generally vary the capacity of the tuning condenser and whenever this condenser is adjusted to the position where its capacity causes its capacitive reactance to be equal to the inductive reactance of the coil for a given frequency, then the circuit will be tuned or resonant to that same frequency.

CALCULATING THE RESONANT FREQUENCY

The thing which you have no doubt been wondering about for sometime is to what frequency a given condenser and inductance combination will resonate. This problem is quite simple, however, because a handy formula again comes to our assistance. This formula is as follows: $f = \frac{1}{2\pi\sqrt{LC}}$ where:

f = frequency in cycles per second at resonance
π = the constant 3.1416
L = Inductance in henries at resonance
C = capacity in farads at resonance.

IN CASE THE PROBLEM, WHICH YOU ARE SOLVING, HAS THE INDUCTANCE EXPRESSED IN MICHROHENRIES AND THE CAPACITY IN MICROFARADS, THEN YOU CAN USE THE FOLLOWING FORMULA: $f = \frac{159{,}000}{\sqrt{LC}}$ WHERE:

f = FREQUENCY IN CYCLES PER SECOND AT RESONANCE
L = INDUCTANCE IN MICROHENRIES AT RESONANCE
C = CAPACITY IN MICROFARADS AT RESONANCE

TO ILLUSTRATE THE USE OF THIS LATTER FORMULA, LET US SUPPOSE THAT WE WISH TO KNOW TO WHAT FREQUENCY A CAPACITY OF .00035 MFD. AND A 300 MICROHENRY INDUCTANCE WILL RESONATE.

THE FORMULA IS: $f = \frac{159{,}000}{\sqrt{LC}}$ AND SUBSTITUTING OUR VALUES INTO THIS FORMULA, WE HAVE $f = \frac{159{,}000}{\sqrt{300 \times .00035}}$ WHENCE $f = \frac{159{,}000}{.324} = 490{,}740$ CYCLES, OR 490.74 KC.

NOW LET US SEE HOW THE FORMULA $f = \frac{1}{2\pi\sqrt{LC}}$ CAN BE USED. TO ILLUSTRATE THIS, LET US SUPPOSE THAT A 30 HENRY CHOKE COIL IS CONNECTED IN SERIES WITH A 2 MFD. CONDENSER SO AS TO FORM A RESONANT CIRCUIT. IN THIS CASE, THE VALUE 2 MFD. WILL HAVE TO BE CHANGED TO FARADS, THUS BECOMING .000002 FARADS. WE THEN HAVE $f = \frac{1}{6.28\sqrt{30 \times .000002}}$ WHENCE $f = \frac{1}{6.28 \times .0077} = 20.6$ CYCLES.

IN DESIGN WORK, YOU WILL FIND THESE CALCULATIONS TO BE STILL SIMPLER BECAUSE VARIOUS TABLES ARE AVAILABLE SO AS TO REDUCE THE AMOUNT OF REQUIRED COMPUTATION. YOU WILL FIND THESE HANDY TABLES IN FOLLOWING LESSONS.

A SERIES RESONANT CIRCUIT

FIG. 5 SHOWS YOU A PRACTICAL EXAMPLE OF A SERIES RESONANT CIRCUIT AS USED IN THE TUNED R.F. STAGE OF A RADIO RECEIVER. THE ACTUAL RECEIVER CIRCUIT IS SHOWN AT THE LEFT OF THIS ILLUSTRATION WHILE THAT AT THE RIGHT IS ITS ELECTRICAL EQUIVALENT FOR EXPLANATORY PURPOSES.

A GREAT MANY PEOPLE CONSIDER THIS TYPE OF A TUNED CIRCUIT AS BEING A PARALLEL RESONANT CIRCUIT BECAUSE THE TUNING CONDENSER IS CONNECTED IN PARALLEL OR SHUNTED ACROSS THE ENDS OF THE COIL. THUS IT IS TRUE THAT AS FAR AS THESE TWO INDIVIDUAL PARTS OF THE CIRCUIT ARE CONCERNED, THEY ARE ACTUALLY CONNECTED IN PARALLEL WITH RESPECT TO EACHOTHER BUT THERE IS STILL ANOTHER PART WHICH EXISTS IN THIS CIRCUIT WHICH IS OVERLOOKED BY MANY PEOPLE AND THAT IS THAT WITH SIGNAL VOLTAGES IMPRESSED UPON THE CIRCUIT, WE HAVE THE EFFECT OF A SMALL HIGH FREQUENCY OR R.F. GENERATOR, WHICH IS CONNECTED IN THIS TUNED CIRCUIT AS ILLUSTRATED IN THE DIAGRAM AT THE RIGHT OF FIG. 5. ALTHOUGH THIS GENERATOR IS NOT PRESENT IN THIS CIRCUIT IN A PHYSICAL SENSE, YET ITS EFFECTS ARE NEVERTHELESS PRESENT DUE TO THE FACT THAT THESE HIGH FREQUENCY CURRENTS ARE INDUCED INTO THE

TUNED CIRCUIT BY MEANS OF THE TRANSFORMER ACTION BETWEEN THE ANTENNA CIRCUIT AND THE TUNED CIRCUIT.

WHENEVER, AN E.M.F. IS INDUCED IN A CIRCUIT AS IN THIS CASE, THE SOURCE OF E.M.F. CAN BE CONSIDERED AS BEING CONNECTED IN SERIES WITH THE TUNED CIRCUIT AS ILLUSTRATED AT THE RIGHT OF FIG. 5. THUS YOU SEE, THAT HERE WE HAVE A SERIES RESONANT CIRCUIT BECAUSE THE SECONDARY WINDING OF THE R.F. TRANSFORMER, THE TUNING CONDENSER AND THE SOURCE OF E.M.F. ARE ALL CONNECTED IN SERIES WITH ONE ANOTHER.

IF THE TUNED CIRCUIT AT THE RIGHT OF FIG. 5 IS TUNED TO RESONANCE WITH LET US SAY A SIGNAL FREQUENCY OF 600 KC., THEN THE IMPEDANCE OF THIS CIRCUIT BECOMES EQUAL TO THE OHMIC RESISTANCE OF THIS CIRCUIT, WHICH WE WILL ASSUME TO BE 10 OHMS. IF THE SIGNAL VOLTAGE INDUCED INTO THE SECONDARY WINDING OF THE FIRST R.F. TRANSFORMER IS 2 MILLIVOLTS (.002 VOLTS) THEN THE CURRENT CAUSED TO FLOW THROUGH THE RESONANT CIRCUIT WILL BE $I = E/R = \frac{.002}{10} = .0002$ AMPERES OR .2 MILLIAMPERE. IF THE CONDENSER AT THIS FREQUENCY SETTING HAS A REACTANCE OF 1326.2 OHMS, THEN THE VOLTAGE DEVELOPED ACROSS ITS PLATES BY THE CURRENT FLOW OF .0002 AMPS. THROUGH IT WILL BE $E = I \times R = .0002 \times 1326.2 = .265$ VOLTS. THIS WILL BE THE VOLTAGE "EG" IN THE ILLUSTRATION AT THE RIGHT OF FIG.5, WHICH IS APPLIED ACROSS THE GRID CIRCUIT OF THE FIRST R.F. TUBE. THUS YOU CAN NOW SEE JUST EXACTLY HOW THE VOLTAGE IS PRODUCED, IN ORDER TO OPERATE THE GRID OF A RADIO TUBE. ALSO NOTE THE VOLTAGE INCREASE FOR GRID APPLICATION AS MADE POSSIBLE BY THIS TUNED CIRCUIT.

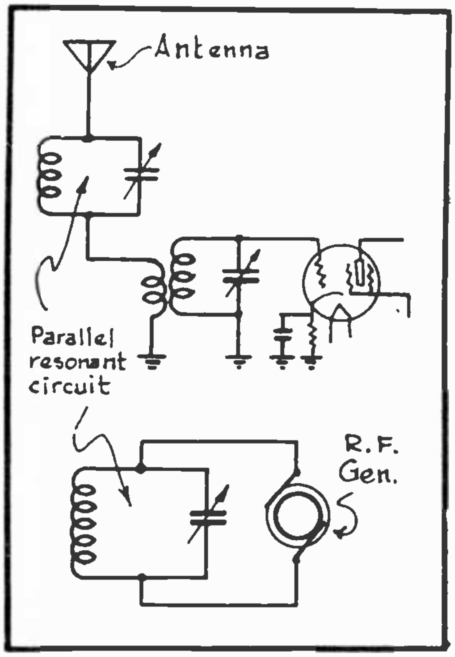


FIG. 6
The Parallel Resonant Circuit.

SINCE AT RESONANCE, THE IMPEDANCE OF THIS SERIES RESONANT CIRCUIT BECOMES EQUAL TO ITS OHMIC RESISTANCE, IT IS OBVIOUS THAT IN ORDER TO HAVE A SENSITIVE CIRCUIT, IT IS NECESSARY TO KEEP THIS OHMIC RESISTANCE DOWN TO AS LOW A VALUE AS PRACTICAL. HERE IS WHERE CAREFUL COIL DESIGN BECOMES SUCH AN IMPORTANT ITEM IN SCIENTIFIC RADIO CONSTRUCTION, FOR IT IS QUITE A PROBLEM TO HAVE INDUCTANCE WITH LITTLE RESISTANCE BECAUSE THE RESISTANCE INCREASES AS MORE TURNS ARE ADDED TO INCREASE A GIVEN COIL'S INDUCTANCE.

CALCULATING THE RESONANT WAVELENGTH

BESIDES THE FORMULA EXPRESSING THE RELATION BETWEEN THE INDUCTANCE AND CAPACITY OF A CIRCUIT FOR A GIVEN FREQUENCY, WE HAVE ANOTHER HANDY FORMULA BY MEANS OF WHICH WE CAN READILY CALCULATE THE WAVELENGTH IN METERS TO WHICH A GIVEN INDUCTANCE AND CAPACITY COMBINATION WILL RESONATE. THIS FORMULA IS AS FOLLOWS:

$$\text{Wave length in meters} = 1885\sqrt{\text{Inductance in Microhenries} \times \text{Capacity in Mfd.}}$$

GENERALLY YOU WILL FIND THIS FORMULA WRITTEN AS: $\lambda = 1885 \sqrt{LC}$, WHERE λ (THE GREEK LETTER "LAMBDA) IS THE SYMBOL FOR WAVELENGTH, "L", THE SYMBOL FOR INDUCTANCE AND "C" THE SYMBOL FOR CAPACITY.

TO ILLUSTRATE THE USE OF THIS FORMULA, LET US SUPPOSE THAT WE WISH TO KNOW TO WHAT WAVELENGTH A 300 MICROHENRY INDUCTANCE AND A .00035 MFD. CONDENSER WILL TUNE. SUBSTITUTING THESE VALUES INTO OUR FORMULA, WE HAVE : $\lambda = 1885 \sqrt{300 \times .00035}$ WHENCE $\lambda = 1885 \sqrt{.1050}$; $\lambda = 1885 \times .324 = 610$ METERS.

PARALLEL RESONANT CIRCUITS

NOW LET US COMPARE A PARALLEL RESONANT CIRCUIT WITH A SERIES RESONANT CIRCUIT AND NOTE THE DIFFERENCES BETWEEN THEM. A PARALLEL RESONANT CIRCUIT IS ILLUSTRATED FOR YOU IN FIG. 6. IN THE UPPER ILLUSTRATION, YOU WILL SEE THE PARALLEL RESONANT CIRCUIT APPLIED AS A WAVE-TRAP IN THE ANTENNA CIRCUIT OF A RECEIVER. OBSERVE THAT THE CONDENSER IN THIS CASE IS ALSO SHUNTED ACROSS THE ENDS OF THE COIL, THE SAME AS IN THE SERIES RESONANT CIRCUIT, WHICH WE CONSIDERED A FEW MOMENTS AGO. THE BIG DIFFERENCE, HOWEVER, IS THAT IN FIG. 6, THE SIGNAL VOLTAGE IS APPLIED ACROSS THE TUNED CIRCUIT. IN OTHER WORDS, YOU CAN CONSIDER THIS CIRCUIT AS PICTURED IN THE LOWER PORTION OF FIG. 6, WHERE THE SOURCE OF E.M.F. OR SIGNAL ENERGY CAN BE THOUGHT OF AS A SMALL R.F. GENERATOR, WHICH IS CONNECTED ACROSS THE CIRCUIT AS ILLUSTRATED.

IN THE CASE OF A PARALLEL RESONANT CIRCUIT SUCH AS THIS, WE HAVE AN ACTION ALTOGETHER DIFFERENT FROM THAT EXPERIENCED WITH THE SERIES RESONANT CIRCUIT, FOR WHEN THE PARALLEL RESONANT CIRCUIT IS TUNED TO RESONANCE WITH SOME GIVEN FREQUENCY, THE IMPEDANCE OF THE CIRCUIT TOWARDS THIS FREQUENCY BECOMES MAXIMUM. IN OTHER WORDS, THIS TYPE OF RESONANT CIRCUIT TENDS TO REJECT THE RESONANT FREQUENCY AND FOR THIS REASON IT CAN BE USED SUCCESSFULLY AS A WAVE OR FREQUENCY TRAP.

SINCE THE CHARACTERISTICS OF A PARALLEL RESONANT CIRCUIT ARE SUCH THAT ITS IMPEDANCE IS MAXIMUM OR GREATEST AT RESONANCE, IT IS NO MORE BUT NATURAL THAT THE LEAST POSSIBLE CURRENT FLOWS THROUGH THE PARALLEL RESONANT CIRCUIT AT THE RESONANCE FREQUENCY.

IT IS INTERESTING TO NOTE, HOWEVER, THAT OUR SAME TWO RESONANCE FORMULA APPLY EQUALLY WELL TO BOTH SERIES AND PARALLEL RESONANT CIRCUITS PROVIDED THAT THE OHMIC RESISTANCE OF THE CIRCUIT IS QUITE LOW. THIS, OF COURSE, IS THE GENERAL CASE IN CIRCUITS WHERE SUCH CONNECTIONS ARE USED. THUS FOR PARALLEL RESONANT CIRCUITS, WE ALSO HAVE THAT $f = \frac{1}{6.28 \sqrt{LC}}$; THAT $f = \frac{159,000}{\sqrt{L \text{ IN MICROHENRIES} \times C \text{ IN MFD.}}}$ AND THAT $\lambda = 1885 \sqrt{LC}$.

POWER IN A.C. CIRCUITS

NOW LET US CONSIDER THE POWER IN A.C. CIRCUITS. FROM YOUR EARLIER LESSONS, YOU WILL RECALL THAT IN ORDER TO CALCULATE THE POWER CONSUMED BY A CIRCUIT THROUGH WHICH A DIRECT CURRENT FLOWED, IT WAS ONLY NECESSARY FOR US TO MULTIPLY THE APPLIED VOLTAGE BY THE CURRENT FLOW IN THE CIRCUIT AND THE RESULT WAS THE POWER IN WATTS. IN THE CASE OF AN A.C. CIRCUIT CONTAINING RESISTANCE ONLY AND NO INDUCTANCE OR CAPACITY, WE CAN FIGURE THE POWER CONSUMED BY THE CIRCUIT IN THE SAME WAY. THAT IS, ALL THAT WE HAVE TO

DO IS TO MULTIPLY THE EFFECTIVE VOLTAGE BY THE EFFECTIVE CURRENT AND THE RESULT WILL BE THE POWER IN WATTS. THIS POWER CONSUMED BY THIS PURE RESISTIVE CIRCUIT WILL BE DISSIPATED IN THE FORM OF HEAT.

IN A.C. CIRCUITS CONTAINING INDUCTANCE OR CAPACITY OR BOTH, WE HAVE AN ENTIRELY DIFFERENT CONDITION TO FACE. FOR EXAMPLE, WHEN A.C. IS PASSED THROUGH AN INDUCTANCE, SOME POWER IS EXPENDED IN ORDER TO ESTABLISH A MAGNETIC FIELD BUT AS THIS FIELD COLLAPSES AGAIN, POWER IS RETURNED TO THE CIRCUIT. WE HAVE A SIMILAR CONDITION IN THE CASE WHERE A CONDENSER ALTERNATELY CHARGES AND DISCHARGES AS AN ALTERNATING CURRENT IS PASSED THROUGH IT. THE ONLY POWER ACTUALLY USED UP BY EITHER OF THESE TWO DEVICES IS THAT WHICH IS DISSIPATED AS HEAT BY THE OHMIC RESISTANCE WHICH THEY CONTAIN.

SINCE THE OHMIC RESISTANCE IS GENERALLY VERY SMALL AS COMPARED TO THE REACTANCE OF SUCH CIRCUITS, WE FIND THAT MUCH MORE POWER IS RETURNED TO THE CIRCUIT THAN IS DISSIPATED AS HEAT. BECAUSE OF THIS CONDITION, IT IS CLEAR THAT IN SUCH CIRCUITS, WE CANNOT MULTIPLY THE EFFECTIVE VOLTAGE BY THE EFFECTIVE CURRENT AND OBTAIN THE TRUE POWER VALUE. THIS CALCULATION GIVES US WHAT IS KNOWN AS THE "APPARENT POWER" OR AS IT IS SOMETIMES EXPRESSED "VOLT-AMPERES". THAT IS, IF WE SHOULD CONNECT A VOLTMETER AND AMMETER TO SUCH A CIRCUIT AND FIND THE VOLTMETER READING TO BE 100 VOLTS AND THE AMMETER READING 3 AMPERES, THE "APPARENT POWER" WOULD BE 300 VOLT-AMPERES AND NOT 300 WATTS.

THE "POWER FACTOR"

TO FIND THE TRUE POWER OF SUCH A CIRCUIT, WE HAVE TO MULTIPLY THE APPARENT POWER BY A NUMBER WHICH WE CALL THE "POWER FACTOR." THIS POWER FACTOR IS DEPENDENT UPON THE ANGLE OF LEAD OR LAG BETWEEN THE VOLTAGE AND CURRENT OF THE CIRCUIT. THUS THE TRUE POWER OR WATTS = "VOLT-AMPERES" X POWER FACTOR AND IT IS EQUALLY TRUE THAT THE POWER FACTOR $= \frac{\text{WATTS}}{\text{"VOLT-AMPERES"}}$.

IN OTHER WORDS, IF THE POWER IN THE CIRCUIT IS MEASURED BY MEANS OF A SPECIAL WATTMETER AND THE APPARENT POWER IS CALCULATED BY MULTIPLYING TOGETHER A VOLTMETER AND AMMETER READING OF THE CIRCUIT, THEN THE POWER FACTOR WILL BE EQUAL TO THE WATTMETER READING DIVIDED BY THE VOLT-AMPERE PRODUCT.

FOR GENERAL RADIO USE, YOU WILL ALSO FIND THAT THE POWER FACTOR OF A CIRCUIT IS EQUAL TO THE OHMIC RESISTANCE OF THE CIRCUIT DIVIDED BY THE IMPEDANCE IN OHMS. THAT IS, POWER FACTOR $= \frac{\text{RESISTANCE IN OHMS}}{\text{IMPEDANCE IN OHMS}}$. THUS IF IF THE RESISTANCE OF THE CIRCUIT IS 10 OHMS AND THE CIRCUITS IMPEDANCE IS 25 OHMS, THEN THE POWER FACTOR OF THE CIRCUIT WILL BE EQUAL TO $\frac{10}{25} = .4$

THE POWER FACTOR OF A PURE RESISTANCE CIRCUIT IS 1 AND FOR ANY A.C. CIRCUIT CONTAINING INDUCTANCE, CAPACITY OR BOTH IN ADDITION TO SOME RESISTANCE, THE POWER FACTOR WILL BE LESS THAN 1. THAT IS, SOMEWHERES BETWEEN 0 AND 1 AND THE GENERAL PRACTICE IS TO EXPRESS IT AS A DECIMAL, SUCH AS .4 ; .7 ; .8 ETC. THEREFORE, SINCE THE APPARENT POWER MUST BE MULTIPLIED BY SOME FACTOR LESS THAN 1, IN ORDER TO GIVE THE TRUE POWER, IT IS OBVIOUS THAT THE TRUE POWER OR POWER ACTUALLY USED BY THE CIRCUIT WILL BE LESS THAN THE APPARENT POWER.

SINCE YOU HAVE LEARNED THAT THE IMPEDANCE OF A RESONANT CIRCUIT BE-

COMES EQUAL TO ITS OHMIC RESISTANCE AT THE RESONANT FREQUENCY, YOU WILL ALSO READILY BE AWARE OF THE FACT THAT THE POWER FACTOR OF SUCH A CIRCUIT AT RESONANCE IS ALSO 1.

RESONANCE CURVES

IN TECHNICAL LITERATURE PERTAINING TO RADIO, YOU WILL COME ACROSS VARIOUS TYPES OF CURVES WHICH ARE USED TO ILLUSTRATE THE PERFORMANCE OF DIFFERENT RADIO UNITS AND AS YOU PROCEED WITH YOUR STUDIES, YOU WILL BECOME ACQUAINTED WITH ALL OF THEM. AT THE PRESENT TIME, WE ARE GOING TO CONSIDER THE RESONANCE CURVES FOR SERIES TUNED CIRCUITS AND YOU WILL FIND THEM TO POINT OUT MANY IMPORTANT FACTS.

LET US SUPPOSE, FOR EXAMPLE, THAT WE APPLY A SIGNAL OF GIVEN VOLTAGE ACROSS A SERIES TUNED CIRCUIT AND AT THE SAME TIME MEASURE THE CURRENT FLOW THROUGH THIS CIRCUIT. WE WOULD FIND THAT WITH THE SIGNAL VOLTAGE VALUE BEING CONSTANT AND ITS FREQUENCY VARIED IN BOTH DIRECTIONS FROM THE FREQUENCY TO WHICH THIS PARTICULAR CIRCUIT IS TUNED, THE CURRENT FLOW THROUGH THE TUNED CIRCUIT WOULD BE MAXIMUM AT THE RESONANT FREQUENCY AND THEN DROP OFF QUITE RAPIDLY BOTH SIDES OF THE RESONANT FREQUENCY.

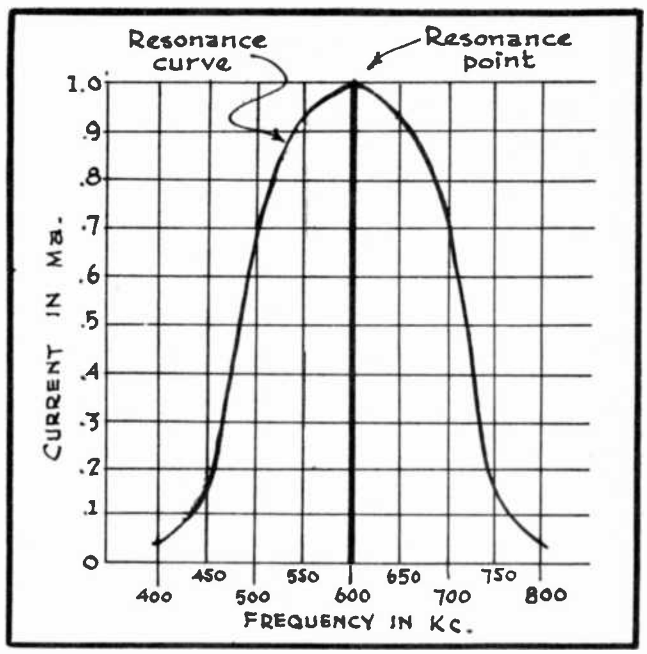


FIG. 7
The Resonance Curve.

FOR INSTANCE LET US ASSUME THAT THE RESONANT FREQUENCY IS 600 KC. AND THAT WITH A GIVEN SIGNAL VOLTAGE AT 600 KC., A CURRENT OF 1 MA. FLOWS THROUGH THE CIRCUIT. WE SHALL FURTHER ASSUME THAT THE CURRENT WITH THE DIFFERENT FREQUENCIES ABOVE RESONANCE IS AS FOLLOWS: .95 MA. AT 650 KC; .7 MA AT 700 KC; .15 MA. AT 750 KC.; .05 MA. AT 800 KC., WHEREAS BELOW THE RESONANT FREQUENCY, THE CURRENT VALUES ARE: .95 MA. AT 550 KC; .7 MA. AT 500 KC; .15 MA. AT 450 KC., AND .05 MA. AT 400 KC.

NOW THEN, PLOTTING THESE VALUES ON A PIECE OF GRAPH PAPER (PAPER MARKED OFF IN SQUARES) AND THEN DRAWING A CONTINUOUS LINE THROUGH THESE POINTS, WE WOULD OBTAIN A CURVE LIKE THAT ILLUSTRATED IN FIG. 7. WE CALL THIS A RESONANCE CURVE.

BY STUDYING FIG. 7, YOU WILL OBSERVE THAT THE RESONANCE CURVE REACHES ITS MAXIMUM HEIGHT AT THE RESONANT FREQUENCY AND THEN DROPS OFF RAPIDLY TOWARD EACH SIDE OF THE RESONANT FREQUENCY. HOWEVER, AS WE GET FARTHER AWAY FROM RESONANCE, THE SLOPE OF THE CURVE BECOMES MORE GRADUAL AND IT COMMENCES TO FLARE OR BROADEN OUT CONSIDERABLY.

FOR RECEIVERS WHICH ARE VERY SELECTIVE, THIS RESONANCE CURVE IS

QUITE NARROW AND ITS SIDES DROP OFF ABRUPTLY TOWARDS EACH SIDE OF THE RESONANT FREQUENCY. THE CURVE THUS SHOWS THE CURRENT TO BE MAXIMUM AT RESONANCE WHILE AT THE SAME TIME BEING REDUCED MATERIALLY AT FREQUENCIES ONLY SLIGHTLY REMOVED FROM THE RESONANT FREQUENCY. IT IS THIS FACT WHICH DETERMINES THE SHARPNESS OF TUNING FOR ANY PARTICULAR CIRCUIT.

ANOTHER IMPORTANT THING TO REMEMBER REGARDING RESONANCE CURVES IS THAT THE D.C. RESISTANCE OF THE TUNED CIRCUIT IN A LARGE MEASURE DETERMINES THE BROADNESS OF THE RESONANCE CURVE. FOR INSTANCE, IN FIG. 8, WE HAVE THREE INDIVIDUAL CURVES, EACH FOR A TUNED CIRCUIT OF DIFFERENT D.C. RESISTANCE AND ALL DRAWN ON THE SAME GRAPH.

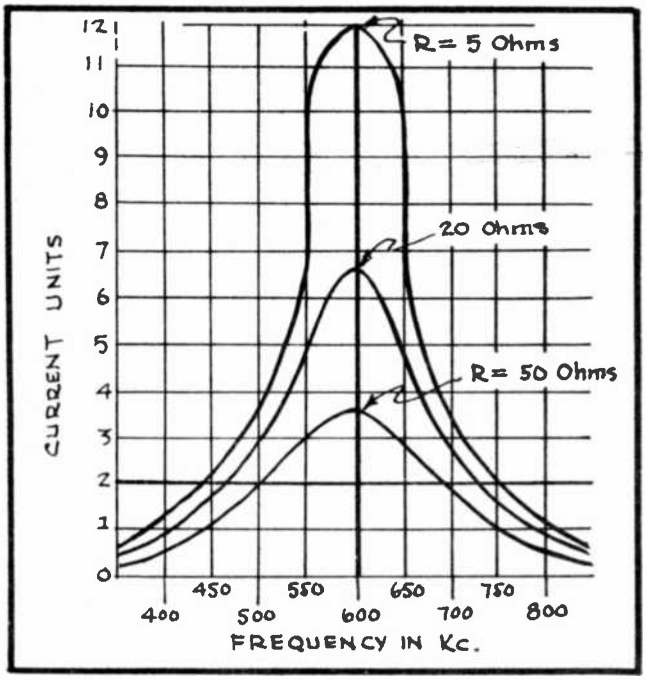


FIG. 8
Effect of Resistance Upon Tuning.

NOTICE ESPECIALLY IN FIG. 8 THAT THE CURRENT AT THE RESONANT FREQUENCY OF 600 KC. IS GREATEST FOR THE TUNED CIRCUIT HAVING THE LEAST D.C. RESISTANCE. ALSO OBSERVE THAT THE SIDES OR SLOPE OF THE CURVE IS STEEPER WHEN THE D.C.RESISTANCE OF THE TUNED CIRCUIT IS LESS AND THAT THE GREATER THE D.C. RESISTANCE OF THE TUNED CIRCUIT, THE BROADER WILL BE THE RESONANCE CURVE.

BY CAREFULLY STUDYING THESE COMPARISONS IN FIG. 8, YOU WILL QUICKLY REALIZE THAT TO HAVE A SHARP TUNING AND SENSITIVE CIRCUIT, ITS D.C. RESISTANCE MUST BE KEPT DOWN TO AS LOW A VALUE AS POSSIBLE.

CHOICE OF BYPASS CONDENSERS

THE CONDENSER CAPACITY RATING TO USE FOR BYPASSING PURPOSES IS DETERMINED BY THE LOWEST FREQUENCY ENCOUNTERED IN THAT THE CAPACITIVE REACTANCE OF THE CONDENSER DECREASES AS THE FREQUENCY INCREASES. THIS NATURALLY MEANS THAT A CONDENSER CAPACITY WHICH IS SATISFACTORY FOR THE LOWEST FREQUENCY BEING HANDLED WILL BE EVEN MORE EFFECTIVE WHEN SUBJECTED TO HIGHER FREQUENCIES.

IN PRACTICE, IT IS GENERALLY THE CUSTOM TO CHOOSE R.F. BYPASS CONDENSERS WHICH HAVE A CAPACITY RATING OF SUCH VALUE THAT ITS CAPACITIVE REACTANCE AT THE LOWEST FREQUENCY BEING HANDLED (500 KC. IN THE CASE OF BROADCAST RECEIVERS) IS LESS THAN FROM ONE-ONE HUNDREDTH TO ONE-ONE THOUSANDTH THAT OF THE RESISTOR ACROSS WHICH IT IS CONNECTED. FOR INSTANCE, IF A CONDENSER IS TO BE USED TO BYPASS R.F. ENERGY AROUND A 2000 OHM RESISTOR IN A BROADCAST RECEIVER AS ILLUSTRATED IN FIG. 9, THEN IN ORDER THAT THIS PARTICULAR BYPASS CONDENSER MAY HAVE A CAPACITIVE REACTANCE EQUAL TO APPROXIMATELY ONE-ONE THOUSANDTH THAT OF THE 2000 OHM RESISTOR, ITS CAPACITIVE REACTANCE AT 500 KC. MUST BE $\frac{2000}{1000} = 2$ OHMS.

A .25 MFD. CONDENSER WILL HAVE A CAPACITIVE REACTANCE OF 1.28 OHMS AT 500 KC., WHILE A .1 MFD. CONDENSER WILL HAVE A CAPACITIVE REACTANCE OF 3.2 OHMS AT THIS SAME FREQUENCY. THE .25 MFD. CONDENSER WOULD THEREFORE BE THE PREFERABLE OF THESE TWO STANDARD SIZES WHICH COME CLOSEST TO OUR DESIRE VALUE.

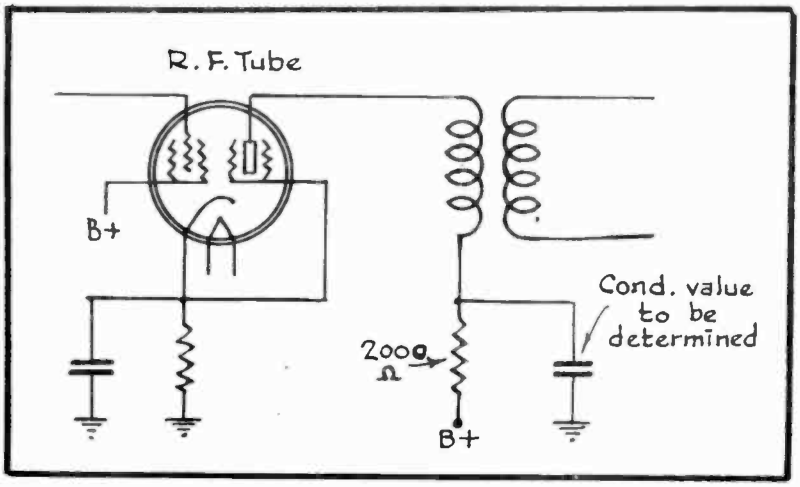


FIG. 9

Calculating the By-pass Condenser Value.

IN THE CASE OF BY PASS CONDENSERS WHICH ARE EXPECTED TO HANDLE AUDIO FREQUENCIES, THE GENERAL PRACTICE IS TO CHOOSE A CONDENSER WHOSE CAPACITY VALUE IS SUCH THAT ITS CAPACITIVE REACTANCE AT THE LOWEST FREQUENCY BEING HANDLED IS ABOUT 1/10 THE RESISTANCE VALUE OF THE RESISTOR WHICH IT BYPASSES. THAT IS, IF A RESISTOR OF 2000 OHMS IN AN A.F. AMPLIFIER IS TO BE BYPASSED BY A CONDENSER AND THE LOWEST FREQUENCY BEING HANDLED IS 50 CYCLES, THEN THE CAPACITIVE REACTANCE OF THIS CONDENSER AT 50 CYCLES SHOULD BE ABOUT $\frac{2000}{10}$ OR 200 OHMS. THIS WOULD THEREFORE CALL FOR A CONDENSER HAVING A CAPACITY RATING OF ABOUT 16 MFD.

TABLE I OFFERS YOU A HANDY MEANS WHEREBY YOU CAN EASILY DETERMINE THE CAPACITIVE REACTANCE OF MOST POPULAR CONDENSER SIZES TO THE FREQUENCY LIMITS REQUIRED OF BYPASS CONDENSERS IN BOTH THE R.F. AND A.F. STAGES.

SINCE THE REACTANCE OF A CONDENSER IS INVERSELY PROPORTIONAL TO THE

TABLE I

CAP. IN MFDS	FREQUENCY IN CYCLES PER SECOND						
	Broadcast Radio Frequencies		Audio Frequencies		Power Supply Frequencies		
	500,000	1,500,000	50	10,000	25	60	120
	CAPACITIVE REACTANCE IN OHMS						
.00005	6,369.4	2,123.1	63,694.267	318,471	127,388,534	53,078,503	26,539,252
.0001	3,184.7	1,061.6	31,847,133	159,235	63,694,267	26,539,252	13,269,626
.00025	1,273.8	424.6	12,738,853	63,694	25.477,706	10,615,600	5,307,850
.0005	636.9	212.3	6,369.426	31,847	12,738,853	5,307,850	2,653,925
.001	318.5	106.2	3,184,713	15,924	6,369,427	2,653,925	1,326,963
.005	63.7	21.2	636,943	3,185	1,273,885	530,785	265,393
.01	31.8	10.6	318,471	1,592	636,943	265,393	132,696
.015	21.2	7.1	212,314	1,061	424,629	176,929	88,464
.02	15.9	5.3	159,235	796	318,471	132,697	66,348
.05	6.4	2.1	63,694	318	127,389	53,078	26,539
.1	3.2	1.1	31,847	159	63,694	26,539	13,270
.25	1.28	.42	12,739	64	25,478	10,616	5,308
.5	.64	.21	6,369	32	12,739	5,308	2,654
1.0	.32	.11	3,184	15.9	6,369	2,654	1,327
2.0	.16	.05	1,592	7.9	3,184	1,327	663
4.0	.08	.03	769	3.9	1,592	664	332
6.0	.05	.02	531	2.6	1,062	442	221
8.0	.04	.01	398	2.0	796	332	166
10.0	.03	.01	318	1.6	637	265	133
15.0	.02	.01	212	1.1	425	177	88

Reactances of Condensers of Standard Capacity at Commonly Used Frequencies.

FREQUENCY AND CAPACITY, DOUBLING THE CAPACITY OF THE CONDENSER WILL REDUCE THE REACTANCE BY ONE-HALF. THIS BEING TRUE, IT IS A SIMPLE MATTER TO CALCULATE MENTALLY THE REACTANCE OF ANY CONDENSER NOT GIVEN IN TABLE I, AT PRACTICALLY ANY FREQUENCY, SIMPLY BY BASING ONE'S CALCULATIONS UPON THE INFORMATION GIVEN IN TABLE I.

THESE PAST FEW LESSONS ON THE "ESSENTIALS OF A.C. CIRCUITS" HAVE PROVIDED YOU WITH A GREAT DEAL MORE VALUABLE INFORMATION. EVEN IF THESE LESSONS APPEAR SOMEWHAT DIFFICULT, REMEMBER THAT THEY ARE IMPORTANT AND THAT IT IS NOT NECESSARY FOR YOU TO MEMORIZE THE VARIOUS FORMULAE. THE MAIN THING IS TO KNOW HOW TO USE THEM, AND WHERE TO FIND THEM WHEN YOU HAVE NEED FOR THEM AT SOME FUTURE TIME.

EXAMINATION QUESTIONS

LESSON NO. 41

1. - IF A CONDENSER OF 8 MFD, AN INDUCTANCE OF 30 HENRIES AND A RESISTANCE OF 1000 OHMS ARE ALL CONNECTED IN SERIES, WHAT WILL BE THE IMPEDANCE WHICH THIS CIRCUIT WILL OFFER TOWARDS A 60 CYCLE CURRENT?

2. - HOW MUCH CURRENT WILL FLOW THROUGH A CIRCUIT OF 11,017 OHMS IMPEDANCE WHEN 100 VOLTS IS APPLIED ACROSS IT?

3. - IF 9 MA. FLOWS THROUGH THE SERIES CIRCUIT DESCRIBED IN QUESTION #1, WHAT WILL BE THE VOLTAGE DROP ACROSS THE CONDENSER, INDUCTANCE AND RESISTOR INDIVIDUALLY?

4. - EXPLAIN THE CONDITION OF RESONANCE IN A TUNED CIRCUIT IN TERMS OF INDUCTIVE REACTANCE, CAPACITIVE REACTANCE AND RESISTANCE.

5. - IF A CONDENSER OF .00025 MFD. IS CONNECTED IN SERIES WITH AN INDUCTANCE OF 250 MICROHENRIES, TO WHAT FREQUENCY WILL THIS CIRCUIT RESONATE?

6. - EXPLAIN THE DIFFERENCE BETWEEN A SERIES RESONANT CIRCUIT AND A PARALLEL RESONANT CIRCUIT?

7. - IF A CONDENSER OF 140 MMFD. AND AN INDUCTANCE OF 100 MICROHENRIES ARE CONNECTED IN SERIES, TO WHAT WAVELENGTH WILL THIS CIRCUIT RESONATE?

8. - WHAT IS MEANT BY THE TERM POWER FACTOR?

9. - DESCRIBE A RESONANCE CURVE FOR A SERIES TUNED CIRCUIT.

10. - HOW DOES THE D.C. RESISTANCE OF A SERIES TUNED CIRCUIT AFFECT THE RESONANCE CURVE AND SELECTIVITY OF THE RECEIVER?

Practical Technical Training In RADIO·TELEVISION AND ALLIED ELECTRONICS

J. A. ROSENKRANZ President — ESTABLISHED 1905

NATIONAL SCHOOLS ★ LOS ANGELES 37, CALIF.

LESSON NO. 42

R. F. COIL DESIGN

THE PERFORMANCE OF A RADIO RECEIVER DEPENDS GREATLY UPON THE PROPER FUNCTIONING OF ITS R-F AMPLIFIER.

ONLY A FEW YEARS AGO, THE CONSTRUCTION OF THIS SECTION OF THE RECEIVER WAS VERY CRUDE, PRIMARILY SO BECAUSE COMPARATIVELY LITTLE WAS KNOWN ABOUT RADIO FREQUENCIES. OUR PRESENT R.F. STAGES, HOWEVER, ARE BUILT WITH UTMOST CARE; AND IT HAS ONLY BEEN THROUGH THE CONSTANT EXPERIMENTS OF STUDIOUS RADIO MEN THAT THIS PORTION OF THE RECEIVER HAS REACHED ITS PRESENT STATE OF DEVELOPMENT. STILL, THERE IS ROOM FOR IMPROVEMENT; AND AS TIME PASSES, MORE AND MORE OF THE PRESENT PROBLEMS WILL BE SOLVED SUCCESSFULLY, SO THAT IT IS REALLY DIFFICULT TO PROPHESY WHAT REMARKABLE ACHIEVEMENTS WILL BE WITNESSED IN THE NEAR FUTURE. YOU SHOULD BE MIGHTY HAPPY THAT YOU HAVE ENTERED THE FIELD OF RADIO AT THIS TIME, WHEN SUCH TREMENDOUS PROGRESS IS BEING MADE.

IN PREPARING YOU TO BECOME A RADIO TECHNICIAN, IT IS OUR EARNEST DESIRE THAT YOU LEARN JUST EXACTLY HOW AND WHY CERTAIN RADIO JOBS MUST BE DONE IN A CERTAIN WAY. THEREFORE, IN OUR PRESENT DISCUSSION OF R.F. AMPLIFIER DESIGN, YOU WILL FIND THAT INSTEAD OF JUST GIVING YOU A LIST OF SPECIFICATIONS TO FOLLOW FOR CONSTRUCTING VARIOUS COILS, ETC., WE ARE GOING TO SHOW YOU EXPLICITLY WHY THESE DIFFERENT SPECIFICATIONS ARE SUITABLE. ALL OF THIS INFORMATION IS GOING TO BE OF GREAT VALUE TO YOU, BECAUSE IT WILL ENABLE YOU TO INTELL-

FIG. 1
MOUNTING THE R.F. TRANSFORMER

IGENTLY LAY OUT WORK THROUGH YOUR OWN THOUGHTS AND EFFORTS INSTEAD OF RELYING SOLELY UPON THE WORK LAID OUT BY OTHERS.

THE R.F. TRANSFORMER

FIRST OF ALL, LET US CONSIDER THE R.F. TRANSFORMER. ALTHOUGH THESE UNITS CAN BE BOUGHT READY MADE AT A PRICE WHICH IS QUITE REASONABLE, YET THERE ARE TIMES WHEN YOU WILL WISH TO CONSTRUCT THEM ACCORDING TO YOUR OWN IDEAS. FURTHERMORE, IT IS PART OF YOUR TRAINING TO LEARN HOW SUCH COIL DESIGNS ARE WORKED OUT.

AS YOU ALREADY KNOW, THE SECONDARY WINDING OF THE R.F. TRANSFORMER IS GENERALLY CONNECTED ACROSS A TUNING CONDENSER AS SHOWN IN FIG.2 AND THE FREQUENCY TO WHICH THIS TUNED CIRCUIT WILL RESONATE, IS DEPENDENT UPON THE INDUCTANCE OF THIS WINDING AND THE CAPACITY OF THE CONDENSER WITH WHICH IT IS USED.

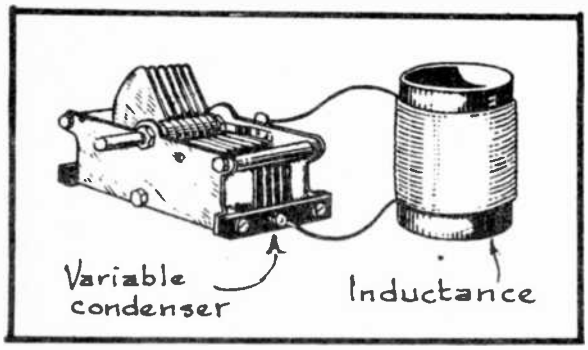


FIG. 2
The Tuned Circuit.

IN ORDER TO ENABLE THIS CIRCUIT TO TUNE OVER A GIVEN RANGE OR BAND OF FREQUENCIES, IT IS OF COURSE NECESSARY TO EITHER VARY THE INDUCTIVE, CAPACITIVE OR BOTH VALUES BUT THE MOST COMMON PRACTICE IS TO USE A FIXED INDUCTANCE AND TO VARY THE CAPACITY WITH THE AID OF A VARIABLE CONDENSER.

ALTHOUGH WE HAVE TOLD YOU CONSIDERABLE ABOUT INDUCTANCE AND ITS VARIOUS EFFECTS AND ACTIONS, YET WE HAVE AS YET NOT TOLD YOU JUST EXACTLY HOW TO GO ABOUT THE TASK OF CALCULATING INDUCTANCE. IN OUR PRESENT DISCUSSION OF R.F. TRANSFORMERS, YOU WILL HAVE NEED FOR THIS INFORMATION AND SO WITHOUT FURTHER DELAY, WE SHALL INVESTIGATE THIS MATTER THOROUGHLY.

CALCULATING THE INDUCTANCE OF SOLENOID TYPE WINDINGS

AT THE PRESENT TIME, TUNING INDUCTANCES OF THE CYLINDRICAL SHAPE SHOWN IN FIG. 2 ARE MOST EXTENSIVELY USED. THE REASON FOR THIS BEING THAT IT HAS BEEN PROVEN TO BE THE MOST EFFICIENT, AS WELL AS THE SIMPLEST TO CONSTRUCT. WE CALL SUCH TUBULAR SHAPED COILS, "SOLENOID COILS OR WINDINGS."

A VERY HANDY FORMULA IS AT OUR DISPOSAL FOR CALCULATING THE INDUCTANCE OF THIS TYPE OF WINDING AND THIS FORMULA IS AS FOLLOWS:

$$L = 0.0251\, D^2\, N\, N_0\, K.$$

THE LETTER "L" IN THIS FORMULA STANDS FOR THE INDUCTANCE EXPRESSED IN MICROHENRIES; THE NUMBER 0.0251 IS A CONSTANT; "D" STANDS FOR THE DIAMETER OF THE COIL IN INCHES; "N" SIGNIFIES THE TOTAL NUMBER OF TURNS; "N_0" IS THE NUMBER OF TURNS PER INCH ON THE WINDING AND "K" IS THE "CORRECTION FACTOR" FOR THE PARTICULAR COIL IN QUESTION. BY ALL MEANS, DON'T BECOME ALARMED WHEN CONFRONTED BY A FORMULA AS THIS BECAUSE IT IS HANDLED EASIER THAN ONE MIGHT AT FIRST SUPPOSE. THIS WILL BE EVIDENT FROM THE EXPLANATION

WHICH IS TO FOLLOW.

FINDING THE CORRECTION OR SHAPE FACTOR

THE COIL DIMENSIONS AS USED IN THIS FORMULA WILL PRESENT NO DIFFICULTY BUT NO DOUBT YOU ARE ALREADY WONDERING WHAT IS MEANT BY THE EXPRESSION "CORRECTION-FACTOR", WHICH IS REPRESENTED BY THE LETTER "K" IN THE FORMULA. THIS CORRECTION FACTOR IS OBTAINED FROM A TABLE, WHICH WE ARE GIVING YOU IN TABLE I AND THE VALUE OF K IS DIFFERENT FOR DIFFERENT SOLENOID COIL SHAPES. THIS VALUE IS ALSO SPOKEN OF AS THE COILS "SHAPE- FACTOR" BECAUSE IT IS DEPENDENT UPON THE RATIO OF THE COIL'S DIAMETER TO ITS LENGTH.

THE VALUE OF "K" TO CHOOSE FROM TABLE I IS DETERMINED AS FOLLOWS: FOR

TABLE I
VALUES OF "K" FOR INDUCTANCE FORMULA

DIAMETER / LENGTH	K	DIAMETER / LENGTH	K	DIAMETER / LENGTH	K
0.00	1.000	1.90	0.538	6.40	0.274
.05	.979	1.95	.532	6.60	.269
.10	.959			6.80	.263
.15	.939	2.00	.526		
.20	.920	2.10	.518	7.00	.258
		2.20	.503	7.20	.254
.25	.902	2.30	.492	7 40	.249
.30	.884	2.40	.482	7 60	.245
.35	.867			7.80	.241
.40	.850	2.50	.472		
.45	.834	2.60	.463	8.00	.237
		2.70	.454	8.50	.227
.50	.818	2.80	.445	9.00	.219
.55	.803	2.90	.437	9.50	.211
.60	.789			10.00	.203
.65	.775	3.00	.429		
.70	.761	3.10	.422	11.0	.190
		3.20	.415	12.0	.179
.75	.748	3.30	.408	13.0	.169
.80	.735	3.40	.401	14.0	.161
.85	.723			15.0	.153
.90	.711	3.50	.394		
.95	.700	3.60	.388	16.0	.146
		3.70	.382	17.0	.139
1.00	.688	3.80	.376	18.0	.134
1.05	.678	3.90	.371	19.0	.128
1.10	.667			20.0	.124
1.15	.657	4.00	.365		
1.20	.648	4.10	.360	22.0	.115
		4.20	.355	24.0	.108
1.25	.638	4.30	.350	26.0	.102
1.30	.629	4.40	.346	28.0	.096
1.35	.620			30.0	.091
1.40	.612	4.50	.341		
1.45	.603	4.60	.336	35.0	.081
		4.70	.332	40.0	.073
1.50	.595	4.80	.328	45.0	.066
1.55	.587	4.90	.324	50.0	.061
1.60	.580				
1.65	.572	5.00	.320	60.0	.053
1.70	.565	5.20	.312	70.0	.047
		5.40	.305	80.0	.042
1.75	.558	5.60	.298	90.0	.038
1.80	.551	5.80	.292	100.0	.035
1.85	.544				
		6.00	.285		
		6.20	.280		

EXAMPLE, IN FIG. 3, WE HAVE A COIL OR INDUCTANCE WHICH IS 1.5" IN DIAMETER AND 3" LONG. BY DIVIDING ITS DIAMETER BY ITS LENGTH, WE HAVE $\frac{1.5}{3} = .5$

LOOKING FOR THIS NUMBER UNDER THE COLUMNS HEADED $\frac{\text{DIAM.}}{\text{LENGTH}}$ IN TABLE I, WE SEE THAT .5 CORRESPONDS TO A SHAPE OR CORRECTION FACTOR OF .818. HENCE THE CORRECTION FACTOR OR VALUE OF K FOR A COIL HAVING THE DIMENSIONS AS INDICATED IN FIG. 3 WILL BE 0.818.

TRUE MEANING OF "LENGTH OF WINDING" AND "TURNS PER INCH"

WHEN REFERRING TO WINDINGS ON SUCH COILS, WE FREQUENTLY SPEAK OF THE COIL AS BEING WOUND WITH A CERTAIN NUMBER OF TURNS TO THE INCH. BY THIS EXPRESSION, WE MEAN THE NUMBER OF TURNS OF THE WINDING THAT ARE CONTAINED IN ONE INCH OF THE WINDING'S LENGTH. THIS IS IMPORTANT BECAUSE QUITE OFTEN, A SPACE IS ALLOWED BETWEEN ADJACENT TURNS OF A WINDING AND THIS HAS A PRONOUNCED EFFECT UPON THE WINDING'S INDUCTANCE. THEN IT IS ALSO APPARENT THAT IN SUCH CASES, WHERE ADJACENT TURNS ARE WOUND SIDE BY SIDE WITHOUT ANY SEPARATIONS, ONE WILL BE ABLE TO WIND MORE TURNS PER INCH WHEN SMALLER WIRE OR WIRE OF THINNER INSULATION IS USED. TABLE II, TELLS YOU HOW MANY TURNS PER INCH CAN BE WOUND WITH STANDARD SIZES AND TYPES OF COPPER WIRE AS USED IN THE CONSTRUCTION OF R.F. TRANSFORMERS. NOTE, THAT IN THE CASE OF THIS TABLE, THE TURNS ARE CONSIDERED WOUND SIDE BY SIDE IN A SINGLE LAYER AND NO SPACE IS ALLOWED BETWEEN ADJACENT TURNS. ALSO BEAR IN MIND THAT THE LENGTH OF THE TUBING, UPON WHICH THE COIL IS WOUND, HAS NOTHING TO DO WITH THE LENGTH OF THE WINDING AND WE ONLY CONSIDER THE SPACE ACTUALLY OCCUPIED BY THE WIRE AS CONSTITUTING THE LENGTH OF THE WINDING. THIS IS ILLUSTRATED CLEARLY IN FIG. 3.

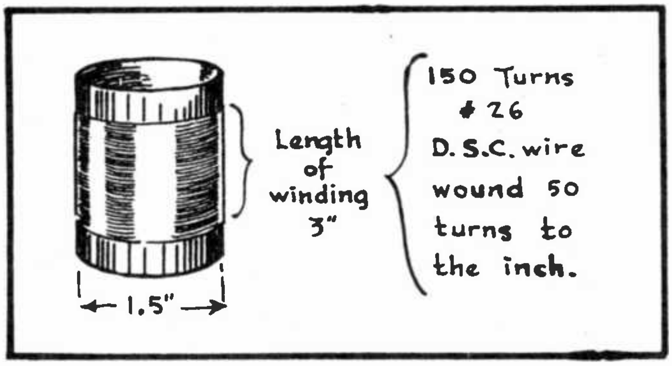


FIG. 3
Calculating Inductance.

YOU CAN CHECK UP ON YOURSELF AS TO YOUR UNDERSTANDING OF TABLE II BY MEANS OF FIG. 3. NOTICE IN THIS ILLUSTRATION, THAT THE COIL IS WOUND WITH 150 TURNS OF #26 DOUBLE SILK COVERED WIRE, WITH THE TURNS WOUND SIDE BY SIDE AND UPON REFERRING TO TABLE II, YOU WILL OBSERVE THAT #26 B&S DOUBLE SILK COVERED WIRE CAN BE WOUND 50 TURNS TO THE INCH AND THIS CHECKS WITH FIG. 3, AS HERE THERE ARE 150 TURNS OF THIS WIRE IN A 3" WINDING LENGTH.

CALCULATING THE INDUCTANCE

NOW LET US PROCEED TO CALCULATE THE INDUCTANCE OF THE COIL WHICH IS ILLUSTRATED IN FIG. 3. FOR THIS, WE WILL USE OUR FORMULA:

$L = 0.0251\, D^2\, N\, N_o\, K$. THE VALUE FOR "D" ACCORDING TO FIG. 3 WILL BE 1.5", THE VALUE FOR "N" WILL BE 150 TURNS, "N_o" WILL BE 50 TURNS PER INCH AND "K" WE HAVE ALREADY FOUND TO BE 0.818.

SUBSTITUTING THESE VALUES IN OUR FORMULA WE HAVE:

$L = 0.0251 \times 1.5^2 \times 150 \times 50 \times .818$, WHENCE $L = 346.47$. THAT IS, THE INDUCTANCE OF THE COIL, WHICH IS SHOWN IN FIG. 3, IS APPROXIMATELY 346.47 MICROHENRIES AS DETERMINED BY CALCULATION.

BEAR IN MIND, THAT THIS INDUCTANCE FORMULA WHICH WAS JUST GIVEN YOU, ONLY APPLIES TO SOLENOID TYPE (AIR CORE) COILS, HAVING A SINGLE LAYER WINDING. FOR BANKED COILS, THAT IS, SOLENOID COILS CONSISTING OF SEVERAL LAYERS OF WINDING, YOU CAN USE THE FORMULA $L = 0.0251\ D^2\ N\ n\ n_0\ K$ WITH CONSIDERABLE ACCURANCY AND IN THIS CASE, "N" SIGNIFIES THE NUMBER OF LAYERS MAKING UP THE WINDING. ALSO REMEMBER, THAT THIS LATTER FORMULA IS ONLY CONSISTENT IN SUCH CASES WHERE THE DEPTH OF THE WINDING IS NOT TOO GREAT AS COMPARED WITH ITS DIAMETER.

IN VARIOUS MAGAZINES OR BOOKS, WHICH YOU MAY READ FROM TIME TO TIME, YOU WILL FIND STILL OTHER FORMULAS FOR CALCULATING THE INDUCTANCE OF SOLENOID TYPE WINDINGS BUT YOU WILL FIND THAT THE ONE WHICH WE HAVE JUST GIVEN YOU IS USED EXTENSIVELY IN RADIO MANUFACTURING CONCERNS BY FOREMOST ENGINEERS.

TABLE II
TURNS PER INCH WOUND SIDE BY SIDE WITH WIRE HAVING FOLLOWING INSULATION

WIRE SIZE GAUGE B & S	BARE WIRE	ENAMELLED	SINGLE SILK	SILK ENAM.	DOUBLE SILK	SINGLE COTTON	COTTON ENAM.	DOUBLE COTTON
# 16	20	19	18	18	17	17	16	16
18	25	23	23	22	22	21	20	19
20	32	29	29	27	27	26	25	23
22	40	37	36	34	33	33	31	29
24	50	46	44	42	41	40	38	34
26	63	57	54	51	50	48	46	41
28	79	74	67	63	60	59	55	47
30	100	90	82	76	71	70	65	54
32	126	112	99	92	83	82	77	60
34	159	141	119	110	97	95	89	67
36	200	178	140	131	111	108	102	74
40	317	270.	200	195	140	139	139	102

THE INDUCTANCE AND CAPACITY RELATION FOR TUNING

NOW THAT YOU ARE FAMILIAR WITH THE MANNER IN WHICH R.F. INDUCTANCES OF THIS TYPE ARE CALCULATED, THE NEXT STEP WILL BE TO SEE WHAT VALUE OF INDUCTANCE TO USE WITH A GIVEN TUNING CONDENSER IN ORDER FOR THE ARRANGEMENT TO TUNE OVER A CERTAIN BAND OF FREQUENCIES.

BY LOOKING AT THE FAMILIAR FORMULA $f = \frac{159,000}{\sqrt{LC}}$, YOU WILL NOTE THAT SINCE THE NUMBER 159,000 IS A CONSTANT IN THIS FORMULA, THE RESONANT FREQUENCY IN THIS FORMULA WILL BE GOVERNED BY THE VALUES L AND C. THAT IS, ACCORDING TO THE INDUCTANCE AND THE CAPACITY. WE GENERALLY REFER TO THIS RELATION BETWEEN L AND C AS THE "LC" FACTOR AND FOR ANY GIVEN FREQUENCY, WE WILL HAVE A DEFINITE "LC" FACTOR. FOR YOUR CONVENIENCE, WE ARE GIVING YOU A COMPLETE TABLE OF LC FACTORS FOR THE ENTIRE WAVELENGTH RANGE BETWEEN 1 AND 1000 METERS OR BETWEEN 300,000 TO 300 KC. THIS HANDY TABLE IS HEAD-

ED TABLE III IN THIS LESSON. LET US NOW SEE HOW THIS TABLE CAN BE USED. FOR OUR FIRST EXAMPLE, LET US ASSUME THAT WE HAVE THE INDUCTANCE OF 346.47 MICROHENRIES, WHICH WAS ALREADY SHOWN YOU IN FIG. 3. IF THIS INDUCTANCE IS USED TOGETHER WITH A TUNING CONDENSER, HAVING A MAXIMUM CAPACITY OF .00035 MFD, THEN TO WHAT FREQUENCY WILL THIS COMBINATION RESONATE? THE LXC FACTOR FOR THIS ARRANGEMENT WILL BE THE INDUCTANCE IN MICROHENRIES MULTIPLIED BY THE CAPACITY IN MICROFARADS OR 346.47 X .00035=.1212645 OR APPROXIMATELY 0.1213. NOW BY LOOKING FOR THE NUMBER 0.1213 UNDER THE LXC COLUMNS OF TABLE III, WE FIND THAT IT LIES BETWEEN THE VALUES OF 0.1208 AND 0.1226. THUS ACCORDING TO TABLE III, YOU ARE SHOWN THAT THIS LXC FACTOR WILL

TABLE III

WAVELENGTH IN METERS -- FREQUENCY IN KC. -- INDUCTANCE IN MICROHENRIES CAPACITY IN MICROFARADS

METERS	FREQ. IN KC.	LXC	METERS	FREQ. IN KC.	LXC	METERS	FREQ. IN KC.	LXC
1	300,000	0.0000003	450	667	0.0570	740	405	0.1541
2	150,000	0.0000111	460	652	0.0596	745	403	0.1562
3	100,000	0.0000018	470	639	0.0622	750	400	0.1583
4	75,000	0.0000045	480	625	0.0649	755	397	0.1604
5	60,000	0.0000057	490	612	0.0676	760	395	0.1626
6	50,000	0.0000101	500	600	0.0704	765	392	0.1647
7	42,900	0.0000138	505	594	0.0718	770	390	0.1669
8	37,500	0.0000180	510	588	0.0732	775	387	0.1690
9	33,333	0.0000228	515	583	0.0747	780	385	0.1712
10	30,000	0.0000282	520	577	0.0761	785	382	0.1734
20	15,000	0.0001129	525	572	0.0776	790	380	0.1756
30	10,000	0.0002530	530	566	0.0791	795	377	0.1779
40	7,500	0.0004500	535	561	0.0806	800	375	0.1801
50	6,000	0.0007040	540	556	0.0821	805	373	0.1824
60	5,000	0.0010140	545	551	0.0836	810	370	0.1847
70	4,290	0.0013780	550	546	0.0852	815	368	0.1870
80	3,750	0.0018010	555	541	0.0867	820	366	0.1893
90	3,333	0.0022800	560	536	0.0883	825	364	0.1916
100	3,000	0.00282	565	531	0.0899	830	361	0.1939
110	2,727	0.00341	570	527	0.0915	835	359	0.1962
120	2,500	0.00405	575	522	0.0931	840	357	0.1986
130	2,308	0.00476	580	517	0.0947	845	355	0.201
140	2,143	0.00552	585	513	0.0963	850	353	0.203
150	2,000	0.00633	590	509	0.0980	855	351	0.206
160	1,875	0.00721	595	504	0.0996	860	349	0.208
170	1,764	0.00813	600	500	0.1013	865	347	0.211
180	1,667	0.00912	605	496	0.1030	870	345	0.213
190	1,579	0.01015	610	492	0.1047	875	343	0.216
200	1,500	0.01126	615	488	0.1065	880	341	0.218
210	1,429	0.01241	620	484	0.1082	885	339	0.220
220	1,364	0.01362	625	480	0.1100	890	337	0.223
230	1,304	0.01489	630	476	0.1117	895	335	0.225
240	1,250	0.01621	635	472	0.1135	900	333	0.228
250	1,200	0.01759	640	469	0.1153	905	331	0.231
260	1,154	0.01903	645	465	0.1171	910	330	0.233
270	1,111	0.0205	650	462	0.1189	915	328	0.236
280	1,071	0.0221	655	458	0.1208	920	326	0.238
290	1,034	0.0237	660	455	0.1226	925	324	0.241
300	1,000	0.0253	665	451	0.1245	930	323	0.243
310	968	0.0270	670	448	0.1264	935	321	0.246
320	938	0.0288	675	444	0.1283	940	319	0.249
330	909	0.0306	680	441	0.1302	945	317	0.251
340	883	0.0325	685	438	0.1321	950	316	0.254
350	857	0.0345	690	435	0.1340	955	314	0.257
360	834	0.0365	695	432	0.1360	960	313	0.259
370	811	0.0385	700	429	0.1379	965	311	0.262
380	790	0.0406	705	426	0.1399	970	309	0.265
390	769	0.0428	710	423	0.1419	975	308	0.268
400	750	0.0450	715	420	0.1439	980	306	0.270
410	732	0.0473	720	417	0.1459	985	305	0.273
420	715	0.0496	725	414	0.1479	990	303	0.276
430	698	0.0520	730	411	0.1500	995	302	0.279
440	682	0.0545	735	408	0.1521	1000	300	0.282

TUNE THE CIRCUIT TO A FREQUENCY OF ABOUT 457 KC. NOTE HOW SIMPLE THAT THIS WORK BECOMES THROUGH THE AID OF TABLE III AND THAT HARDLY ANY CALCULATION IS NECESSARY.

NOW LET US SUPPOSE THAT WE HAVE A TUNING CONDENSER WITH A CAPACITY RATING OF .00035 MFD. THIS RATING, AS GIVEN BY THE MANUFACTURER, IS THE MAXIMUM CAPACITY OF THE CONDENSER. SO WITH THIS CONDENSER AT HAND, LET US ASSUME THAT WE ARE REQUIRED TO CONSTRUCT AN R.F. TRANSFORMER, WHOSE SECONDARY WINDING WILL TUNE WITH THIS GIVEN VARIABLE CONDENSER OVER A FREQUENCY RANGE OF APPROXIMATELY 541 KC TO 1500 KC.

THE FIRST THING THAT WE WILL HAVE TO DO IN THIS CASE IS TO DETERMINE THE INDUCTANCE, WHICH IS REQUIRED FOR THE SECONDARY WINDING OF THIS TRANSFORMER. THE MAXIMUM INDUCTANCE WHICH IS REQUIRED IN THIS INSTANCE IS WHEN THE TUNING CONDENSER PLATES ARE ALL THE WAY IN MESH, SO THAT THE CIRCUIT IS TUNED TO THE LOWEST FREQUENCY LIMIT, THAT IS, TO 541 KC. SO WE BEGIN BY LOOKING UP THE "L x C" FACTOR FOR 541 KC IN TABLE III AND WE FIND IT TO BE 0.0867.

SINCE THE VALUE OF "C" IN THIS PROBLEM IS KNOWN TO BE .00035 MFD; THE L x C FACTOR 0.0867; AND SINCE L x C = 0.0867, THEN IT IS ALSO TRUE THAT THE REQUIRED INDUCTANCE "L" $= \frac{0.0867}{C}$ OR $L = \frac{0.0867}{.00035} = 247.71$ MICROHENRIES. SO THE SECONDARY WINDING OF THE TRANSFORMER WHICH WE ARE TO CONSTRUCT MUST HAVE AN INDUCTANCE OF 247.71 MICROHENRIES.

NOW THAT WE HAVE DETERMINED THE INDUCTANCE VALUE, SO THAT THE CIRCUIT WILL RESONATE TO THE LOWEST FREQUENCY LIMIT REQUIRED, OUR NEXT STEP WILL BE TO FIND OUT IF THESE CIRCUIT CONSTANTS WILL ALSO PERMIT THE CIRCUIT TO BE TUNED TO THE HIGHEST FREQUENCY LIMIT, OR 1500 KC. SINCE THE VALUE OF THE INDUCTANCE REMAINS FIXED, IT IS CLEAR THAT THE RESPONSE OF THE CIRCUIT TO THE HIGHEST FREQUENCY WILL BE DETERMINED ENTIRELY BY THE MINIMUM CAPACITY WHICH THE GIVEN TUNING CONDENSER OFFERS.

IF THE CONDENSER MANUFACTURER SPECIFIES THAT HIS .00035 MFD CONDENSER HAS A MINIMUM CAPACITY OF .000038 MFD, THEN ALL THAT YOU HAVE TO DO IS TO MULTIPLY THIS MINIMUM CAPACITIVE VALUE BY THE INDUCTANCE OF YOUR COIL IN ORDER TO FIND THE L x C FACTOR FOR THE HIGHEST FREQUENCY LIMIT. THAT IS, IN OUR PARTICULAR EXAMPLE, THE L x C FACTOR FOR 1500 KC WILL BE AS FOLLOWS: $247.71 \times .000038 = 0.00941298$, OR APPROXIMATELY 0.00941.

THUS, BY LOOKING UP THIS L x C FACTOR IN TABLE III, WE FIND THAT THIS VALUE CORRESPONDS TO A FREQUENCY SOMEWHERE BETWEEN 1579 AND 1667 KC. HENCE THIS INDUCTANCE AND VARIABLE CONDENSER COMBINATION WILL COVER THE RANGE OF FREQUENCIES BETWEEN 541 AND 1500 SATISFACTORILY WITH A LITTLE TO SPARE.

THE MINIMUM CAPACITY OF AVERAGE-TYPE TUNING CONDENSERS

WHENEVER THE EXACT MINIMUM CAPACITY OF A TUNING CONDENSER IS NOT KNOWN, THEN IT IS GENERAL PRACTICE TO ASSUME THE MINIMUM CAPACITY TO BE 10% OR 1/10 THAT OF THE CONDENSER'S RATED OR MAXIMUM CAPACITY. IN OTHER WORDS, WE WOULD CONSIDER A .00035 MFD TUNING CONDENSER AS HAVING A MINIMUM CAPACITY OF .000035 MFD. BY WORKING ON THIS BASIS, WE FIND THAT THE L x C FACTOR FOR THE HIGHEST FREQUENCY LIMIT IN OUR PARTICULAR PROBLEM WOULD BE 1/10 OF THE L x C FACTOR FOR THE LOWEST FREQUENCY LIMIT. THAT IS, THE L x C FACTOR FOR THE 541 KC FREQUENCY AS PER TABLE III IS 0.0867 AND 1/10

OF THIS VALUE IS 0.00867. HENCE, BY LOOKING UP THE LxC FACTOR OF 0.00867 IN TABLE III, WE FIND THAT IT CORRESPONDS TO A FREQUENCY BETWEEN 1667 AND 1764 KC. FROM THIS, WE AGAIN SEE THAT THE 247.71 MICROHENRY INDUCTANCE WILL TUNE SATISFACTORILY WITH THE .00035 MFD. CONDENSER OVER THE 541-1500 KC. RANGE. TABLE III ALSO SHOWS THAT THIS PARTICULAR INDUCTANCE-CONDENSER COMBINATION TUNES OVER A WAVE LENGTH RANGE OF FROM APPROXIMATELY 185 METERS TO 555 METERS, THUS COVERING A LITTLE MORE THAN THE STANDARD BROADCAST BAND.

CALCULATING THE TURNS REQUIRED

IT IS, OF COURSE, IMPOSSIBLE TO CALCULATE THE EXACT NUMBER OF TURNS; BUT BY MEANS OF A LITTLE MATHEMATICS, WE CAN DETERMINE THE APPROXIMATE NUMBER OF TURNS. THEN, AFTER THE COIL IS CONSTRUCTED, ADJUSTMENT CAN BE MADE ON THE WINDING SO AS TO OBTAIN THE EXACT VALUE.

A SIMPLE FORMULA FOR DETERMINING THE APPROXIMATE NUMBER OF TURNS TO USE IS AS FOLLOWS:

$$N^2 = \frac{L\,(3D + 9B)}{0.2D^2}$$

WHERE N = THE NUMBER OF TURNS, L = COIL'S INDUCTANCE IN MICROHENRIES, B = LENGTH OF THE WINDING IN INCHES, D = DIAMETER OF THE WINDING IN INCHES.

FOR THE SAKE OF ILLUSTRATION, LET US ASSUME THAT A COIL DIAMETER OF 3 INCHES IS PRACTICAL FOR THE PROJECT IN QUESTION. KNOWING THE DIAMETER, OUR NEXT STEP IS TO SELECT THE PROPER LENGTH FOR THE COIL.

> RULE: A SINGLE-LAYER SOLENOID WINDING WILL PROVIDE A GIVEN INDUCTANCE WITH THE LEAST AMOUNT OF WIRE WHEN ITS DIAMETER IS 2.46 OR APPROXIMATELY 2.5 TIMES ITS LENGTH. THE COIL WILL THEN HAVE THE LEAST AMOUNT OF RESISTANCE FOR A GIVEN AMOUNT OF INDUCTANCE; THEREBY PROVIDING MAXIMUM EFFICIENCY AND PERMITTING SHARPEST TUNING.

APPLYING THE ABOVE RULE TO OUR PARTICULAR PROBLEM, IT IS EVIDENT THAT IF THE DIAMETER OF THE COIL IS TO BE 2.5 TIMES ITS LENGTH, AND 3 INCHES WAS SELECTED AS THE DIAMETER, THE MOST SUITABLE LENGTH FOR THIS COIL WOULD BE EQUAL TO 3 DIVIDED BY 2.5 OR 1.2 INCHES. THIS WINDING LENGTH TAKES INTO ACCOUNT THE FACT THAT ADJACENT TURNS ARE TO BE APPLIED SIDE BY SIDE, WITH NO SPACING BETWEEN TURNS.

> NOTE: TO CONSERVE SPACE ON THE RECEIVER CHASSIS AND PERMIT AS COMPACT AN ASSEMBLY AS POSSIBLE, THE LENGTH OF PRESENT DAY COILS IS GENERALLY GREATER THAN THEIR DIAMETER. THE BETTER SHIELDING, SHORTER LEADS, ETC., ACCOMPLISHED THROUGH THE USE OF "SLENDER" COILS (AND MODERN HIGH-MU TUBES) MORE THAN COMPENSATES FOR THE LOSS EXPERIENCED BY DEPARTING FROM THE RULE IN ESTABLISHING THE RATIO BETWEEN THE DIAMETER AND LENGTH OF THE COIL.

SINCE WE ARE PRIMARILY INTERESTED IN MAINTAINING COIL EFFICIENCY IN THIS PARTICULAR DISCUSSION, WE WILL WORK OUT THE DESIGN FOR THE COIL HAVING A DIAMETER OF 3 INCHES AND A LENGTH OF 1.2 INCHES. RETURING TO OUR FORMULA, $N^2 = \frac{L(3D + 9B)}{0.2D^2}$, WE HAVE: L = 247.71 MICROHENRIES; D = 3" AND B = 1.2." SUBSTITUTING THESE VALUES IN THE FORMULA:

$$N^2 = \frac{247.71\ [(3 \times 3) + (9 \times 1.2)]}{0.2 \times 3^2} = \frac{247.71\ [(9 + 10.8)]}{1.8}$$

$$N^2 = \frac{247.71 \times 19.8}{1.8} = \frac{4904.658}{1.8} = 2724.81 \text{ THEREFORE,}$$

$$N = \sqrt{2724.81} = 52.2 \text{ OR APPROXIMATELY 52 TURNS.}$$

DETERMINING THE WIRE SIZE TO USE

KNOWING THAT ABOUT 52 TURNS WILL HAVE TO BE WOUND IN A SPACE 1.2" LONG, WE CAN CALCULATE THE TURNS PER INCH BY DIVIDING 52 BY 1.2". THAT IS, 52 ÷ 1.2 = 43.3 TURNS PER INCH. THE NEXT STEP IS TO FIND OUT WHAT KIND OF WIRE CAN BE WOUND AT APPROXIMATELY 43.3 TURNS PER INCH; FOR WHICH INFORMATION, WE REFER TO TABLE II OF THIS LESSON. HERE, YOU WILL FIND THAT #24 B&S SINGLE SILK COVERED WIRE CAN BE WOUND 44 TURNS PER INCH, WHICH IS SATISFACTORY FOR OUR PURPOSE.

SO, FROM ALL THIS INFORMATION WHICH WE HAVE GATHERED, WE WOULD WIND THIS PARTICULAR R.F. COIL WITH 52 TURNS OF #24 SINGLE SILK COVERED WIRE, MAKING THE COIL 3" IN DIAMETER. IN PRACTICE, YOU WILL FIND THAT BY MEANS OF THIS METHOD OF CALCULATION, YOU WILL HAVE A FEW MORE TURNS OF WIRE ON THE COIL THAN YOU ACTUALLY NEED. THIS, HOWEVER, IS PERMISSIBLE BECAUSE WHEN YOU TEST THE INDUCTANCE VALUE, AS WILL BE SHOWN LATER, YOU CAN UNWIND A FEW TURNS IN ORDER TO BRING THE COIL'S INDUCTANCE DOWN TO THE EXACT VALUE. NEVERTHELESS, BY CALCULATING THE APPROXIMATE REQUIRED NUMBER OF TURNS FIRST, YOU HAVE A GOOD IDEA OF THE NUMBER OF TURNS NEEDED; THEN YOU WILL NOT BE WORKING IN THE DARK, SO TO SPEAK, AND SIMPLY GUESSING AS TO HOW MANY TURNS TO PUT ON THE COIL.

WITH RESPECT TO THE CALCULATED COIL VALUES, ONE MUST ALSO CONSIDER THE FACT THAT THE R.F. TRANSFORMER SHIELD CANS HAVE A TENDENCY TO INCREASE THE "EFFECTIVE INDUCTANCE" OF THE TRANSFORMER WINDINGS DUE TO THE ADDITIONAL CAPACITY EFFECT WHICH THE SHIELD CANS OFFER. THIS MEANS THAT WHEN TESTING THE FINISHED TRANSFORMERS WITH THE SHIELD CANS IN PLACE, ONE WILL FIND IT NECESSARY TO REMOVE A FEW TURNS FROM THE SECONDARY WINDINGS IN ORDER TO COMPENSATE FOR THE ADDITIONAL CAPACITY INTRODUCED BY THE SHIELD CANS.

THE ABOVE CONDITION CAN BE READILY DETERMINED BY NOTING HOW THE FINISHED TRANSFORMER PERMITS THE TUNING CONDENSER TO COVER THE DESIRED RANGE WITH THE SHIELD CANS IN POSITION. IF, UNDER THESE CIRCUMSTANCES, IT IS FOUND THAT THE BROADCAST STATION OF LOWEST FREQUENCY CAN BE TUNED IN WITHOUT THE TUNING CONDENSER PLATES BEING COMPLETELY MESHED, WHILE AT THE SAME TIME THE STATIONS OCCUPYING THE HIGHER FREQUENCY RANGES IN THE BAND CANNOT BE OBTAINED WITH THE CONDENSER PLATES ALL THE WAY OUT OF MESH, THEN THE TEST INDICATES THAT THE INDUCTANCE OF THE R.F. TRANSFORMER SECONDARY WINDINGS IS TOO GREAT. THEREFORE, IT BECOMES NECESSARY TO REMOVE SECONDARY TURNS UNTIL THE DESIRED BAND OF FREQUENCIES CAN BE PROPERLY COVERED.

SIMPLIFIED COIL FORMULAS

A SIMPLE FORMULA FOR DETERMINING THE INDUCTANCE OF A PLAIN SINGLE LAYER SOLENOID TYPE COIL, AND WHICH CAN BE APPLIED VERY EASILY IS AS FOLLOWS: $L = \frac{A^2 N^2}{9A + 10B}$ WHERE L IS THE INDUCTANCE EXPRESSED IN MICROHENRIES, N THE TOTAL NUMBER OF TURNS, "B" THE WINDING LENGTH IN INCHES AND "A" BEING ½ THE COIL DIAMETER EXPRESSED IN INCHES. THESE DIMENSIONS ARE ALL INDIC

ATED IN FIG. 4 SO THAT THERE WILL BE NO DOUBT IN YOUR MIND CONCERNING THEM.

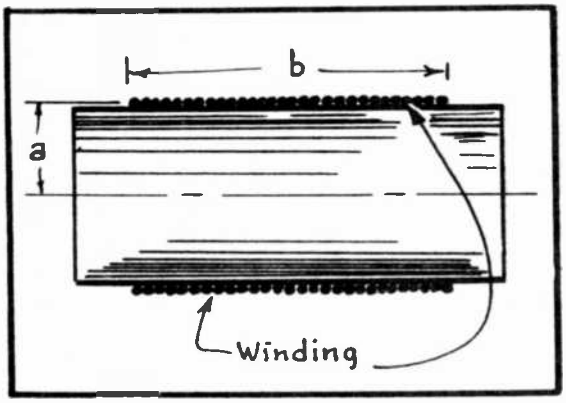


FIG. 4
The Plain Solenoid

FOR INSTANCE, IF THE COIL IN FIG. 4 CONSISTS OF 60 TURNS OF WIRE AND THE DIMENSIONS "A" AND "B" ARE 1" AND 3" RESPECTIVELY, THEN BY SUBSTITUTING THESE VALUES IN THE PRECEDING FORMULA, WE HAVE AS FOLLOWS:

$$L = \frac{1^2 \times 60^2}{(9 \times 1) + (10 \times 3)} = \frac{3600}{9 + 30} = \frac{3600}{39} = 92.3 \text{ MICROHENRIES.}$$

SHOULD THE WINDING IN QUESTION BE OF THE MULTI-LAYER TYPE AND HAVE A CROSS-SECTION AS ILLUSTRATED IN FIG. 5, SUCH AS MIGHT BE USED IN THE INTERMEDIATE-FREQUENCY TRANSFORMER OF A SUPERHETERODYNE RECEIVER, THEN YOU CAN CALCULATE ITS INDUCTANCE BY EMPLOYING THE FOLLOWING FORMULA: $L = \frac{.8A^2N^2}{6A + 9B + 10C}$, WHERE L = THE INDUCTANCE IN MICROHENRIES, N THE TOTAL NUMBER OF TURNS AND "A", "B" AND "C" THE DIMENSIONS AS SPECIFIED IN FIG. 5, EACH OF WHICH IS EXPRESSED IN INCHES.

ASSUMING, FOR INSTANCE, THAT SUCH A COIL CONSISTS OF 800 TURNS, "A" BEING .5"; "C", .5"; AND "B", .4". SUBSTITUTING THESE VALUES IN OUR FORMULA, WE HAVE

$$L = \frac{.8 \times .5^2 \times 800^2}{(6 \times .5) + (9 \times .4) + (10 \times .5)} = \frac{.8 \times .25 \times 640000}{3 + 3.6 + 5} = \frac{128{,}000}{11.6} =$$

11,034.4 MICROHENRIES, APPROX. 11 MILLIHENRIES.

FINALLY, IF THE COIL IS IN THE FORM OF A HELICAL OR SPIRAL WINDING SUCH AS FREQUENTLY USED FOR A PRIMARY WINDING OF AN R.F. TRANSFORMER, AS AN ANTENNA COUPLING, ETC., THE CROSS SECTION OF WHICH APPEARS IN FIG. 6, THEN YOU CAN USE THE FORMULA $L = \frac{A^2N^2}{8A + 11C}$ IN WHICH CASE L IS AGAIN THE INDUCTANCE IN MICROHENRIES, N THE TOTAL NUMBER OF TURNS IN THE WINDING AND "C" AND "A" THE DIMENSIONS DESIGNATED IN FIG. 6 AND EXPRESSED IN INCHES.

IN THIS CASE, IF 300 TURNS ARE USED AND DIMENSIONS "A" AND "C" ARE .5" AND .1", RESPECTIVELY, THEN

$$L = \frac{.5^2 \times 300^2}{(8 \times .5) + (11 \times .1)} = \frac{.25 \times 90000}{4 + 1.1} = \frac{22500}{5.1} = 4411.7 \text{ MICROHENRIES OR } 4.41 \text{ MILLIHENRIES}$$

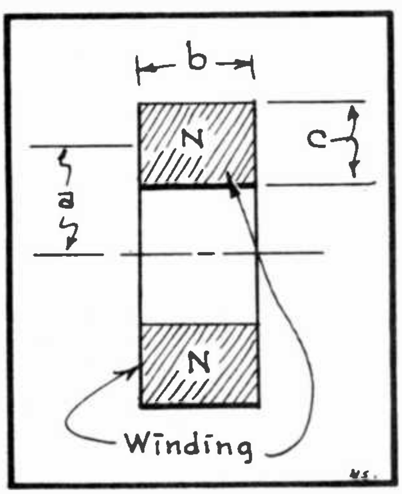


FIG. 5
The Multi-Layer Winding.

DESIGNING SINGLE-LAYER SOLENOID COILS BY MEANS OF GRAPHS

THE TASK OF DESIGNING SINGLE-LAYER SOLENOID COILS, WHICH ARE THE MOST EXTENSIVELY USED TYPE OF TUNED WINDING FOR R.F. TRANSFORMERS, CAN BE STILL FURTHER SIMPLIFIED THROUGH THE USE OF CHARTS AND GRAPHS. WITH THIS METHOD, CALCULATION IS ELIMINATED ENTIRELY.

IN TABLE IV, FOR EXAMPLE, YOU ARE GIVEN A CHART WHEREBY YOU CAN DETERMINE TO WHAT FREQUENCY ANY GIVEN CONDENSER AND COIL COMBINATION WILL RESONATE IN A MOST SIMPLE MANNER.

THE VERTICAL LINE AT THE LEFT OF TABLE IV IS CALIBRATED FOR CAPACITY EXPRESSED IN MICRO-MICROFARADS, THE VERTICAL LINE AT THE CENTER FOR FREQUENCY IN KILOCYCLES AND THE VERTICAL LINE AT THE RIGHT FOR INDUCTANCE IN MICROHENRIES. NOW THEN, YOU CAN DETERMINE ANY ONE OF THESE THREE VALUES IN TERMS OF THE OTHER TWO, SIMPLY BY CONNECTING THE TWO KNOWN VALUES TOGETHER WITH A STRAIGHT EDGE OR RULER AND NOTING THE POINT AT WHICH IT CROSSES THE THIRD VERTICAL LINE FOR THE VALUE BEING SOUGHT.

FOR INSTANCE, IF YOU WANT TO KNOW TO WHAT FREQUENCY A .00035 MFD. CONDENSER AND A 240 MICROHENRY COIL WILL RESONATE, SIMPLY LAY A STRAIGHT EDGE ACROSS TABLE IV SO THAT IT CUTS THROUGH THE CAPACITY LINE AT THE 350 MARK (.00035 MFD = 350 MMFDS.) AND THE INDUCTANCE LINE AT THE 240 MARK. THIS POSITION OF THE STRAIGHT EDGE IS INDICATED BY THE DOTTED LINE IN TABLE IV. AS YOU WILL OBSERVE, THE STRAIGHT EDGE WILL CUT THE FREQUENCY LINE AT THE 550 MARK, WHICH MEANS THAT THIS PARTICULAR CONDENSER AND COIL COMBINATION WILL RESONATE AT 550 KC.

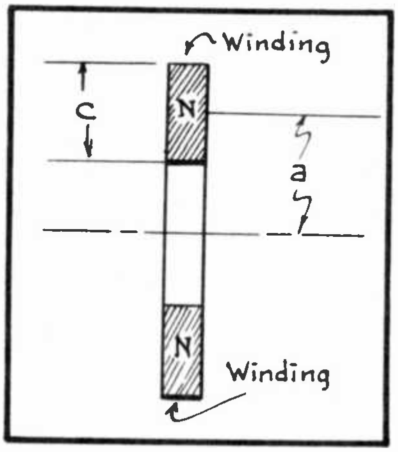


FIG. 6
The Helical Winding

YOU CAN ALSO USE THIS CHART IN STILL OTHER WAYS. FOR EXAMPLE, IF YOU HAVE A .00035 MFD. TUNING CONDENSER AND WANT TO KNOW HOW MUCH INDUCTANCE TO USE TO CONSTRUCT A CIRCUIT WHICH WILL RESONATE AT 550 KC., THEN LAY THE STRAIGHT EDGE THROUGH THE 350 MMFD. AND THE 550 KC. MARKS AND NOTE WHERE IT PASSES THROUGH THE INDUCTANCE LINE. THIS POINT ON THE INDUCTANCE LINE TELLS YOU THE INDUCTANCE EXPRESSED IN MICROHENRIES — 240 MICROHENRIES IN THIS PARTICULAR CASE.

HAVING THUS ESTABLISHED THE CORRECT RELATION BETWEEN CAPACITY, INDUCTANCE AND FREQUENCY, YOU CAN DETERMINE THE REST OF THE COIL DESIGN CONSTANTS WITH THE CHART IN TABLE V, AIDED BY THE INFORMATION OBTAINED FROM TABLE II.

TO BETTER EXPLAIN THE USE OF TABLE V, LET US EMPLOY A SPECIFIC PROBLEM, NAMELY TO DETERMINE THE DESIGN DATA FOR THE 240 MICROHENRY WINDING WHICH WE HAVE JUST BEEN DEALING WITH. WE SHALL ASSUME THAT THIS COIL IS TO BE WOUND WITH #28 B&S ENAMELED WIRE AND ON A FORM 2" IN DIAMETER.

BY FIRST REFERRING TO TABLE II, YOU WILL NOTICE THAT THIS PARTICULAR WIRE CAN BE WOUND AT APPROXIMATELY 74 TURNS PER INCH.

THE NEXT STEP IS TO LAY A STRAIGHT EDGE UPON THE CHART OF TABLE V SO THAT IT WILL PASS THROUGH THE 240 MARK ON THE INDUCTANCE LINE AND THROUGH THE FORM DIAMETER LINE AT THE POINT MARKED "2". THE POSITION OF THE STRAIGHT EDGE AT THIS TIME IS INDICATED BY THE DOTTED LINE #1. WITH THE STRAIGHT EDGE IN THIS POSITION, CAREFULLY NOTE THE POINT OF INTERSECTION ON THE "TURNING SCALE".

TABLE IV

RELATION BETWEEN FREQUENCY, INDUCTANCE AND CAPACITY

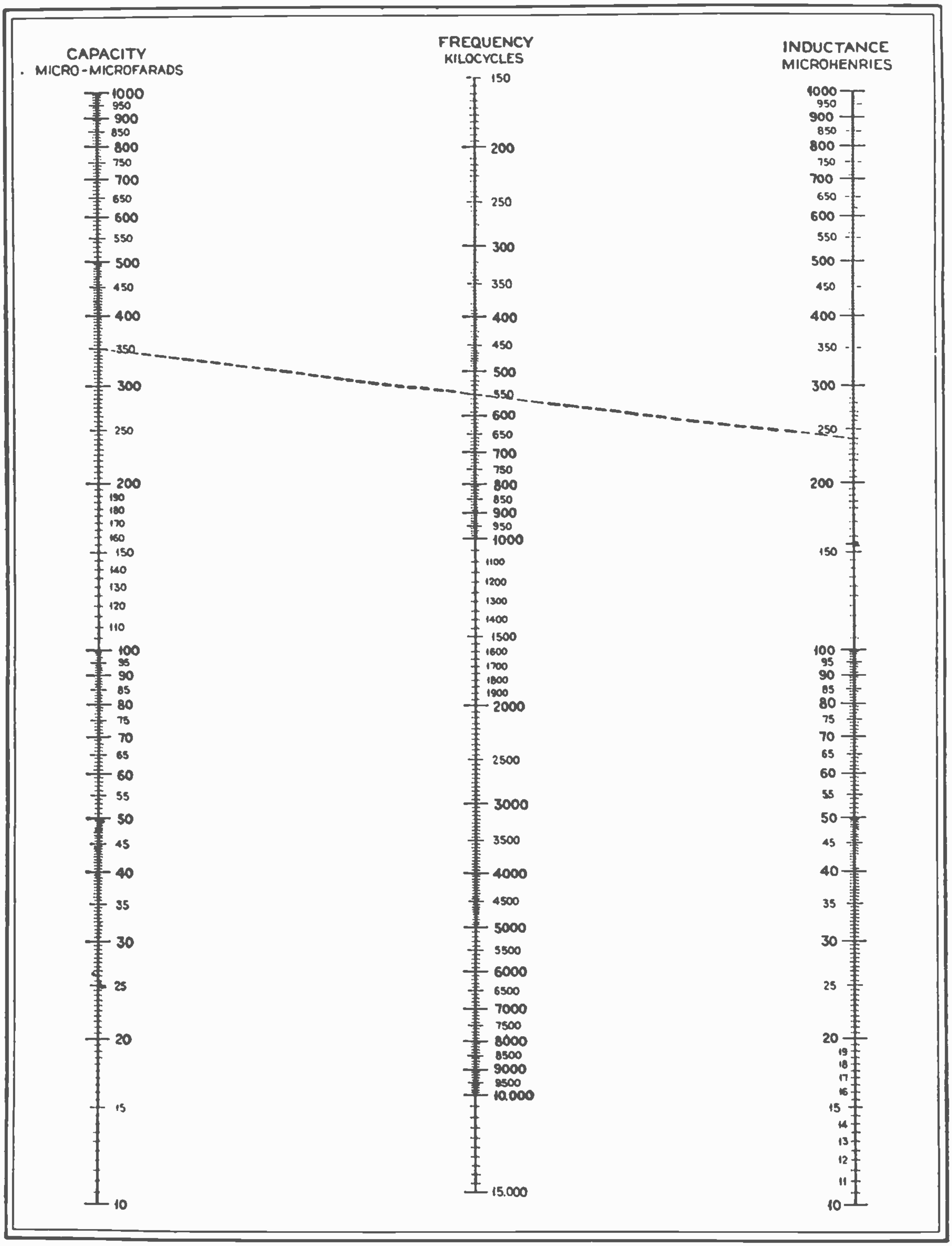
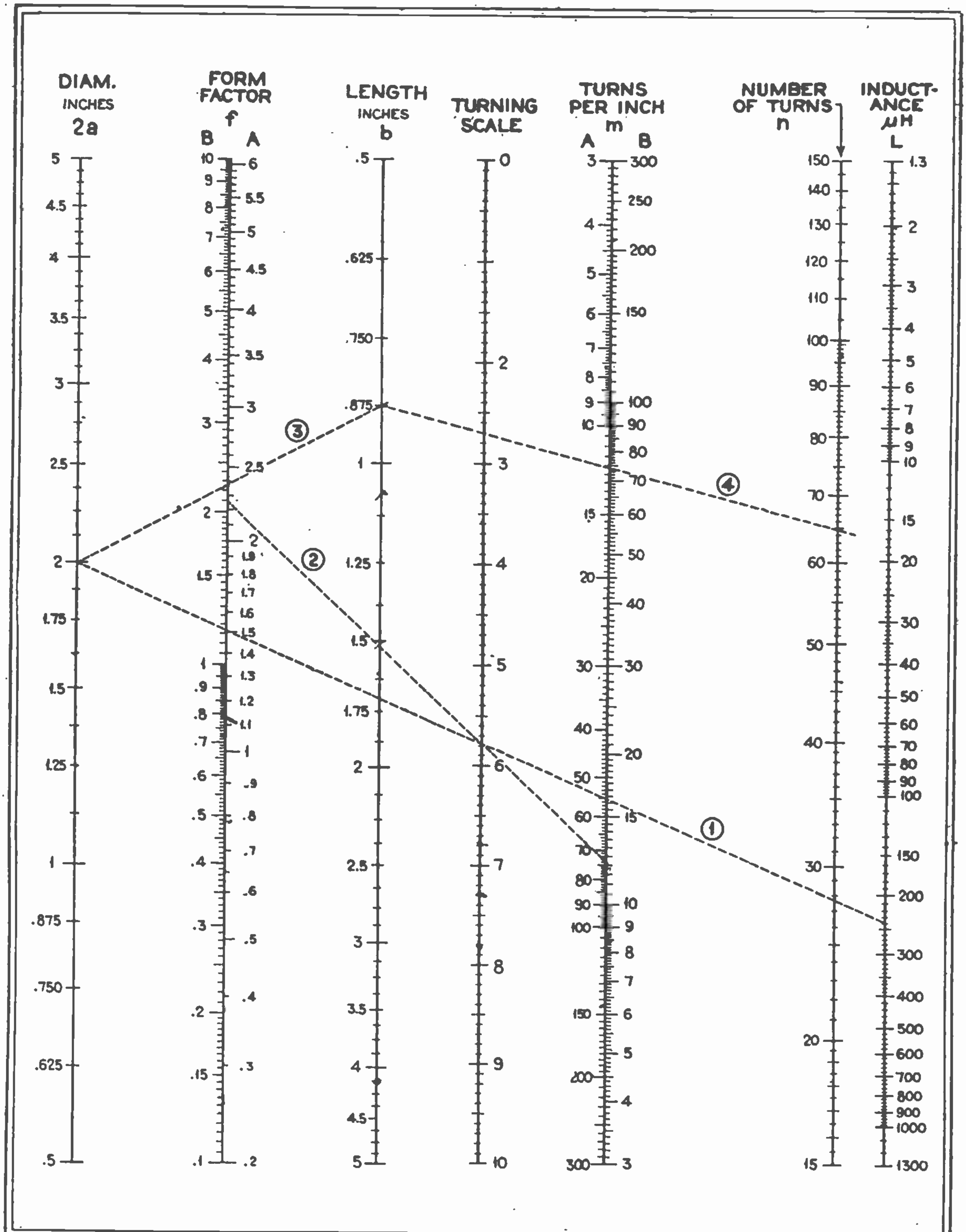


TABLE V

THE DESIGN OF SINGLE-LAYER SOLENOID COILS



Now pass your straight edge through this same point on the turning scale as well as through the 74 mark on the "A" scale of the "turns per inch" line. The position of the straight edge will now be as indicated by the dotted line #2. Notice carefully at this instant, where the straight edge intersects the "A" scale of the "form factor line" — you will find it to be 2.25 for our present example.

The next step is to pass the straight edge through the 2 mark of the diameter line and through the 2.25 mark on the "B" scale of the "form factor line" as shown by the dotted line #3. Observe where it intersects the "length" line — this you will find to be the .875 mark. This means that the length of this winding is .875" or approximately 7/8".

The final step is to lay the straight edge through the .875 mark of the "length" line and the 74 mark on the "B" scale of the turns per inch line as shown by dotted line #4. Now observe where the straight edge intersects the "number of turns" line and you will find it to be at the 65 mark. In other words, for the particular coil under our immediate attention, we would employ 65 turns of #28 B&S enameled wire wound on a form 2" in diameter and to a winding length of 7/8".

You can work out any similar problem by means of these charts in the same manner as just explained. Theoretically, the most efficient coil has a form factor of 2.46. However, since the efficiency does not fall off very rapidly on both sides of this value, we can accept as the best range for the form-factor from 1.5 to 4.

If you wish to design your coils starting with a definite form-factor, you can still do so with the same chart in TABLE V. For example, if we should set the form-factor to a value of 2.25 rather than starting with the wire size, then for the second position of the straight edge, we would run it through the 2.25 mark on the "A" scale of the form factor line and thru the previously determined point on the "turning scale" and note the point at which it intersects the "A" scale of the "turns per inch" line. By thus finding the turns per inch to be 74, we find by reference to TABLE II that we can use either #28 B&S enameled wire or a #36 B&S double cotton covered wire. All other operations will remain the same as already described.

ANOTHER FORM OF COIL DESIGN GRAPH

Radio concerns, who engage in the manufacture of R.F. transformers, have gained a great deal of knowledge and data which they accumulated over a period of years. From the information obtained from these previous experiences, most of them plot "coil design graphs" for future use. An example of such a graph is shown you in Fig. 7 and this graph applies only to a single layer solenoid type coil 2.75" in diameter.

This graph, as you will note, consists of cross-ruled paper, which is also known as "graph-paper". The number of turns required for various inductances are marked along the bottom of the graph, starting with "0" at the far left. Each of the heavier vertical lines are then successively marked 10-20-30 etc. toward the right. You will find that there are 10 thinner vertical lines between each pair of the numbered vertical lines and each of these thin vertical lines stands for 1 turn of wire. Thus the

VERTICAL LINE HALF WAY BETWEEN THE NUMBER 30 AND 40 WILL SIGNIFY 35 TURNS ETC.

THE REQUIRED INDUCTANCES OF THE COILS ARE MARKED ALONG THE RIGHT EDGE OF THE GRAPH AS 100 MICROHENRIES, 200 MICROHENRIES ETC., FROM THE BOTTOM TOWARD THE TOP. IN THIS CASE, THE INDUCTANCE INCREASES BY 5 MICROHENRIES AS WE MOVE UPWARD 1 HORIZONTAL LINE AT A TIME. HENCE THE HEAVY HORIZONTAL LINE BETWEEN THE VALUES OF 200 AND 300 MICROHENRIES WILL REPRESENT 250 MICROHENRIES.

NOW LET US SEE HOW SUCH A COIL DESIGN GRAPH IS USED. SUPPOSE, FOR EXAMPLE, THAT WE WISH TO CONSTRUCT A SINGLE LAYER, CLOSELY WOUND (TURNS PLACED SIDE BY SIDE WITH NO SPACING) COIL 2.75" IN DIAMETER WITH AN INDUCTANCE OF 300 MICROHENRIES BY MEANS OF THIS GRAPH. TO DO THIS, WE BEGIN BY LOOKING ALONG THE RIGHT HAND EDGE OF THIS GRAPH UNTIL WE COME TO THE HORIZONTAL LINE WHICH IS MARKED 300.

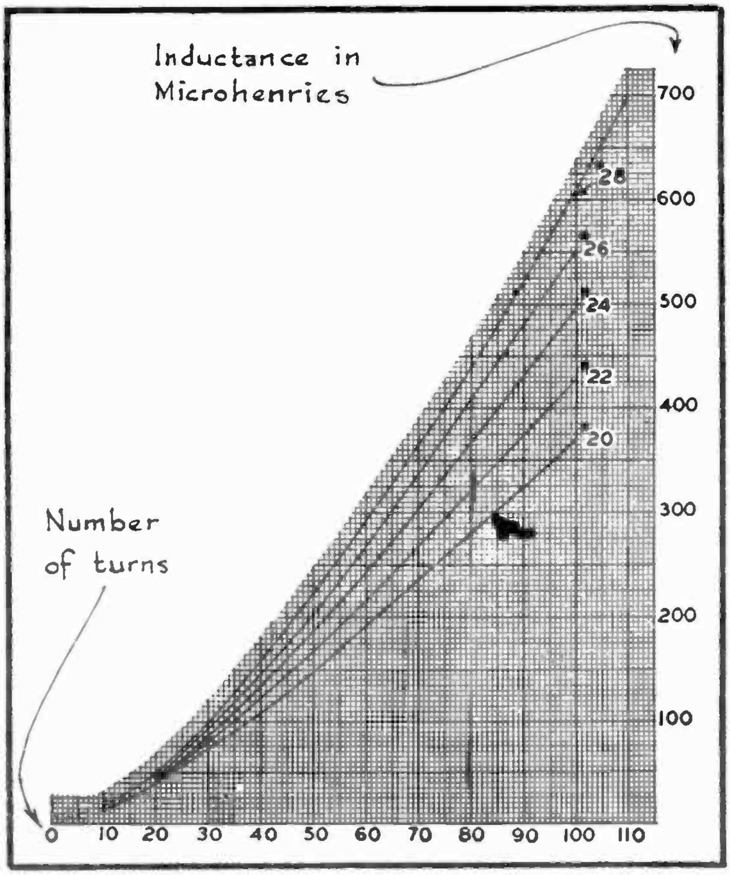


FIG. 7

Example of a Coil Design Graph.

NOW THEN, YOU WILL SEE THAT FIVE CURVED LINES, WHICH ARE RESPECTIVELY MARKED #20, #22, #24, #26 AND #28, CROSS THIS GRAPH IN A DIAGONAL FASHION. IF WE WISH TO WIND THIS 300 MICROHENRY COIL WITH #20 WIRE, WE NOTE THE POINT AT WHICH THE CURVED LINE MARKED #20 CROSSES THE "300" HORIZONTAL LINE. FOR YOUR CONVENIENCE, WE ARE INDICATING THIS POINT IN FIG. 7 WITH AN ARROW. NOW IF YOU WILL MOVE YOUR PENCIL POINT STRAIGHT DOWN FROM THIS POINT, YOU WILL FIND ACCORDING TO THE NUMBERS ALONG THE BOTTOM OF THE GRAPH THAT APPROXIMATELY 84½ TURNS OF #20 WIRE ARE REQUIRED TO WIND A COIL OF THIS SIZE SO AS TO HAVE AN INDUCTANCE OF 300 MICROHENRIES.

SHOULD YOU WISH TO USE #22 WIRE TO CONSTRUCT THIS 300 MICROHENRY COIL OF 2.75" DIAMETER, THEN NOTE WHERE THE CURVED LINE LABELED #22 CROSSES THE "300" HORIZONTAL LINE. YOU WILL FIND THAT THE #22 LINE CROSSES THE "300" LINE ON A VERTICAL LINE OF THE GRAPH WHICH CORRESPONDS TO 76 TURNS. THUS ONLY 76 TURNS OF #22 WIRE IS REQUIRED. THIS GRAPH HAS BEEN WORKED OUT FOR DOUBLE SILK-COVERED WIRE OF THE DESIGNATED SIZES ONLY.

FOR COILS OF A DIFFERENT DIAMETER, OR FOR WIRE OF A DIFFERENT TYPE

OF INSULATION, ANOTHER GRAPH IS REQUIRED. THUS IT IS OBVIOUS THAT COIL MANUFACTURERS HAVE MANY OF SUCH COIL DESIGN GRAPHS IN THEIR FILES TO WHICH THEY CAN REFER. BY MEANS OF SUCH GRAPHS, IT IS CLEAR THAT COILS CAN BE DESIGNED RAPIDLY WITHOUT THE NEED OF LENGTHY CALCULATIONS, THEREBY RESULTING IN A GREAT SAVING OF TIME. OTHER GRAPHING METHODS HAVE ALSO BEEN WORKED OUT AND THEIR USE WILL BE APPARENT UPON INSPECTION.

IN THIS LESSON, WE HAVE DISCUSSED BOTH THE CALCULATION AND GRAPH METHODS OF DESIGNING R.F. TRANSFORMER SECONDARY WINDINGS, SO THAT YOU WILL HAVE A KNOWLEDGE OF BOTH OF THESE METHODS. THUS IF YOU ARE PROVIDED WITH DATA FOR EITHER OF THESE TWO METHODS AT SOME FUTURE TIME, YOU WILL HAVE NO DIFFICULTY IN EFFECTING A SOLUTION BECAUSE YOUR KNOWLEDGE OF THE SUBJECT IS NOW QUITE THOROUGH.

Examination Questions

1. - WHAT IS MEANT BY THE EXPRESSION "SOLENOID TYPE WINDING"?
2. - IF A CERTAIN R.F. TRANSFORMER SECONDARY WINDING IS 4" LONG AND HAS A DIAMETER OF 2", WHAT IS ITS "SHAPE FACTOR"?
3. - IF YOU ARE GOING TO WIND A COIL WITH #30 B&S ENAMELED WIRE WITHOUT ANY SPACING BETWEEN ADJACENT TURNS, THEN HOW MANY TURNS OF THIS WIRE WILL YOU BE ABLE TO WIND PER INCH OF THE WINDING LENGTH?
4. - IF A CIRCUIT IS TO BE TUNED TO 600 KC. WHAT WILL BE ITS "L C" FACTOR OR CONSTANT?
5. - IF A VARIABLE CONDENSER IS SPECIFIED AS HAVING A .0005 MFD. CAPACITY RATING, WHAT WILL BE ITS APPROXIMATE MINIMUM CAPACITY?
6. - IF FROM THE COIL DESIGN GRAPH OF FIG. 7, YOU WANTED TO CONSTRUCT A COIL 2.75" IN DIAMETER AND HAVING AN INDUCTANCE OF 400 MICROHENRIES, HOW MANY TURNS OF #22 B&S SILK COVERED WIRE WOULD YOU USE?
7. - IS THE LENGTH OF A SOLENOID TYPE COIL ASSUMED TO BE THE SAME AS THE LENGTH OF THE FORM UPON WHICH IT IS WOUND?
8. - IF YOU SHOULD WISH TO CONSTRUCT AN R.F. TRANSFORMER TO COVER THE BROADCAST BAND WHEN USED WITH A STANDARD TUNING CONDENSER OF .00035 MFD. RATING, WHAT INDUCTANCE VALUE SHOULD THE SECONDARY WINDING OF THIS R.F. TRANSFORMER HAVE?
9. - IF A CERTAIN SOLENOID WINDING IS 1" IN DIAMETER AND IS WOUND WITH 180 TURNS OF WIRE AT 90 TURNS PER INCH, WHAT WILL BE THE APPROXIMATE INDUCTANCE VALUE OF THIS WINDING?
10. - ASSUME THAT A TUNING CONDENSER OF .00035 MFD. IS AVAILABLE, TOGETHER WITH A COIL FORM OF 1¼" DIAMETER. THE WIRE TO BE USED FOR THE TUNED WINDING IS #30 B&S ENAMEL COATED. HOW MANY TURNS OF THIS WIRE WILL BE REQUIRED SO THAT THIS COIL AND CONDENSER COMBINATION WILL COVER THE BROADCAST BAND WITH 550 KC. BEING THE LOWEST FREQUENCY? (WORK OUT THIS PROBLEM WITH THE AID OF TABLES IV, AND V AS GIVEN IN THIS LESSON.)

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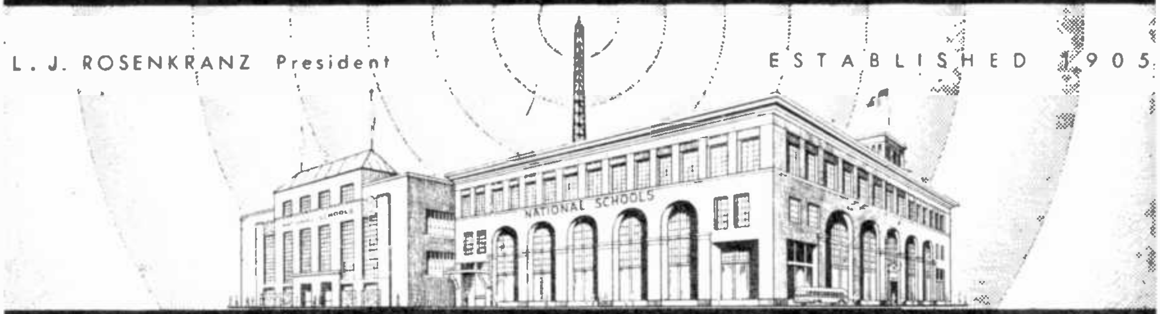

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LESSON NO. 43

PRE-SELECTOR AND BAND-PASS CIRCUITS

In the pioneering days of radio, the problem of SELECTIVITY was almost a negligible factor since, (1) there were fewer broadcasting stations, (2) these were spread comparatively far apart throughout the broadcast frequency band and (3) they did not possess the radiating power of the modern broadcast station transmitter.

The receiving range of a radio receiving set was of greatest importance in "them th'ar days"; and, since the amplification factor of the early type tubes was relatively low, receivers were equipped with many stages of r-f amplification to increase their sensitivity. Each stage of r-f amplification included a tuned circuit so that even though the number of broadcast stations increased, as time went on, these receivers provided satisfactory selectivity because of the number of r-f tuned circuits employed between the antenna and the detector stage.

However, with the advent of the extremely high-mu tubes (tubes that are extremely sensitive and provide a high ratio of amplification), and because of the greatly increased amount of power employed by modern broadcasting stations, we no longer find

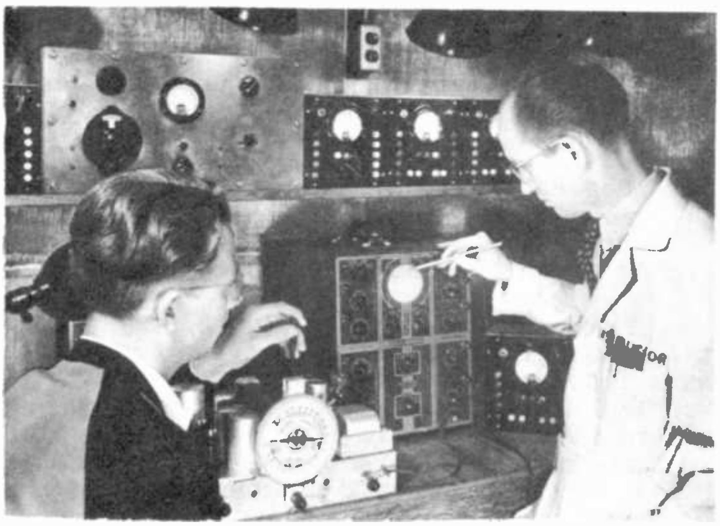

FIG. 1
OSCILLOSCOPE USED IN ALIGNING RECEIVER EQUIPPED WITH BAND-PASS SELECTOR CIRCUIT

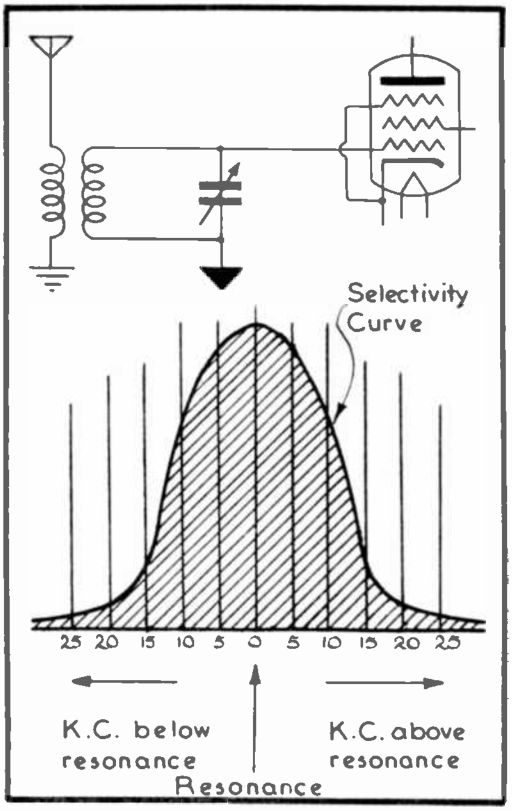

FIG. 2
TUNING RESPONSE OF A SINGLE TUNED CIRCUIT

it necessary to use many stages of r-f amplification. Most of the smaller receivers of today, therefore, have no more than one or two stages of r-f amplification.

Because of this, the selective properties of the receiver are impaired since, by reducing the number of r-f stages, we have automatically reduced the number of tuned circuits. Of course, as a compensatory measure we may employ a loop antenna (as is done in many modern receivers), but there are many instances where a loop antenna is not desirable--or feasible; and so many receiver manufacturers often resort to the use of a BAND-PASS type of selector circuit--or "pre-selector" circuit, as it is sometimes referred to.

Band-pass selector circuits have another desirable feature in that they not only provide an extremely effective means of improving the selectivity of a receiver, but can be designed in such a manner as to allow passage to a specific number of "side-band" frequencies (audio-frequency modulations impressed upon the carrier-frequency). This means that by properly designing a band-pass "pre-selector" circuit, we can enjoy excellent selectivity between stations without cutting off or suppressing any of the higher audio-frequency notes transmitted during a radio broadcast program; a feature which the ordinary type of selector circuit can hardly equal--and, a feature that closely approaches the IDEAL tuning circuit.

Technically speaking, the band-pass type of selector circuit provides a flatter response-curve with steeper sides than can be obtained with a single-tuned circuit; thus providing more uniform amplification over a wider range of frequencies, with sharp cut-off so as to reject undesired frequencies.

THE SIMPLE TUNED CIRCUIT

Before analyzing the various types of band-pass selector circuits --often referred to as band-pass filter circuits or "b-p" filters-----let us pause for a moment and consider the selectivity curve of a simple tuning circuit, such as is illustrated in the upper portion of Fig. 2.

In the graph shown in Fig. 2, the vertical line marked "0" indicates the RESONANT FREQUENCY. Each vertical line toward the right of the "0" mark indicates an INCREASE of 5 kc ABOVE the resonant frequency. Each vertical lines toward the left of "0" indicates a DECREASE of 5 kc BELOW the resonant frequency. By observing the width of this selectivity curve, you will note that it extends 25 kc on each side of the resonant frequency. Since standard broadcast stations are assigned to a frequency channel only 10 kc wide, it is obvious that the selectivity of such a tuned circuit would be quite inadequate; and, that there would be considerable interference between stations. Such poor selective qualities are referred to as "broad" tuning.

MULTIPLE TUNED CIRCUITS

By increasing the number of tuned r-f stages, as shown in the upper portion of Fig. 3, we thereby increase the selective properties of the receiver somewhat, as illustrated by the selectivity curve in the lower portion of Fig. 3. In doing so, however, we must take precautions that the tuning circuit of the receiver does not become too selective; otherwise, the FIDELITY of the receiver will suffer. How the fidelity of a receiver may be detrimentally affected by tuning circuits that tune "too sharply", will now be explained.

SIDE-BAND SUPPRESSION

SIDE-BANDS

In the case of Amplitude-Modulation (A-M), the broadcast signal wave carries not only the assigned carrier-wave frequency but, in addition, "side-frequencies". These side-frequencies are created by the audio-frequency modulations that have been impressed upon the carrier-frequency wave at the broadcast station transmitter.

The manner in which the "side-frequencies" accompany the carrier wave is as follows:

> For example, if the frequency of the carrier-wave is 1000 kc and we modulate it with a 1000 cycle (1 kc) note, two side frequencies are created; one whose frequency is 1 kc LOWER than the carrier frequency and the other, 1 kc HIGHER than the carrier frequency. Consequently, this 1000 cycle note will be heard from a point of 999 kc on the tuning dial (1000 kc - 1 kc = 999 kc) to 1001 kc (1000 kc + 1 kc = 1001 kc).

As you probably realize, broadcast-station programs do not merely consist of one single tone but of many (musical or voice) audio frequencies. In that case, the side-frequencies are not confined to a mere SINGLE upper and lower side-frequency but by a BAND of upper and lower side-frequencies. Hence, the term "side-<u>bands</u>" when referring to these side-frequencies.

Although the audio-frequency scale or range is considered to extend up to approximately 20,000 cycles, sounds having frequencies higher than 5000 cycles are seldom transmitted by the majority of broadcast stations. For this reason, a tuning circuit that passes a 10 kc (10,000 cycle) band is considered to be satisfactory for receiver use.

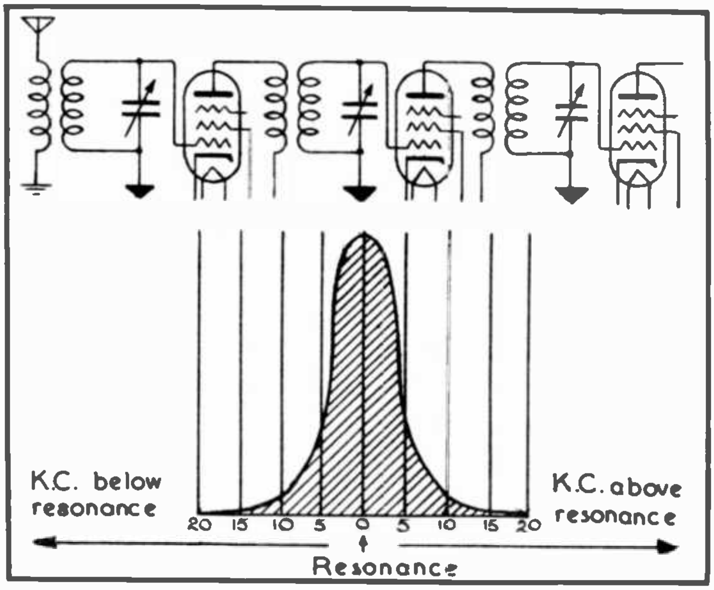

FIG. 3
TUNING RESPONSE OF MULTIPLE-TUNED CIRCUITS

Should the selectivity of the receiver be too sharp, it is apparent that the FIDELITY of the receiver will be impaired. For example, if the selectivity curve is only 5 kc wide at the resonant point, audio-frequency signals up to 2,500 cycles will be permitted to enter into the tuned circuit; thereby

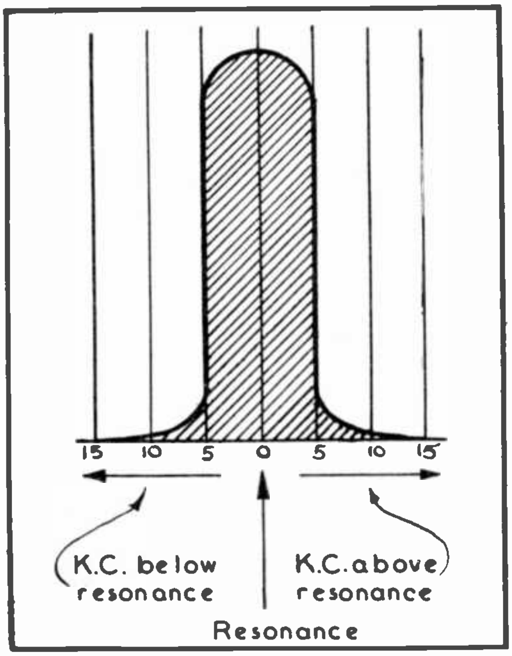

FIG. 4
IDEAL SELECTIVITY CURVE

"suppressing" all notes and tones above this frequency. When a portion of the audio-frequency notes are suppressed by the tuned circuits of a receiver in this fashion, we refer to such a condition as "side-band suppression"; a feature which is highly undesirable in those receivers designed for faithful reproduction of all audio-frequency tones transmitted by the broadcast station(High-fidelity receivers).

Side-band suppression is, however, a desirable feature in the reception of unmodulated, C-W Commercial or Amateur telegraph signals (code). The transmission bands used for these purposes are extremely crowded; hence, selectivity between stations is of paramount importance in such cases. Furthermore, the range of radio-frequencies handled in this type of communication is not as great as is the case during the transmission and reception of musical programs.

THE IDEAL SELECTIVITY CURVE

Up to this point in our discussion, we have considered selectivity from two extremes: (1) too broad tuning--as offered by the conventional type of single-tuned circuit; and (2) too sharp tuning, as offered by the use of too many tuned stages. The happy medium or IDEAL type of tuning curve is shown in Fig. 4. By closely analyzing this curve, you will note that the sides are perpendicular and the curve is confined (practically) to a 10 kc width throughout its entire length.

Such an ideal selectivity curve denotes that the receiver is capable of affording complete separation between broadcast stations without suppressing any of the audio-frequency notes or "side-bands"; thus, providing faithful or high-fidelity reception. A receiver possessing such ideal tuning characteristics is spoken of as offering "10 kc separation". How the tuning characteristics of the band-pass type selector circuits may be designed to approach this ideal condition will now be explained.

Q FACTOR--SHARPNESS OF RESONANCE

There is an extremely important property of a coil--and also of the tuning condenser--that greatly affects the sharpness or selectivity of a tuned circuit. This property is known as the Q-FACTOR which, mathematically, is expressed as:

$$Q = \frac{X}{R}$$

By analyzing the above equation closely, we can see that the Q of a coil--or condenser--is the ratio of the reactance (X) to the resistance (R). Since the Q of the condenser far surpasses that of the best coil, it is the coil that generally limits the overall Q of the entire tuning circuit.

As we pointed out, the sharpness of tuning is determined by the Q of the circuit; more specifically, by the resistance contained within the circuit. The lower the resistance, the sharper will be the tuning and the less amount of signal loss will be encountered in that circuit. Hence, to realize maximum selectivity and minimum loss within a tuning circuit, it would be to our advantage to employ all methods of keeping the resistance at a minimum; thereby maintaining a high Q level within the circuit.

Some of the factors that determine the Q of a coil are:

1. Surface area:

As the frequency of the current flowing through a conductor is increased, the resistance of that conductor is increased. The reason for this is primarily due to what is known as SKIN-EFFECT, which may be explained as follows:

As the frequency of the current is increased, the current flow is confined more and more towards the SURFACE of the conductor rather than within the center of the conductor. Consequently, as the frequency is increased, the effective conducting (cross-sectional) area of our conductor is decreased which, automatically, increases the resistance of the conductor. This, in effect, is the same as though we were to physically drill out the center of our wire so that there is now less conducting area to carry the current.

One popular theory regarding the skin-effect of conductors, is as follows:

When a d-c voltage of constant intensity (such as obtained from a battery) is applied to a conductor, the current flow through the conductor builds up from zero to its maximum value. The time-period involved is, of course, determined by the impedance of the conductor.

During the interval that the e.m.f. is applied to the conductor--to the moment that current attains its full, maximum value the current distribution throughout the conductor is not uniform. This is due to self-induced e.m.f.'s in the wire, caused by the building up of a magnetic field within itself (self-induction). Such self-induced voltages tend to oppose the current flow in the center part of the wire moreso than they oppose the current flowing towards the surface, resulting in what we refer to as the "skin-effect".

When dealing with high-frequency currents, we are dealing with currents that are varying continuously--at an extremely rapid rate. The magnetic field surrounding the conductor varies in step with the frequency of the current. The resultant self-induced e.m.f.'s thereby become appreciable as the frequency is increased; consequently, increasing the skin-effect and the resistance of the wire. Also, since the heat developed within a conductor carrying current is proportional to the square of the current, it is readily apparent how the heat rises rapidly as the conductive area becomes further and further reduced with an increase in frequency. This, in turn, causes a further increase in the resistance of the conductor.

To keep resistance of this kind at a minimum, it is best to use conductors having a large SURFACE area, rather than a large cross-sectional area. Thin-walled, hollow wire or tubing will serve even more efficiently as a conductor of high-frequency current than will solid wire of the same diameter. Losses due to skin-effects may also be reduced by using a number of enamel-covered wires stranded together to form Litzendraht ("Litz") wire. However, this wire is beneficial only in the lower radio-frequencies; normally up to a frequency of approximately 1,000 kc to 2,000 kc.

2. Physical dimensions of the coil:

   a. From a theoretical standpoint, the Q of a single-layer, cylindrical coil is highest when the diameter is 2.46 times the length. Such a coil is quite clumsy, however, and does not adapt itself well to the limited space alloted to coils in the popular-sized radio receivers. Also, we find that the distributed capacity is higher than that of a coil having a smaller diameter; consequently, coils whose diameters are equal to, or slightly less than their length, are commonly used.

   b. The Q of the bank-wound, "universal" or "honey-comb" type coils is highest (theoretically) when the inner diameter of the coil is twice the width of the winding, and the outer diameter is three times the width of the winding.

   c. Although the gain in Q is slight, the distance between turns should equal the diameter of the wire, wherever possible. Especially should this be true if the coil is to handle currents whose frequencies are in the region of 15 megacycles or above.

3. Type of windings:

   a. In experiments carried out with various types of coils and windings, it was found that the single-layer solenoid and the loose, "basket-weave" type of coils have the highest Q inthe frequency range of 300 to 1,500 kc. Next in order, is the "spider-web" or radial, basket-weave type of winding.

   b. The simple, multi-layer (many-layer) type coil is worthless at high frequencies because of its high internal distributed capacity.

   c. Although the single-layer coil, made up of the same amount of wire, has considerably less inductance than does the bank-wound coil, the resistance of the single-layer winding is so much lower that it is used almost exclusively at frequencies above 3,000 kc.

REACTION OF INDUCTIVELY COUPLED TUNED CIRCUITS

In Fig. 5, we show two tuning circuits that are inductively coupled to one another. By this, we mean that the coils are placed in such physical and electrical relationship to one another that the magnetic lines of force of one coil must pass through the other coil to complete its magnetic circuit. From a previous lesson, we know that MUTUAL INDUCTION (M), exists between these two coils.

If each of these coils had a high-Q, and we separated them so that no coupling existed between them, each would present a selectivity curve very similar to that illustrated in Fig. 3. However, when placed in an inductive relation to one another, the resistance of one is REFLECTED into the other; so that, as they are brought into closer inductive relationship to one another, more COUPLING RESISTANCE is reflected into the primary (or driver)tuned circuit.

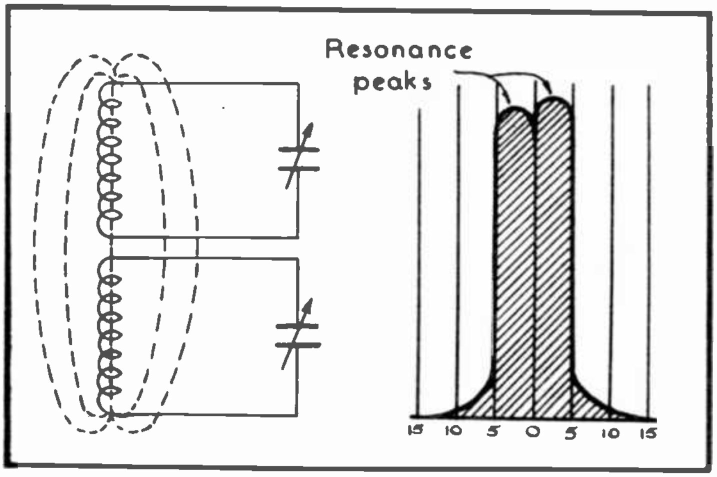

FIG. 5
INDUCTIVELY COUPLED TUNED CIRCUITS

CRITICAL COUPLING

When the value of the coupling or reflected resistance equals that of the primary or driver resistance, we say that CRITICAL COUPLING exists between the two resonant circuits.

At the point of CRITICAL COUPLING, maximum transferrence of energy occurs between the two resonant circuits. In other words, the current flow in the secondary circuit is at maximum and the selectivity of the secondary circuit is at maximum.

However, beyond the point of critical coupling (when the two coils are moved closer towards each other), the amount of current flow in the secondary coil suffers and the selectivity of the secondary is also impaired.

By referring to Fig. 5, you will note that the amplitude of the curve takes a dip, denoting a loss in gain. This loss is due to the lowered Q resulting from the excessive amount of coupling-resistance reflected back into the primary tuned circuit. As the coupling is tightened between the two coils, this dip in amplitude becomes more and more pronounced (See Fig. 6).

To correct this condition, we may resort to two measures. One, would be to "loosen" the coupling between the two coils; the alternative would be to detune the circuit slightly to a higher or lower frequency. By detuning either of the tuned circuits to a higher or lower frequency, the amplitude rises because of the reduction in coupling-resistance. This is the reason for the two humps on either side of the resonant frequency ("0" line) in the curve shown in Fig. 5. Notice how these two humps spread out in Fig. 6, showing how too close coupling affects the selectivity-width of the tuned circuit.

Of the two measures mentioned above, a slightly greater gain may be realized by decreasing the coupling between the two coils rather than by employing the detuning method. And, if the Q's of both tuning circuits are unequal, double humps do not appear in the secondary circuit until the coupling SLIGHTLY EXCEEDS THE CRITICAL VALUE!

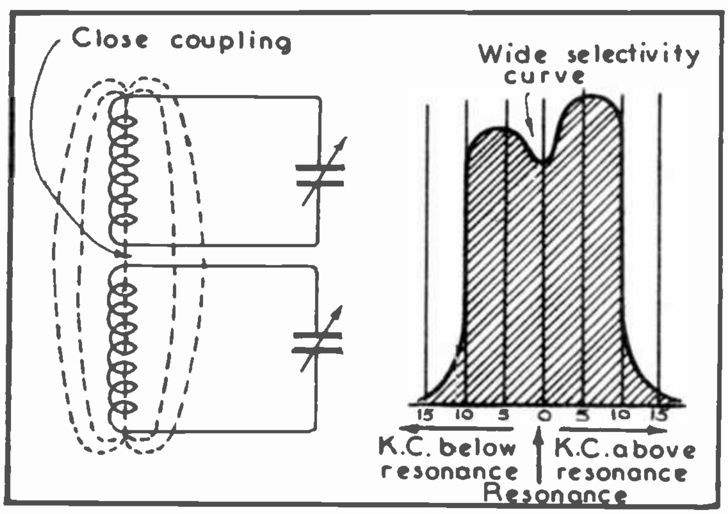

FIG. 6
CLOSE COUPLING WIDENS CURVE

HOW COUPLING AFFECTS FIDELITY

Upon interpreting the WIDTH of the curve shown in Fig. 6, we find that "close" or "tight" coupling causes the tuned circuit to

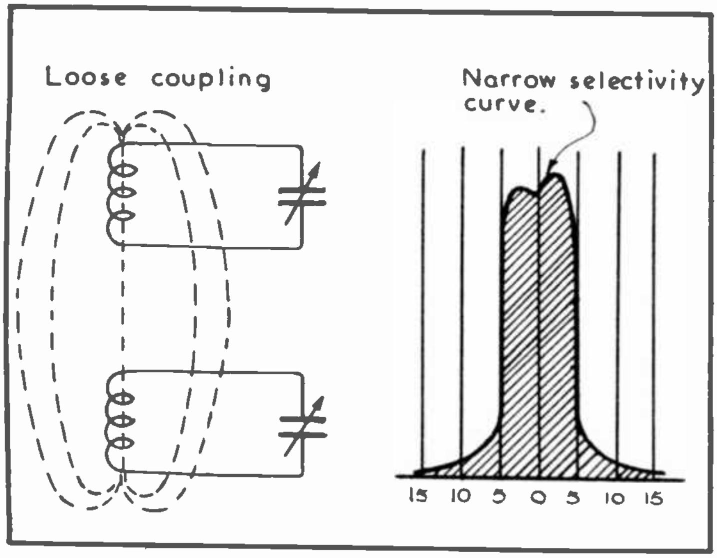

FIG. 7
LOOSE COUPLING NARROWS CURVE

pass a wide channel of side-bands, yet produces a sharp "cut-off" at both sides of the resonant frequency. Fig. 7, on the other hand, illustrates a curve revealing how the fidelity of a receiver is affected when too little or too "loose" coupling exists between the tuned circuits. As the coupling is loosened (decreased), the selectivity of the circuit increases to the extent that some of the important higher musical notes are eventually cut off; thus impairing the fidelity of the receiver.

Hence, too little coupling between two coupled circuits not only results in an insufficient transfer of energy from the primary (driver) circuit to the secondary circuit, but may increase the selectivity of the circuit to the extent of causing "side-band suppression". As stated previously, this feature is undesirable in broadcast receivers of the high-fidelity type.

APPLICATION OF BAND-PASS PRINCIPLES

Having familiarized ourselves with the basic principles relating to band-pass effects, let us now proceed to see how these principles are applied to the practical design of radio receivers.

A typical band-pass circuit of the more simple type is shown in Fig. 8. Here, we have an antenna transformer, the primary winding of which is connected to the antenna and ground. The secondary of this transformer is tuned by a variable condenser which is "ganged" or mechanically coupled to the variable condensers of the other tuning circuits (denoted by the dotted lines). In inductive relation with the secondary coil of the antenna transformer is yet another band-pass secondary winding which serves as part of the tuning circuit for the first r-f amplifying tube. (Note: the curved arrow, drawn through both coils, denotes that they are inductively coupled).

Thus, we have two tuned circuits preceding the 1st r-f tube. The remainder of the circuit is of conventional design and requires no further explanation at this time.

TYPICAL BANDPASS COIL ASSEMBLY

A representative band-pass coil assembly is shown in Fig. 9. Here, the antenna or primary winding is placed directly over secondary winding #1 at the lower end of the coil form. This constitutes the antenna trans-

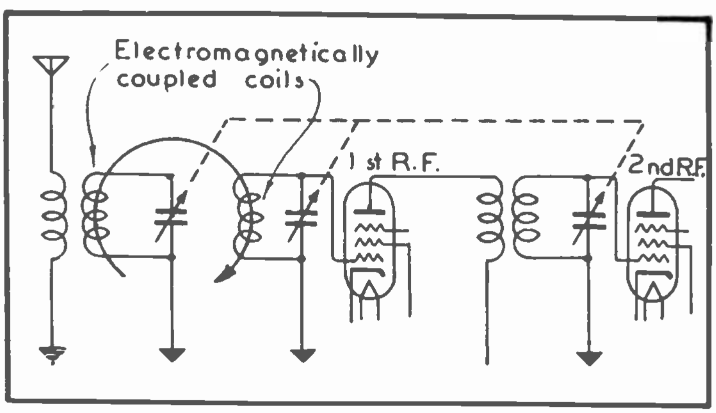

FIG. 8
BAND-PASS CIRCUIT USED IN A T-R-F RECEIVER

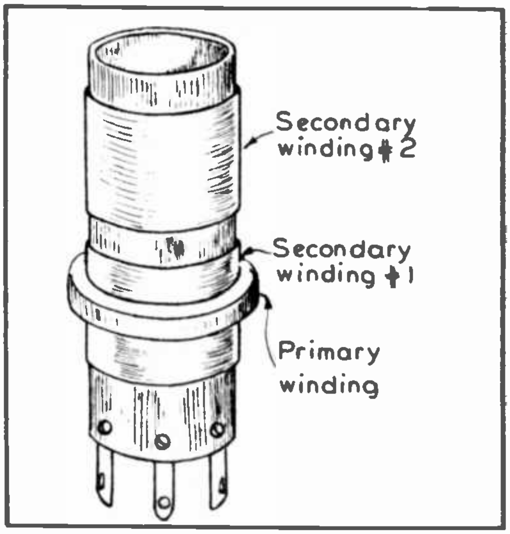

FIG. 9
BAND-PASS COIL ASSEMBLY

former. Spaced a short distance away, on the same form--and wound in the same direction--is secondary winding #2. The latter winding functions as the grid coil for the 1st r-f tube. THE SPACE BETWEEN THESE TWO SECONDARY COILS IS AN EXTREMELY IMPORTANT FACTOR, since it determines the band-pass characteristics of the assembly.

Secondary windings #1 and #2 have the same inductance value, and tuning condensers of identical capacity are connected across these two windings. By the use of identical tuning condensers, it is simple to align the two circuits so that "tracking" and, consequently, "single dial tuning" is easily achieved.

COMMON-IMPEDANCE BAND-PASS CIRCUITS

We have just discussed a band-pass circuit in which coupling between the tuned circuits was accomplished by means of mutual induction (through the medium of a magnetic field, as in Fig. 8). Another method of coupling is by means of a COMMON IMPEDANCE. This method employs a single impedance that is COMMON to (or connected to) both of the tuning circuits so that the current flow through one coil has a direct effect upon the current flow through the other coil. This COMMON coupling or "link" may be in the form of inductance, capacity, or a combination of both.

COMMON-INDUCTANCE TYPE COUPLING

A typical band-pass selector circuit employing an inductance as the common coupling impedance is illustrated in Fig. 10. Here, you will observe that the primary winding P of a conventional antenna transformer is connected between the antenna and ground--in the usual manner. The secondary winding S-1 of this transformer is connected to the stator section of one of the ganged variable condensers. The opposite end of this winding is connected to an independent--and completely isolated (shielded) second coil, S-2. The physical and electrical characteristics of coil S-2 are identical to those of S-1, except that it has no primary winding. The upper end of coil S-2 is connected to the second stator section of the ganged variable condenser and also to the control-grid of the 1st r-f amplifying tube. The lower extremities of windings S-1 and S-2 are both grounded through the small coupling coil L.

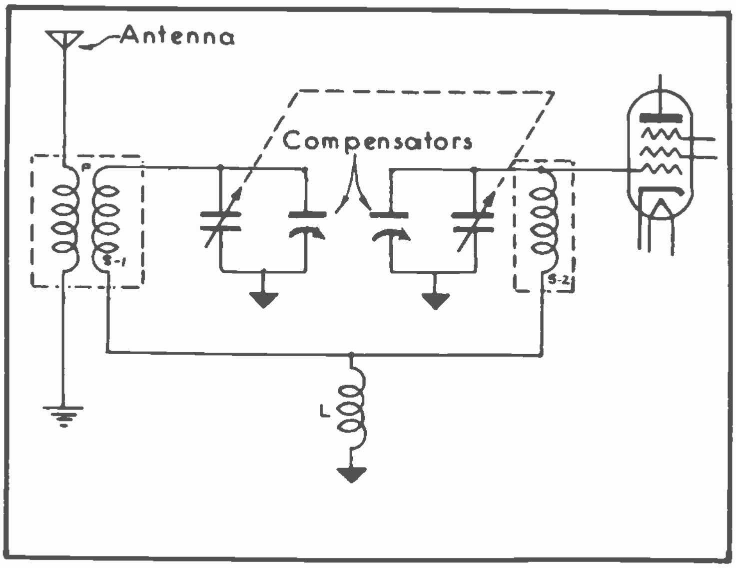

FIG. 10
BAND-PASS CIRCUIT WITH COUPLING COIL

So that we may more readily understand the operation of this circuit,

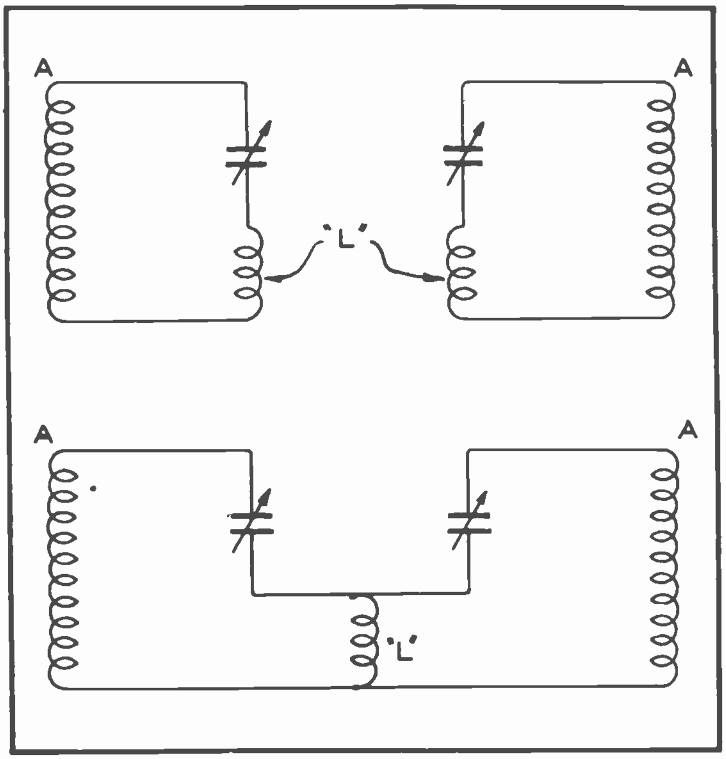

FIG. 11
COUPLING COIL METHOD

let us refer to the diagram presented in Fig. 11. Here, we have two tuned circuits; each consisting of a tuning coil "A" connected in series with a variable condenser and a small inductance (coil) "L". Coupling is affected between the two circuits by means of the mutual induction that exists between coils "L", which are inductively (electromagnetically) coupled to one another.

In the lower portion of Fig. 11, we have replaced the two coils "L" with a single coil "L". The two tuned circuits are now CONDUCTIVELY as well as inductively coupled to one another; coil "L" functioning as the COMMON COUPLING IMPEDANCE for the two tuning circuits.

The degree of coupling existing between the two coils "A" now depends entirely upon the inductance value of coil "L". The greater the inductance value of this coupling coil, the greater effect will one tuning circuit have upon the other and the greater will be the amount of energy transferred from one circuit to the other. Thus, as the number of turns on coil "L" is increased, the louder will be the signal; however, the selectivity will be impaired so that less selectivity or "broader" tuning occurs. By decreasing the inductance of coil "L", this circuit becomes more selective so that it now passes a narrower band of frequencies; thus causing the tuning to be sharper and the selectivity curve to become narrower.

By selecting the PROPER value of inductance for coil "L", it is possible to adjust the band selector circuit to permit the desired 10 kc frequency selection.

As a practical example of the construction of such a band-selector (shown in Fig. 10) the following data may be used, providing the tuning condensers have a capacity rating of .00035 mfd. If the tuning coils S-1 and S-2 are wound on individual tubular forms of 1" diameter, 130 turns of #30 B & S enameled wire may be used for both of these windings. The pri-

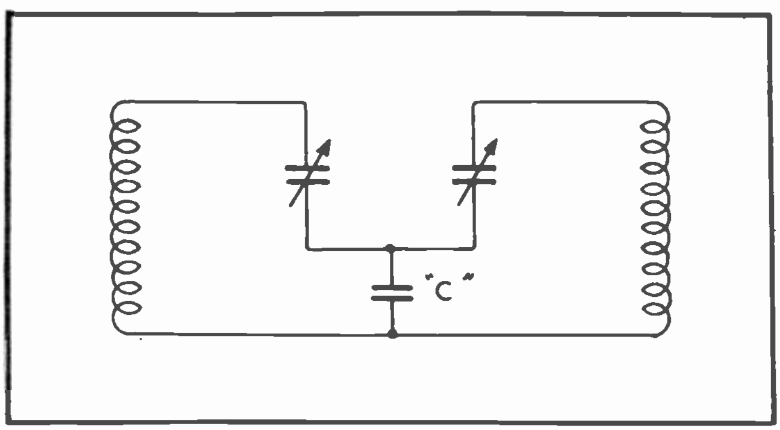

FIG. 12
CAPACITIVE COUPLING

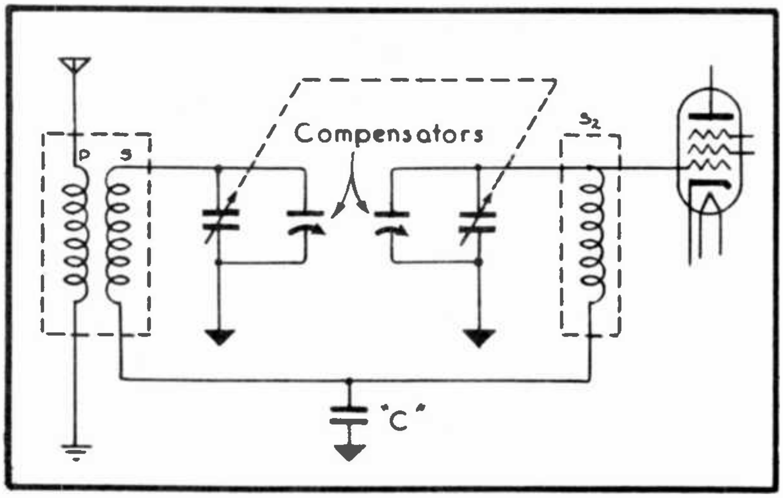

FIG. 13
APPLICATION OF BAND-PASS CIRCUIT WITH CAPACITY COUPLING

mary winding for coil S-1 should, preferably, be of the high-impedance type so that with the added capacity of the antenna and ground it will more nearly resonate to a lower frequency of the broadcast band.

The small coupling coil "L" is wound on an individual form, mounted in such a position that no electromagnetic coupling exists between it and the other coils. This coil consists of from 2 to 6 turns of #30 B & S enameled wire, wound on a form having a diameter of 1". The exact number of turns to use will have to be determined by experiment; the number of turns providing optimum selectivity and satisfactory fidelity, being the determining factors.

CAPACITY-COUPLED BAND-PASS CIRCUIT

As stated previously, a capacitor or condenser may also be used as the common coupling device for the two tuned circuits. Such an arrangment appears in Fig. 12. Upon analyzing this circuit, you will observe that it is very similar to the band-pass circuit using an inductance for the coupling device; with the exception that a capacitor replaces the coupling coil.

The value of the common capacitor or coupling condenser "C" determines the sharpness of tuning provided by this band-pass circuit. The lower the capacity value of condenser "C" the greater will be the transferrence of signal energy from one tuned circuit to the other; which is equivalent to closer or "tighter" coupling between the two tuned circuits. The greater the capacitive value, the lesser will be the amount of signal energy transferred from one tuned circuit to the other, and is equivalent to "loosening" the coupling between the two circuits.

The manner in which this type of "pre-selector" band-pass selector tuning system is applied to actual receiver design is illustrated in Fig. 13. This circuit is almost an exact duplication of that shown in Fig. 10, with the exception that condenser "C" is used as the common coupling device.

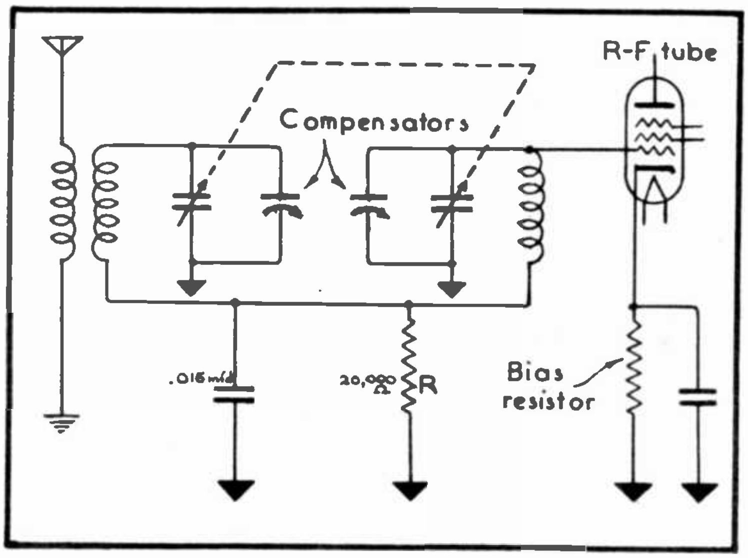

FIG. 14
APPLYING BIAS VOLTAGE TO THE SYSTEM

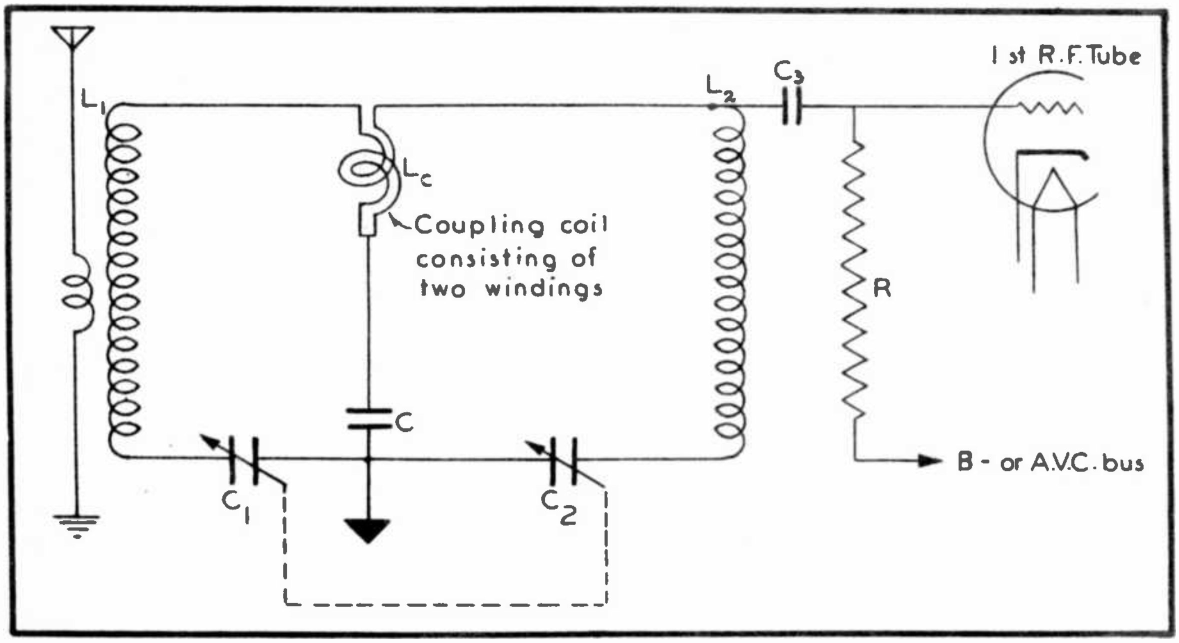

FIG. 15
COMBINATION INDUCTIVE AND CAPACITIVE TYPE BAND-PASS SELECTOR CIRCUIT

The coupling condenser "C" may be located at any convenient point in the circuit. To obtain the desired band-pass tuning characteristics, it will be necessary to experiment with the capacity value of this condenser. To cover the standard broadcast band, a capacity of .015 mfd is a good average value to employ, providing the capacity of both variable tuning condensers is approximately .00035 mfd.

Note: In Fig. 13, you will observe that the grid-return circuit of the first r-f tube is "open" as far as the d-c component (grid-biasing voltage) of the circuit is concerned. This is corrected by inserting a resistor "R" between the return-end of the r-f tube's grid coil and ground, B-minus, or AVC bus, as shown in Fig. 14.

COMBINATION INDUCTIVE AND CAPACITIVE BAND-PASS CIRCUIT

When using either inductive or capacitive type coupling in a band-selector circuit, the WIDTH of each signal tuned in varies with the frequency. That is, in the case of inductive coupling, this width increases as the frequency increases. In other words, the receiver tunes broader at the higher frequencies. With capacitive coupling, we have just the reverse condition; namely, that as the frequency is increased, the receiver tunes sharper. It is logical, therefore, that if we could combine both of these coupling circuits in the proper manner, our band width would be almost constant throughout the entire tuning range. A circuit employing the combination of inductive and capacitive coupling is shown in Fig. 15.

Typical constants for a circuit like this, having a tuning range from 550 kc to 1,700 kc, are as follows:

- L-1 R-F transformer whose secondary winding has an inductance value of approximately 175 microhenries.
- L-2 The secondary winding of a similar r-f transformer whose primary winding has been removed.
- C-1 C-2 Two-gang .00035 mfd variable condenser.
- C Mica coupling condenser of approximately .06 mfd.
- L_C Mutual coupling transformer consisting of two coils wound "side by side".

The "start" ends of the coils L_C are connected to the secondary windings of the r-f transformers; whereas, the "finish" ends of the coils are connected to coupling condenser "C". The inductive value of each winding is approximately 3.2 microhenries.

(Note: Experiments should be conducted with respect to the exact number of turns to be used. The number of turns that affords 10 kc selectivity throughout the entire tuning range is the optimum number to use).

C-3 R-F coupling condenser; preferably of the mica-dielectric type. The function of this condenser is to transfer the r-f signal into the control-grid circuit of the first r-f tube. Optimum capacity value for this condenser will have to be determined by experiment. The approximate range of values for this purpose is 100 to 500 mmfd.

As the capacity value of this condenser is increased, a greater transfer of r-f energy (signal) will take place; thus, a stronger signal will be impressed upon the control-grid of the first r-f tube. However, by increasing its capacity value, we are automatically increasing the (capacitive) shunting effect upon the tuning circuit; which, in turn, will have an effect upon the band-width. (In fact, the inter-electrode capacity of the 1st r-f tube also has an effect on this circuit. The smaller the inter-electrode capacity of the tube, the larger may be the value of this coupling condenser).

PRE-SELECTORS IN SUPERHETERODYNE CIRCUITS

The performance of a superheterodyne receiver may be greatly improved by incorporating a band-pass pre-selector tuned circuit in the input (grid) circuit of the translator (1st detector) stage, as shown in Fig. 16. If an r-f stage precedes the translator circuit, the pre-selector may be used in this stage.

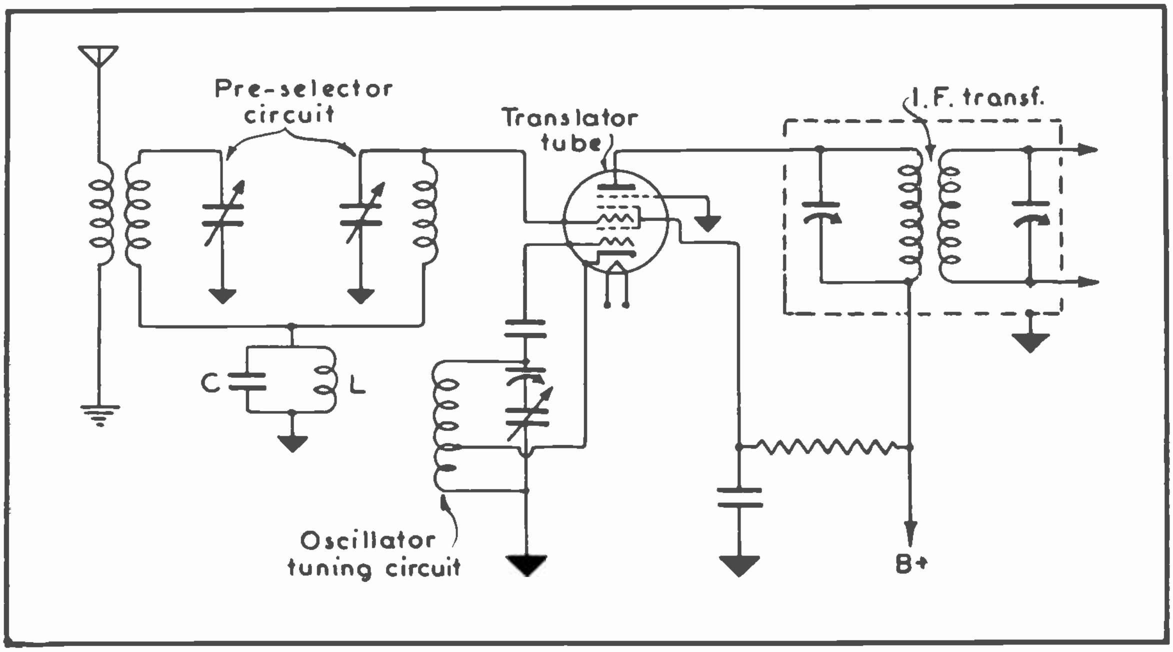

FIG. 16
SUPERHETERODYNE RECEIVER EMPLOYING A BAND-PASS PRE-SELECTOR R-F CIRCUIT

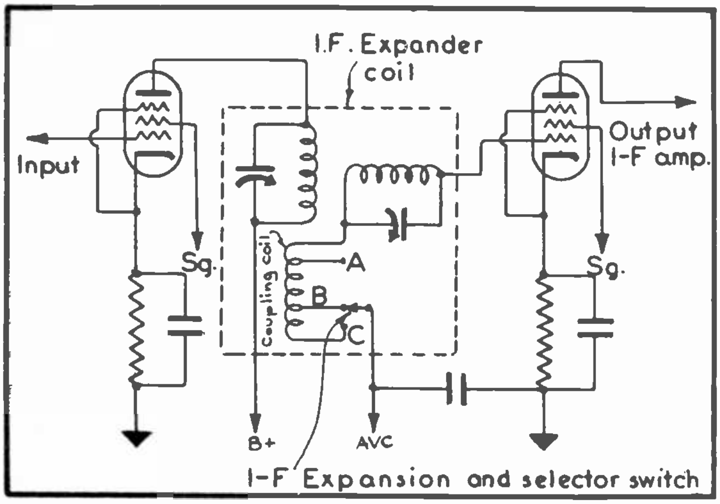

FIG. 17
I-F EXPANSION CIRCUIT

When only one tuned circuit precedes the translator stage, too little selectivity is provided to the translator circuit so that more than one station may be "mixed" with the oscillator frequency. Although the interfering signal will be subsequently removed by the highly selective properties of the i-f stages, the wave-form of the desired signal has been distorted by the "cross-modulation" effects of the interfering signal. Thus, if we can provide sufficient selectivity to the desired signal before it undergoes "mixing" (in the translator stage), distortion of the wave-form from this source is thereby prevented.

Two other types of interference may also be minimized by the use of a pre-selector in the superheterodyne circuit. The i-f stages, as you know, are generally tuned to a frequency from 175 kc to 500 kc. Maritime and aircraft transmissions (generally, in the form of telegraphic code signals) are carried out on these frequencies and, if such a station is located within 100 miles of the receiver, it is possible that the signal from this nearby station will be picked up by the i-f stages. When this occurs, the interfering station is heard at almost the same volume intensity "all over the dial".

The conventional manner of eliminating such type interference is by the use of a wave-trap tuned to the interfering frequency. However, when a pre-selector tuning circuit is employed in the receiver, the selective qualities of the receiver are so enhanced that the use of a wave-trap is seldom necessary.

Superheterodyne receivers have an annoying tendency to create interfering "image" frequencies. Such source of interference may also be minimized by the use of a tuned pre-selector. A brief review of "image" frequencies will not be amiss here:

The i-f stages of a superheterodyne receiver are tuned to 450 kc. When we tune the receiver to a station broadcasting on a frequency of 1,000 kc., this means that the r-f portion of the circuit is now tuned to 1,000 kc. The oscillator circuit, on the other hand, is tuned to 1450 kc., to produce the i-f beat frequency of 450 kc. (1450 - 1,000 = 450 kc).

However, if the r-f tuned circuit is insufficiently selective, it may allow admittance to a 1900 kc. signal -- which will also beat with the 1450 kc. oscillator signal to the "tune of 450 kc." (1900 — 1450 = 450 kc). Thus, not only will we hear the 1000 kc broadcast station program but also the program being broadcast by the station on 1900 kc. This latter interfering frequency is referred to as the "image" frequency. By the use of a properly designed pre-selector, the reception of "image" broadcast frequencies may be entirely eliminated. On short-waves, however, the design of the pre-selector must be quite efficient to reduce image-frequency response to a minimum.

I-F EXPANSION

In the conventional type of i-f transformer, the physical distance between the primary and secondary coils is fixed. This means that the mutual inductive relationship between the two coils is fixed. Varying the band-pass or selectivity characteristics of such type transformer is therefore quite limited since this can only be accomplished by varying the degree of resonance existing between the two windings.

However, radio engineers and receiver designers frequently find it expedient to employ i-f transformers in which the coupling between the two coils may be varied at will. By the use of such transformers, greater selectivity may then be provided to those receivers destined to be operated in cities or locales where the air-lanes are congested and, on the other hand, improved tonal qualities may be provided to those receivers in which selectivity is of secondary importance.

The manner in which the coupling between the two coils is varied may be accomplished by two methods:

1. Mechanical: One method of accomplishing this is by winding one of the coils upon a movable form so that it may be moved closer to or farther from the other coil.

2. Electrical: The primary and secondary windings are generally spaced farther apart than usual; or, placed in such a position (in relation to one another) so that minimum coupling exists between them. Coupling between the two coils is accomplished by the use of a third coil, known as the "coupling" coil. This coil is wound in close, mutual-inductive relationship to the primary coil and is tapped, as shown in Fig. 17. Each tap connects to its respective selector switch contact point, and the coupling between the primary and secondary windings is varied by rotating the selector switch so that more or less of the coupling coil turns are connected into the secondary (grid) circuit.

For example, by referring to Fig. 17, you will note that when the selector switch is rotated to position "A", the least number of coupling turns are utilized so that maximum selectivity is obtained in this position (refer to curve "A" in Fig. 18). When the selector switch is rotated to position "B", more coupling turns are being used so that the coupling between the primary and secondary windings is increased ("tightened"). The transformer now tunes broader and passes a wider band of audio-frequencies (refer to curve "B" in Fig. 18). With the selector switch rotated to position "C", the receiver tunes still broader and passes a yet wider band of side-frequencies.

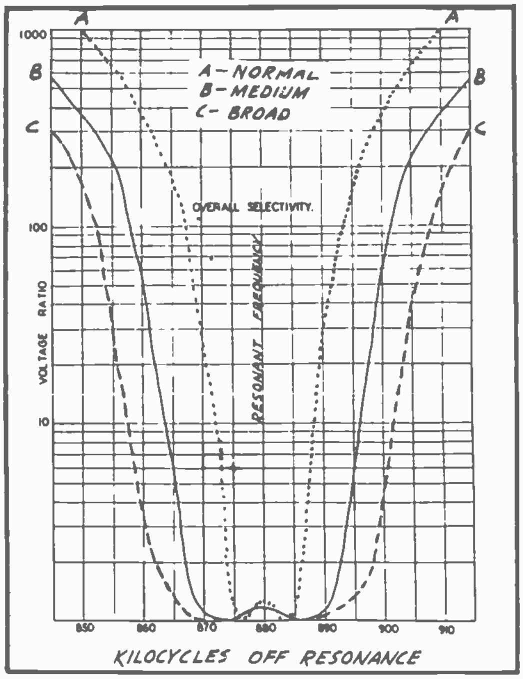

FIG. 18
HOW I-F EXPANSION VARIES THE RESONANCE CURVE

The above method is referred to as i-f EXPANSION; which implies that the broadness of the tuning, and band-pass, may be increased or expanded. This is a desirable feature and is often incorporated in receivers of better quality.

By the use of such a control, conveniently located, the operator may increase the selectivity of the receiver when listening to stations surrounded by more powerful, interfering stations; or, may increase the tonal qualities of the receiver when listening to musical proprams being broadcast by stations which are free from interference.

EXAMINATION QUESTIONS

LESSON NO. 43

1. - What is the chief advantage of using band-pass selector circuits in the r-f amplifier of a radio receiver?

2. - Why is it that the selectivity curve for a band-pass selector circuit has two resonance peaks?

3. - What do we mean by the "Q" of a coil?

4. - In Fig. 13 of this lesson, does increasing the capacity value of the coupling condenser (C) cause this band-pass selector circuit to tune sharper or broader?

5. - What is the reason for using both inductive and capacitive coupling in the band-pass selector circuit illustrated in Fig. 15 of this lesson?

6. - How does reducing the number of turns on the coupling coil (L) in Fig. 10 affect the performance of this circuit?

7. - (a) What is meant by the expression "side-band suppression"?
   (b) How does side-band suppression affect the performance of a receiver?

8. - What is the advantage of using a band-pass pre-selector circuit in a superheterodyne receiver?

9. - Why are some radio receivers equipped with an i-f expansion circuit?

10.- Mention three factors that determine the "Q" of a coil.

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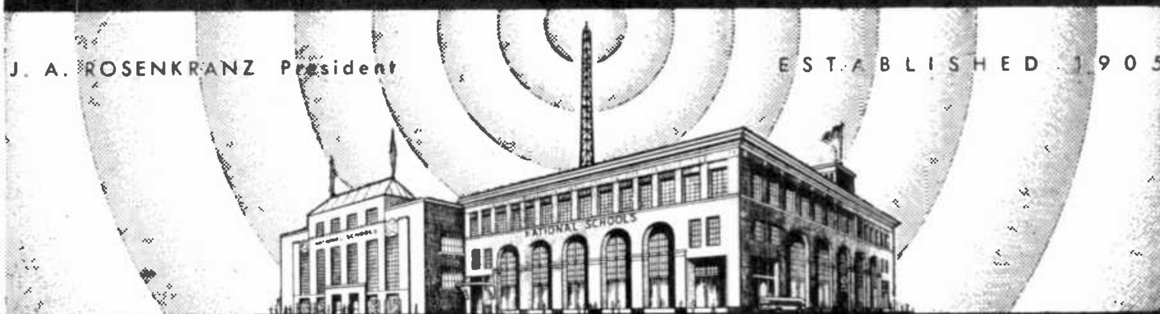


NATIONAL SCHOOLS ★ LOS ANGELES 37, CALIF.

LESSON NO. 44

WINDING R.F. COILS
MEASURING INDUCTANCE AND CAPACITY

You are making rapid progress with your studies of R.F. amplifiers, so now we are ready to go about the task of winding R.F. transformers or coils. The first coil design which we shall consider is the popular solenoid type.

WINDING A SOLENOID COIL

Of course, many coil winders have favorite tricks of their own, gained from experience in this kind of work; and after you have wound a number of coils you will also, no doubt, develop winding ideas of your own. Nevertheless, the suggestions given in this lesson will give you a basic understanding of how coil-winding problems are handled.

First, let us center our attention on Fig. 2. Here, we have a tubular winding form made of some such material as a rigid cardboard tube or bakelite. We begin, by choosing a suitable point on this form at which to start the winding. It is important not to start the winding too near the end of the coil form.

At the point where the winding is to start, make two small holes through the coil form as shown in Fig. 2. These holes need only be large enough to permit the coil wire to be threaded through them, and may be approximately 1/16" apart.

Fig. 1
Set-Up for Winding
R. F. Transformer

COIL WIRE IS GENERALLY BOUGHT ON SPOOLS, SO TAKE HOLD OF THE FREE END OF THIS SPOOL OF WIRE AND THREAD IT ABOUT TWICE THROUGH THESE TWO FIRST HOLES OF YOUR WINDING FORM. THIS LOOP WILL SERVE AS THE ANCHORING POINT FOR THE BEGINNING OF YOUR WINDING, SO DRAW IT TIGHT, BEING CAREFUL, HOWEVER, THAT THE WIRE IS NOT BROKEN IN THE CASE VERY SMALL SIZE WIRE IS BEING USED. ALSO PROVIDE A SUFFICIENTLY LONG FREE END OF THE WINDING SO THAT YOU CAN MAKE THE PROPER ELECTRICAL CONNECTIONS TO IT LATER ON.

WHEN WINDING THE COIL BY HAND AND YOU ARE RIGHT HANDED, THEN HOLD THE COIL FORM IN YOUR LEFT HAND AT THE STARTING END AND WIND THE WIRE ON THE FORM IN THE DIRECTION INDICATED. DRAW WIRE FROM THE SPOOL AS IT IS NEEDED, BEING VERY CAREFUL THAT IT DOES NOT KINK AND DRAW THE TURNS UP TIGHT SO THAT THEY WON'T SLIP ON THE WINDING FORM. ALSO BE SURE THAT THE TURNS ARE ALL WOUND RIGHT NEXT TO EACHOTHER WITHOUT ANY SPACING BETWEEN THEM IN SUCH CASES WHERE THE COIL DESIGN CALLS FOR COILS OF THE NON-SPACE WOUND TYPE.

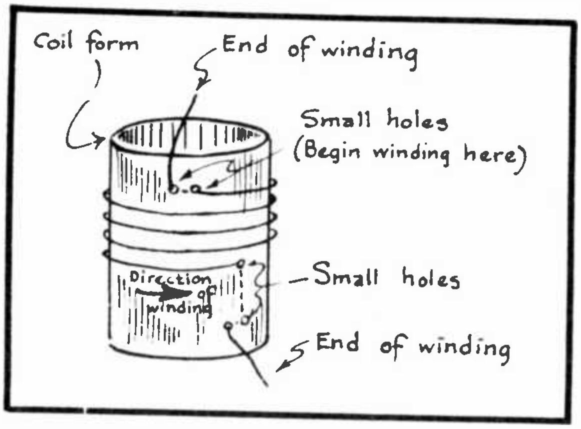


FIG. 2
An Example of Winding.

COUNT THE NUMBER OF TURNS AS YOU WIND, USING YOUR STARTING HOLES AS YOUR REFERENCE POINT. FINALLY, WHEN YOU HAVE APPLIED THE NUMBER OF TURNS CALLED FOR, MAKE ANOTHER SMALL HOLE IN THE WINDING FORM DIRECTLY AT THE POINT WHERE THE WINDING FINISHES. HOLD DOWN THE LAST TURN FIRMLY WITH THE THUMB OF YOUR LEFT HAND, SO THAT NO SLACK WILL DEVELOPE IN THE COIL AND THEN CUT THE WIRE FROM THE SPOOL, LEAVING A SUFFICIENT SURPLUS LENGTH FOR MAKING CONNECTIONS.

NOW PASS THE FINISHING END OF THE WIRE THROUGH THIS LAST HOLE, DRAWING IT TIGHT AND PULL IT DOWNWARDS ALONG THE INNER WALL OF THE COIL FORM. AT THE LOWER END OF THIS COIL FORM MAKE TWO MORE SMALL HOLES AND THREAD THE WIRE THROUGH THEM TIGHTLY-APPROXIMATELY TWICE. THUS THE FINISHING END OF THIS WINDING IS ALSO NOW ANCHORED AND YOU WILL HAVE A TIGHT, NEAT LOOKING WINDING.

LOCATING COIL TERMINALS

LET US CONSIDER FOR A MOMENT, THE MOST ADVANTAGEOUS POINTS AT WHICH SUCH WINDINGS SHOULD BE TERMINATED ON THE COIL FORM. THIS CAN PROBABLY BE ILLUSTRATED BEST BY MEANS OF THE ILLUSTRATION SHOWN YOU IN FIG. 3 WHERE WE HAVE A SHIELDED R.F. TRANSFORMER ASSEMBLY AS GENERALLY USED IN AMPLIFIERS EMPLOYING SCREEN-GRID CIRCUITS. IN THIS CASE, THE SHIELD CAN HAS BEEN PARTIALLY CUT-AWAY, SO THAT YOU CAN SEE THE ARRANGEMENT INSIDE.

NATURALLY, THE TYPE OF COIL MOUNTING TO BE USED ETC. SHOULD BE DECIDED UPON BEFORE WINDING THE COILS SO THAT THE COIL TERMINALS CAN BE LOCATED TO BEST SUIT THE PARTICULAR TYPE OF INSTALLATION. IN THE POPULAR METHOD OF FIG. 3, FOR EXAMPLE, WHERE THE CONTROL-GRID LEAD EMERGES FROM THE TOP OF THE SHIELD, IT IS LOGICAL THAT THE GRID END OF THE SECONDARY WINDING SHOULD TERMINATE AT THE UPPER END OF THE COIL FORM. TO FACILITATE WIRING, IT IS ADVISABLE TO MOUNT TERMINAL LUGS ON THE WINDING FORM AND

TO SOLDER, THE ENDS OF THE WINDING TO THESE. THUS THE PROPER CIRCUIT WIRE CAN THEN LATER BE SOLDERED TO THIS SAME LUG VERY EASILY. IT IS ALSO ADVISABLE TO WRAP THE COIL WIRE AROUND THE LUG SEVERAL TIMES BEFORE SOLDERING IT TO THE LUG, FOR THIS WILL PREVENT THIS LEAD FROM BECOMING DETACHED WHEN MELTING THE SOLDER, AT THE TIME THE CIRCUIT WIRE IS SOLDERED TO THE LUG LATER ON. THIS IS JUST A MATTER OF CONVENIENCE.

IF SUB-PANEL WIRING IS USED FOR THE WIRING OF THE RECEIVER, AS IS GENERALLY THE CASE, THEN THE PRIMARY WINDING SHOULD TERMINATE AT THE LOWER END OF THE WINDING FORM AS ILLUSTRATED, AS SHOULD ALSO THE GROUND, FILAMENT OR CATHODE END OF THE SECONDARY. HERE TOO, SOLDERING LUGS WILL BE FOUND CONVENIENT. SO KEEP ALL OF THESE POINTS IN MIND WHEN CONSTRUCTING R.F. TRANSFORMERS AND YOU WILL DO A BETTER JOB.

A COIL WINDING MACHINE

IF YOU DO NOT HAVE OCCASSION TO WIND A GREAT NUMBER OF R.F. TRANSFORMERS, THEN THE HAND METHOD OF WINDING, AS JUST DESCRIBED, WILL BE FOUND SATISFACTORY ENOUGH BUT WINDING MANY COILS AT A TIME IN THIS WAY BECOMES RATHER TIRESOME. TO SPEED UP THIS WORK, A SIMPLE COIL WINDING MACHINE, AS ILLUSTRATED IN FIG. 4, WILL BE FOUND VERY HANDY. BY STUDYING FIG.4 IN CONJUNCTION WITH FIG. 5, YOU SHOULD OBTAIN A GOOD IDEA OF THE CONSTRUCTIONAL FEATURES OF THIS SIMPLE MACHINE, SO THAT YOU CAN READILY BUILD ONE FOR YOURSELF SHOULD YOU CHOOSE TO DO SO.

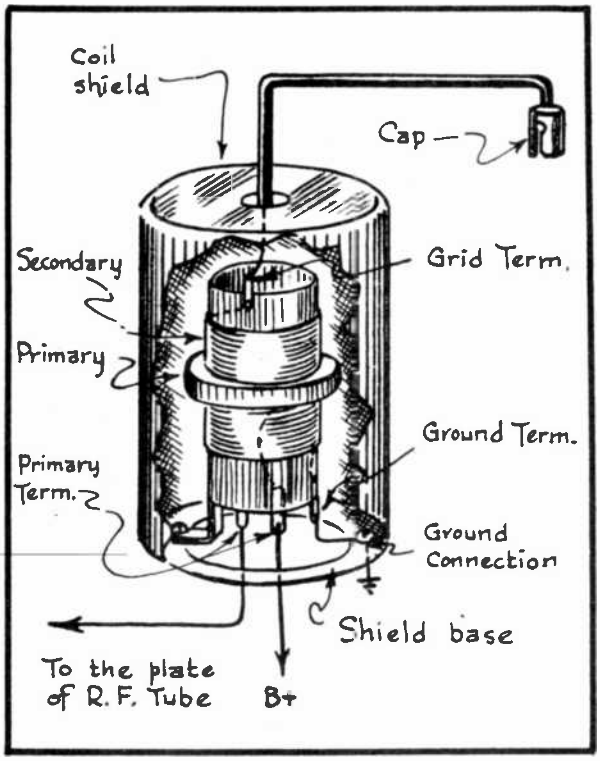


FIG. 3
Locating Coil Terminals for Screen Grid Circuits.

THIS APPARATUS CONSISTS ESSENTIALLY OF TWO BLOCKS OF WOOD SERVING AS BASES. TO THESE TWO BASES, YOU CAN FASTEN A PAIR OF STEEL STRAPS, SLIGHTLY SEPARATED FROM EACHOTHER SO AS TO FORM TWO RAILS. THE TWO UPRIGHTS CAN BE MADE FROM THIS SAME STEEL STOCK, BENDING THEM INTO RIGHT ANGLES, DRILLING A HOLE AT THEIR UPPER END TO RECEIVE THE SHAFT AND ANOTHER HOLE AT THE LOWER END TO RECEIVE THE HOLD-DOWN BOLTS.

THE CONE-SHAPED WEDGES CAN BE MADE FROM WOOD, BEING TURNED DOWN TO A CONICAL SHAPE IN A LATHE. A HOLE, LARGE ENOUGH TO PERMIT THESE WEDGES TO SLIP FREELY UPON THE SHAFT, IS DRILLED THROUGH THEIR CENTER. A CRANK IS FASTENED ON ONE END OF THE SHAFT.

TO USE THE APPARATUS, ILLUSTRATED IN FIG. 5, LOOSEN THE RIGHT HOLD-DOWN BOLT AND THE SET SCREW OF THE COLLAR, WHICH IS MOUNTED ON THE RIGHT END OF THE SHAFT. NOW SLIDE THE RIGHT UPRIGHT TOWARD THE RIGHT AND SLIP

THE RIGHT COLLAR AND WEDGE OFF THE SHAFT. THIS DONE, PLACE THE COIL FORM IN THE POSITION ILLUSTRATED IN FIG. 5 AND REPLACE THE RIGHT HAND WEDGE AND COLLAR. SLIDE THE RIGHT HAND WEDGE TOWARD THE LEFT FAR ENOUGH SO THAT ITS CONICAL SURFACE LOCKS TO THE HOLE IN THE COIL FORM AND LOCK IT IN POSITION WITH THE RIGHT HAND COLLAR. THE RIGHT HAND UPRIGHT CAN THEN BE MOVED UP AGAINST THE COLLAR AND ITS WING NUT TIGHTENED.- THE COIL OR WINDING FORM IS THUS CENTRALLY WEDGED BETWEEN THE TWO CONES, SO THAT IT WILL ROTATE WHEN THE CRANK IS TURNED AS ILLUSTRATED IN FIG. 4 AND IF YOU WISH, YOU CAN MOUNT A VERTICAL STUD ON THE BASE OPPOSITE THE CRANK END OVER WHICH TO SLIP THE SPOOL OF WIRE SO THAT IT WON'T BE ROLLING ALL OVER THE WORK BENCH WHILE YOU ARE WINDING. WHEN THE WINDING HAS BEEN COMPLETED, THE COIL FORM CAN READILY BE REMOVED FROM THE WINDING MACHINE.

FIG. 4
A Practical Coil Winding Machine for Ordinary Use.

YOU WILL FIND A WINDING MACHINE BUILT UPON THIS PRINCIPLE TO SATISFACTORILY HANDLE A VARIETY OF COIL SIZES AND OF COURSE, YOU CAN CHANGE ANY OF ITS CONSTRUCTIONAL FEATURES TO SUIT YOURSELF.

NATURALLY, IN FACTORIES WHERE COILS ARE WOUND IN PRODUCTION LOTS, YOU WILL FIND THAT THE COILS ARE WOUND ON ELECTRICALLY OPERATED WINDING MACHINES WHICH OPERATE ON THE PRINCIPLE OF OUR MODERN LATHES.

AFTER THE COILS ARE WOUND, IT IS A COMMON PRACTICE TO COAT THEM WITH HIGH GRADE CLEAR VARNISH OR SHELLAC, SO AS TO PROTECT THEM AGAINST MOISTURE ABSORPTION. SPECIAL PREPARATIONS ARE ALSO AVAILABLE FOR THIS PURPOSE AND WHEN DRY, THE COIL IS NOT ONLY OFFERED THIS PROTECTIVE COATING BUT ITS GENERAL STRUCTURE IS MADE MORE RIGID AS WELL. IN ALL CASES, HOWEVER, YOU DO NOT FIND COILS "DOPED" IN THIS WAY.

THE "BASKET-WEAVE" COIL

YOU WILL PROBABLY ALSO BE INTERESTED IN BECOMING FAMILIAR WITH THE CONSTRUCTION OF COILS OTHER THAN THE PLAIN SOLENOID TYPE. SO LET US NEXT CONSIDER THE "BASKET-WEAVE" COIL.

THE SET-UP FOR WINDING A BASKET-WEAVE COIL IS ILLUSTRATED IN FIG. 6. IN THIS CASE, WE USE A DISC-SHAP-

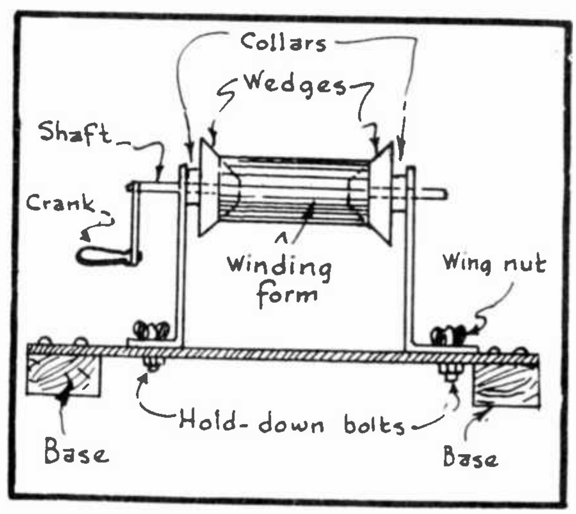


FIG. 5
Constructional Detail of Coil Winder.

ED PIECE OF WOOD ABOUT 3/4" THICK. HOLES ARE DRILLED AROUND THE FACE OF THIS DISC CLOSE TO THE OUTER EDGE AND INTO THESE HOLES WE INSERT WOODEN PEGS WHICH ARE ABOUT $1\frac{1}{2}$" LONG AND APPROXIMATELY 1/8" IN DIAMETER. THESE PEGS SHOULD FIT INTO THE HOLES RATHER TIGHT. THE GENERAL PRACTICE IS TO USE 13, OR 15 OF THESE PEGS FOR COILS WHOSE DIAMETER ACROSS OPPOSITE PEG CENTERS MEASURES RESPECTIVELY $2\frac{1}{2}$" AND $2\frac{5}{8}$".

WITH A SAW, WE CUT NOTCHES AROUND THE RIM OF THE WOODEN DISC NEXT TO EACH PEG AND BY MEANS OF A THREE-CORNERED FILE OR A KNIFE, THE ENTRANCE OF THE NOTCH CAN BE WIDENED SOMEWHAT. THESE NOTCHES SHOULD EXTEND ALL THE WAY TO THE HOLES IN WHICH THE PEGS ARE INSERTED.

THUS WITH THE WINDING FORM COMPLETED, IT CAN BE FASTENED TO SOME SORT OF A SUPPORT AS PICTURED IN FIG.6 IN SUCH A WAY THAT THE WINDING FORM CAN BE ROTATED ABOUT ITS CENTER.

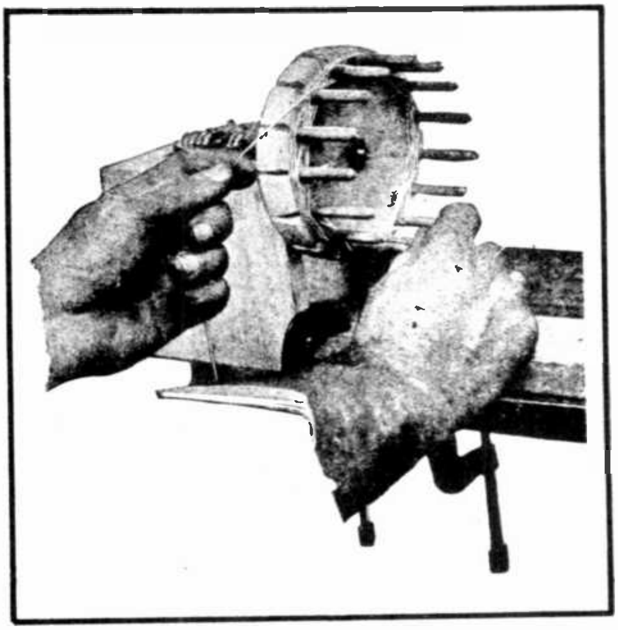


FIG. 6
Winding the Basket-Weave Coil.

TO START, ONE END OF THE WIRE CAN BE TEMPORARILY ANCHORED TO ONE OF THE PEGS. THE WINDING FORM IS THEN SLOWLY ROTATED AS THE FIRST TURN IS WOUND. NOTE THAT WE FIRST WIND OVER ONE PEG, THEN UNDER THE NEXT, OVER THE FOLLOWING PEG ETC. THEN DURING THE SECOND REVOLUTION OF THE WINDING FORM, THE SECOND TURN, IN OTHER WORDS, WE WILL WIND UNDER THE PEGS WHERE OUR PREVIOUS TURN WENT OVER THEM AND VICE VERSA. WE CONTINUE IN THIS WAY UNTIL THE REQUIRED NUMBER OF TURNS HAVE BEEN WOUND AND WE TEMPORARILY FASTEN THE END OF THE WINDING TO A PEG.

THE NEXT STEP IS TO REMOVE THE PEGS BUT WE DO THIS CAREFULLY BY REMOVING FIRST ONE OF THE PEGS TO WHICH NEITHER OF THE ENDS OF THE WINDING ARE FASTENED. AS SOON AS THIS PEG IS WITHDRAWN, WE TAKE A FLEXIBLE NEEDLE AND STRONG THREAD, INSERT THE NEEDLE THROUGH THE OPENING IN THE WINDING FROM WHICH THE PEG WAS REMOVED, THUS PULLING THE THREAD THROUGH. THIS IS ILLUSTRATED IN FIG. 7 AND IT IS FOR THE EASE IN THREADING THAT THE SLOTS ARE PROVIDED AROUND THE RIM OF THE FORM.

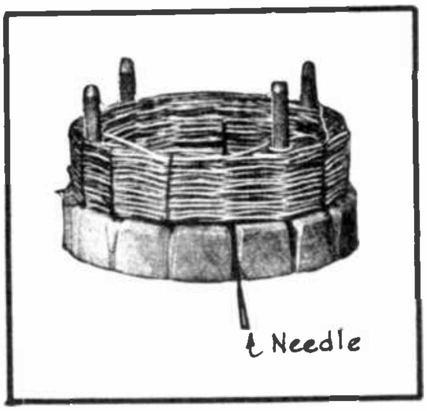


FIG.7
Binding the Basket-Weave Coil.

THUS WITH THE THREAD DRAWN THROUGH THIS WINDING OPENING, WE TIE A LOOP, DRAWING IT TIGHT AND KNOTTING IT, AND IN THIS WAY, THE TURNS ARE FIRMLY FASTENED TOGETHER AT THIS POINT. WE REMOVE ONE PEG AT A TIME, IMMEDIATELY BINDING THE TURNS AT THAT POINT AS JUST DESCRIBED UNTIL ALL PEGS HAVE BEEN REMOVED.

A SATISFACTORY NEEDLE FOR THIS THREADING PURPOSE CAN BE MADE QUITE READILY BY TAKING A PIECE OF #20 B&S BARE OR ENAMELED COPPER WIRE, BENT DOUBLE SO AS TO FORM A LOOP AT ONE END. THE OTHER ENDS CAN BE CONNECTED TOGETHER WITH A DROP OF SOLDER, WHICH CAN BE DRESSED DOWN WITH EMERY CLOTH SO AS NOT TO PRODUCE ANY OBSTRUCTION WHEN THREADING WITH IT. A NEEDLE OF THIS TYPE IS QUITE FLEXIBLE AND THEREFORE LENDS ITSELF WELL TO WORKING IN AND AROUND ABRUPT CORNERS.

THE PEGS AT WHICH THE WINDING'S ENDS ARE FASTENED ARE REMOVED LAST. THUS THE COIL IS REMOVED FROM ITS FORM AND IT CAN THEN BE DOPED WITH AN INSULATIVE COMPOUND AS DESCRIBED RELATIVE TO SOLENOID WINDINGS AND WHEN DRY, THE COIL WILL BE RIGID SO THAT WHEN HANDLED WITH CONSIDERATION, THERE WILL BE LITTLE CHANCE OF ITS LOSING ITS SHAPE.

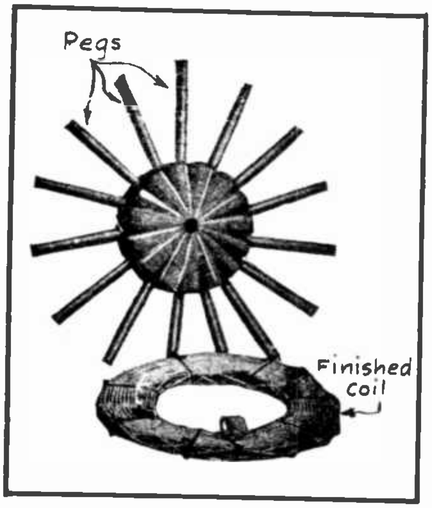


FIG. 8
The spider-Web Coil and its winding Form

FOR A BASKET-WEAVE TYPE COIL, HAVING A DIAMETER OF 2-1/2" TO 2-5/8" AND 13 OR 15 PEGS, AS MENTIONED PREVIOUSLY IN THIS DISCUSSION, APPROXIMATELY 80 TURNS WILL BE NEEDED FOR THE SECONDARY TO TUNE OVER THE BROADCAST BAND WHEN USED WITH A .00035 MFD. CONDENSER AND ABOUT 65 TURNS, WHEN USED WITH A .0005 MFD. TUNING CONDENSER. IN BOTH CASES, #24 B&S DOUBLE SILK COVERED WIRE CAN BE USED.

THE PRIMARY IS WOUND IN THE SAME MANNER AS THE SECONDARY, BEING WOUND NEXT TO THE SECONDARY ON THE SAME WINDING FORM BEFORE THE PEGS ARE REMOVED, AND IT IS TIED TO THE SECONDARY BY MEANS OF THE SAME PIECE OF THREAD PREVIOUSLY DESCRIBED. THE NUMBER OF TURNS TO USE ON THE PRIMARY SHOULD BE APPROXIMATELY 1/3 OF THE NUMBER OF TURNS PLACED IN THE SECONDARY WINDING. IF A TENDENCY TOWARD OSCILLATION IS NOTICED, WHEN THE RECEIVER IS TESTED WITH THESE COILS, PEEL OFF SOME PRIMARY TURNS, PROBABLY SIX TURNS OR SO UNTIL OSCILLATION CEASES.

WINDING A "SPIDER WEB" COIL

THE SPIDER WEB COIL AND ITS WINDING FORM ARE SHOWN YOU IN FIG. 8. IN THIS CASE, WE AGAIN MAKE A DISC-SHAPED FORM WITH A MOUNTING HOLE AT ITS CENTER BUT THE PEGS, HOWEVER, ARE ALL INSERTED IN HOLES, WHICH ARE DRILLED AROUND THE RIM OF THE DISC. THE NOTCHES ARE CUT SO THAT THEY RADIATE FROM THE VARIOUS PEGS TOWARD THE CENTER.

THE COIL IS WOUND AROUND THE RIM OF THIS FORM IN MUCH THE SAME MANNER AS DESCRIBED RELATIVE TO THE BASKET-WEAVE. THAT IS, WE WIND OVER ONE PEG, UNDER THE NEXT, ETC. AND WHEN COMPLETE, THE COIL WILL BE "FLAT-SHAPED" AS SHOWN AT THE BOTTOM OF FIG. 8. HERE TOO, ONE PEG AT A TIME IS EXTRACTED FROM THE FORM AND THE TURNS ARE TIED TOGETHER WITH THREAD. THE FINISHED COIL IS THEN DOPED AS ALREADY PREVIOUSLY DESCRIBED.

TABLE 1 GIVES YOU WINDING SPECIFICATIONS FOR SPIDER WEB COILS TO BE USED WITH A .0005 MFD. CONDENSER OVER THE BROADCAST BAND. THE NUMBER

OF SECONDARY TURNS IN THIS TABLE ARE ONLY APPROXIMATE; BUT IF IT IS FOUND, AFTER COMPLETION, THAT THE COIL CAN BE TUNED TO FREQUENCIES BELOW THE BROADCAST BAND BUT NOT TO THE HIGHER FREQUENCY LIMIT OF THE BROADCAST BAND, THEN ONE SECONDARY TURN AT A TIME CAN BE REMOVED, UNTIL THE DESIRED RESULTS ARE OBTAINED.

TABLE I

WINDING DATA FOR SPIDER - WEB COILS FOR BROADCAST BAND

WIRE SIZE	INSIDE DIAMETER	NUMBER OF PEGS	NO. OF TURNS WITH .0005 MFD. CONDENSER	NO. OF TURNS WITH .00035 MFD. CONDENSER
#24 D.S.C.	1	15	52	82
#20 D.C.C.	2"	17	46	77
#24 D.C.C.	1½"	11	50	80

THE NUMBER OF PRIMARY TURNS TO USE ON THE SPIDER WEB COIL SHOULD ALSO BE APPROXIMATELY 1/3 THE NUMBER OF TURNS USED ON THE SECONDARY, THE SAME AS DESCRIBED RELATIVE TO THE BASKET-WEAVE COIL.

THE HONEYCOMB COIL

FINALLY, IN FIG. 9, WE SEE THE HONEYCOMB COIL. IN THIS CASE, THE COIL CONSISTS OF A WINDING MADE UP OF SEVERAL LAYERS, WITH EACH LAYER WOUND APPROXIMATELY AT RIGHT ANGLES TO THE LAYER BELOW IT. THIS TYPE OF COIL IS USED WHERE CONSIDERABLE INDUCTANCE IS DESIRED IN THE FORM OF A SMALL COMPACT WINDING. IN MODERN RADIO PRACTICE, THE HONEYCOMB COIL IS COMMONLY EMPLOYED FOR THE PRIMARY WINDING OF R.F. TRANSFORMERS, FOR I.F. TRANSFORMER WINDINGS, ETC.

ALTHOUGH WE HAVE DISCUSSED SEVERAL DIFFERENT TYPES OF SECONDARY WINDINGS FOR R.F. TRANSFORMERS IN THIS LESSON, REMEMBER THAT THE SIMPLE SOLENOID TYPE IS THE MOST EFFICIENT OF ALL. FOR GENERAL PURPOSES, YOU ARE ADVISED TO USE THIS TYPE IN PREFERENCE TO THE OTHER MORE COMPLICATED WINDINGS WHICH WERE DESCRIBED.

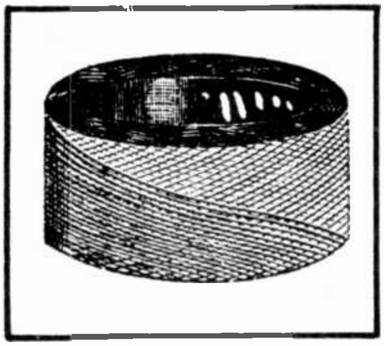


FIG. 9
The Honeycomb Coil.

SINCE R.F. TRANSFORMERS OF MANY DIFFERENT STANDARD TYPES CAN BE PURCHASED AT A NOMINAL PRICE, IT IS NOT ALWAYS PRACTICAL TO WIND THEM YOURSELF. HOWEVER, IN ORDER FOR YOUR TRAINING TO BE COMPLETE, YOU SHOULD BE FAMILIAR WITH THE FACTORS INVOLVED IN THE DESIGN AND CONSTRUCTION OF SUCH UNITS.

SUGGESTIONS FOR PRIMARY WINDINGS

ALL OF OUR ATTENTION SO FAR HAS BEEN DIRECTED TOWARD THE DESIGN OF THE SECONDARY WINDING OF THE TRANSFORMER BUT FOR GOOD RESULTS, IT IS ALSO ESSENTIAL THAT THE PRIMARY WINDING OF THIS TRANSFORMER BE PROPERLY DESIGNED.

THE PRIMARY WINDING, OF COURSE, IS NOT GENERALLY INTENDED FOR TUNING PURPOSES AS IS THE SECONDARY. THE ESSENTIAL PURPOSE OF THE PRIMARY IS TO TRANSFER THE SIGNAL ENERGY FROM THE ANTENNA OR PLATE CIRCUIT OF ONE TUBE

TO THE GRID CIRCUIT OF THE SUCCEEDING TUBE BUT IN ORDER TO DO THIS EFFICIENTLY, IT IS NECESSARY THAT THE PROPER NUMBER OF TURNS OF WIRE ALSO BE USED ON THE PRIMARY WINDING.

FROM YOUR EARLY STUDIES OF TRANSFORMERS, YOU WILL RECALL THAT A GREATER VOLTAGE STEP-UP IS OBTAINED WHEN THE NUMBER OF SECONDARY TURNS IS LARGE IN COMPARISON TO THE NUMBER OF PRIMARY TURNS. ACCORDING TO THIS FACT, ONE WOULD NATURALLY ASSUME THAT WE SHOULD USE THE LEAST NUMBER OF TURNS POSSIBLE ON THE PRIMARY.

ALTHOUGH THIS RULE APPLIES QUITE WELL WITH IRON-CORE TRANSFORMERS, YET IT FALLS SHORT IN THE CASE OF AIR-CORE TRANSFORMERS DUE TO THE GREAT MAGNETIC LEAKAGE WHICH EXISTS BETWEEN THE PRIMARY AND SECONDARY WINDINGS OF THE AIR-CORE TRANSFORMER. FURTHERMORE, THE CHARACTERISTICS OF THE CIRCUIT IN WHICH THE PRIMARY WINDING IS CONNECTED ALSO HAS A PRONOUNCED EFFECT UPON THE DESIGN OF THE PRIMARY WINDING.

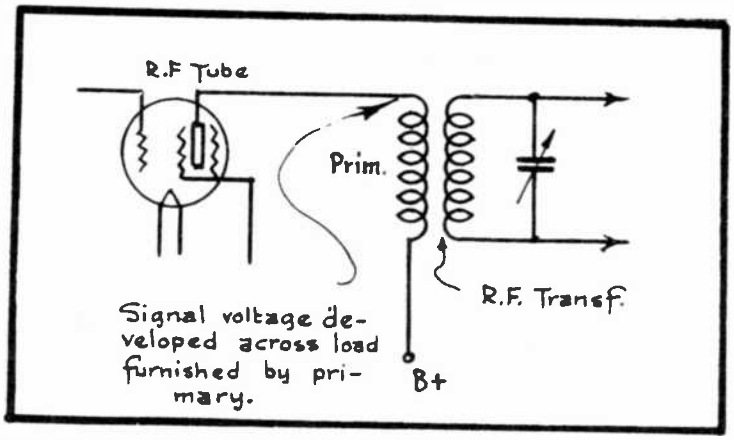


FIG. 10
Primary Winding as Load in Tube Plate Circuit.

THE PRIMARY WINDING, AS ILLUSTRATED IN FIG. 10, SERVES AS THE LOAD IN THE PLATE CIRCUIT OF THE R.F. AMPLIFIER TUBE. THE GREATER THE IMPEDANCE OFFERED BY THIS LOAD, THE GREATER WILL BE THE SIGNAL VOLTAGE DEVELOPED ACROSS ITS EXTREMETIES AND IN PRACTICE IT WORKS OUT THAT IN ORDER TO REALIZE 75% OF THE TUBE'S AMPLIFICATION FACTOR, THE LOAD IN THE TUBE'S PLATE CIRCUIT (PRIMARY WINDING IN THIS CASE) SHOULD OFFER AN IMPEDANCE EQUAL TO APPROXIMATELY 3 TIMES THAT OF THE TUBES PLATE RESISTANCE. (THE PLATE RESISTANCE OF A TUBE IS THE RESISTANCE WHICH THE PLATE CURRENT ENCOUNTERS WITHIN THE TUBE, BETWEEN THE PLATE AND CATHODE OR FILAMENT, AND IN LATER LESSONS YOU WILL RECEIVE MORE DETAILED INFORMATION REGARDING THIS TUBE CONSTANT AS WELL AS OTHER VALUABLE TUBE CONSTANTS). SO CONSIDERING CONDITIONS FROM THIS LATTER ANGLE, WE WANT A PRIMARY WINDING OF MANY TURNS SO AS TO INCREASE ITS INDUCTANCE AND LIKEWISE ITS IMPEDANCE.

FROM THE FOREGOING EXPLANATION, YOU WILL SEE THAT THE NET RESULT IS THAT ON ONE HAND, WE WANT MANY TURNS OF PRIMARY WINDING WHEREAS CONSIDERING CONDITIONS FROM THE OTHER POINT OF VIEW, WE WANT ONLY A FEW TURNS OF PRIMARY WINDING. HENCE THE ONLY THING TO DO IN THIS CASE IS TO COMPROMISE AND USE A MORE OR LESS AVERAGE NUMBER OF PRIMARY TURNS SO AS TO ATTAIN MAXIMUM AMPLIFICATION WITHOUT THE POSSIBILITY OF CIRCUIT OSCILLATION. FOR SCREEN GRID TUBES, IN WHICH THE PLATE RESISTANCE IS VERY HIGH, YOU WILL FIND THAT IT HAS BECOME THE GENERAL PRACTICE AMONG MANUFACTURERS TO CONSTRUCT THEIR PRIMARY R.F. TRANSFORMER WINDINGS WITH 40 OR MORE TURNS. FOR TUBES OF THE NONE SCREEN-GRID TYPE, WHEN USED AS AN R.F. AMPLIFIER, THEN BETWEEN 8 AND 15 TURNS OF PRIMARY ARE GENERALLY USED. THE REASON BEING THAT TUBES OF THIS LATTER TYPE HAVE A COMPARATIVELY LOWER PLATE RESISTANCE THAN DO THE SCREEN-GRID R.F. AMPLIFIER TUBES.

THE EFFECTS OF COUPLING

NOW THERE IS STILL ANOTHER IMPORTANT POINT RELATIVE TO THE DESIGN OF THE PRIMARY WINDING OF THE R.F. TRANSFORMER AND THAT IS THE MATTER OF COUPLING. IN OTHER WORDS, ONE MUST DECIDE AS TO HOW CLOSE TO PLACE THE PRIMARY WINDING TO THE SECONDARY OF THE R.F. TRANSFORMER, AS THIS POINT HAS A PRONOUNCED EFFECT UPON THE PERFORMANCE OF THE TRANSFORMER.

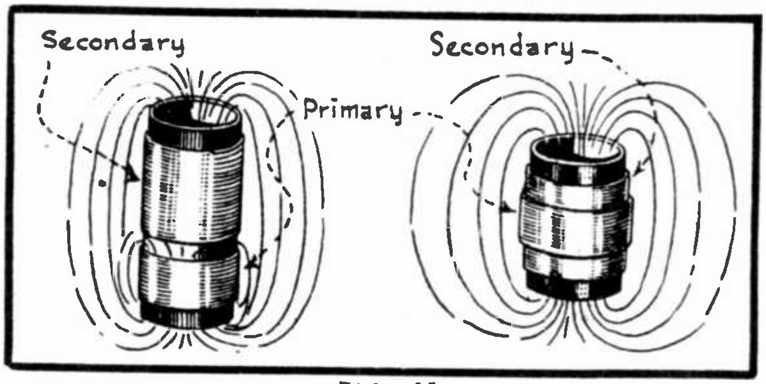


FIG. 11
Example of Loose and Close Coupling.

TWO TYPES OF COUPLING ARE ILLUSTRATED IN FIG. 11. AT THE LEFT, THE PRIMARY WINDING IS SPACED AT SOME DISTANCE FROM THE SECONDARY AND WE WOULD CLASSIFY THIS RELATION BETWEEN THE TWO WINDINGS AS BEING "LOOSE COUPLING".

IT IS OBVIOUS THAT THE FARTHER WE PLACE THE PRIMARY FROM THE SECONDARY, THE LOOSER WILL BE THE COUPLING. THIS IN TURN WILL MEAN THAT A LESS NUMBER OF THE PRIMARY WINDING'S LINES OF FORCE WILL LINK THE SECONDARY WINDING AND BECAUSE OF THIS FACT, THERE WILL BE LESS ENERGY TRANSFER BETWEEN THESE TWO WINDINGS AND THEREFORE THE AMPLIFICATION WILL DECREASE AS THE COUPLING IS MADE LOOSER. REMEMBER THIS.

NOW BESIDES AMPLIFICATION, THERE IS ALSO ANOTHER IMPORTANT RECEIVER QUALITY, WHICH IS AFFECTED BY THE COUPLING OF THE WINDINGS ON THE R.F. TRANSFORMER AND THAT IS SELECTIVITY. IT SO HAPPENS THAT THE LOOSER THE COUPLING BETWEEN THE PRIMARY AND SECONDARY WINDINGS, THE MORE SELECTIVE WILL BE THE CIRCUIT. THIS OF COURSE MEANS THAT IF YOU WANT THE RECEIVER TO TUNE SHARP, THEN YOU SHOULD USE LOOSE COUPLING ON THE R.F. TRANSFORMERS.

SO YOU SEE, HERE AGAIN WE HAVE TWO CONDITIONS WHICH WORK OPPOSITE TO EACHOTHER BECAUSE IF WE LOOSEN THE COUPLING SO AS TO INCREASE SELECTIVITY, WE ARE AT THE SAME TIME REDUCING THE AVAILABLE AMPLIFICATION AND VICE VERSA. HENCE, IN THIS CASE IT IS ALSO NECESSARY TO COMPROMISE AND TO USE A TYPE OF COUPLING WHICH WILL GIVE SATISFACTORY AMPLIFICATION AND SUFFICIENTLY SHARP TUNING.

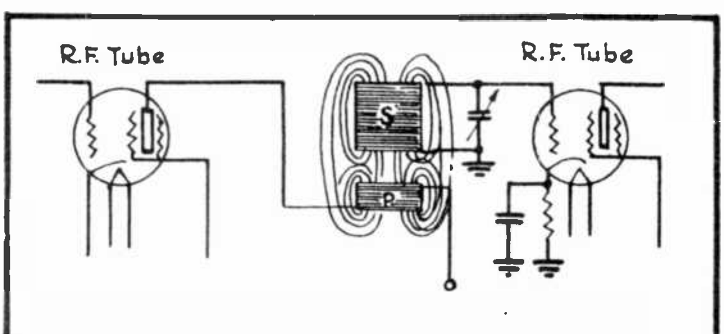


FIG. 12
Interaction Between Primary & Secondary Windings.

IN THIS RESPECT ONE SHOULD ALSO CONSIDER THE FACT THAT IT IS POSSIBLE TO COUPLE THE TRANSFORMER WINDINGS TOO LOOSE, WITH THE RESULT THAT THE RECEIVER WILL BECOME "OVER-SELECTIVE", THEREBY

PREVENTING RECEPTION OF THE HIGHER AUDIO FREQUENCIES. THIS WILL SERIOUSLY AFFECT THE RECEIVER'S TONE QUALITY AND SHOULD THEREFORE, BE GUARDED AGAINST. EXPERIMENT WILL SHOW WHAT EXTENT OF COUPLING GIVES BEST ALL AROUND PERFORMANCE FOR THIS PARTICULAR RECEIVER WHICH IS BEING DESIGNED AND CONSTRUCTED.

ANOTHER INTERESTING FEATURE RELATIVE TO COUPLING IS THAT THE AMPLIFICATION ONLY INCREASES UP TO A CERTAIN "CRITICAL VALUE" AS THE PRIMARY WINDING IS BROUGHT CLOSER TO THE SECONDARY. THIS IS DUE TO THE "INTERACTION" BETWEEN THESE TWO WINDINGS AS ILLUSTRATED IN FIG. 12. THAT IS, A MAGNETIC FIELD IS ALSO ESTABLISHED AROUND THE SECONDARY WINDING BY THE SIGNAL CURRENT FLOWING THROUGH IT AND THIS CURRENT WILL BE MAXIMUM AT RESONANCE. THIS RESULTING MAGNETIC FIELD TENDS TO OPPOSE THAT ESTABLISHED BY THE PRIMARY WINDING AND IF THE COUPLING IS TOO CLOSE, THEY REACT UPON EACHOTHER SO AS TO REDUCE THE EFFECTIVE FIELD AND THUS BRING ABOUT A REDUCTION IN AMPLIFICATION. AN EXAMPLE OF CLOSE COUPLING IS SHOWN AT THE RIGHT OF FIG. 11, WHERE THE PRIMARY IS WOUND DIRECTLY OVER THE SECONDARY WITH A PAPER OR OTHER INSULATION BETWEEN THEM.

THE MAIN OBJECT OF THE PRECEDING DISCUSSION ON COUPLING IS TO WARN YOU, SO THAT YOU WILL USE DISCRETION IN THIS RESPECT WHEN CONSTRUCTING R.F. TRANSFORMERS. IF YOU DIDN'T KNOW ANYTHING ABOUT THESE IMPORTANT EFFECTS OF COUPLING, IT IS OBVIOUS THAT YOU WOULDN'T BE QUALIFIED TO CONSTRUCT A REALLY EFFICIENT UNIT.

HIGH-GAIN TRANSFORMERS

YOU WILL ALSO REMEMBER THAT BESIDES THE CONVENTIONAL TYPE OF R.F. TRANSFORMERS, WE ALSO HAVE WHAT ARE KNOWN AS HIGH-GAIN OR CONSTANT-GAIN TYPE COILS AND WHICH WERE ALREADY DESCRIBED TO YOU IN LESSON #24. IN THIS CASE, THE INDUCTANCE VALUE OF THE PRIMARY WINDING IS QUITE HIGH SO THAT THE PRIMARY CIRCUIT RESONATES SLIGHTLY BELOW THE BROADCAST BAND SO THAT MAXIMUM GAIN THROUGH THE COIL CAN BE OBTAINED IN THE LOWER PORTION OF THE BROADCAST BAND. IN ADDITION, A CAPACITIVE COUPLING IS INTRODUCED BETWEEN THE PRIMARY AND SECONDARY WINDINGS SO THAT APPROXIMATELY THE SAME GAIN IS MAINTAINED AT THE HIGHER BROADCAST FREQUENCIES.

THERE IS NO NEED FOR GOING INTO FURTHER DETAILS AT THE PRESENT TIME REGARDING THESE COILS AS YOU ARE ALREADY ACQUAINTED WITH THEIR GENERAL CONSTRUCTION.

THE "WHEATSTONE BRIDGE"

NOW THAT YOU HAVE LEARNED HOW TO DETERMINE THE INDUCTIVE VALUE OF THE POPULAR SOLENOID TYPE COILS BY CALCULATION, AS WELL AS THE METHODS FOR WINDING VARIOUS COIL TYPES, YOU WILL AT THIS TIME NO DOUBT BE GREATLY INTERESTED IN THE MANNER BY WHICH INDUCTANCE CAN BE MEASURED WITH TESTING DEVICES. THE SIMPLEST METHOD OF MEASURING INDUCTANCE, WHERE THE EXPENSE OF ELABORATE TESTING EQUIPMENT IS PROHIBITIVE, IS BY USING A TESTING DEVICE KNOWN AS A "SLIDE-WIRE" WHEATSTONE BRIDGE. THIS SAME DEVICE CAN ALSO BE USED TO MEASURE RESISTANCE, INDUCTANCE OR CAPACITY AND THE CONSTRUCTION OF THIS APPARATUS IS CLEARLY ILLUSTRATED IN FIG. 13.

A WHEATSTONE BRIDGE OF THIS TYPE CAN BE CONSTRUCTED AT HOME VERY EASILY BY FOLLOWING FIG. 13 AND THE FOLLOWING SUGGESTIONS: THE BASE MAY

CONSIST OF A BOARD 45" LONG, 8" WIDE AND ABOUT 1/2" THICK. MOUNT A METER STICK FIRMLY UPON THE UPPER FACE OF THE BASEBOARD AS SHOWN IN THE ILLUSTRATION AND THEN ARRANGE FIVE BRASS STRAPS, EACH 1/2" WIDE AND 1/4" THICK, IN THE FORM AS ALSO ILLUSTRATED AND FASTEN THEM FIRMLY TO THE FACE OF THE BASEBOARD WITH WOOD SCREWS.

STRAPS #1 AND #5 CAN BE 6" LONG, STRAPS #2 AND #4 CAN BE 10" LONG AND STRAP #3 CAN BE 15" LONG. MOUNT TERMINALS AT POINTS A, B, C, D, E, F, G AND H. CONNECT TERMINAL "A" TO THE BRASS STRAPS #4 AND #5 THROUGH A SINGLE POLE SWITCH, RUNNING THE CONNECTING WIRE ALONG THE UNDERSIDE OF THE BASE IN ORDER TO ADD TO THE APPEARANCE OF THE FACE. CONNECT TERMINAL "F" TO STRAPS #1 AND #2, ALSO RUNNING THIS CONNECTING WIRE ALONG THE UNDERSIDE OF THE BASE.

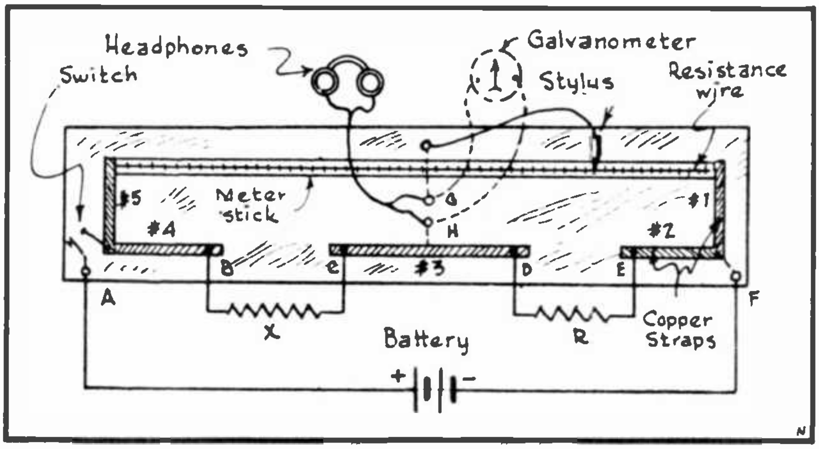


FIG. 13
The Wheatstone Bridge

TERMINAL "H" IS CONNECTED TO STRAP #3 IN LIKE MANNER AND TERMINAL "G" IS CONNECTED TO A SLIDER BY MEANS OF A LONG FLEXIBLE INSULATED WIRE. THE SLIDER OR "STYLUS", AS IT IS SOMETIMES CALLED, MAY BE MADE FROM A PIECE OF 1/8" BRASS ROD ABOUT 3" LONG PROVIDED WITH A BAKELITE OR HARD RUBBER HANDLE. THE POINT OF THIS STYLUS SHOULD BE GROUND TO A "KNIFE EDGE".

THE FINAL STEP IN THE CONSTRUCTION OF THIS APPARATUS IS TO STRETCH A PIECE OF RESISTANCE WIRE ACROSS THE LENGTH OF THE METER STICK, AND TO ATTACH ITS ENDS SECURELY TO STRAPS #1 AND #5 SO THAT A GOOD ELECTRICAL CONNECTION IS AFFECTED AT THESE POINTS. THIS WIRE MAY BE ANY HIGH GRADE RESISTANCE ALLOY AND ALTHOUGH MANGANIN IS PREFERABLE, NICHROME OR ANY OTHER SUITABLE RESISTANCE ALLOY MAY BE SUBSTITUTED SATISFACTORILY. A #24 OR #28 B&S GAUGE WILL BE FOUND MOST CONVENIENT FOR THIS USE.

IT IS IMPORTANT THAT THIS RESISTANCE WIRE BE STRETCHED TAUT DIRECTLY ABOVE THE FACE OF THE METRIC SCALE, BEING MOUNTED SO THAT IT IS ELEVATED APPROXIMATELY 1/16" ABOVE THE METER SCALE.

LET US NOW CONTINUE WITH THE EXPLANATION REGARDING ITS USE. WE SHALL BEGIN THIS EXPLANATION WITH THE APPLICATION OF THIS APPARATUS IN THE MEASUREMENT OF RESISTANCE AND THEN IN TURN FOR MEASURING INDUCTANCE AND CAPACITY.

MEASURING RESISTANCE

NOW THEN, FIG. 13 CLEARLY ILLUSTRATES THE "SET UP" FOR A RESISTANCE MEASUREMENT AND FOR THIS WORK, THE RESISTANCE TO BE MEASURED IS CONNECTED ACROSS TERMINALS B AND C, AND WE REFER TO THIS UNKNOWN RESIS-

TANCE VALUE AS "X". THE NEXT STEP IS TO CONNECT A STANDARD RESISTANCE "R" ACROSS THE TERMINALS D AND E.

THE EXACT OHMIC VALUE OF THIS STANDARD RESISTANCE "R" MUST BE KNOWN BEFOREHAND. PRECISION TYPE NON-INDUCTIVE RESISTORS, WHICH ARE GUARANTEED TO BE ACCURATE TO WITHIN 1% OF THEIR RATED VALUE, CAN BE PURCHASED AND USED TO SERVE AS THE STANDARD RESISTANCE "R". SUCH RESISTORS ARE AVAILABLE IN A VAST NUMBER OF DIFFERENT VALUES AND FOR ANY "BRIDGE TEST," ONE SHOULD USE A RESISTANCE VALUE FOR R, WHICH IS ESTIMATED AS BEING AS EQUAL AS POSSIBLE TO THE VALUE OF THE UNKNOWN RESISTOR X.

BALANCING THE BRIDGE

PROCEED BY CONNECTING A PAIR OF HEADPHONES OR A GALVANOMETER ACROSS TERMINALS G AND H AND A BATTERY ACROSS TERMINALS A AND F. CLOSE THE SWITCH AND BRING THE SLIDER OR STYLUS INTO FIRM CONTACT AT VARIOUS POINTS ALONG THE TAUT RESISTANCE WIRE. IF USING THE GALVANOMETER, THIS INSTRUMENT WILL OFFER DIFFERENT READINGS AS THE STYLUS IS BROUGHT IN CONTACT WITH VARIOUS POINTS ALONG THE RESISTANCE WIRE, SO CONTINUE TESTING ALONG THIS RESISTANCE WIRE UNTIL YOU HAVE FINALLY LOCATED A POINT ON THIS WIRE WITH YOUR STYLUS AT WHICH THE GALVANOMETER READS ZERO. THE WHEATSTONE BRIDGE IS NOW SAID TO BE IN A STATE OF BALANCE, SO NOTE CAREFULLY AT WHICH MARK OF THE METER STICK AT WHICH THE STYLUS MAKES CONTACT WITH THE RESISTANCE WIRE IN ORDER TO CAUSE THE GALVANOMETER TO READ ZERO.

IF USING HEADPHONES INSTEAD OF THE GALVONOMETER, YOU WILL HEAR CLICKS OF VARYING INTENSITY AS THE STYLUS IS BROUGHT IN CONTACT WITH VARIOUS POINTS ALONG THE METER SCALE. IN THIS CASE, CONTINUE CONTACTING THE STYLUS AT DIFFERENT POINTS ALONG THE METER SCALE UNTIL YOU LOCATE THE POINT AT WHICH NO CLICK IS HEARD IN THE HEADPHONES UPON MAKING CONTACT. THE WHEATSTONE BRIDGE WILL NOW BE IN A STATE OF BALANCE, SO CAREFULLY TAKE NOTE OF THE STYLUS POSITION AT THIS INSTANT WITH RESPECT TO THE METRIC SCALE.

LET US ASSUME THAT UNDER THE CONDITIONS OF AN ACTUAL TEST, THE WHEATSTONE BRIDGE IS BALANCED UNDER THE CIRCUMSTANCES ILLUSTRATED IN FIG. 14. HERE THE STANDARD RESISTOR "R" HAS A VALUE OF 10 OHMS AND THE BRIDGE IS BROUGHT TO A STATE OF BALANCE WITH THE STYLUS OR SLIDER CONTACTING POINT "A" ON THE RESISTANCE WIRE.

CALCULATING RESISTANCE

NOW THEN, TO CALCULATE THE VALUE OF THE UNKNOWN RESISTOR "X", WE EMPLOY THE FOLLOWING MATHEMATICAL RELATION, $X = \frac{R\,S}{T}$. PUTTING THIS MATHEMATICAL FORMULA IN WORDS, IT HAS THE FOLLOWING MEANING: TO FIND THE VALUE IN OHMS OF THE UNKNOWN RESISTOR "X", MULTIPLY THE OHMIC VALUE OF THE STANDARD RESISTOR "R" BY LENGTH "S" OF THE RESISTANCE WIRE (S IS EQUAL TO THE DISTANCE FROM THE ZERO POINT ON THE METRIC SCALE TO THE POINT "A" AT WHICH THE STYLUS TOUCHES THE WIRE IN ORDER TO BALANCE THE SYSTEM); DIVIDE THIS PRODUCT BY "T" (THE DISTANCE FROM POINT "A" IN FIG. 14 TO THE OTHER EXTREMETY OF THE METRIC SCALE).

AS A PRACTICAL EXAMPLE, LET US SUPPOSE THAT THE STANDARD RESISTOR "R" IN FIG. 14 HAS A VALUE OF 10 OHMS, DISTANCE "S" IS EQUAL TO 40 CM. AND DISTANCE "T" TO 60 CM., WITH THE SYSTEM IN A STATE OF BALANCE. APPLY-

ING OUR FORMULA $X = \frac{R\ S}{T}$ TO THIS PARTICULAR EXAMPLE, WE HAVE: $X = \frac{10 \times 40}{60} = \frac{400}{60} = 6.66$ OHMS.

THE SIZE BATTERY TO USE FOR THIS TEST WILL BE GOVERNED BY THE RESISTANCE VALUES IN THE SYSTEM. THE PRACTICAL THING TO DO IS TO USE A BATTERY VOLTAGE WHICH WILL GIVE A LEGIBLE READING ON THE GALVANOMETER AND A DISTINCT CLICK IN THE HEADPHONES WHEN THE SYSTEM IS NOT BALANCED. ORDINARILY, A 4½ VOLT "C" BATTERY WILL SERVE THE PURPOSE.

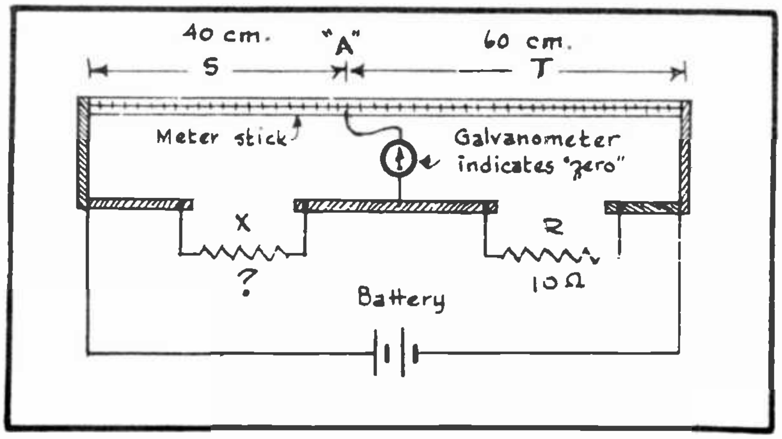


FIG. 14
Data for Calculating Resistance.

MEASURING INDUCTANCE

FIG. 15 SHOWS YOU HOW TO SET UP THE BRIDGE FOR MEASURING INDUCTANCE. IN THIS CASE, THE UNKNOWN INDUCTANCE "Lx" IS CONNECTED ACROSS THE SAME TERMINALS ACROSS WHICH THE UNKNOWN RESISTANCE WAS FORMERLY CONNECTED FOR THE RESISTANCE MEASUREMENT AND A STANDARD INDUCTANCE OF KNOWN INDUCTIVE VALUE "L S" IS CONNECTED TO THE BRIDGE AS ALSO PICTURED IN FIG. 15.

NOW INSTEAD OF CONNECTING A BATTERY DIRECTLY ACROSS THE BRIDGE, WE NEED A SOURCE OF A.C., HAVING APPROXIMATELY A 1000 CYCLE FREQUENCY. THIS A.C. SUPPLY CAN BE OBTAINED BY CONNECTING AN ORDINARY BUZZER IN SERIES WITH TWO SERIES CONNECTED No.6 DRY CELLS AND IN TURN CONNECTING THIS COMBINATION ACROSS THE PRIMARY WINDING OF A TRANSFORMER. THIS TRANSFORMER MAY BE AN ORDINARY TELEPHONE TRANSFORMER OR ELSE IT CAN BE CONSTRUCTED BY WINDING A PRIMARY OF 100 TURNS AND A SECONDARY OF 1000 TURNS AROUND AN IRON CORE. THE WIRE SIZE IS NOT CRITICAL. THE SECONDARY WINDING OF THIS TRANSFORMER IS THEN CONNECTED ACROSS

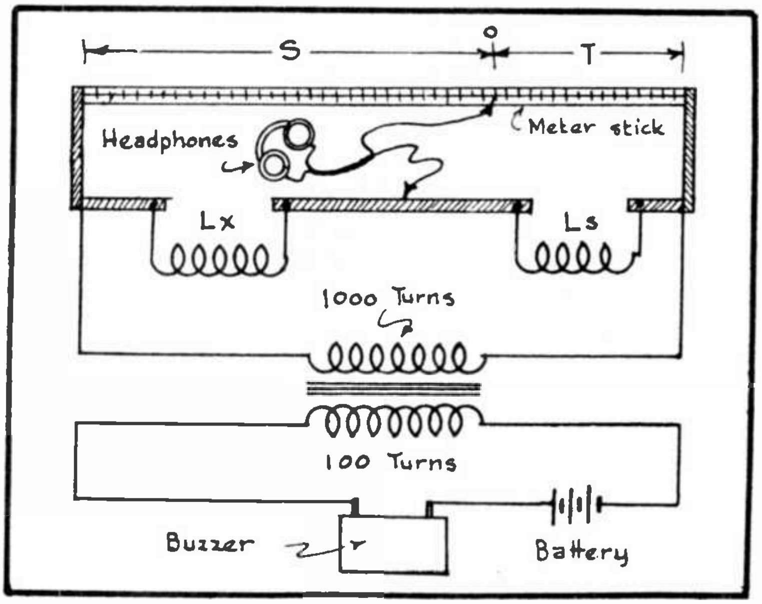


FIG. 15
Measuring Inductance.

THE BRIDGE CIRCUIT AS SHOWN AND IN THIS WAY AN A.C. SUPPLY OF APPROXIMATELY 1000 CYCLES IS APPLIED ACROSS THE BRIDGE CIRCUIT.

WITH THE SET-UP AS ILLUSTRATED IN FIG. 15, A DECIDED BUZZING SOUND WILL BE HEARD IN THE HEADPHONES AS THE SLIDER MAKES CONTACT WITH VARIOUS POINTS ON THE RESISTANCE WIRE. LOCATE THE POSITION ON THIS WIRE WHERE THE MINIMUM BUZZING SOUND IS DETECTED IN THE HEADPHONES. THIS INDICATES THAT THE BRIDGE IS BALANCED, SO CAREFULLY TAKE NOTE OF THE SLIDER'S POSITION OVER THE METRIC SCALE AT THIS INSTANT.

THE INDUCTIVE VALUE OF L X IN FIG. 15 CAN NOW BE DETERMINED BY USING THE FOLLOWING FORMULA: $Lx = \frac{S}{T} \times Ls$ IN WORDS, THIS MEANS THAT TO FIND THE VALUE OF THE INDUCTANCE, DIVIDE LENGTH "S" OF FIG. 15 BY LENGTH T AND MULTIPLY THIS QUOTIENT BY THE INDUCTIVE VALUE OF THE KNOWN INDUCTANCE "Ls". THE ANSWER WILL BE EXPRESSED IN THE SAME INDUCTANCE UNITS AS USED FOR Ls.

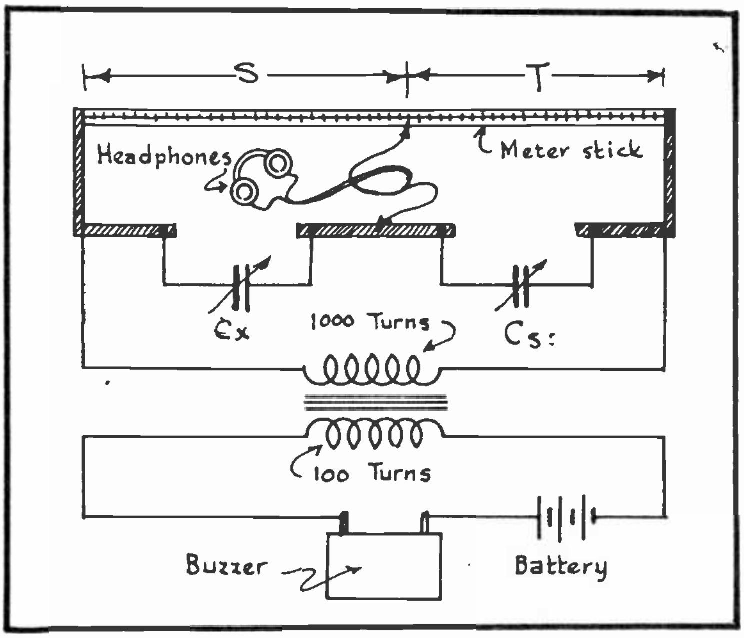


FIG. 16
Measuring Capacity of a Variable Condenser.

AS A PRACTICAL EXAMPLE, LET US ASSUME THE STANDARD INDUCTANCE Ls IN FIG. 15 AS HAVING A VALUE OF 130 MICROHENRIES AND THE BRIDGE BEING IN A STATE OF BALANCE WITH THE SLIDER CONTACTING THE RESISTANCE WIRE OVER THE 60 CM. MARK. DISTANCE "S" THUS BECOMES 60 CM. AND "T" IS 40 CM. THENCE BY APPLYING THE FORMULA $Lx = \frac{S}{T} \times Ls$, WE HAVE $Lx = \frac{60}{40} \times 130 = 1.5 \times 130 = 195$ MICROHENRIES.

HENCE COIL Lx HAS AN INDUCTANCE OF 195 MICROHENRIES.

THE MOST CONVENIENT INDUCTANCE STANDARD, Ls IN FIG. 15, IS GENERALLY A WELL CONSTRUCTED VARIOMETER. THIS MAY BE MOUNTED WITH A VERNIER DIAL (GEARED DIAL MOVEMENT), THE UNIT BEING PREVIOUSLY CALIBRATED WITH A CURVE PLOTTED BY SOME TESTING LABORATORY AND SHOWING THE INDUCTANCE FOR ANY DIAL SETTING. THIS FORM OF STANDARD INDUCTANCE WILL SERVE WELL FOR MOST INDUCTIVE MEASUREMENTS CONCERNING R.F. COILS.

MEASURING CONDENSER CAPACITY

THE BRIDGE ASSEMBLY CAN ALSO BE USED FOR MEASURING THE CAPACITY OF UNKNOWN CONDENSERS. FOR THIS WORK, WE USE THE SAME SET UP AS WHEN MEASURING INDUCTANCE AND AS ILLUSTRATED IN FIG. 15, ONLY THAT THE UNKNOWN CONDENSER AND A CALIBRATED STANDARD CONDENSER ARE CONNECTED INTO THE CIRCUIT AS SHOWN YOU IN FIG. 16.

IN THIS CASE, THE STANDARD CONDENSER CAN BE A GOOD VARIABLE AIR CONDENSER OF LOW DIELECTRIC LOSS AND EQUIPPED WITH A VERNIER DIAL FOR WHICH A GRAPH HAS BEEN PLOTTED IN ORDER TO SHOW THE EXACT CAPACITY OF THE STANDARD CONDENSER CORRESPONDING TO ANY DIAL SETTING.

THE BRIDGE IS BALANCED BY ADJUSTING THE SLIDER TO THE POINT WHERE THE LEAST BUZZING SOUND IS HEARD IN THE HEADPHONES. THE CAPACITY OF THE UNKNOWN CONDENSER IS THEN FOUND BY USING THE FORMULA $Cx = \frac{Cs\ T}{S}$ AS APPLIED TO FIG. 16.

LET US SUPPOSE, FOR EXAMPLE, THAT THE STANDARD CONDENSER IN FIG. 16 IS ADJUSTED TO A CAPACITY OF .00025 MFD. AND THAT THE BRIDGE IS BALANCED WITH THE SLIDER CONTACTING THE RESISTANCE WIRE AT THE 65 CM. MARK OF THE METRIC SCALE. THIS MEANS THAT DISTANCE $S = 65$ CM. AND $T = 35$ CM. APPLYING THE CONDENSER FORMULA, WE HAVE $Cx = \frac{.00025 \times 35}{65} = \frac{.00875}{65} = .00013$ APPROXIMATELY. THUS, THE UNKNOWN CONDENSER IS FOUND TO HAVE A CAPACITY OF ABOUT .00013 MFD.

WE HAVE NOW CONSIDERED R.F. TRANSFORMER DESIGN AND THE APPLICATIONS OF THE WHEATSTONE BRIDGE QUITE THOROUGHLY, SO WITH THIS INFORMATION ADDED TO YOUR GROWING RADIO KNOWLEDGE, WE SHALL CONCLUDE THIS LESSON.

ALTHOUGH WE HAVE BY NO MEANS COMPLETED ALL OF OUR STUDIES PERTAINING TO R.F. AMPLIFIERS, YET WE SHALL LEAVE THIS SUBJECT FOR A LITTLE WHILE AND GO INTO A.F. AMPLIFIERS MORE THOROUGHLY. BY THUS HAVING A CHANGE OF SUBJECT FOR AWHILE, WE CAN PREVENT YOUR STUDIES FROM BECOMING TIRESOME AND MONOTENOUS, WHILE AT THE SAME TIME ENABLING YOU TO ADVANCE THROUGH THE ENTIRE RADIO FIELD AS A WHOLE MORE RAPIDLY AND IN EASY, LOGICAL STEPS.

EXAMINATION QUESTIONS

LESSON NO. 44

Of all the virtues, patience is the most essential to success.

J. A. ROSENKRANZ

1. - DESCRIBE HOW YOU WOULD GO ABOUT THE TASK OF WINDING A SOLENOID-TYPE R. F. COIL?

2. - WHAT IMPORTANT FACTS SHOULD BE TAKEN INTO CONSIDERATION AS REGARDS PLACEMENT OF THE TERMINAL LUGS ON AN R. F. TRANSFORMER?

3. - DESCRIBE HOW A BASKET-WEAVE COIL MAY BE WOUND?

4. - WHAT ARE SOME OF THE MORE IMPORTANT FACTORS TO BE CONSIDERED RELATIVE TO THE PRIMARY WINDING OF R.F. TRANSFORMERS OF THE SOLENOID TYPE?

5. - DESCRIBE THE CONSTRUCTION OF A WHEATSTONE BRIDGE.

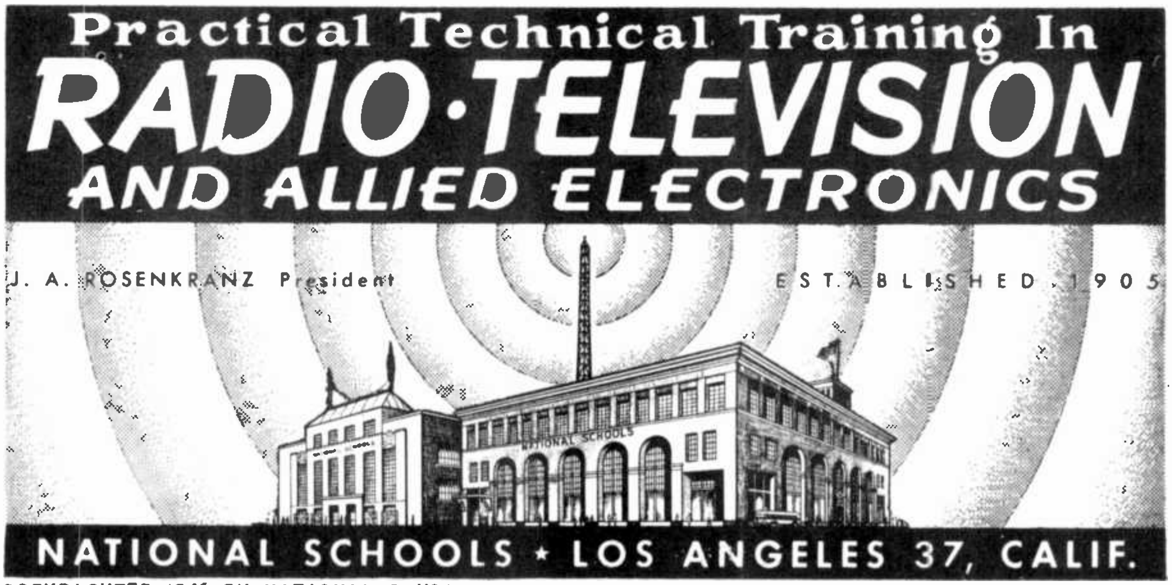
6. - EXPLAIN HOW THE VALUE OF AN UNKNOWN RESISTOR MAY BE MEASURED BY MEANS OF A WHEATSTONE BRIDGE.

7. - HOW CAN THE INDUCTANCE OF A WINDING BE MEASURED WITH A WHEATSTONE BRIDGE?

8. - EXPLAIN HOW THE VALUE OF AN UNKNOWN CONDENSER MAY BE MEASURED BY MEANS OF A WHEATSTONE BRIDGE.

9. - DESCRIBE A SIMPLE COIL-WINDING MACHINE.

10. - WHAT TYPE OF R.F. TRANSFORMER SECONDARY WINDING IS MOST EFFICIENT?



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LESSON NO. 45

A. F. AMPLIFIER DESIGNING FACTORS

(Vacuum Tube Characteristics)

Audio frequency amplifiers are designed to amplify weak impulses (voltages) in the audible frequency range or spectrum (Fig. 1).

Theoretically, the audio-frequency spectrum extends up to 20,000 cycles. However, frequencies of lower than 30 cycles or higher than 10,000 cycles are rarely transmitted, and so if we will consider our audio frequency design factors on this basis, they will serve for most purposes.

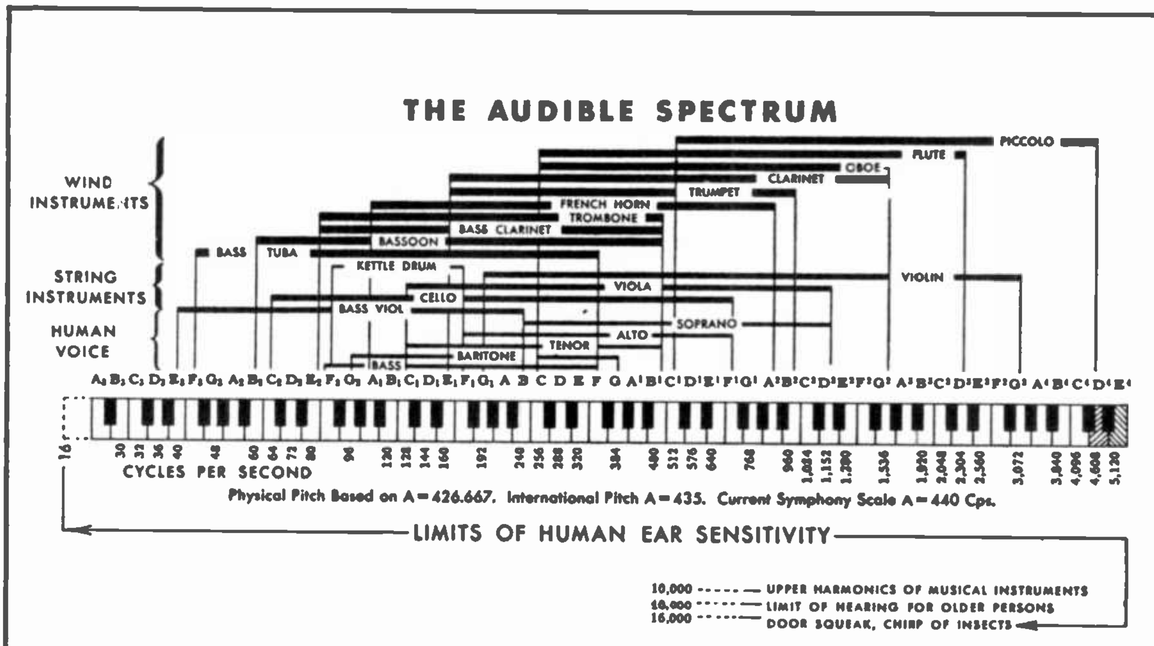

FIG. 1
THE AUDIBLE SPECTRUM

These audio impulses may be obtained from a radio circuit consisting of several stages of r-f amplification and detector, or from an electric phonograph pick-up or microphone. The amplified audio voltage is then usually applied to a loudspeaker or other device in order to convert the electrical energy into mechanical energy.

The amplification obtainable from a single STAGE or a CASCADE of stages (a number of stages in succession) is dependent upon:

1. The type of amplifying tube used.

2. The voltages used to operate these tubes.

3. The type of interstage coupling employed.

4. The losses occurring within the parts employed in the circuit.

CLASS OF AMPLIFYING TUBES

Since the amplifying capabilities and power output capacity of an amplifying stage is largely dependent upon the particular type of tube employed in the circuit, it is important that we familarize ourselves with the characteristics of amplifier tubes. Such tubes may be classified into three general types, as follows:

1. High-mu or voltage amplifier tubes.

2. Low-mu and power amplifiers.

3. Medium-mu or general-purpose tubes.

The amplifying ability of the high-mu tubes make them particularly adaptable for use when only a relatively weak input (grid voltage) is available, and where it is desirable to step this weak impulse up to a high level; For example, when using too few or no stages of r-f and i-f amplification; or, when using a diode (non-amplifying) type of detector stage, the audio voltage available at the output of such an arrangement is generally insufficient to excite the grid of a power-amplifier tube adequately. A high-mu voltage amplifier is therefore interposed between the detector and power amplifier tube to "boost" this voltage up to a proper level so that efficient operation of the power amplifier stage may then be realized.

Technically stated: When the excitation (signal) voltage is relatively weak and we require a large change in plate current---per change of grid voltage---the high-mu type of amplifier tube would be the one to select.

Although a relatively large plate-current CHANGE is realized from a very small change in grid-voltage, the total amount of plate current that the high-mu tube is capable of handling, is comparatively small. To take advantage of this great variation in plate-current, it is therefore necessary to convert the CURRENT changes to VOLTAGE changes. These large voltage-changes or variations are then passed on to a succeeding tube (the power amplifier stage in the typical receiver) that is capable of handling heavier amounts of current. Because of the greater amount of plate current (and thus wattage) that the latter type tubes can handle and deliver, the operation of a powerful loudspeaker or other reproducing device is then possible.

To summarize the above: On the one hand, we have a class of tubes that are extremely sensitive to small or weak input (grid) impulses (excitation voltages). These cause a large variation in the number of electrons that flow from the cathode to the plate; thus, a correspondingly large variation in the amount of current flowing thru the plate-circuit. Such tubes, however, are usually incapable of carrying large amounts of current. And so, although the variations in plate-current are large, the total amount of current flowing between the cathode and plate---and thus thru the plate-circuit---is of a small value; usually insufficient to drive a loudspeaker or other mechanical device.

To realize maximum amplification from such tubes, it is necessary to convert these CURRENT variations into VOLTAGE variations, by having the relatively small amount of current flow thru a high value of impedance such as offered by a resistor or inductance. Since the flow of current thru an impedance produces a voltage-drop ($E_{vd} = I \times Z$), the large value of voltage-drop, thus produced, is allowed to actuate a condenser which, in turn, transfers this amplified voltage to the grid of the succeeding amplifying tube. These high-mu, low-current tubes are therefore commonly referred to as VOLTAGE AMPLIFYING tubes.

Low-mu and power amplifying tubes, on the other hand, are not as sensitive to grid voltage changes as are the high-mu tubes, but they are capable of handling larger amounts of current. Hence, such tubes usually follow the high-mu tube, converting the voltage variations into variations of heavy amounts of CURRENT (POWER) variations which are then used to produce mechanical work.

Medium-mu tubes are a compromise between the voltage and current amplifier type tubes, and are generally referred to as GENERAL PURPOSE tubes. These are comparatively sensitive to weak input signals and are able to carry heavier amounts of plate-current than the high-mu tubes. Such types may be used for either voltage or current amplification.

AMPLIFICATION FACTOR OR "MU"

Although you were introduced to the AMPLIFICATION FACTOR of a tube in a previous lesson, we shall consider it in greater detail at this time.

Let us think of the mu (μ) of a tube as being a RATIO. A ratio between the following two factors:

(1), the PLATE-VOLTAGE change (ΔE_p) and (2), the GRID-VOLTAGE change (ΔE_g)---TO PRODUCE THE IDENTICAL AMOUNT OF PLATE CURRENT CHANGE (ΔI_p).

(Note: The Greek letter "Delta", written as Δ (sometimes also written in the form of a small letter "d") is the technical symbol used to signify a CHANGE or VARIATION in value. The symbols E_p, E_g and I_p designate plate voltage, grid voltage and plate current respectively. Thus, ΔE_p signifies a change in plate voltage; ΔI_p, a change in plate current, etc. Mathematically, Amplification Factor is expressed as:

$$\mu = \frac{\Delta E_p}{\Delta E_g} \qquad \text{or} \qquad \mu = \frac{E_{p2} - E_{p1}}{E_{g2} - E_{g1}}$$

Note: The amplification or "mu" of a tube (μ) is expressed only as a numerical (relative) value; no unit of measurement having been assigned to it.

Amplification factor may be considered to be the ratio of output to the input. For example, if we injected 1/10 volt into the grid or input of a vacuum tube circuit and obtained an output voltage of 1 volt from the plate circuit, the amplification factor would be 10.

Certain type tubes have an amplification factor of several thousand. This, however, does not necessarily imply that the output realized from such tubes will be thousands-of-times greater than the input. For, to realize the greatest portion of the amplification factor of a tube, other factors must also be carefully considered---such as the values of the parts used in conjunction with the tube, the efficiency or "Q" of the parts employed in the circuit, etc. Of great importance is the particular type and specific value of the OUTPUT or LOAD circuit best suited to the tube being used. Proper selection of the load circuit can only be made when the PLATE RESISTANCE of the tube is known.

PLATE RESISTANCE

As you probably realize, the function of a vacuum tube depends upon the flow of electrons between the cathode and the plate. The number of electrons that will ultimately reach the plate is dependent upon many factors. Some of these are:

1. Physical structure of the tube.
   a. The distance between the various elements within the tube.
   b. The area of the cathode and plate.
   c. The manner in which the various elements are constructed, shaped, etc.
2. The polarity and value of the control-grid voltage.
3. The value of the screen suppressor and plate voltage.
4. The amount of space charge or secondary emission.
5. The presence of gas molecules within the tube (either due to imperfect evacuation during manufacture or to the liberation of gas from the electrodes during normal tube operation).

Since the PHYSICAL structure of the tube is fixed, the opposition (resistance) presented by this factor (to the stream of electron flow) is also of a fixed value. However, various values of voltage may be applied to the plate, control-grid and the other electrodes of the tube so that the number of electrons allowed passage from cathode to plate will be largely dependent upon these voltages. Hence, when referring to a Tube Manual for plate current information, it is important to note the specific values of voltage placed upon the various elements of the tube. Only under such conditions will we obtain the value of plate-current flow specified. In respect to this, it is important to remember that a change in any of the voltages specified, will automatically cause a change in the value of plate-current flow.

The TOTAL internal opposition offered by all of the above factors is referred to as the PLATE RESISTANCE of the tube. When the plate VOLTAGE and the plate CURRENT values are known, it is then possible to determine the plate resistance of the tube. This may be computed by dividing the plate-voltage (E_p) by the plate-current (I_p). As you probably realize, the plate current value must be expressed in AMPERES when making this calculation.

The above method of determining the plate resistance of a tube is known as the STATIC or "stationary" method. This means that the voltage upon each electrode of the tube is stationary, fixed and non-varying.

DYNAMIC PLATE RESISTANCE

When designing an amplifying stage, the STATIC characteristics of a tube are of little value since the voltage upon the control-grid is constantly being varied by the a-c alternations of the incoming signal. This means that the value of plate-current is also varying constantly; and, since the output voltage of an amplifier is dependent upon the amount of current flowing thru the plate circuit, we can readily see that this voltage will also vary accordingly.

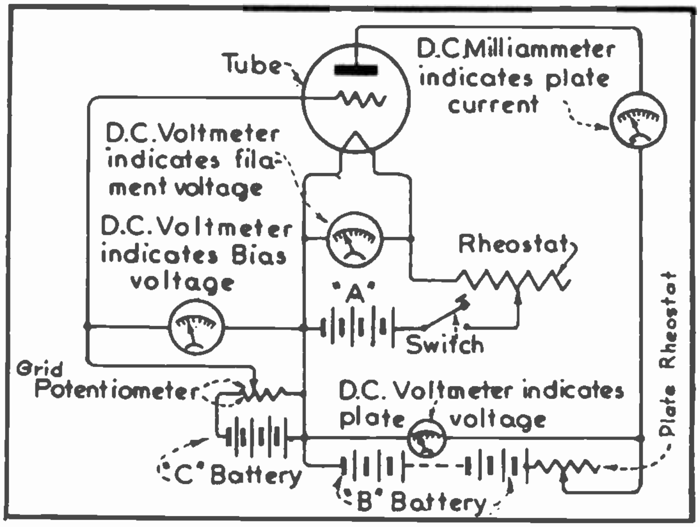

FIG. 2
CIRCUIT FOR DETERMINING TUBE CHARACTERISTICS

Hence, to determine the effective gain that may be realized from a tube during operation, we must consider its characteristics under actual, operating conditions. We refer to this as the DYNAMIC characteristics of a tube.

Under dynamic conditions, the plate current is constantly varying or "swinging". If we can determine:

1. The MAXIMUM value of the plate-current swing and the MINIMUM value of the plate-current swing; and, divide this into

2. The maximum and minimum plate VOLTAGE swing THAT OCCURS BECAUSE OF THIS, we may then compute the DYNAMIC PLATE RESISTANCE or "PLATE IMPEDANCE" of the tube.

This may be expressed mathematically, as:

$$r_p = \frac{E_p \text{ max} - E_p \text{ min}}{I_p \text{ max} - I_p \text{ min}} \text{ ; or } r_p = \frac{\Delta E_p}{\Delta I_p}, \text{ in which}$$

ΔE_p = the plate VOLTAGE change and ΔI_p = the plate CURRENT change.

As a practical demonstration of how the dynamic plate resistance of a vacuum tube may be determined, let us employ the circuit illustrated in Fig. 2. For the purpose of explanation, we will use a triode designed for operation with 135 volts applied to its plate and a -9 volt bias. With the circuit connected as shown, we then proceed to make measurements in the following manner:

1. Adjust the Plate Rheostat so that the D.C. Plate Voltmeter reads 135. This indicates the 135 volts is being applied to the plate of the tube.

2. The Grid Potentiometer is then adjusted so that the Grid Bias Voltmeter reads 9 volts.

3. Under the above conditions, let us assume that the D.C. Milliammeter indicates a plate-current reading of 3 milliamperes.

4. We now reduce the plate voltage by re-adjusting the Plate Rheostat so that the Plate Voltmeter reads 125 volts.

5. A glance at the Plate Milliammeter shows that the plate current has dropped to 2 milliamperes because of this reduction in plate voltage.

From the above experiment we have thus obtained the two values necessary for our formula. These are:

1. $\Delta E_p = 135$ v. - 125 v. = 10 v. change.

2. $\Delta I_p = 3$ ma. - 2 ma. = 1 ma. or .001 ampere change.

With these two values known, we may now solve for the third or UNKNOWN value; which, in this case, is the plate resistance of the tube. Thus:

$$r_p = \frac{\Delta E_p}{\Delta I_p}$$

$$r_p = \frac{10 \text{ volts}}{.001 \text{ ampere}} = 10{,}000 \text{ ohms}$$

(Dynamic plate resistance is expressed in Ohms, since the internal resistance of the tube is the ratio of voltage to current).

An important point to note at this time---and to remember---is the following:

High-mu tubes generally have a high plate resistance.

Low-mu tubes generally have a low plate resistance.

TRANSCONDUCTANCE

The effect that the GRID-VOLTAGE has upon the PLATE CURRENT is expressed by the term Grid-Plate TRANSCONDUCTANCE--symbolized by the letters S_m. An older term, synonymous to transconductance, is MUTUAL CONDUCTANCE; symbolized by the letters G_m.

The expression "Mutual" Conductance is more of a general term denoting the relationship between the voltage-change applied to one element and the resultant current-flow CHANGE that occurs (because of this), in another element. Thus, the reason for the term "mutual".

The prefix "trans", according to Webster's dictionary, expresses the idea of change or "translation" of one thing or quality over into another. Since transconductance expresses the relationship of GRID VOLTAGE CHANGE to PLATE CURRENT CHANGE, the use of this prefix becomes apparent.

In order to realize a plate-current change, it is necessary to change the current-carrying ability of the tube---and since the current-carrying ability of a conductor is expressed as the "conducting-properties" or CONDUCTANCE of the conductor---one can readily understand why the term "transconductance" was selected to include the above effects and properties of a tube.

Mathematically, transconductance is expressed thus: $S_m = \frac{\Delta I_p}{\Delta E_g}$

HOW TO DETERMINE THE TRANSCONDUCTANCE OF A TUBE

To demonstrate how the transconductance of a tube may be obtained, we again use the test circuit illustrated in Fig. 2, but proceed as follows:

1. Assuming that the tube is to be operated with a plate voltage of 180 and a bias of -13 volts, adjust the plate voltage to 180 by means of the Plate Rheostat.

2. Adjust the grid-bias to -13 volts by means of the Grid Potentiometer.

3. Under these conditions, the plate current, as indicated by the D.C. Milliammeter, will read 5.5 ma.

4. Now increase the grid-bias to -14 volts by means of the Grid Potentiometer.

5. Result: The plate current will drop to 4.5 ma.

From the above experiment, we find that a change of 1 volt upon the grid causes a plate-current change of 1 milliampere.

The transconductance of the tube may now be determined by converting this 1 ma. to .001 ampere and substituting our numerical values for the symbols in the formula:

$$S_m = \frac{.001}{1} = .001 \text{ mho.}$$

When dealing with vacuum tubes, the unit MICROMHO, rather then "mho", is generally used since the conductance within tubes are of extremely small values. Hence, the above value would be expressed as 1,000 micromhos, instead of .001 mho. (If one mho is equivalent to 1,000,000 micromhos, .001 mho is therefore equivalent to .001 x 1,000,000 = 1,000 micromhos).

The transconductance of a tube may be computed <u>directly</u> in terms of micromhos by employing the following formula:

$$S_m \text{ in micromhos} = \frac{\Delta I_p \text{ in MICRO amperes}}{\Delta E_g \text{ in volts}}$$

The preceding problem would then be resolved in the following manner: Since 1 milliampere is equivalent to 1,000 microamperes, our formula would appear as thus:

$$S_m = \frac{1000 \text{ microamperes}}{1 \text{ volt}} = 1{,}000 \text{ micromhos}$$

The term "mho", you will recall, is the measuring unit of CONDUCTANCE (the ability of a conductor or conducting medium to CONDUCT current). Since conductance is <u>inversely</u> proportional to resistance--in other words, just the reverse of <u>resistance</u>, its unit is spelled m-h-o, which is o-h-m spelled backwards.

Mathematically, we would say that the Mho is the RECIPROCAL of Ohm; and express it in this manner: $\text{Mho} = \frac{1}{\text{Ohm}}$

Hence, if an electrical conductor is said to have an ohmic resistance value of 20 ohms, its conductance would then be:

$$\frac{1}{20} = .05 \text{ mho}$$

In practice, let us think of transconductance (or mutual conductance) as being the change in plate-current for a change of ONE (1) volt upon the grid. Thus, if a tube is rated as having a transconductance of 5,000 micromhos (at the plate and grid voltages specified), this means that with a change of 1 volt upon the grid, we will have a 5 ma. change in plate current. To demonstrate this mathematically:

Step 1. Convert the micromhos to mho: 5,000 x .000001 = .005 mho

" 2. Transpose our formula: $S_m = \frac{\Delta I_p}{\Delta E_g}$ to $\Delta I_p = \Delta E_g \times S_m$

" 3. Substitute the numerical values for the above symbols:

ΔI_p = 1 volt x .005 mho = .005 ampere or 5 milliamperes.

Another method of resolving this formula would be in the following manner:

ΔI_p = 1 volt x 5,000 micromhos = 5,000 microamperes or 5 ma. change.

SUMMARY

The foregoing CHARACTERISTICS of amplifying tubes represent the most important characteristics of such tubes. To summarize this discussion, let us review these important facts and relationships:

> The Amplification Factor of a tube denotes the relative or comparative effects of the grid and plate voltages upon the plate-current flow. Another manner of expressing this ratio or relationship, would be to say:
>
> The change of grid voltage necessary to return the plate current back to its original value after a change of plate voltage has been made. The lower the value of grid voltage necessary for this restoration, the more sensitive is the tube. We then say that the tube has a high amplification factor or "mu".

Since the grid element has the ability to cause such a radical change in plate-current, it is evident that the physical structure and placement (position) of this element within the tube is of extreme importance. So important are these two factors, that the mu of a tube is said to be dependent, primarily, upon the geometry of the tube; that is, upon the distance between the plate and grid, the number of grid-loops, the space between each grid loop, and the gauge of the grid wire.

In general, the amplification factor increases as the distance between the control-grid and plate is increased; as the radius of the grid wire is increased, and as the spacing between the grid wire is decreased. Although the values of grid and plate voltages may be altered, the control effect of the grid and mu-RATIO remain the same so that the amplification factor of a tube may be considered practically a CONSTANT, decreasing only slightly at the lower plate voltages.

The PLATE RESISTANCE of a tube does not refer so much to the direct current type of resistance existing between the cathode and plate, as it does to the "valvular" effects of the various elements within the tube. In other words, this refers to the amount of repelling or attracting effect that each element offers to the electron stream; thus, allowing a certain number of electrons to reach the plate. However, we consider the plate resistance to be the ratio between the plate-voltage CHANGE per plate-current CHANGE. And, since this is a ratio between the voltage and current, it is permissible to express this ratio in the measuring unit of "Ohm".

One of the most important factors of an amplifying tube is the Grid-Plate TRANSCONDUCTANCE or MUTUAL CONDUCTANCE of a tube. To emphasize the importance of this factor, let us present it in the following manner:

1. Whereas, the Amplification Factor of a tube is dependent upon the structure of the grid and the grid-to-plate distance;

2. The Plate Resistance depends upon the mu; the emitting surface of the cathode, surface area of the plate; grid-to-cathode distance; and the applied voltages;

3. THE TRANSCONDUCTANCE OF A TUBE DEPENDS UPON---AND INCLUDES---THE EFFECT OF ALL OF THESE FACTORS!

Mathematically, the relationship between the three above factors may be expressed in the following manner:

$$\mu = r_p S_m \; ; \quad r_p = \frac{\mu}{S_m} \; ; \quad S_m = \frac{\mu}{r_p}$$

Before progressing into the graphical analysis of tube function, it is best that we also realize this extremely important fact:

A steady or non-varying flow of plate-current cannot produce a sound in a radio receiver. In the audio-frequency amplifying section of the receiver, the plate-current must vary in step with the voice or music modulations that were separated from their carrier-wave by the detector or "de-modulator". The GREATER THESE PLATE VARIATIONS, THE LOUDER WILL BE THE SOUND IN THE SPEAKER.

The greater the variation in plate-current per grid-voltage variation, the greater is the TRANSCONDUCTANCE of the tube. Therefore, the greater TRANSCONDUCTANCE a tube has, the greater will be the AMPLIFICATION REALIZED FROM THE TUBE.

CHARACTERISTIC CURVES OF TUBES

It is a common practice to illustrate tube characteristics by means of a graph. A graph presenting the relationship between the grid-voltage (E_g) and plate-current (I_p) is illustrated in Fig. 3. The line which is drawn thru the various points, marked off on this cross-ruled paper, is commonly referred to as a GRID VOLTAGE-PLATE CURRENT "curve", and is plotted from data obtained in the following manner:

The tube, in question, is inserted in the test circuit shown in Fig. 2. Let us assume that we apply 135 volts to the plate; and, varying the grid bias voltage in steps of 1 volt from -8 to -18 volts, we obtain plate-current readings which we tabulate as shown in Table I.

Having obtained this data, we then proceed to PLOT these values upon our graph paper. The negative grid voltages are scaled horizontally from the right to the left, along

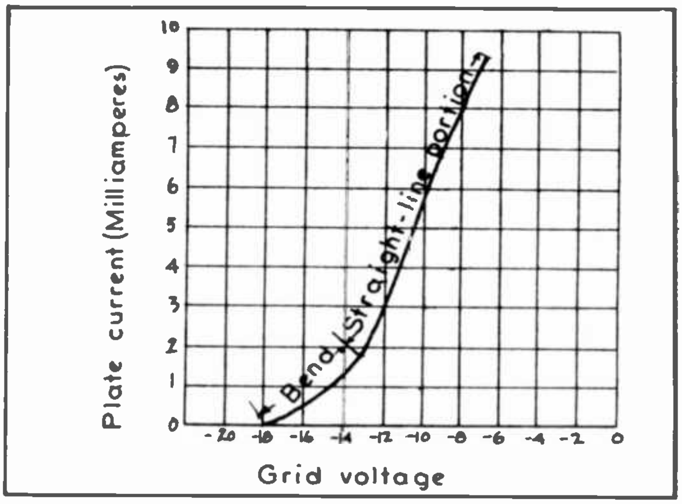

FIG. 3
GRID VOLTAGE - PLATE CURRENT CHARACTERISTIC CURVE

TABLE I	
NEGATIVE GRID POTENTIAL	CORRESPONDING PLATE CURRENT
-18 VOLTS	0 MA.
-17 VOLTS	.25 MA.
-16 VOLTS	.5 MA.
-15 VOLTS	.75 MA.
-14 VOLTS	1.25 MA.
-13 VOLTS	1.75 MA.
-12 VOLTS	3.00 MA.
-11 VOLTS	4.5 MA.
-10 VOLTS	5.75 MA.
-9 VOLTS	7.00 MA.
-8 VOLTS	8.00 MA.

the bottom of the graph paper. The plate-current values are scaled vertically, starting from zero at the bottom and, increasing in steps of one milliampere up to ten milliamperes at the very top of the graph.

Using Table I as a guide, we now plot our "markers" or points-of-intersection upon the graph paper. For instance by referring to Table I, we note that a grid-voltage of -18 volts causes the plate current to cease flowing entirely ("cut-off" voltage). We therefore locate the -18 volt line on the bottom of the graph paper and mark off a dot where this line intersects the zero (0) plate-current line. We then mark off a point at the intersection of -17 volts and .25 milliampere. We do likewise at -16 volts and .5 milliampere, etc. When all of the intersections have been thus located and marked off, we then draw a connecting line between all intersections. In most cases, this line will resemble a curve; thus, the reason for referring to this graphical representation as a CHARACTERISTIC "CURVE"---in this particular case, a "grid-voltage-plate current (Eg-Ip) curve".

At this time, let us observe the slope of the curve. Note that we have a relatively heavy flow of current at the lower values of grid-bias voltage, and that the reduction in plate current--per increase in grid-voltage--is comparatively uniform along the steep portion of the curve. This steep portion of the curve is commonly referred to as the STRAIGHT PORTION OF THE CHARACTERISTIC CURVE. It is on this portion of the curve that the greatest uniformity or "linearity" of plate-current change--per grid-voltage change--occurs. Compare this to the Ip change--per Eg change-- that occurs at the lower portion or "bend" (sometimes referred to as the "knee") of the curve (where the slope is more rounded). Fig. 4 demonstrates the grid voltage-plate current relationships of a tube at various plate voltages. Such a graph is commonly referred to as a "plate family" of curves.

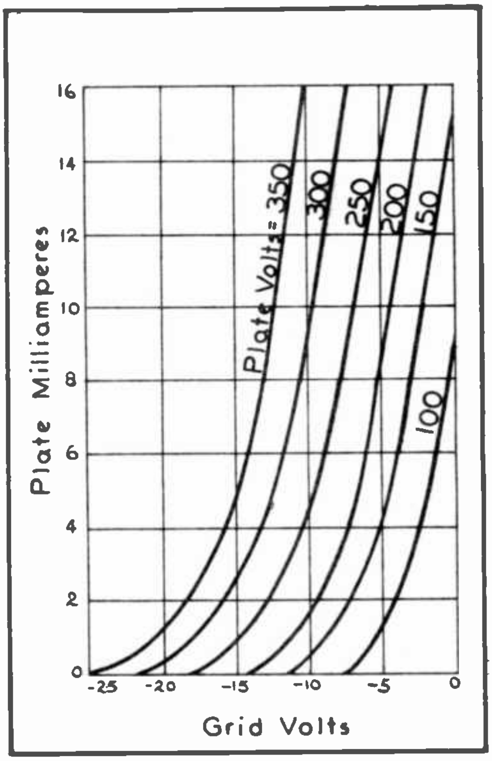

FIG. 4
PLATE "FAMILY" OF CURVES FOR A TRIODE

THE TUBE OPERATING AS AN AMPLIFIER

Another graph, illustrated in Fig. 5, has been prepared to show you how the study of a grid voltage-plate current characteristic curve is useful in determining the behavior of a tube when functioning as an amplifier.

This characteristic curve was plotted while the tube was operating at a plate-voltage of 250 volts and a grid-bias potential (Ec) of -8 volts. The value of grid-voltage is marked off by a vertical, dotted line. The plate-current that flows when the -8 volt bias is applied to the tube is represented by the horizontal dotted line (referred to as the OPERATING POINT or "Axis" of the grid-volt swing). Proper selection of this operating point is of extreme importance, since it will determine the wave-form of the output sine wave.

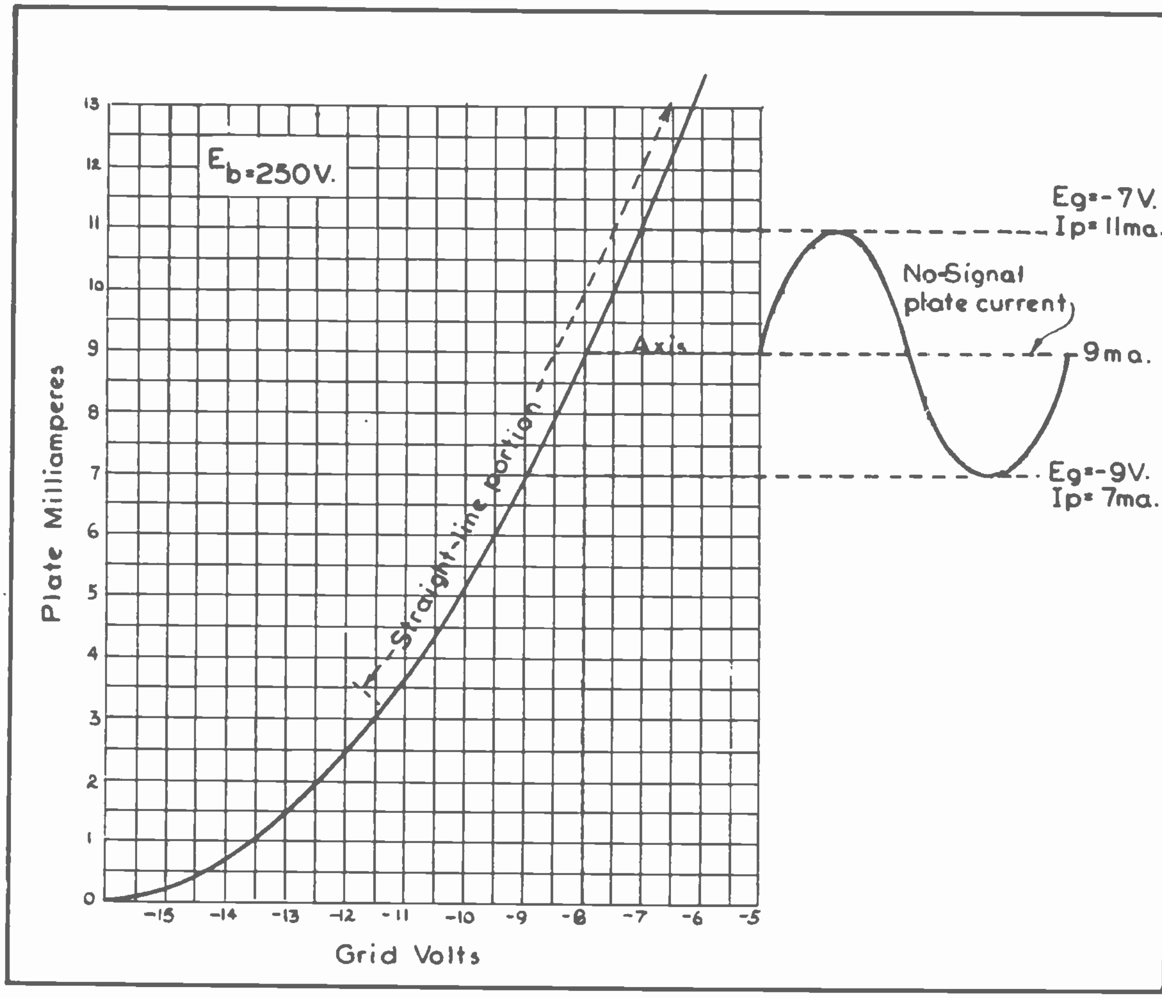

FIG. 5
PLATE CURRENT VARIATIONS WHEN TUBE FUNCTIONS AS AN AMPLIFIER

The incoming signal, as we know, is of an a-c nature; and in the form of a sine-wave. The shape of this sine-wave is symmetrical and uniform (sinusoidal). By this, we mean that the amplitude of the positive-half of the cycle is identical to the negative-half. To realize distortionless amplification, the OUTPUT sine-wave of the amplifying tube must also be uniform and symmetrical, in this respect.

Let us assume that the amplifier tube is in operation, and that no incoming or INPUT signal is present, as yet. According to our graph, we note that the tube draws 9 milliamperes. We now introduce a signal upon the grid of this tube; the intensity of which is -1 volt. This means that on the positive-half of the signal cycle, the grid voltage swings down 1 volt below the -8 volt axis value; thus making it -7 volts (-8 + [+1] = -7). On the negative-half of the signal cycle, the grid voltage swings 1 volt above the -8 volt axis value; thus, becoming -9 volts (-8+ [-1] = -9).

What happens to the plate current in the meantime? When the grid-bias voltage was reduced to -7 volts,the plate current flow increased to 11 ma. When the grid voltage was increased to -9 volts, the plate current decreased to 7 ma. The resultant sine wave is illustrated in Fig. 5. Because the increase in plate-current above the Operating Point or Axis is identical in amplitude to the decrease in plate-current below the axis, the resultant output wave-form is identical to that of the input sine-wave---which means that the amplifying tube has performed its duty faithfully (without distorting the signal).

Compare this to the resultant output sine-wave that would be obtained if the Operating Point were at the bend of the characteristic curve, as is the case in Fig. 6. Notice here, how the increase in plate current above the no-signal value is much greater than the decrease in plate current below the no-signal value. This difference in amplitude between the two halves of the audio-frequency cycle represents distortion.

IMPORTANCE OF THE LOAD IMPEDANCE

Off-hand, it would seem that the optimum position of the operating point on the Characteristic Curve would be in the dead-center of the Straight-Line portion of the curve. Surprisingly, however, this is not so! The reason for this is that we must take into account the LOAD IMPEDANCE that the tube works into. This is an extremely important factor, since the plate current flows thru this impedance. Flowing thru this impedance, a voltage-drop is produced across it which automatically varies the value of voltage being applied to the plate of the tube. This, in turn, will have a direct effect upon the plate-current increases-and-decreases as brought about by the change in grid-voltage at the input.

The plate current is always lower for a given value of grid-bias and plate-supply voltage WITH THE LOAD RESISTANCE in the circuit---than it is without it!

A Characteristic Curve, showing the relationship between the grid voltage-plate current change WHEN A PLATE RESISTANCE IS CONNECTED IN THE PLATE CIRCUIT is called a DYNAMIC Characteristic Curve. Such a curve includes the effects of the load resistance upon the performance of the tube during actual working conditions; and thus, is more indicative of the performance of the tube as an amplifier. Many characteristics of performance may be determined and predicted from such a curve.

A Static Characteristic Curve (Fig. 3), which graphically reveals the electrical behaviour of the tubes when operating with fixed voltages---and without reference to the load impedance---may be converted into a dynamic characteristic curve by drawing in a LOAD LINE to represent the variation of the plate current and voltage for the particular type of load being used.

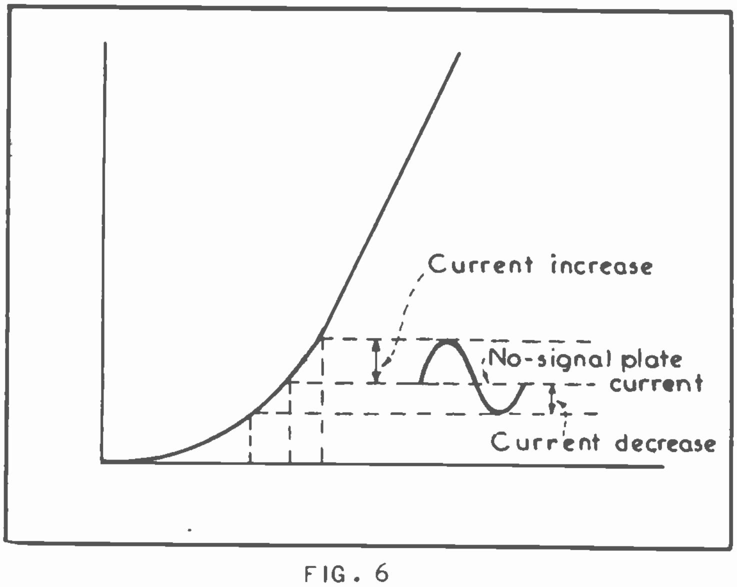

FIG. 6

PLACING THE OPERATING POINT AT THE BEND OF THE CHARACTERISTIC CURVE RESULTS IN DISTORTION

In Fig. 7, we demonstrate how a Load Line is drawn on the static characteristic curve. The horizontal axis of this graph represents the plate voltage; whereas, the vertical axis represents the plate current. From the intersection of 400 volts and zero (0) plate-current, to the intersection of 8 ma. and zero plate-volts, runs a straight line. This line is referred to as the LOAD LINE. To construct a Load Line for a specific plate resistance load, proceed as follows:

1. Divide the value of plate supply voltage (E_b) by the value of the load resistance R_L, which gives us a third value, I_b.

2. Draw a line on the static curve between I_b and E_b (8 ma. and 400 volts, respectively, in Fig. 7). This line now becomes the Load Line for the given voltages specified upon the graph.

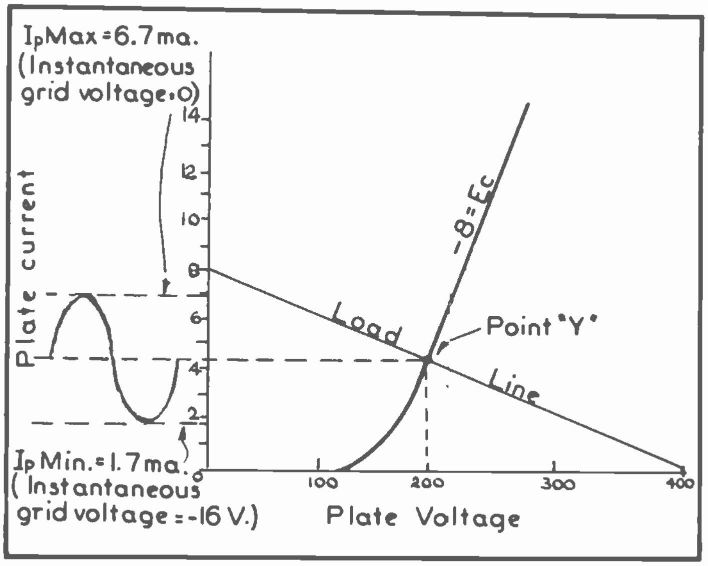

FIG. 7

LOAD LINE APPLIED TO STATIC E_p-I_p CURVE

DYNAMIC ANALYSIS

To exemplify the use of such a graph, let us analyze the characteristics and amplifying properties of a triode connected in a typical amplifying circuit as shown in Fig. 8. Note, especially, that the value of the plate resistor is 50,000 ohms. The value of the plate-supply voltage is given as 400 volts and the value of the grid-bias (E_c) is -8 volts. According to the procedure outlined in the preceding paragraph, we can plot our Load Line as follows:

$$\frac{400}{50,000} = .008 \text{ ampere or 8 ma.}$$

We now place a straight edge between the 8 milliampere point on the graph in Fig. 7, and draw a line from this point to that corresponding to 400 volts. Where this Load Line intersects the static curve, represents the optimum Operating Point to be used with a Load resistor of 50,000 ohms. For instance, at point "Y", we draw a horizontal line to the plate-current axis. This informs us that the plate current (during no-signal) will be 4.2 ma. Drawing a line from the Operating Point down to the plate-voltage axis, we find that the no-signal plate voltage is 200 volts. By varying the grid-bias voltage so that the tube draws 4.2 ma. (when the voltage at the plate is 200 volts), we can then determine the required value of grid-bias voltage. In this case, we find that the grid-bias voltage should be -8 volts.

We may then say that under STATIC conditions (no-signal present), the grid-bias voltage, applied to the grid of the tube, should be -8 volts; which, in this case, is obtained by the "self" or "automatic" biasing method (a resistor in series with the cathode).

Let us now assume that a signal enters the grid circuit. The signal is of such an intensity that its peak voltage is 8 volts. The a-c alternations of the signal ADD TO, and SUBTRACT FROM, the bias voltage. This means that on the positive peak of the signal cycle, the total (bias plus signal) voltage impressed upon the grid of the tube will be zero; and on the negative peak of the signal cycle, the total grid-voltage will be -16.

By referring to the graph in Fig. 7, we note that at the instant the grid becomes zero (0) volts, the plate-current rises to an instantaneous value of 6.7 ma. When the grid "swings" to an instantaneous voltage of -16 volts, the plate-current will swing down to 1.7 ma.

What has happened to the plate voltage in the meantime? Before discussing this point, let us first review one of the basic fundamental rules regarding amperage flow thru a resistor and the voltage-drop it creates:

> When the current flow thru a resistor (or impedance) increases, the VOLTAGE DROP across that resistor increases. Mathematically: Evd = I x R, in which I = the amount of current flowing thru the resistor, in AMPERES; and R = the value of the resistance, in Ohms.

In the circuit under discussion (Fig. 8), we heve a 50,000 ohm load resistor (R_L) in series with the plate circuit. Because of the a-c signal being impressed upon the grid of the tube, the plate-current swings or varies from 6.7 ma. to 1.7 ma. (See Fig. 7). When the plate-current reaches a value of 6.7 ma., a 335 volt drop occurs across the plate load resistor (E_{vd} = .0067 ampere x 50,000 ohms = 335 volts). This leaves an e.m.f. of 65 volts to be impressed upon the plate of the tube. ($E_b - E_{vd} - E_c = 400 - 335 - 0 = 65$ volts)

On the negative half of the signal-cycle, when the plate-current drops to an instantaneous low value of 1.7 ma., the voltage-drop across this resistor is 85 volts (.0017 ampere x 50,000 ohms = 85 volts). The voltage that will be impressed upon the plate of the tube, at this time, will be 299 volts (400 - 85 - 16 = 299 volts).

From the above figures, it can be readily seen that the plate-voltage varies from 299 to 85 volts during each signal-cycle. The total voltage variation across the plate load resistor, therefore, is 214 volts (299 - 85 = 214 volts) during this cycle. This represents the useful peak-to-peak output voltage that may be used to pass on to a succeeding stage of amplification.

With a peak-to-peak output of 214 volts, in respect to a peak-to-peak input of 16 volts, the amplification or gain realized from this tube equals:

$$\frac{\text{Plate peak-to-peak output voltage}}{\text{Grid peak-to-peak input voltage}} = \frac{214 \text{ volts}}{16 \text{ volts}} = 13.37 \text{ times.}$$ (This represents a ratio of 1 : 13.37).

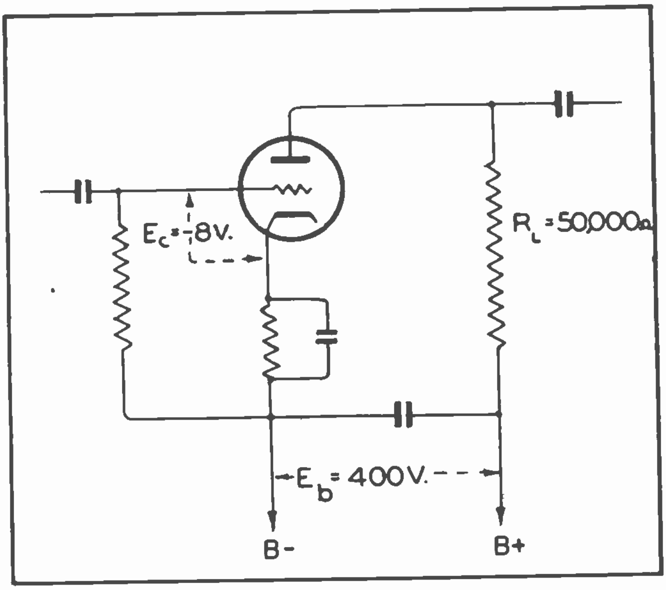

FIG. 8
APPLICATION OF TRIODE IN AMPLIFIER CIRCUIT

DISTORTION

As we learned in a previous lesson, in order to realize distortionless amplification, the plate-current increases must be of the same magnitude or amplitude as the plate-current decreases. In analyzing the graph shown in Fig. 7, observe that the Operating Point corresponds to a no-signal plate-current value of 4.2 ma. On the positive-half of the signal cycle, we realize a plate-current increase of 2.5 ma., as the plate current rises to 6.7 ma. (6.7 ma. - 4.2 ma. = 2.5 ma.). On the negative-half of the signal cycle, the plate current is decreased to an extent of 2.5 ma., as it swings down from 4.2 ma. to 1.7 ma. (See the signal waveform at the left in Fig. 7).

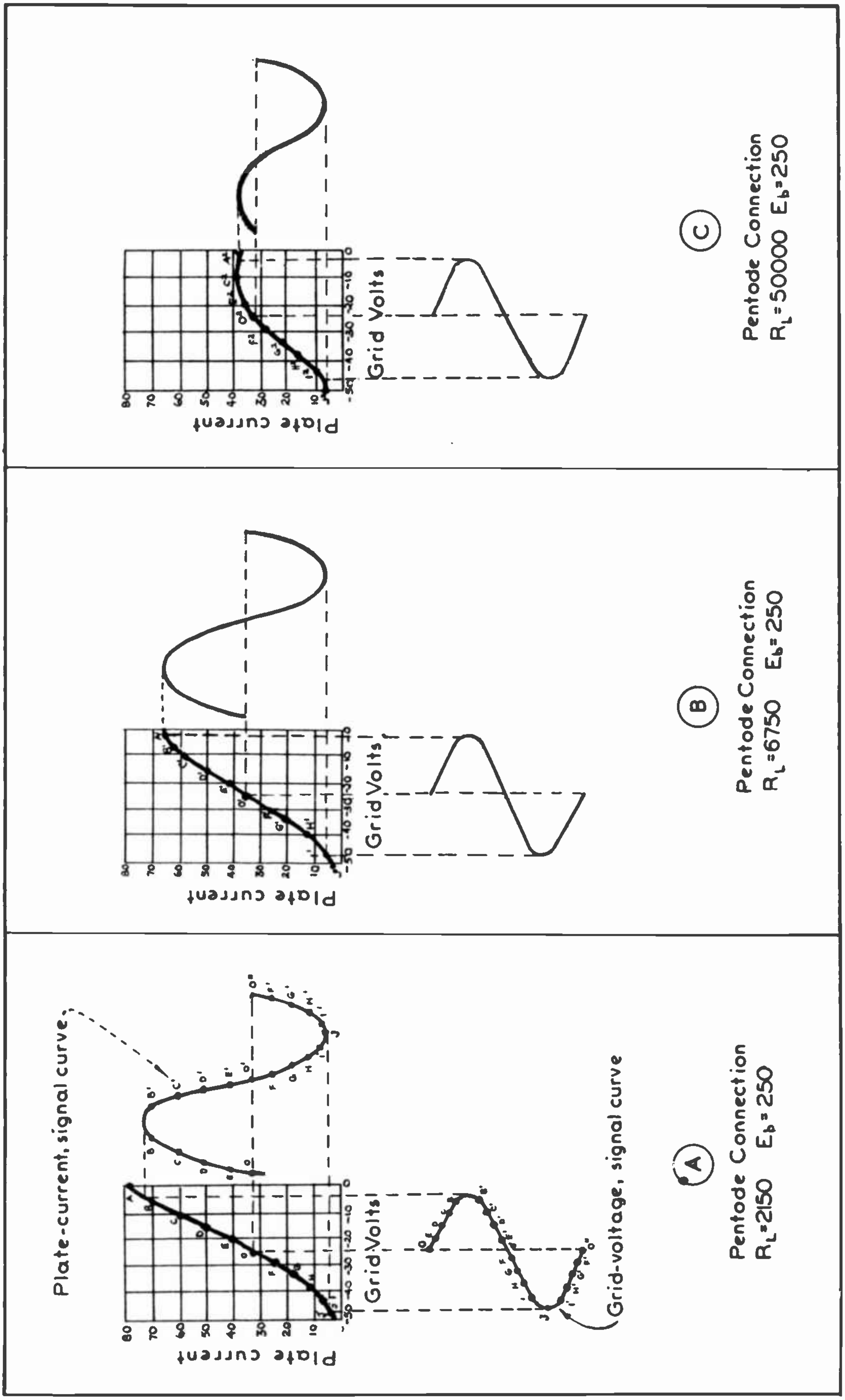

FIG. 9
OUTPUT DISTORTION CAUSED BY INCORRECT VALUES OF LOAD RESISTANCES. VALUE IN (A) IS TOO SMALL; (B) IS CORRECT; (C) IS TOO HIGH.

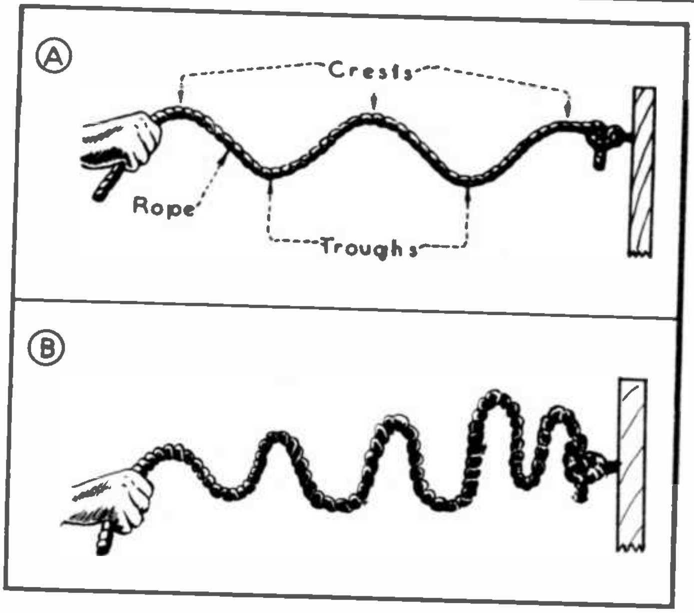

FIG. 10
COMPARISON OF TRUE SINE WAVE AND DISTORTED WAVE-FORM

It is obvious, therefore, that the plate-current increase of 2.5 ma. is equal to the plate current decrease of 2.5 ma. In that case, the output wave resembles the input wave-form, with the exception that it has now been amplified.

Fig. 9 illustrates the wave form obtained from a vacuum tube operating with the proper value of load resistance, in comparison to the wave-forms derived from this same vacuum tube when operated in conjunction with a too-low or too-high plate load resistor. The latter wave-forms represent NON-LINEAR (non-uniform) distortion.

The letters on the Grid-voltage-signal curve in illustration (A), represent points that were projected upward to the Characteristic Curve. From here, they were then projected toward the right---to produce the plate-current curve. For example, when point "E" (on the Grid-voltage-signal curve) is projected upward along a vertical line, this vertical line will intersect the Characteristic Curve at point "E". Now, if a horizontal line is drawn from point "E" on the Characteristic Curve, toward the right, it will establish the point "E" thru which the Plate-current signal curve is drawn. Similarly, the lettered points on the Grid-voltage-signal curve, correspond to points of the same letter on the Characteristic Curve and Plate-current signal curve.

PRODUCTION OF HARMONICS

Distortion in vacuum tube amplifiers often creates undesirable harmonics in the output wave-form. Since a distorted output wave-form is not a true sine-wave, it does not represent ONE frequency but a composite of frequencies. This may be readily proved by a mathematical analysis of the distorted wave-form. For our purpose, however, let us compare it to a small length of rope that we flip in such a manner so that it produces a wave. If we flip the rope with a constant rhythm, the shape of the waves, thus formed, will be symmetrical and uniform (sinusoidal), as in Fig. 10(A). However, if we were to interrupt each wave before it had a chance to complete its cycle (by giving the rope a tug or an extra flip), the resultant wave-form of the rope would no longer be composed of one frequency but a series of frequencies of various amplitudes as illustrated in (B) of Fig. 10.

Forier, the eminent scientist, has proven mathematically, that all repeating functions may be broken up into a series of sine-waves; the frequencies of which are each a multiple of the lowest frequency present. These are referred to as HARMONICS.

For instance, if we were to feed a pure sine wave, whose frequency was lower than 100 cycles, into an instrument capable of analyzing its harmonic content, we would find that such a wave has a 2-1/2% harmonic content. A sine-wave of a higher frequency signal would have a harmonic content of approximately 4%. If we were now to "mix" these two signals, the harmonic content would be in the order of 10% or more! The reason for this is that we now have not only two fundamental frequencies and their accompanying harmonics present, but also the additional frequencies resulting from the HETERODYNING of the two fundamental frequencies, PLUS the harmonics of these new BEAT frequencies to contend with! And so, it becomes readily apparent why a distorted signal is excessively rich in harmonics.

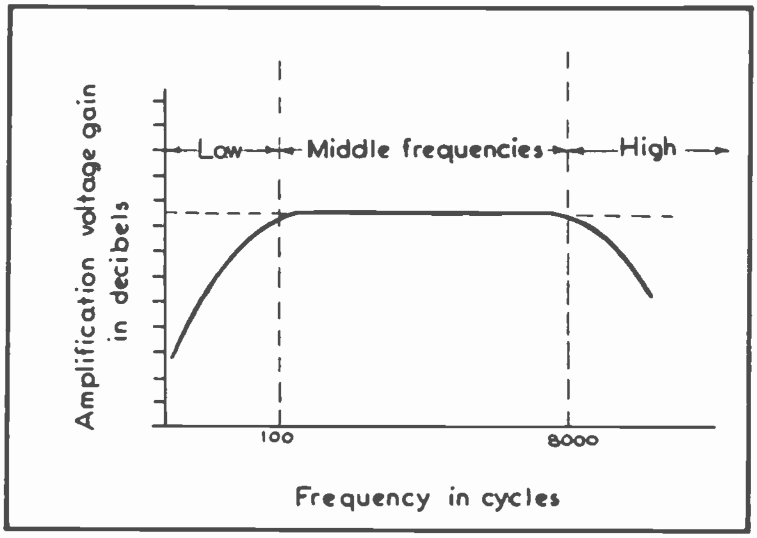

FIG. 11
TYPICAL FREQUENCY-RESPONSE CURVE OF AN AUDIO-FREQUENCY AMPLIFIER

The lower order of harmonics; namely, those whose frequencies are twice and three times that of the fundamental, are generally strongest. The presence of strong second and third harmonics in the output of an audio-frequency amplifying stage gives rise to appreciable speech or music distortion. When these exceed 5% of the output volume, they become annoyingly apparent to the average human ear and it is therefore important that they be kept below this threshold tolerance-level. Of the two, the third harmonic is more apparent to the human ear--since it is of a higher frequency.

In triode type tubes, second harmonic distortion predominates. With pentode and beam tubes, however, considerable third and fourth harmonic content may be expected. Also, regardless of the type of amplifying tubes employed, appreciable third and fourth harmonic content appears when the distortion is excessive or when the input signal is of such intensity that it drives the grid actually positive.

FREQUENCY DISTORTION

Another type of distortion is known as FREQUENCY DISTORTION. This type of distortion occurs when the amplification gain thruout the audio-frequency range is not uniform.

The ideal audio-frequency amplifier would amplify all frequencies uniformly; that is, to the same degree. In analyzing the frequency-response curve or graph of such an amplifier, we would find that the amplifier responds equally well to all frequencies so that the frequency-response-"curve", is in reality, a straight line. However, in actual practice, the frequency-response-curve of a typical audio-frequency amplifier greatly resembles that shown in Fig. 11. (Note: The decibel is a unit for expressing changes in the intensity or volume of sound. It is explained in detail, later in the Course).

You will note, in Fig. 11, that the amplification is quite constant throughout an audio-frequency range of 100 cycles to approximately 8000 cycles. Below and above these frequencies, the amplification falls off comparatively rapid; so that the lower and higher audio-frequency notes suffer amplification discrimination. The output signal, as a whole, is then said to have undergone FREQUENCY DISTORTION. The factors causing such type of distortion will be discussed as the lesson progresses.

PHASE DISTORTION

Phase distortion is encountered when long TRANSMISSION LINES are used between amplifier stages or between an amplifier and speaker(s). This form of distortion is encountered especially in lengthy telephone lines that are used to carry high-quality broadcast (network or remote-control) programs.

Transmission lines contain much inductance. Capacity is also present between the lines themselves---and between the lines and the ground. The inductive reactance of the transmission lines has a delaying effect upon the various audio-frequency currents it is carrying, since these are of an a-c or varying nature. Capacitive reactance has a similar effect upon the audio-frequency currents; but in a manner directly opposite to that of inductive reactance.

Whereas, the delaying effect of inductive reactance upon the audio-frequency currents is DIRECTLY proportional to the frequency of these currents; capacitive reactance is INVERSELY proportional to their frequency. This means that the inductance of the transmission lines will have the greatest delaying effect upon currents of high frequency (those corresponding to the higher musical notes); whereas, the capacitive reactance, existing in the line, will have its greatest delaying effect upon currents of lower frequency (those corresponding to the lower musical notes).

When one exceeds the other to an appreciable extent, we refer to such a condition as PHASE DISTORTION. To correct this, EQUALIZERS consisting of small capacitors shunted across the line or small inductive reactors (chokes) inserted in series with the line, are used so as to slow down the faster traveling frequencies to equal the speed of the slower ones.

SUMMARY--DISTORTION

Distortion may be minimized by observing the following precautions:

1. By operating the tube at the rated voltages and currents, as recommended by the tube manufacturer. In respect to this, it is important to remember that the voltage upon the plate of the tube will be less than the SUPPLY VOLTAGE (E_b) because of the voltage-drop that occurs thru the plate load resistor or impedance in series with the plate.

2. By proper selection of the plate load-resistance (impedance) value for the type of tube being used. Generally, this value is specified by the tube manufacturer and may be found in the more complete Tube Manuals under "Tube Characteristics"; or in a "Resistance-Coupled Amplifier Chart"--also included in many Tube Manuals.

3. By proper selection of the OPERATING POINT.

4. By selecting the proper type of tube and circuit so that the stronger signals do not drive the grid positive. This occurs when the positive-half of the signal cycle is of such intensity that it completely neutralizes the negative grid-biasing voltage. Two methods may be used to prevent this:

   1. Attenuate (reduce the intensity of) the signal.

   2. Employ the proper type of tube and circuit so that this cannot occur. (Of the two, the latter method is to be preferred).

The uniformity of gain with frequency is primarily a function of the type of coupling employed between the stages of the amplifying tubes. The various classes of amplification, and the designing factors relating to the various types of coupling employed for such purpose, will be discussed in the next lesson.

EXAMINATION QUESTIONS

LESSON NO. 45

1. - What is the difference between the meaning of the terms "static plate resistance" and "plate impedance", as applied to vacuum tubes?

2. - What factors in the construction of a tube govern the value of the tube's amplification factor?

3. - Why is the transconductance of a tube such a very important factor?

4. - If a change of 3 volts at the grid of a tube is able to produce the same change in plate current as a change of 150 volts at the plate, what is the amplification factor of the tube?

5. - When designing a resistance-coupled amplifier, what is the most simple method for determining the correct value of plate-load resistor to use?

6. - If a change of 3 volts at the grid of a tube causes a 6 ma. change in plate current, what is the transconductance of this tube?

7. - How would you proceed to construct a load line for a specific resistance on a static Eg - Ip characteristic curve of a tube?

8. - For what service is the high-mu type of amplifier tube particularly well suited?

9. - Do high-mu tubes generally have a high or a low plate resistance?

10. - What do we mean by the expression, "plate family" of grid voltage - plate current curves?

Of all the virtues, patience is the most essential to success.

J. A. ROSENKRANZ

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LESSON NO. 46

AUDIO-FREQUENCY DESIGNING FACTORS (CIRCUIT ANALYSIS)

To extend the terminology that each radio technician and engineer must familiarize himself with, it is necessary that we learn of the various classes of amplifiers currently employed in the radio field. Although these will be discussed in greater detail later in the series of lessons on Amplifying Systems, a brief outline of them will be presented at this time.

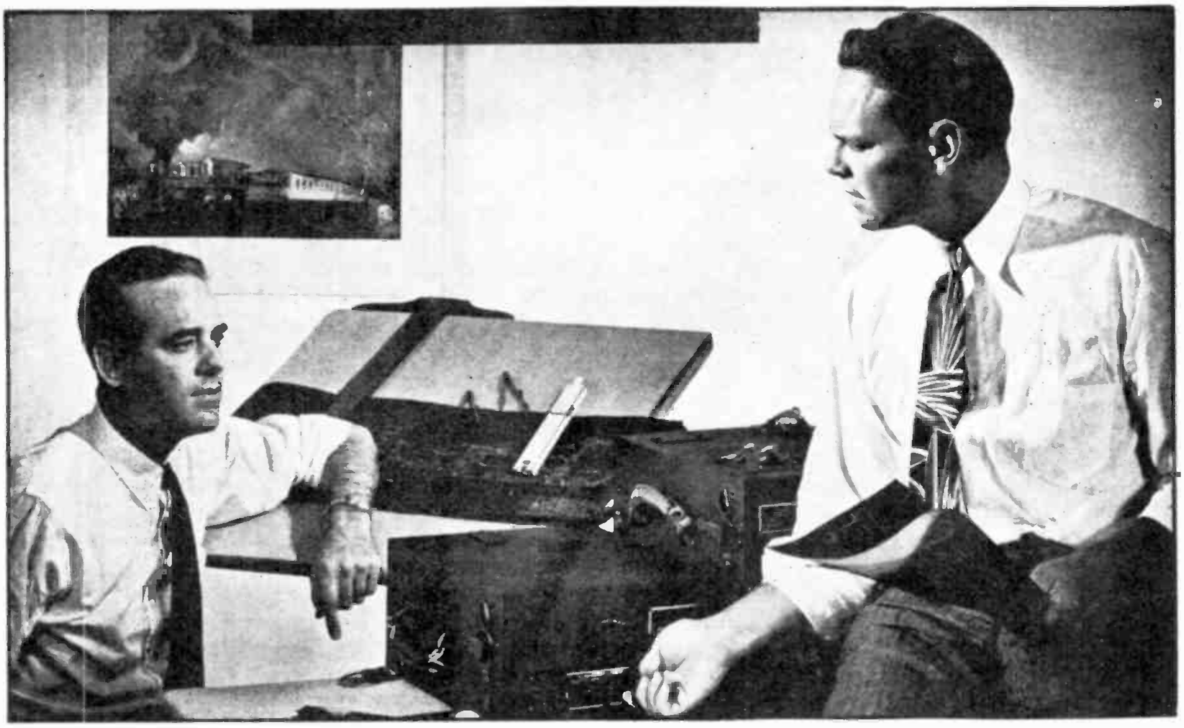

FIG. 1
THE DESIGNING OF A-F EQUIPMENT IS AN INTERESTING AND PROFITABLE FIELD

CLASS A

Up to this point in our lessons on audio-frequency amplifiers, we have confined our discussion to the Class A mode of amplifier operation. A tube may be classified as functioning as a Class A amplifier when the operating conditions meet the following specifications:

1. The OPERATING POINT (as determined by the grid-biasing voltage) lies in the optimum region of the LINEAR portion of the characteristic curve so that the plate-current INCREASES are identical to the plate-current DECREASES during each signal cycle.

2. D-C plate current flows at all times (continuously thruout the entire 360° of the signal cycle).

3. The output wave-form is an exact reproduction of the input signal wave-from----except that it has been amplified.

The chief feature of Class A amplification is the fidelity or faithfullness with which it amplifies the input signal. And so, this type of amplifier finds much favor with radio receivers designed for high fidelity, telephone transmission lines, high-frequency measuring instruments, etc.

The unfavorable features of the Class A amplifiers are:

1. The intensity of the input signal must be limited or restricted to the extent that it does not completely neutralize the negative grid-biasing voltage during the positive-half of the signal cycle; otherwise distortion results.

2. The ratio of power-output, in relation to the signal-input, is small; compared to Class B and AB type of amplification.For this reason, it is generally necessary to employ a cascade of amplifying stages---rather than one stage--to realize a degree of amplification that would be suitable for large auditoriums, theatres, etc.

3. Plate current flows constantly thru the tube--regardless of whether the tube is in the process of amplifying a signal or during the no-signal period. This tends to heat the tube considerably so that a large percentage of the amplifier's operating wattage is dissipated as wasteful heat. For this, and the above reasons, the efficiency of the Class A amplifier is considered to be low.

CLASS A PUSH-PULL OPERATION

To increase the power obtainable from a single tube operating under Class A conditions, two tubes operating in a push-pull arrangement are frequently used. (Fig. 2). Briefly, the control-grids of the two push-pull tubes function 180° out of phase with one another. This means that as the control-grid of one tube is driven more positive, the control-grid of the opposite tube is driven more negative. Referring to Fig. 3, let us analyze the push-pull circuit function during that part of the signal cycle when the control-grid of V-1 has been driven more positive, and the control-grid of V-2 more negative. An increase in plate-current flow thru V-1 and P-1 occurs at this time; whereas, a decrease in plate-current flow occurs thru V-2 and P-2. Because of this, the magnetic field created by the increased current flow thru P-1 is expanding; whereas the magnetic field of P-2 is contracting.

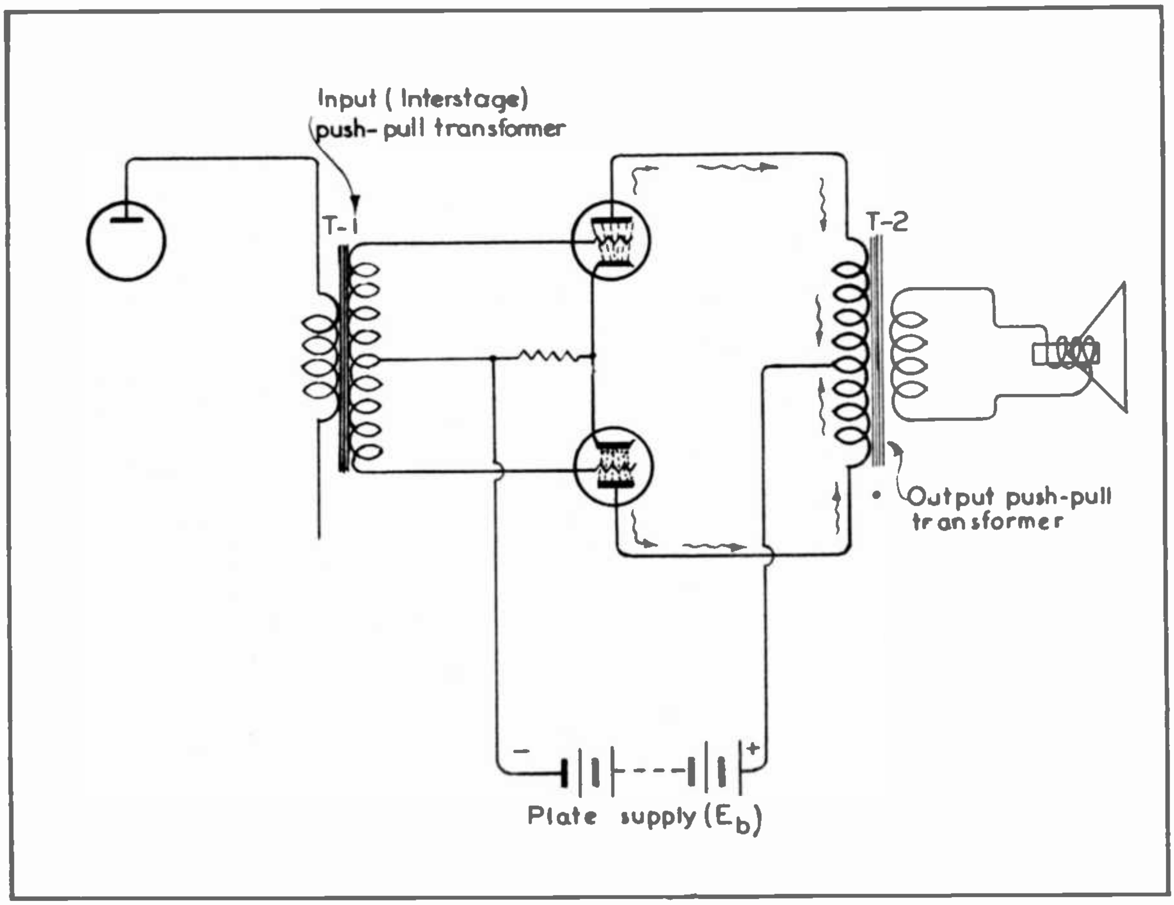

FIG. 2
TYPICAL CLASS A PUSH-PULL AMPLIFYING STAGE

Now, let us consider the magnetic polarity of the fields surrounding these two windings (P-1 and P-2).

The magnetic polarity of the winding, as you know, is dependent upon:

1. The direction in which it is wound.

2. The direction of current flow thru the winding.

Glancing at the diagram, you will note that P-1 and P-2 are wound in the same direction. However, because the plate-current flow thru each of these windings is in an opposite direction, their magnetic fields are in opposition to each other. This means that if they were both expanding at the same time, they would buck and thus neutralize each other. However, since one field is expanding while the other is contracting, their magnetic lines of force do not neutralize each other; instead, they combine their forces so that a more intense magnetic flux now "cuts" the secondary winding of the output transformer. Because of this, the output of a push-pull amplifier is much greater than that of an amplifier in which a single tube is used (often referred to as "single-ended" amplifier stage).

Besides providing a greater amplification (gain) and power output, push-pull amplification also affords other highly desirable features. For example, the d-c plate currents of the two tubes flow in opposite directions in the transformer primary winding so that the magnetic fields, due to these currents, cancel each other out. The output transformer is therefore capable of handling greater values of plate current than it could ordinarily handle, without danger of saturating the core. Any a-c ripples, due to a poorly filtered power-supply, are also thus canceled out. (This advantage applies only to hum originating from this source, since any a-c hum ripple introduced in any of the preceding stages will be amplified just as well as the signal voltage).

Push-pull operation of amplifiers also tends to eliminate all distortion due to the second and all even harmonics. The reason for this is that these harmonics are in phase with each other so that the flow of plate currents, resulting from this source, are in opposite directions thru the transformer winding and so cancel out. Even harmonics have a tendency to distort the signal wave so that the lower half of the wave is flattened (especially is this so when too high a value of grid-bias voltage is used). In push-pull amplification, however, the top half of the current wave of the "push" tube is added to the bottom half of the "pull" tube so that a more symmetrical resultant wave-form is obtained. Because twice the output of a single tube may be realized with less distortion, it is possible to obtain more than twice the output with the same distortion afforded by a single tube.

Before concluding this discussion on push-pull amplification, let us point out at this time, that although the a-f signal components of the plate-current flow add to their effects in the primary winding of the output transformer, they cancel each other out when flowing thru the common B+ lead so that no a-f component (except out-of-phase ODD harmonics, which are not cancelled out) flows thru the plate-supply and plate-return (cathode) circuit. Hence, it is not necessary to use a by-pass condenser across the cathode biasing resistor.

CLASS B AMPLIFICATION

To derive greater power output from push-pull amplification, and to overcome some of the disadvantages of Class A type amplification, Class B and AB operation is frequently employed.

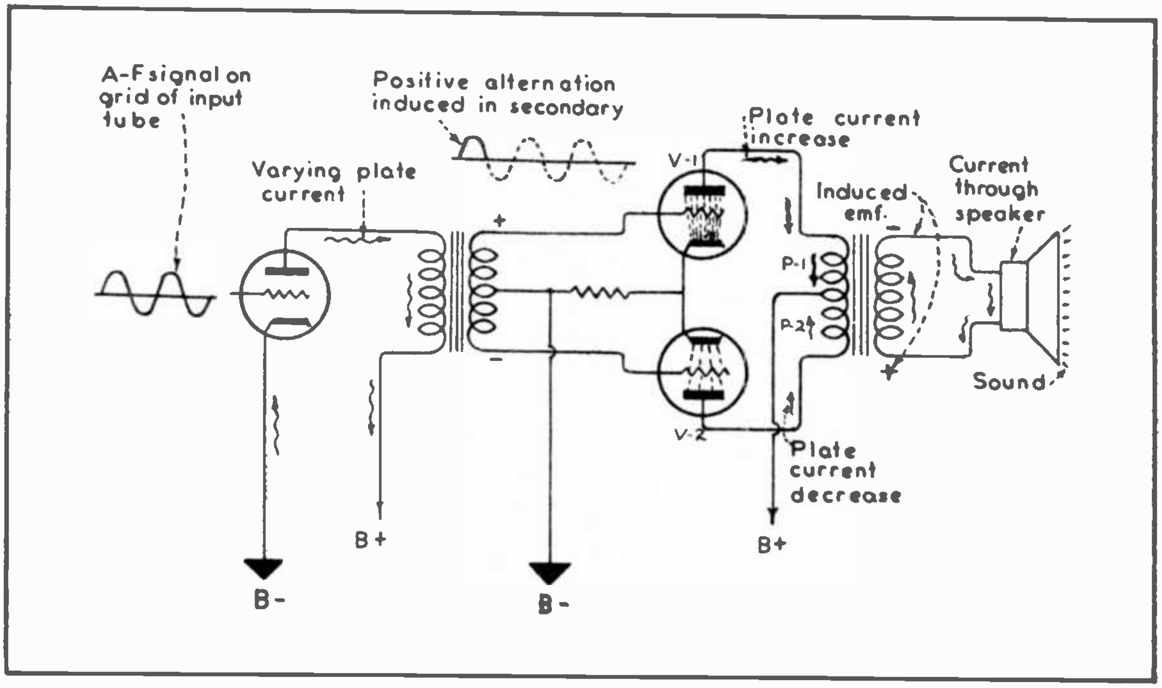

FIG. 3
DYNAMIC ANALYSIS OF PUSH-PULL OPERATION

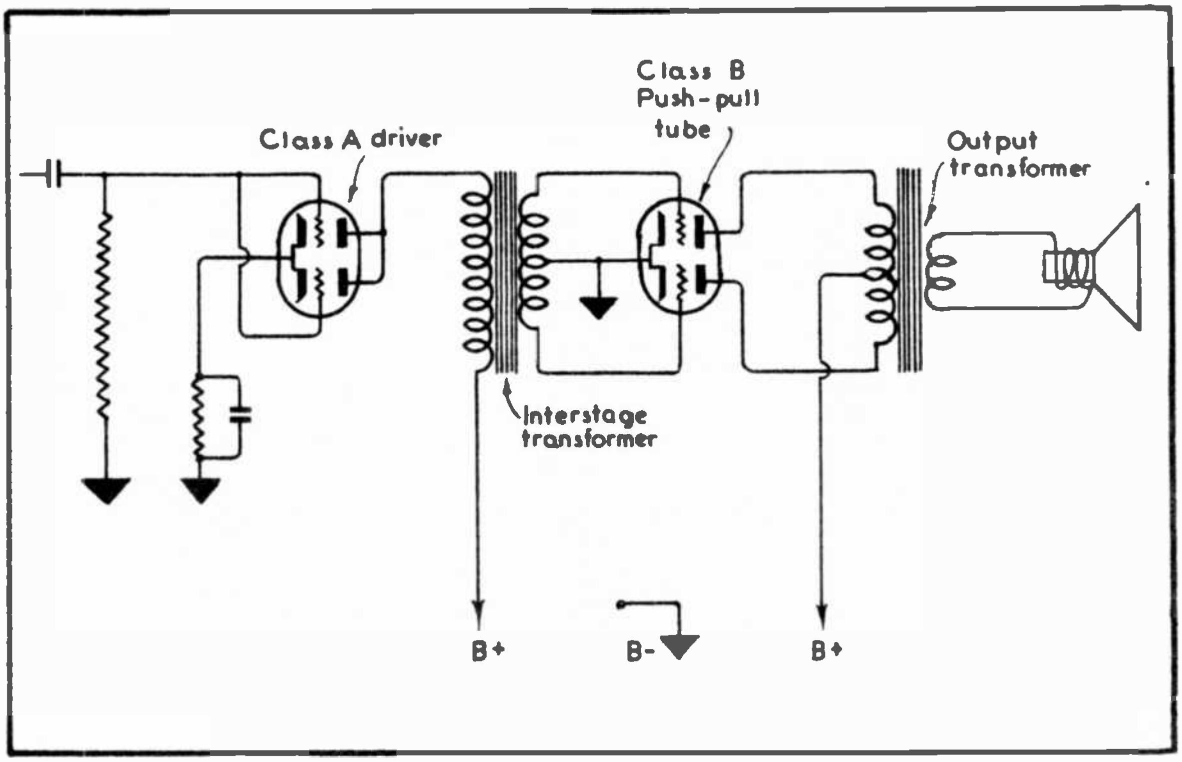

FIG. 4

CLASS B PUSH-PULL AMPLIFIER EMPLOYING TWIN TRIODES

As we have already noted, d-c plate current flows constantly in Class A amplification. If we were now to operate the amplifying tubes in such a manner so that little or NO d-c plate current flowed during the no-signal periods, not only would we realize a saving in operating-power but the tubes would operate much cooler and we would then be able to excite their grids with a greater positive voltage. The resultant (heavy) plate-current flow would then be of an intermittent (pulse) nature rather than flowing constantly.

> Technically: Class B amplification may be defined as that type in which the plate-current flow is approximately zero during the no-signal ("idling") period, and flows during approximately one-half (180°) of each signal.

Tubes, especially designed for Class B operation, are generally employed for the push-pull stage of such an amplifier. These tubes have a low input impedance and a high output (plate) impedance. Because of their high plate impedance, they draw very little plate current at ZERO biasing (grid) voltage. These tubes are therefore operated at zero bias; which eliminates the necessity for cathode biasing resistors or other forms of bias voltage supply.

Im many cases, both push-pull tubes are contained within the same glass or metal bulb; thus affording a conservation of chassis space and the saving of a socket. Each set of tube electrodes functions independently of the other; just as if they were contained within their own individual envelope (bulb).

CLASS B DRIVER STAGE

A powerful Class A amplifier stage (driver) precedes the Class B push-pull stage. This driver may be of the conventional type power amplifying tube, or may be a Class B (single or dual) type of tube whose elements are tied together so that it functions as a single Class A type power amplifier. A dual type Class B tube whose grids, plates and cathodes are connected in parallel for Class A operation is used as the driver stage in Fig. 4.

With a powerful driver stage preceding the Class B push-pull tubes, the grids of the latter tubes are alternately driven highly positive and negative. Grid-current flows in the grid circuit of each class B tube as its grid becomes positive. This represents a loss of power; since a voltage-drop occurs in the secondary impedance of the grid circuit. The efficiency of the driver stage must therefore be such that it is capable of supplying the additional power necessary to compensate for the loss of power expended in the push-pull grid circuit of the class B stage. However, it is advisable that the driver tube function at conservative operating voltages since any distortion created in this stage will be highly amplified in the succeeding stage.

GRID CURRENT FLOW---DISTORTION

Because of the grid-current flow, the impedance of the grid circuit must be as low as possible so that a minimum of voltage-drop occurs here. For that reason, a step-down type of interstage transformer is best suited; since such a transformer affords a low impedance secondary winding for the grid circuit of each Class B tube and a high impedance primary winding to match the plate impedance of the driver tube. Further details regarding this transformer will be presented in the chapter entitled "Push-Pull Transformers" of this lesson.

Observing the proper precautions in the design of such type of amplifier; and, because of the manner in which Class B type tubes are designed, distortion due to grid-current flow does not become intolerable even when the grids are driven highly positive. The greatest percentage of distortion is usually present at the lower bend of the characteristic curve (near the plate-current "cut-off" point). One of the unfavorable features of Class B amplification, therefore, is the presence of appreciable distortion at the lower volume levels. All even harmonics are cancelled in the output transformer just as they are in Class A type of amplification.

CLASS B POWER SUPPLY

The amount of plate current drawn by each Class B tube varies considerably during the time it is amplifying signals. This means that the current drain upon the power-supply varies considerably. Unless proper precautions are observed, the VOLTAGE furnished by the power-supply will also vary considerably. When the voltage delivered to the amplifier tubes---and to the remainder of the receiver---varies considerably because of the variations in the current drained from the power-supply, we refer to such a condition as poor VOLTAGE REGULATION of the power-supply.

At the time that the Class B tubes are amplifying the stronger signals, the current drain from the power-supply is maximum. The plate-supply voltage is apt to drop to a considerably lower level unless the power-supply has been designed to have excellent VOLTAGE-REGULATORY qualities. On the other hand, during the period of weak signal amplification---or during the no-signal "idling" periods, when the plate-current drain is at a minimum---the voltage may rise to an exceedingly high level . Such variation in the power-supply output voltage not only tends to create distortion thruout the entire receiver but also endangers the life of the condensers, tubes and other parts of the receiver.

To circumvent this undesirable characteristic, it is best to incorporate all possible means within the power-supply to stabilize or maintain the output voltage at a constant value regardless of current-load variations imposed upon the power-supply unit.

The power transformer should therefore have an ample core and be wound with sufficiently large wire to conservatively handle the normal-load current drain. The rectifier tube must be capable of delivering the required maximum current with minimum voltage-drop. In this respect, mercury-vapor type rectifier tubes are superior to the vacuum type and are therefore frequently used for Class B amplifiers.

The choke-input type of filter is recommended in this case, since the voltage regulatory qualities of such a filter circuit far surpasses the condenser-input type. The size of wire and core used in the filter chokes must be such that they do not over-heat or allow core-saturation to occur during the heavier passages of plate current. Also, the capacity of the filter condensers should be higher than usual, to provide adequate filtering during heavy current surges. In most cases, a bleeder resistor of greater wattage-rating than ordinarily used is placed across the d-c output and, in some cases, a voltage-regulator tube is incorporated into the power-supply circuit to help further stabilize the voltage. (This subject will be discussed in further detail in a later lesson).

SUMMARY --- CLASS B AMPLIFICATION

In summarizing the preceding discussion, Class B amplification provides greater amplification than does the Class A type. By observing the proper precaution in the design of a Class B amplifier with respect to: (1) the type of tubes employed; (2) the design of the interstage (step-down) transformer; and (3) the use of a power-supply that possesses excellent voltage-regulation properties, distortion may be held down to a satisfactory level. A greater percentage of distortion is present, however, at the lower volume-levels---thus, the popularity of the Class AB_2 type of amplifier, which will be discussed in the following chapter.

Theoretically, plate current flows in the Class B amplifier tubes only during the presence of a signal upon the grid. The flow of plate-current, therefore, is entirely proportional to the amplitude of the exciting grid-voltage. (Note: In Class A amplification, plate current flows even in the absence of a signal and so is not wholly proportional to the signal excitation voltage).

Since power (P) is proportional to the square of the current (I^2), the power output of a Class B amplifier is said to be proportional to the square of the exciting grid-voltage. A Class B amplifier is further characterized as having plate efficiencies from 40% to 70%.

CLASS AB AMPLIFICATION

Class A type of operation provides excellent tonal qualities but does not provide the high output of the Class B amplifier. Class B provides a more powerful output per stage, but lacks the faithfullness of reproduction and fidelity at the lower volume levels. A compromise between these two systems is the Class AB mode of operation.

CLASS AB_1

There are two forms of Class AB amplifiers. In the first type, referred to as Class AB_1, the amplifier circuit and type of tubes employed are identical to that of Class A amplification. The only difference exists in the value of grid-biasing voltage and, possibly, the use of higher plate and screen voltages. By the use of a slightly higher grid-biasing voltage, a stronger signal may be impressed upon the grid without completely neutralizing the biasing voltage during the positive half of the signal cycle. This means that the Class AB_1 amplifier is capable of amplifying a stronger signal and thus providing a greater output without distortion. Single-ended or push-pull amplifying stages may be operated in this manner.

(Note: The suffix numeral "1" denotes that the grid is never driven positive and that grid current never flows during any part of the signal cycle).

CLASS AB_2

In Class AB_2 amplification, the grids are biased even higher; yet not high enough so that plate-current flow is blocked completely. Conventional type tubes are used for the push-pull stage and, in most cases, a similar type tube precedes this stage, functioning as a driver tube. Because of the powerful output of this driver stage, the grids of the push-pull stage are driven positive on the stronger signals so that grid current does flow at this time. As in Class B amplification, a step-down transformer couples the output of the driver stage to the input of the push-pull stage; thereby, minimizing distortion during the period of grid-current flow. As with Class B amplification, it is important that the power-supply have good voltage-regulation qualities.

Here also, must the power output of the driver stage be such that it is capable of supplying the additional power necessary to compensate for the loss of power expended in the grid circuit of the push-pull tubes during the period of grid-current flow. It is also extremely important that the driver stage be efficiently designed so as to be capable of supplying the required peak power with minimum distortion; since any distortion created in the driver stage will be amplified manifold in the powerful push-pull stage.

In comparison to Class B operation, Class AB_2 affords superior tonal fidelity at the lower volume levels but does not equal the power output of the Class B amplifier.

Class AB amplifiers are characterized as offering low distortion for small signal intensities and high efficiency at high signal levels. Technically defined: A Class AB amplifier is one in which the grid-bias and alternating grid-voltages are such that plate current flows for appreciably more than half---but less than---the entire electrical cycle, when delivering maximum output.

RESISTANCE-CAPACITY COUPLED AMPLIFIERS

The use of high-mu tubes in conjunction with resistance-capacitance type coupling (commonly referred to as "resistance-coupling" or "R-C coupling"), affords a very economical means---both in cost and weight---of achieving a high degree of VOLTAGE gain (voltage amplification) with less frequency distortion. Also, since very little electro-magnetic field surrounds the resistor-condenser combination, in contrast to the magnetic field surrounding a transformer---or inductance(in impedance type coupling)---there is less possibility for undesirable interaction to occur between a-c or a-f fields. This means that less hum modulation or feedback is apt to occur in R-C type of amplifying stages. So that the key points of our discussion may be more clearly understood, a triode type tube, working into the simplest form of resistance coupling, is illustrated in Fig. 5.

PLATE LOAD RESISTOR (R_L)

Of great importance, is the value of the plate load resistor R_L. Variations in plate current, flowing thru this resistor, produce an (a-f) voltage-drop which is passed on to the control-grid of the succeeding tube capacitively (thru coupling condenser C).

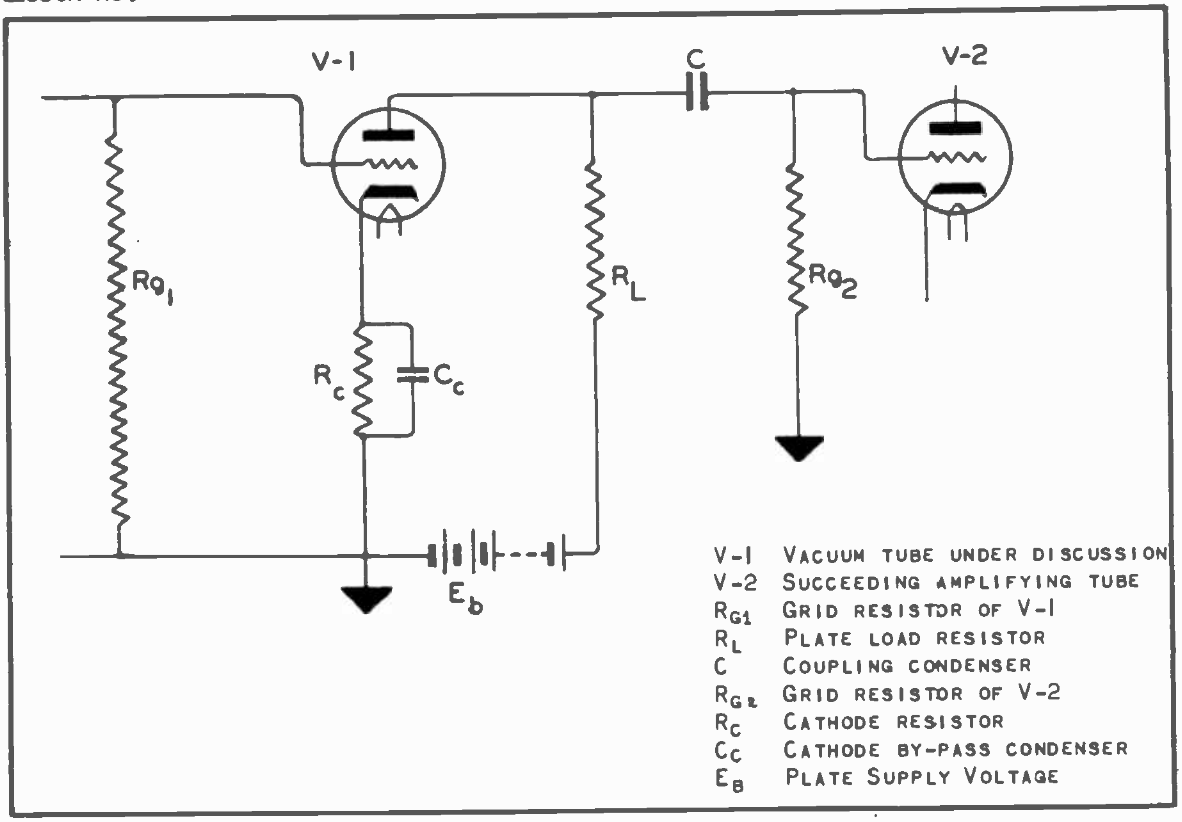

FIG. 5
TYPICAL R-C STAGE OF AMPLIFICATION

In general, the greater the value of this resistor, the greater will be the voltage-drop developed across it. The greater the voltage-drop developed here, the greater will be the force (e.m.f.) impressed upon the control-grid of the succeeding tube thru coupling condenser C. By analyzing the foregoing process, it is evident, therefore, that the greater the voltage-drop developed across R_L, the greater will be the voltage amplification gain realized from the R-C stage.

However, there is a limit to the amount of resistance we may use for R_L since the voltage-drop across this resistor is not solely dependent upon the amount of resistance it offers,but also ON THE AMOUNT OF PLATE CURRENT FLOWING THRU IT! (E_{vd} = I x R). The amount of plate current that the tube will pass is, as you know, dependent upon the value of plate voltage. If too high a resistance is employed, the value of plate voltage applied to the tube may be reduced to such an extent that the rated amount of plate-current will no longer flow thru the plate circuit (thus thru the resistor); which would defeat its own purpose.

And so, when designing this part of the circuit, we employ a high value of resistance here,but not so high that it reduces the plate-current flow below that amount recommended by the tube manufacturer. Tables, listing the recommended value of load resistors ("load impedance"---as it is often referred to) are usually contained in the more complete Tube Manuals. Another method of determining the proper value to use, for the particular PLATE SUPPLY VOLTAGE being employed, is to insert a milliammeter in series with the plate circuit and note the reading under STATIC (no-signal) conditions. This reading should conform with the tube manufacturer's rating.

From the foregoing, it is obvious that the higher the plate-supply voltage, the higher the value of plate resistor we may use. And so, when designing resistance-coupling type amplifiers, it is well to keep this point in mind and provide a power-supply pack capable of supplying a plate-supply voltage that is higher than usual.

CIRCUIT ANALYSIS---A-F ASPECT

Before entering into the discussion of the various components employed in the circuit shown in Fig. 5, let us first analyze this circuit as far as the AUDIO-FREQUENCY CURRENTS are concerned. Analyzing the circuit from this aspect, we find that our circuit appears to have undergone quite a change (Fig. 6), where:

E_s = The incoming signal voltage.
R_p = The plate resistance of the tube.
C_{cp} = Inter-electrode capacity existing between the cathode and plate electrodes of V-1 plus the additional capacities existing between connecting leads, etc.
C = Coupling condenser which, in reality, should be represented by a small variable resistor, as shown by dotted lines at "A"; since this condenser acts as a very low opposing (reactive) path to the high-frequency audio signals, and offering greater opposition to the audio signals of lower frequency.
R_{g2} = V-2 grid resistor.
C_{cg} = Inter-electrode capacity between the cathode and grid of V-2 (plus any stray capacity effects between connecting wires of this circuit).
E_b = Plate-voltage supply. (Note: the internal resistance of the plate-voltage supply may be disregarded, since it is amply by-passed by condenser C_b as far as audio-frequency currents are concerned.

From this "equivalent" circuit diagram, we can readily see that the audio-frequency currents not only have the resistors and condensers to contend with, but are also affected by:

1. The internal resistance of the tubes.
2. The internal inter-electrode capacity existing between the various elements of the tube.
3. All stray capacities that exist between the various components and connecting leads of the circuit.

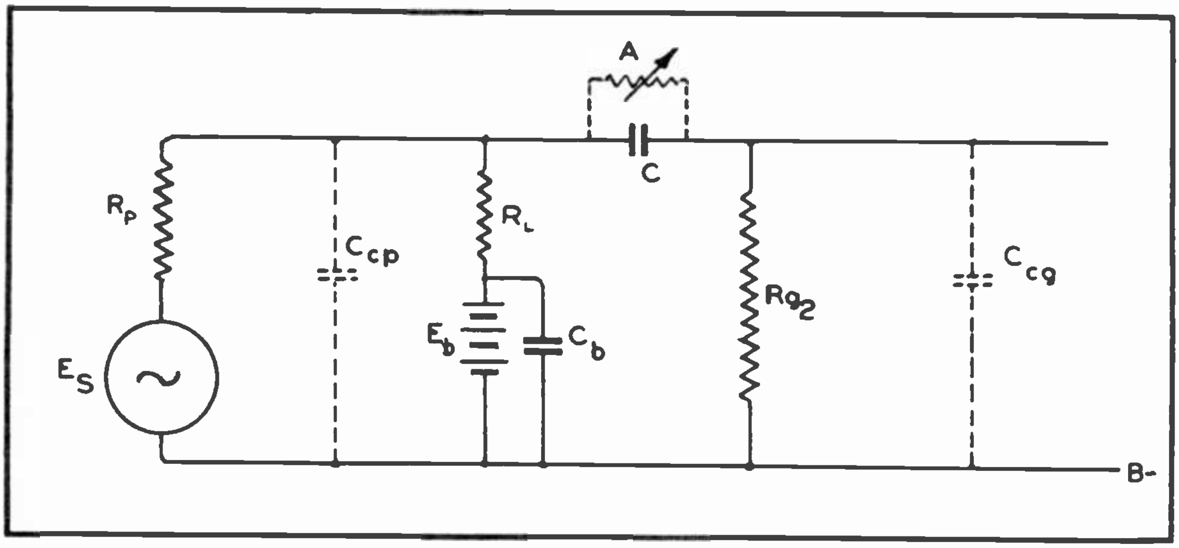

FIG. 6
A-F EQUIVALENT CIRCUIT

In interpreting this diagram, it is apparent that it is almost a purely parallel circuit. Note that the internal capacity of the tube (C_{cp}) is in parallel with the plate load resistor R_L. Coupling condenser C is in series with the plate load resistor; but because of the low reactance it offers to the majority of the audio-frequency currents, its effect as a series impedance may almost be disregarded except for the lower audio-frequencies. If this impedance is to be disregarded, it is then evident that R_{g2} is in parallel with R_L and that the inter-electrode capacity (C_{cg}) of V-2 is also part of this parallel family.

To realize optimum gain from our amplifier, it would be to our greatest advantage to produce the largest amount of voltage-drop across the plate load resistor R_L. However, since we are dealing with a-f currents which are pulsating in nature, C_{cp} becomes a "problem child" since it acts as an effective path for the higher frequency a-f currents.

Consequently, at the higher audio-frequencies, more and more of the signal current is by-passed by C_{cp}; which means that less current flows thru R_L to produce a voltage-drop. Thus, the reason for the decline in voltage output (therefore, amplification) at the higher audio-frequencies. Another contributing factor to this decline, is the similar effect that C_{cg} has in shunting a portion of these higher frequency a-f currents away from the grid resistor R_{g2}.

The dropping off of amplification at the very low frequencies is due to the reactance of the coupling condenser C. Because of the reactance this condenser offers to the lower frequency signals, voltage is expended (used up) and thus lost in effecting the transfer of output voltage thru the condenser. In the middle a-f range, the reactance of this condenser becomes of such low value that it may be considered to be equivalent to a short circuit. The reactance of the shunting capacities C_{cp} and C_{cg} are quite high so that they are practically equivalent to an open circuit. From this, it becomes readily apparent why the amplification in the mid-frequency band is maximum. Also, why more uniform amplification may be realized thruout the entire audio-frequency range by the use of tubes having minimum inter-electrode capacity and the use of a high-capacity coupling condenser.

COUPLING CONDENSER

In certain type sets such as the A-C/D-C, or other receivers where inadequate plate-supply filtering is employed, a low value of capacity is often used for the coupling condenser so as to reduce the response to the 60-cycle ripple---and thus, hum. In high-fidelity amplifiers, a fairly large value of capacity is employed for this purpose (.05 - .1 mfd.).

The quality of this condenser is very important. Not only must it be capable of withstanding the full plate voltage when minimum voltage-drop occurs across R_L (on the negative peak of a strong signal); but it must also have excellent dielectric (insulation) qualities, so that there will be minimum leakage thru it.

A leaky condenser, at this point, allows a small portion of the plate current to flow thru it and is likely to establish a positive potential on the control-grid of the following tube. Such would not only result in distortion, but would also increase the plate current of the tube to the extent of causing possible damage to the tube or to the other components of the circuit.

A good point to remember in respect to this, is: The higher the capacity value of the condenser, the more leakage current flows thru the dielectric. And so, when employing high capacity values for this purpose, it is best to select a condenser of the best quality.

GRID RESISTOR

In general, the value of the grid resistor of the succeeding tube should also be of a high resistance value. However, there is a limit to the value of resistance that may be employed. This resistor should not be of such a high value that it prevents the stray electrons, collected on the grid, from "leaking off" to the cathode. These represent a negative potential and, if a sufficient quantity of them are allowed to accumulate upon the grid of the tube, they will increase the negative bias of the control-grid to the extent of blocking the plate-current flow. Such a condition is manifested by that well-known symptom recognized as a "putt-putt" sound (referred to as "motor-boating").

When employing tubes having an oxide-coated cathode, we have another factor to contend with. In these tubes, small amounts of barium or strontium tend to deposit upon the control-grid. As the tube attains its normal operating temperature, these deposits also attain a temperature that enables them to emit electrons on their own accord. The electrons, thus emitted, are attracted over to the cathode and plate, since both of these elements are at a higher positive potential than the grid. Consequently, the grid circuit is completed within the tube---by the electronic stream flowing between the control-grid electrode and the cathode. Current thus flows thru the grid resistor, causing a voltage-drop to occur across it.

The direction of this grid-current flow is such that the grid-end of the resistor becomes positive; thereby, partially neutralizing the negative grid-bias voltage applied to the grid. As a result of the reduction in grid voltage, more plate current flows thru the tube; thus, increasing the internal temperature of the tube and, consequently, the temperature of the control-grid electrode.

The above action is further aggravated by the ionization of gases that were not removed during the manufacture of the tube; also by the gases that are liberated from the metal of the electrodes, during the operation of the tube.

> Atoms, which have lost some of their normal quota of electrons, are referred to as IONS. Since the atoms of the residual gases present within the tube are constantly being bombarded by the electrons emitted from the cathode, they are soon converted into ions. Possessing a positive charge, these ions are attracted to the grid, which is negative. The free electrons, dislodged from these atoms are, in turn, attracted to the control-grid when it becomes positive.

The above effects may be greatly reduced by employing a grid resistor of a lower value so that the voltage-drop created by the above factors, is small. The maximum value of grid resistance for most tubes having an oxide-coated cathode is from .5 to 1 megohm.

In those type tubes whose normal operating plate-current is comparatively large, the allowable grid-circuit resistance must be considerably lower; especially, if fixed bias is employed. Self (automatic) - bias tends to prevent the cumulative increase of plate current, since an increase of plate current automatically increases the voltage-drop across the cathode resistor (Ohm's Law); thereby increasing the grid-bias voltage. This is the reason for allowing the use of a higher grid resistor value with self or automatic type bias than is recommended for fixed-bias type circuits.

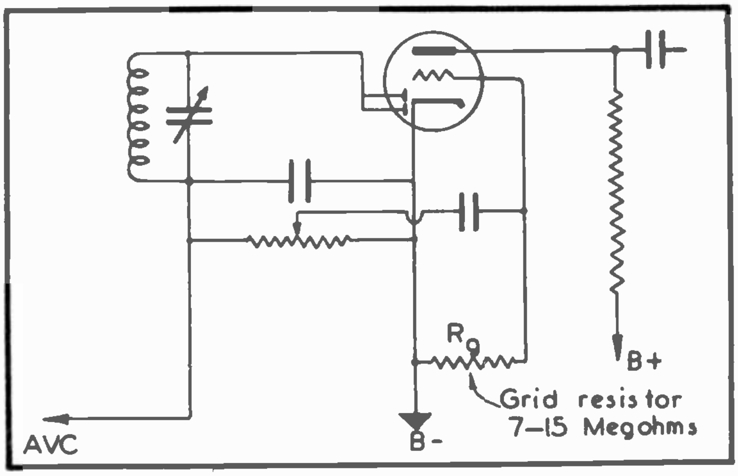

FIG. 7
AMPLIFIER CIRCUIT EMPLOYING CONTACT-POTENTIAL BIAS

GRID RESISTOR VALUE IN CONTACT-BIAS CIRCUITS

As an exception to the foregoing, grid resistors of extremely high value may be used in those circuits utilizing the "contact-bias" type circuit. In such a circuit, no cathode resistor or battery is employed to provide a biasing voltage to the amplifying tube. Instead, the cathode and grid-return circuit are connected together and are, therefore, of the same electrical potential. (Refer to Fig.7).

Since the control-grid in Fig. 7 is of the same potential as the cathode, it does not repel the cathode-emitted electrons (as it would if it were negative with respect to the cathode) but, instead, attracts these electrons towards itself. The electrons, therefore, bombard the control-grid. Due to this bombardment, a "contact e.m.f." or "contact-potential" is created within the grid electrode which causes a flow of (grid) current to occur thruout the entire grid circuit. Flowing thru the grid resistor, a voltage-drop is developed here, which serves as the grid-biasing voltage.

In operation, the grid-current flow thru the grid resistor increases and decreases in step with the signal voltage being applied to the control-grid electrode. This means that a variable loading effect is imposed upon the preceding (driver) stage; which has a tendency to create distortion. To minimize this undesirable effect, the grid resistor R_g (Fig. 7), is made very high in value---usually from 7 to 15 megohms. Because of this exceedingly high value of resistance, only a small amount of grid current can flow under all conditions of operation; thereby reducing the variable loading effect to negligible proportions.

The biasing voltage developed by this method is generally of a low value; approximately -1 volt. This low value of biasing voltage, however, is sufficient for most high-mu tubes when the signal-input voltage is below this value.

SUMMARY---R-C TYPE CIRCUIT

In summarizing the foregoing, the first step in the design of a resistance-capacity type amplifier is to select tubes whose amplification factor exceeds the gain-per-stage desired. If high-fidelity reproduction is of paramount importance, the tubes selected should have a low value of inter-electrode capacity. The value of the plate load resistor should be as high as possible; but not so high that it prevents the normal amount of plate current to flow under static conditions.

Consequently, it would be to our greatest advantage to use a power-pack with an exceptionally high voltage output so that higher values of plate resistors may be used without reducing the plate current flow to a subnormal value. In respect to this, the amplifying tube and coupling condenser must be able to withstand this higher voltage; for, we must remember that they will have to withstand the full brunt of the supply voltage until the tubes have warmed up to their normal operating temperature. When the tube commences to draw plate current, a voltage-drop is developed across R_L which automatically lowers the voltage impressed upon these parts.

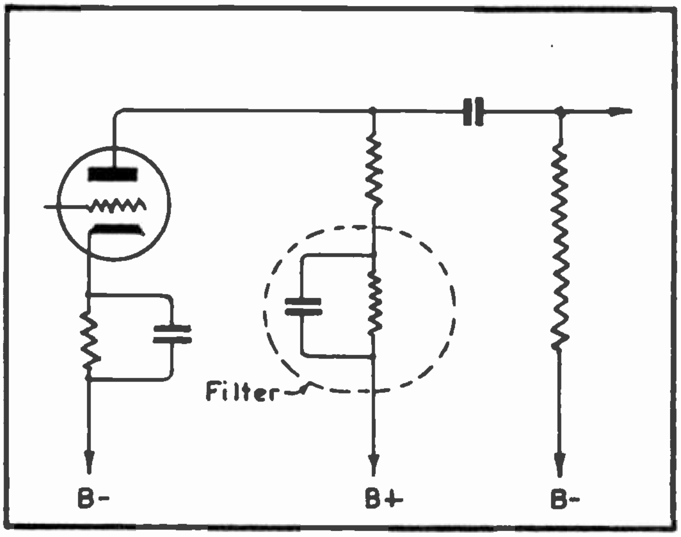

FIG. 8
APPLICATION OF FILTER TO IMPROVE LOW-FREQUENCY RESPONSE

It is noteworthy to point out at this time that the maximum operating plate voltage, as specified by the tube manufacturers, is conservatively rated (approximately 50% of the voltage value that the tube can safely withstand). The working voltage of the coupling condenser should be at least 1.41 times the maximum voltage output of the plate supply voltage.

All condensers have a slight dielectric leak so that an extremely small value of current does leak thru the dielectric. The larger the capacity of the condenser, the greater the amplification at the lower audio-frequencies; however, the greater the leakage current.

Condensers of the highest quality should be selected for this purpose, since a leakage from the plate circuit over into the grid circuit of the succeeding tube may partially---or completely---neutralize the grid-biasing voltage. Not only would this create distortion, but it may cause the following tube to draw so much plate current as to damage the tube or other components associated with the tube.

IMPROVING THE FREQUENCY RESPONSE OF R-C AMPLIFIERS

The low-frequency response of resistance-coupled amplifiers may be improved by shunting a portion of the plate coupling resistor with a condenser, as shown in Fig. 8. On the other hand, the high notes may be emphasized by using either of the following methods:

1. By inserting a resistance-capacity parallel bank in series with the plate of the tube, as shown in Fig. 9.
2. By the use of a small inductance (L) in series with the plate coupling resistor, as shown in Fig. 10.

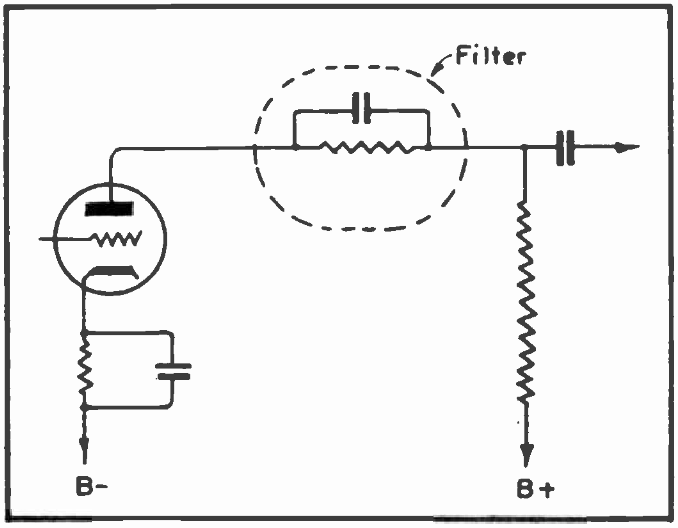

FIG. 9
APPLICATION OF FILTER TO IMPROVE HIGH-FREQUENCY RESPONSE

IMPEDANCE-COUPLED AMPLIFIERS

As we pointed out in the preceding chapter, one of the chief disadvantages of the resistance-coupled type amplifier is the d-c voltage-drop that occurs thru the plate coupling resistor; thus lowering the positive d-c potential applied to the plate. If we were now to substitute a coil of wire having a high inductance value for this resistor, there would be very little opposition offered to the D-C plate-supply voltage exerted thru it; yet an exceedingly high value of (inductive) reactance (impedance) to the A-F signal trying to pass thru it. The higher the value of this impedance (inductor, "choke" or reactor, as it is sometimes called), the greater will be the a-f volt-drop across it; consequently, the greater will be the amplification realized from the tube. A typical impedance-coupled amplifier is illustrated schematically in Fig. 11.

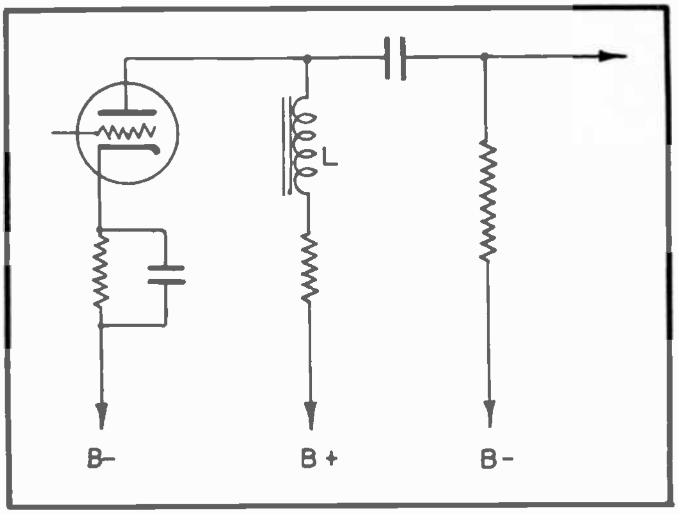

FIG. 10
INDUCTANCE USED TO IMPROVE HIGH-FREQUENCY RESPONSE

Iron-core reactors, having an inductance value of from 10 to 800 henries, are commonly used for this purpose. The core of these reactors should be as large as possible to avoid the occurrence of core-saturation during the time when heavy current flows through the winding.

Impedance-coupling is of great advantage when employed in conjunction with tubes drawing high values of plate current; amounts of current that a plate resistor could not handle very well. However, with the high-mu, low plate-current type of amplifying tubes now available, it is rarely necessary to resort to the use of impedance coupling.

Since the inductance of the reactor is shunted by the inter-electrode capacity between the plate and cathode of the tube V-1 (C_{pc}), plus the internal distributed capacity existing between its own windings, the reactor thus forms a parallel resonant circuit. This means that maximum amplification will occur at the resonant frequency of this tuned circuit.

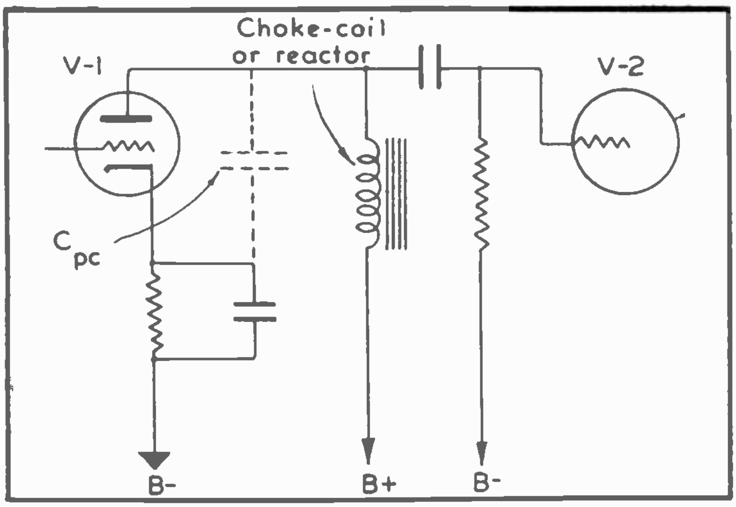

FIG. 11
IMPEDANCE-COUPLED AMPLIFYING CIRCUIT

Since reactance---and thus impedance---is directly proportional to frequency, a decrease in amplification occurs at the lower frequencies because of the lowered value of inductive reactance (therefore impedance) existing at these frequencies. At the higher a-f frequencies, the gain is reduced because of the by-passing effect of the distributed capacity present between the turns and layers of the reactor's winding. For these reasons, the frequency-response of the impedance-coupled amplifier is less uniform and inferior to that of the resistance-coupled amplifier.

TRANSFORMER-COUPLED AMPLIFIERS

Transformer coupling is also best suited for low-mu tubes. Such tubes generally do not afford much amplification in themselves and so, an auxiliary device, such as a step-up transformer, must therefore be resorted to in order to boost the amplification(gain)per stage.

By using a transformer whose secondary winding consists of more turns than the primary winding, the output voltage of an amplifier is thereby "stepped-up" so that a higher voltage is now available to be impressed upon the grid of the succeeding tube.

Transformer coupling thus provides a means for increasing the voltage amplification of a stage when little voltage gain is realized from the tube itself.

As we learned in an earlier lesson, the function of a transformer is dependent upon the amount of flux (developed by the primary winding) that "cuts" the secondary winding. The flux, in turn, is dependent upon the AMPERE-TURNS of the primary winding. It is obvious, therefore, that here is another reason why transformers are better suited to the low-mu tubes, since tubes of this type:

(1) Draw heavier amounts of plate current.
(2) Have a comparatively low value of plate resistance.

This means that:

(1) A lesser number of turns may be used on the primary, to develop the required amount of flux.
(2) A lesser amount of primary impedance is required to match the low plate impedance of such type tubes.

When transformer coupling is used with high-mu tubes, the response is poor at the lower audio-frequencies because of the low ratio of primary impedance in relation to the high plate impedance of such type tubes. At the higher a-f frequencies, the response is poor because of the shunting effects of the internal (distributed) capacity contained within the transformer. In general, therefore, the use of transformer coupling, in conjunction with high-mu tubes, is not recommended.

Since the transformer contains inductance and capacity, it constitutes a tuned circuit to the a-f signal in the same manner that an antenna or r-f transformer tunes to a specific r-f frequency. This means that the transformer will resonate to one particular audio frequency; at which frequency maximum amplification will occur. The amplification at this "resonant" frequency will be so great that it may drive the grid of the succeeding tube positive on the positive-half of the signal-cycle. Because of this, grid current would flow; thus, distorting the signal. On the negative-half of the signal cycle, the grid may be driven so highly negative that complete blockage of plate current flow may occur; which also represents distortion. Graphically,

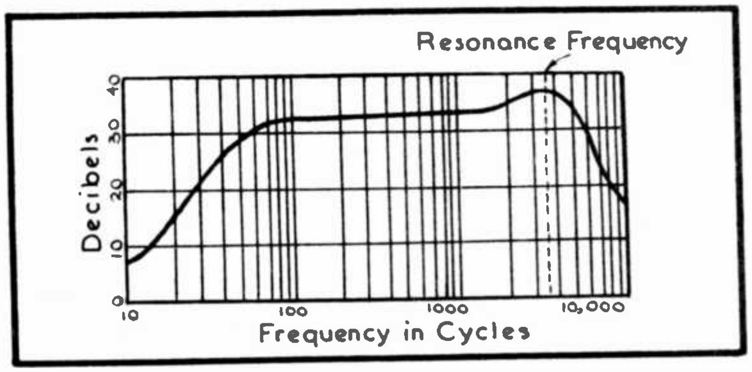

FIG. 12
TYPICAL FREQUENCY RESPONSE CURVE OF A TRANSFORMER-COUPLED AUDIO-FREQUENCY AMPLIFIER

the resonance peak of a transformer-coupled amplifier stage may be recognized by a sudden increase in amplification at one particular frequency. (Fig. 12).

CLASS B STEP-DOWN TRANSFORMER

Although the subject of Class B amplification will be discussed thoroughly in the series of lessons on Amplifying Systems, it is best to point out at this time the reason why step-down transformers are used as interstage coupling devices---rather than resistors, impedances or the usual type of (step-up) transformer.

> In this type of amplification, the control grid of each push-pull tube is driven positive, alternately. When such occurs, grid current flows in each half of the grid circuit, alternately. This means that the input circuit actually uses power (wattage---both voltage and current). Since this wattage must be supplied by the driver (preceding stage), it is obvious that the driver tube must be of the "power" type and not a mere voltage amplifier. This also means that the coupling transformer must be capable of supplying both voltage AND CURRENT ---in contrast to the usual type of transformer.

And so, of necessity, we must use a heavier gauge of wire for the secondary winding; a wire heavy enough to carry the current flowing in the grid circuit. As the gauge of wire is increased, the distributed capacity within the transformer is increased. So that this value does not become excessive, fewer turns must be used herein.

Since grid-current flows, it is further important that the resistance and impedance of the secondary winding be of a low value; otherwise, an excessively high voltage-drop will be developed across this winding as the signal strength increases. (We refer to such as "distortion of the input signal-voltage"). The output signal of the push-pull stage would consequently be an amplified version of this distortion.

Because of the above factors, tubes expressly designed for Class B amplification have a low input-impedance. To match this low input-impedance to the relatively higher plate-impedance of the driver tube, it is obvious why a step-down type of transformer is used as the interstage coupling device.

OUTPUT TRANSFORMER

The function of the output transformer, as you probably realize by now, is to match the plate impedance of the power amplifier tube to the load (speaker, headphone or other reproducing device).

In determining the proper type of output transformer for the load to be used (we will assume that it is a dynamic type speaker), it is necessary to have the following information on hand:

1. Plate current value for type of power tube being used.
2. Recommended Load Resistance (R_L) value, as specified by the tube manufacturer.
3. Impedance of the voice-coil at the (standardized measuring) frequency of 400 cycles.

The first of these two values may be obtained by referring to a Radio Tube Manual or other data-sheet listing the characteristics of radio tubes. These generally list the value of load resistance or impedance recommended for maximum undistorted power output. The third point of information is generally stamped upon the speaker frame; or, may be obtained from

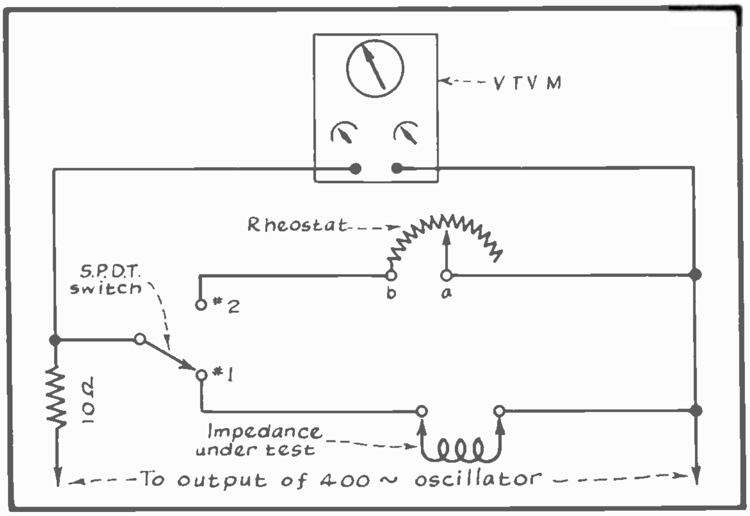

FIG. 13
TEST CIRCUIT FOR MEASURING LOAD IMPEDANCE

the manufacturer's descriptive bulletin or radio parts catalog.

A suggested method of obtaining the latter information, when it is unavailable from a more convenient source, is illustrated in Fig. 13. This test is applied as follows:

Throw the S.P.D.T. (single-pole, double-throw) switch to the #1 position. Apply the 400-cycle voltage and note the reading upon the vtvm (vacuum tube voltmeter). Throw the switch to the #2 position and vary the rheostat setting until an identical reading is obtained on the vtvm. Disconnect the 400-cycle voltage source, flip the switch back to position #1, and measure the resistance value of the rheostat BETWEEN POINTS "a" AND "b" with an accurate ohmmeter. The resistance value, thus obtained, represents the impedance value of the voice coil.

The impedance of the output transformer may also be determined by this method. In checking the primary impedance of the transformer, it is best that the voice coil (or resistor having an equivalent value as that of the voice-coil impedance) be connected to the secondary of the transformer under test.

TURNS-RATIO OF A TRANSFORMER

The turns-ratio of an output transformer may be determined quickly by impressing a known a-c voltage upon the primary winding and reading the voltage obtained from the secondary winding. The ratio of the two voltages will then correspond to the turns-ratio of the transformer.

Mathematically, the turns ratio required for an output transformer may be determined by the following formula:

$$\text{Turns ratio} = \sqrt{\frac{\text{Speaker Voice-coil Impedance}}{\text{Recommended Plate Load Impedance}}}$$

For example, if the recommended load impedance for the particular tube we are using is 3600 ohms and the voice-coil impedance of the speaker is 4 ohms, as in Fig. 14, the turns-ratio of the output transformer will then have to be:

$$\text{Turns Ratio} = \sqrt{\frac{4}{3600}} = \frac{2}{60}$$

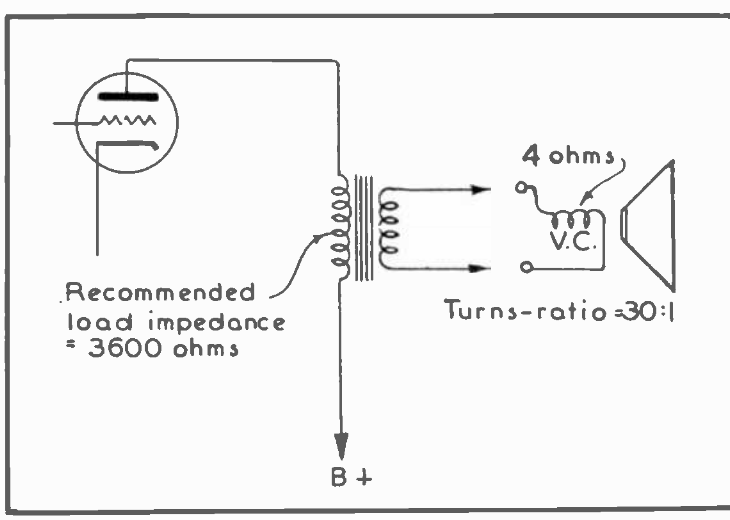

FIG. 14
MATCHING PLATE LOAD IMPEDANCE TO SPEAKER VOICE COIL

Instead of saying that the transformer has a turns-ratio, of 60:2, we usually resolve it down to its lowest proportions (X : 1). To do so, merely divide the smallest of the above numbers by itself to reduce it down to the value of one (1). Thus, in our fraction, we divide 2 ÷ 2 = 1. Since we divided the upper part of the fraction by 2 we must do likewise to the lower part of the fraction; thus, 60 ÷ 2 = 30. The turns-ratio of this transformer is a STEP-DOWN ratio of 30 : 1. This means that for every thirty turns wound on the primary coil, we must wind one turn on the secondary coil. When push-pull type of amplification is used, the turns-ratio will be twice this amount (60:1), with the B+ tap taken off at the electrical center of the primary winding.

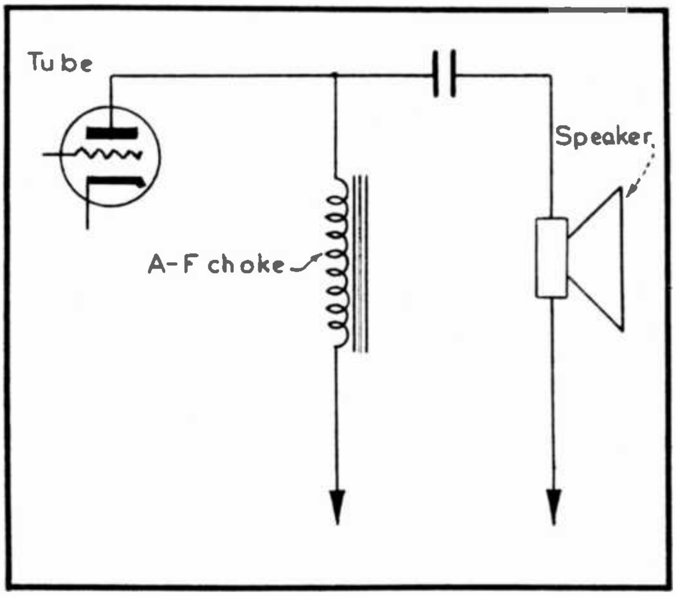

FIG. 15
HIGH-IMPEDANCE SPEAKER COUPLED TO OUTPUT OF AMPLIFIER

It is important that the gauge of wire used on the primary winding be sufficiently large to carry the plate current of the tube without over-heating excessively. Also, the core of the transformer should be as large as possible to prevent core-saturation---and thus distortion---during the greatest signal amplification.

SELECTION OF THE OUTPUT TRANSFORMER

To afford optimum performance from the transformers they manufacture, most manufacturers include a descriptive bulletin with each output transformer, listing the proper model transformer to employ for a specific output tube---or tubes. If such information is not provided with the transformer, reference may be made to a Parts Supply Catalog where this information is generally listed.

Output transformers of the "universal" variety are also manufactured by most transformer concerns. These types are very convenient for the radio serviceman; especially to take out on service calls when the model number or brand of the radio (or type of speaker used in the radio) is unknown. Both the primary and secondary windings are tapped so that almost any type of power output tube or tubes may be matched to almost any type of dynamic speaker.

Other kinds of speakers, such as the once popular "magnetic" type, have an impedance of from hundreds to thousands of ohms. Special type transformers whose secondary winding matches this high value of impedance, must therefore be used. An expedient method of coupling such a speaker to the output of an amplifier, when the proper output transformer is unavailable, is by the use of a choke coil whose impedance approximates the recommended load resistance and a .1 to 2 mfd. condenser, as shown in Fig. 15. Such method of coupling cannot be successfully used with the dynamic type of speaker since the impedance of the voice coil is of too low a value.

In the lessons that you have just studied, regarding the designing factors of audio-frequency amplifiers, you have learned that there are various classes of amplification: Class A, AB and B. Each of these have found their particular niche in industry. For example, Class A amplification is generally employed where fidelity is of utmost importance, and where the installation (constructional) and maintenance cost is secondary in consideration.

Where power output and cost are the more important factors, yet good tonal qualities are required, Class AB mode of amplifier operation is to be preferred; Class AB_1 offering better tonal qualities---yet a lesser output---than Class AB_2. Hence, such type of amplification (particularly AB_2) is especially adapted to dance-halls; skating rinks; and auditoriums where musical programs are held. This type of amplifier also adapts itself very nicely to phonograph amplifiers, both for the home or where coin-operated phonographs are used.

Where a yet greater economy of installation and operation is desired, and where the programs are confined largely to speeches and announcements (lodge-halls, election campaigns, call systems, etc.,) the Class B amplifier is to be recommended. Especially, is such an amplifier desirable where the noise-level is high, since a stronger input signal is required to operate the amplifier than is required by the other classes of amplifiers.

How such amplifiers are to be adapted to installations, other than the home, will be discussed in a special series of lessons in this course devoted to Amplifying Systems.

EXAMINATION QUESTIONS

LESSON NO. 46

1. - How does Class B amplification differ from Class A amplification, with respect to operating principle?

2. - Why is the voltage-regulatory quality of the power-supply for a Class B amplifier so very important?

3. - Generally speaking, how does the resistance value of the plate load resistor R_L affect the performance of an R-C amplifying stage?

4. - (a) How does the capacity of the coupling condenser affect the performance of an R-C amplifying stage?
   (b) Why is the dielectric quality of the coupling condenser in an R-C amplifying stage important?

5. - Is transformer coupling best suited for low-mu tubes or high-mu tubes?

6. - Why is a step-down transformer used as the means of coupling between the driver and a Class B power amplifier stage instead of resistance-capacity or impedance coupling?

7. - What factors determine the turns-ratio of an output transformer?

8. - What is a "universal" output transformer?

9. - What advantages does a push-pull stage of Class A amplification have to offer over a single-ended Class A power amplifier stage?

10. - How do tubes that are designed especially for Class B operation differ from those designed for use as Class A power amplifiers?

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LESSON NO. 47

DESIGNING POWER TRANSFORMERS

IT IS OF COURSE TRUE THAT IN THE GENERAL PROCEDURE OF RADIO SERVICE WORK, IT IS THE CUSTOMARY PRACTICE TO REPLACE A BURNED OUT POWER TRANSFORMER WITH A NEW ONE, WHICH AS A RULE CAN BE READILY OBTAINED FROM ANY RADIO SUPPLY STORE. NEVERTHELESS, ONE IS FREQUENTLY FACED WITH THE PROBLEM OF NOT BEING ABLE TO PURCHASE THE PARTICULAR TYPE OF POWER TRANSFORMER NEEDED; AND UNDER SUCH CIRCUMSTANCES, THE ONLY SOLUTION IS TO DESIGN AND CONSTRUCT SUCH A UNIT TO FULFILL THE REQUIRED SPECIFICATIONS. FURTHERMORE, IN ORDER FOR YOUR RADIO TRAINING TO BE COMPLETE, YOU SHOULD HAVE AN UNDERSTANDING OF THIS SUBJECT.

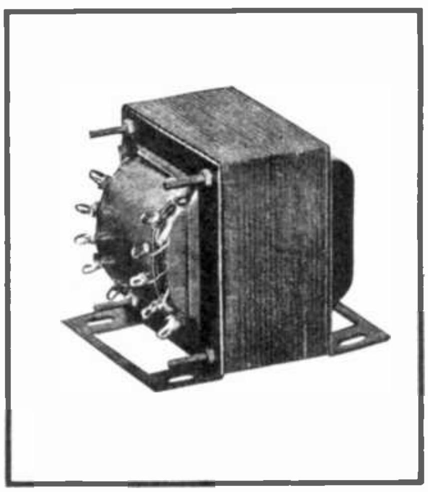

FIG. 1
TYPICAL POWER TRANSFORMER

THIS TYPE OF WORK IS NOT DIFFICULT, PROVIDED THAT ONE HAS THE NECESSARY KNOWLEDGE TO WORK OUT THE DESIGN IN A SYSTEMATIC MANNER. A GREAT DEAL HAS BEEN PUBLISHED IN THE PAST AS TO POWER TRANSFORMER DESIGN; BUT IN MANY CASES, THIS INFORMATION HAS BEEN PRESENTED IN SUCH A MANNER AS TO CONFUSE THE READER RATHER THAN TO ASSIST HIM IN GAINING A CLEAR CONCEPTION OF HOW PROBLEMS OF THIS NATURE SHOULD BE TREATED.

IN THE PREPARATION OF THIS LESSON, WE HAVE MADE SPECIAL EFFORT TO PRESENT YOU WITH THE MOST PRACTICAL AND EASILY APPLIED METHODS SO FAR DEVISED FOR TRANSFORMER DESIGN PRACTICE, AND WE ARE CERTAIN THAT YOU ARE GOING TO FIND THIS INFORMATION VERY VALUABLE AS WELL AS EASY TO UNDER-

X

STAND. THE SPECIAL FORMULAS, WHICH WE ARE GIVING YOU IN THIS LESSON, ARE SIMPLE IN THEIR APPLICATION BUT AT THE SAME TIME SUFFICIENTLY ACCURATE AS TO THE RESULTS OBTAINED THROUGH THEIR USE FOR ALL PRACTICAL PURPOSES.

ADAPTING A POWER TRANSFORMER TO A GIVEN CIRCUIT

THE FIRST THING TO CONSIDER IS THE CIRCUIT IN WHICH THE POWER TRANSFORMER IS TO BE USED. TO ILLUSTRATE THIS POINT, LET US CONSIDER THE CIRCUIT OF FIG.2, WHERE WE HAVE A CONVENTIONAL FORM OF SEVEN-TUBE, A.C. OPERATED RECEIVER.

BY INSPECTING THIS CIRCUIT DIAGRAM, WE IMMEDIATELY NOTICE THAT THIS RECEIVER EMPLOYS TWO TYPE -35 "VARIABLE-MU" TUBES, A -24 POWER DETECTOR, A -27 AUDIO TUBE, TWO TYPE -45'S IN A PUSH-PULL POWER STAGE AND A TYPE -80 FULL-WAVE RECTIFIER. WITH ONLY THIS AMOUNT OF INFORMATION AVAILABLE, WE ARE

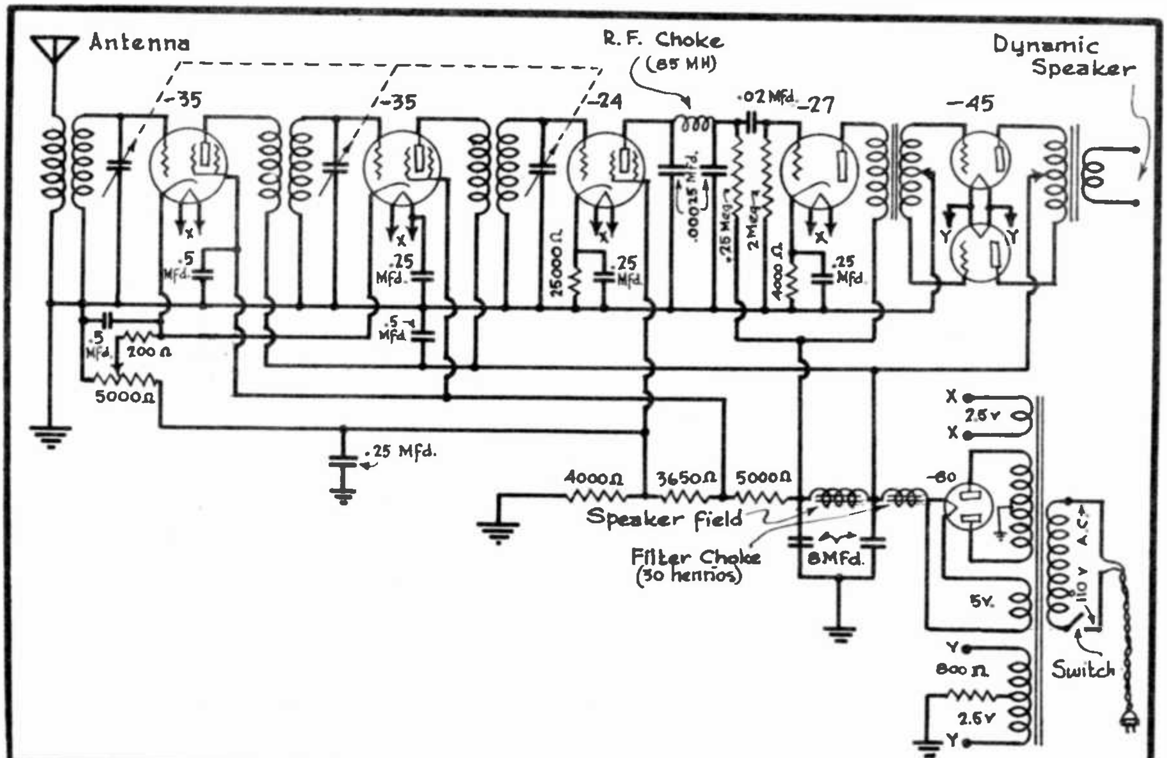

FIG. 2

A Seven-Tube A.C. Operated Receiver.

IN A POSITION TO DETERMINE THE POWER WHICH IS GOING TO BE REQUIRED FROM THE POWER TRANSFORMER, WHICH WE ARE CALLED UPON TO DESIGN FOR THIS PARTICULAR RECEIVER.

FILAMENT CURRENT DEMANDS

WE COMMENCE BY CALCULATING THE CURRENT WHICH IS TO BE CONSUMED BY THE VARIOUS FILAMENT CIRCUITS. FOR EXAMPLE, THE FILAMENTS FOR EACH OF THE -35, -24 AND -27 TUBES ARE TO BE OPERATED AT A VOLTAGE OF 2.5 VOLTS AND UNDER SUCH CONDITIONS WILL DRAW 1.75 AMPERES OF FILAMENT CURRENT. (THIS INFORMATION IS OBTAINED FROM A TABLE OF TUBE CHARACTERISTICS, SUCH AS YOU HAVE ALREADY RECEIVED AMONG YOUR LESSONS). THE FILAMENTS OF THESE AFORE-

MENTIONED TUBES ARE ALL TO BE CONNECTED IN PARALLEL AND TOGETHER CONNECTED ACROSS THE 2.5 VOLT SECONDARY WINDING, WHOSE EXTREMETIES ARE MARKED "X" IN FIG. 2. THEREFORE, THE TOTAL CURRENT WHICH IS TO BE DELIVERED BY THIS SECONDARY WINDING WILL BE 4 X 1.75 OR 7 AMPERES.

THE FILAMENTS OF THE TWO TYPE -45 POWER TUBES ARE TO BE CONNECTED TOGETHER IN PARALLEL AND ACROSS A DIFFERENT 2.5 VOLT SECONDARY WINDING, WHOSE EXTREMETIES ARE MARKED AS "Y" IN FIG. 2. EACH OF THESE -45 TUBES WILL DRAW A FILAMENT CURRENT OF 1.5 AMP. AND SO TOGETHER, THEY WILL DRAW 2X1.5 OR 3 AMPS. FROM THE SECONDARY "Y".

THE -80 RECTIFIER TUBE HAS ITS INDIVIDUAL 5 VOLT SECONDARY WINDING, FROM WHICH IT WILL DRAW A FILAMENT CURRENT OF 2 AMPERES.

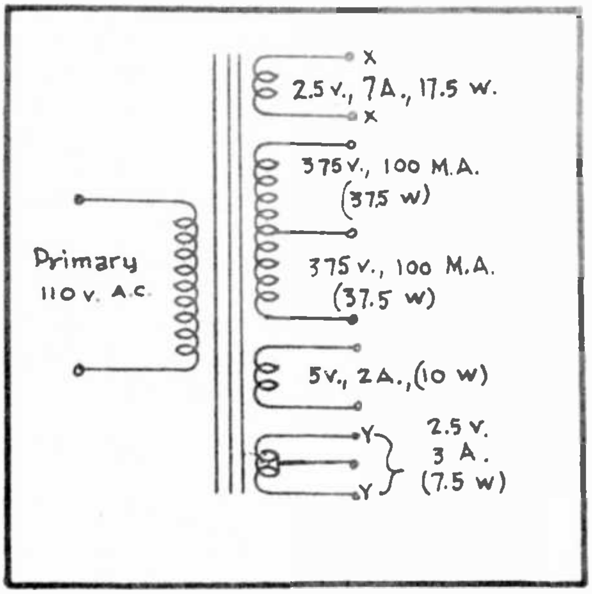

FIG. 3
Lay-out of the Transformer.

"B" CIRCUIT REQUIREMENTS

WE CONTINUE OUR ESTIMATE OF POWER CONSUMPTION BY NEXT CONSIDERING THE CURRENT WHICH IS REQUIRED BY THE "B" SUPPLY. TO BEGIN WITH, EACH OF THE TYPE -35 TUBES WILLDRAW A PLATE CURRENT OF ABOUT 6.5 MA., IN ADDITION TO A SCREEN-GRID CURRENT OF SLIGHTLY LESS THAN 1/3 THIS AMOUNT OR VERY NEARLY 2 MA. THE TOTAL "B" CURRENT DRAWN BY EACH OF THESETUBES CAN THUS BE CONSERVATIVELY ESTIMATED AS BEING 6.5+2. OR 8.5 MA. BOTH OF THESE -35 TUBES TOGETHER WILL DRAW VERY NEARLY 2 X 8.5 = 17 MA.

THE -27 A.F. AMPLIFIER TUBE WILL DRAW A PLATE CURRENT OF APPROXIMATELY 5 MA., WHILE THE TWO -45 POWER TUBES WILL TOGETHER DRAW 64MA. (32 MA. PER TUBE). THE POWER DETECTOR DRAWS VERY LITTLE "B" CURRENT, AT THE MOST, NOT EXCEEDING .5 MA. ALTOGETHER, THE "B" DEMAND FROM THE ENTIRE TUBE ASSEMBLY BECOMES 17+5+64+.5 = 86.5 MA.

IN ORDER TO AVOID "MOTOR BOATING" (A PUTT-PUTT SOUND SIMILAR TO THE NOISE PRODUCED BY THE EXHAUST OF A MOTOR BOAT), A BLEEDER CURRENT OF AT LEAST 6 TO 12 MA. SHOULD BE ALLOWED FOR THE "B" SUPPLY OF THE POWER PACK. THIS BLEEDER CURRENT WILL BE GOVERNED BY THE VALUE OF THE RESISTOR WHICH IS CONNECTED BETWEEN B- AND THE LOWEST B+ POTENTIAL USED IN THE CIRCUIT (THE 4000 OHM RESISTOR IN THE CASE OF FIG. 2). ADDING AN ALLOWABLE BLEEDER CURRENT OF 12 MA. TO OUR "B" CURRENT DRAWN BY ALL TUBES, WE FIND THE TOTAL "B" CURRENT DRAWN TO BE 86.5+12 = 98.5 MA.

TO SIMPLIFY MATTERS, WE WILL ASSUME A VALUE OF 100 MA. AS BEING THE TOTAL DIRECT CURRENT WHICH IS TO BE DRAWN FROM THE "B" SUPPLY OF THE POWER PACK. REMEMBER, THAT IT IS A GOOD PRACTICE TO ASSUME ALL LOAD REQUIREMENTS SOMEWHAT HIGH RATHER THAN LOW. THIS IS TRUE IN RESPECT TO ALL TRANSFORMER CALCULATIONS.

WE CAN NOW LAY OUT OUR TRANSFORMER IN THE DIAGRAM FORM AS SHOWN YOU

IN FIG. 3. OBSERVE THAT ON THIS DIAGRAM WE ARE INDICATING THE VOLTAGE AND CURRENT TO BE SUPPLIED BY EACH OF THE SECONDARY WINDINGS ACCORDING TO THE CALCULATIONS WHICH WE HAVE JUST COMPLETED. THE HIGH VOLTAGE WINDING, YOU WILL NOTE, IS BEING CONSIDERED AS DEVELOPING 375 VOLTS ACROSS EACH HALF, OR 750 VOLTS ACROSS THE ENTIRE WINDING.

WATTAGE REQUIREMENTS

OUR NEXT STEP IS TO CALCULATE THE WATTAGE OR POWER WHICH IS TO BE CONSUMED BY EACH OF THESE SECONDARY WINDINGS. BY APPLYING THE FORMULA "WATTS=VOLTS X AMPERES", WE FIND THE WATTAGE OF THE 2.5 VOLT SECONDARY, MARKED "X" IN FIG. 3, AS BEING 2.5 X 7=17.5 WATTS.

NOW IN THE CASE OF THE HIGH VOLTAGE SECONDARY, WHEN USED WITH FULL-WAVE RECTIFICATION, WE FIND THAT ONLY ONE-HALF OF THIS WINDING WILL DRAW CURRENT DURING EACH HALF OF THE A.C. CYCLE. THEREFORE, THE POWER CONSUMED BY EACH HALF OF THIS WINDING BECOMES 375 X .1=37.5 WATTS(100 MA=.1 AMP.). FURTHERMORE, SINCE ONLY HALF OF THIS WINDING DRAWS CURRENT DURING EACH HALF OF THE A.C. CYCLE, THE HIGH VOLTAGE SECONDARY WINDING, AS A WHOLE, WILL ONLY BE RATED AS HAVING A 37.5 WATT POWER CONSUMPTION OR THE SAME AS ONLY HALF OF THIS SAME WINDING.

THE 5 VOLT SECONDARY WINDING DRAWING 2 AMPERES, HAS A POWER CONSUMPTION OF 5 X 2=10 WATTS, WHILE THE 2.5 VOLT SECONDARY WINDING "Y" WILL REQUIRE 2.5 X 3=7.5 WATTS.

THE PRIMARY WATTAGE

WE ARE NOW READY TO CALCULATE THE WATTAGE OF THE POWER TRANSFORMER'S PRIMARY WINDING AND IN DOING THIS, WE MUST TAKE INTO CONSIDERATION A SLIGHT LOSS WHICH IS ENCOUNTERED BY THE TRANSFER OF ENERGY THROUGH THE CORE. THIS LOSS IS KNOWN AS THE "CORE LOSS" AND IS DISSIPATED IN THE FORM OF HEAT. FOR TRANSFORMERS HAVING A POWER RATING OF 500 TO 1500 WATTS, AN EFFICIENCY OF 95% CAN BE EXPECTED (THIS MEANS A 5% LOSS). FOR 100 TO 500 WATTS, THE EFFICIENCY DROPS TO ABOUT 90% (A 10% LOSS); WHILE IN SMALLER TRANSFORMERS, THE EFFICIENCY WILL PROBABLY BE IN THE NEIGHBORHOOD OF 85% (A 15% LOSS).

IN ORDER TO DETERMINE THE PRIMARY WATTAGE, WE HAVE A CONVENIENT FORMULA WHICH IS AS FOLLOWS:

PRIMARY WATTAGE=TOTAL SECONDARY WATTAGE÷EFFICIENCY EXPRESSED AS A DECIMAL FRACTION.

BY ADDING TOGETHER THE WATTAGES DEMANDED BY THE VARIOUS SECONDARY WINDINGS OF OUR TRANSFORMER WE HAVE: 17.5+37.5+10+7.5=72.5 WATTS. THIS VALUE CORRESPONDS TO THE "TOTAL SECONDARY WATTAGE", AS EXPRESSED IN THE ABOVE FORMULA. WE CAN NOW SEE AHEAD THAT OUR PARTICULAR TRANSFORMER IS GOING TO HAVE A RATING OF LESS THAN 100 WATTS, THEREFORE WE SHALL ASSUME AN EFFICIENCY OF 85% FOR THE UNIT, WHICH IS EQUIVALENT TO A LOSS OF 15%.

WE ARE NOW IN A POSITION TO SUBSTITUTE THESE VALUES IN OUR FORMULA IN THE FOLLOWING MANNER:

PRIMARY WATTAGE=72.5 ÷ .85=85.3 WATTS (NOTE THAT IN ORDER TO CONVERT

PERCENTAGE TO A DECIMAL FRACTION, IT IS ONLY NECESSARY TO DROP THE PERCENT SIGN AND MOVE THE DECIMAL POINT TWO PLACES TOWARDS THE LEFT. HENCE 85% BECOMES .85). FOR THE SAKE OF SIMPLICITY, WE WILL CONSIDER THE PRIMARY WATTAGE AS 85 WATTS.

CALCULATING THE TURNS PER VOLT

THE NEXT STEP IS TO DETERMINE THE "TURNS PER VOLT" FOR THE VARIOUS WINDINGS AND TO ASSIST US IN THIS WORK, WE HAVE A SERIES OF VERY HANDY FORMULAS AVAILABLE. HERE THEY ARE: IF THE TRANSFORMER CORE IS TO BE OF THE "CORE TYPE" AND THE UNIT IS TO BE OPERATED FROM A 60 CYCLE A.C. SUPPLY, THEN THE TURNS PER VOLT $= \dfrac{41}{\sqrt{\text{PRIMARY WATTAGE}}}$. IF THE TRANSFORMER CORE IS TO BE OF THE "CORE TYPE" AND THE UNIT IS TO BE OPERATED FROM A 25 CYCLE A.C. SUPPLY, THEN THE TURNS PER VOLT $= \dfrac{97}{\sqrt{\text{PRIMARY WATTAGE}}}$.

ON THE OTHER HAND, IF THE TRANSFORMER CORE IS TO BE OF THE "SHELL TYPE" AND THE UNIT IS TO BE OPERATED FROM A 60 CYCLE A.C. SUPPLY, THEN THE TURNS PER VOLT $= \dfrac{32}{\sqrt{\text{PRIMARY WATTAGE}}}$.

FINALLY, IF THE TRANSFORMER CORE IS TO BE OF THE "SHELL TYPE" AND THE UNIT IS TO BE OPERATED FROM A 25 CYCLE A.C. SUPPLY, THEN THE TURNS PER VOLT $= \dfrac{77}{\sqrt{\text{PRIMARY WATTAGE}}}$.

FIG. 4 CLEARLY ILLUSTRATES THE DIFFERENCE BETWEEN A "CORE TYPE" AND "SHELL TYPE" TRANSFORMER CORE. AS YOU WILL OBSERVE FROM THIS ILLUSTRATION, THE WINDINGS ARE ALL WOUND ON ONE SIDE OR "LEG" OF THE CORE, IN THE CASE OF THE CORE TYPE ASSEMBLY, WHEREAS ON THE "SHELL TYPE" UNIT, THE WINDINGS ARE ALL PLACED ON A SPECIAL LEG AT THE CENTER OF THE ASSEMBLY. THE "CORE TYPE" UNIT IS EASIER TO CONSTRUCT BUT THE "SHELL TYPE" UNIT IS MORE EFFICIENT, THEREFORE, MOST COMMERCIAL TRANSFORMERS ARE OF THE "SHELL TYPE".

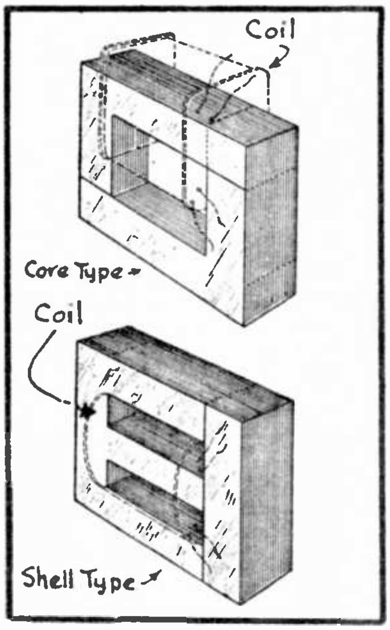

FIG. 4
The Transformer Cores.

YOU WILL ALSO NOTICE THAT THE VARIOUS FORMULAS WHICH WERE GIVEN YOU IN REGARDS TO THE "TURNS PER VOLT," APPLY DIRECTLY ONLY TO THE TWO MOST COMMON A.C. LIGHTING SUPPLY FREQUENCIES OF 25 AND 60 CYCLES. HOWEVER, A TRANSFORMER DESIGNED FOR ONE PARTICULAR FREQUENCY CAN ALWAYS BE USED ON A SLIGHTLY HIGHER FREQUENCY THAN THAT FOR WHICH IT IS DESIGNED. THAT IS TO SAY, WE MAY USE A 25 CYCLE DESIGN FOR ANY FREQUENCY SLIGHTLY GREATER THAN 25 CYCLES AND A 60 CYCLE DESIGN FOR A FREQUENCY SLIGHTLY HIGHER THAN 60 CYCLES WITH OF COURSE, SOME LOSS OF POWER WHICH IS DISSIPATED IN THE FORM OF HEAT. THE 60 CYCLE TRANSFORMER WILL ALSO OPERATE SATISFACTORILY ON A 50 CYCLE LINE.

LET US ASSUME THAT THE SEVEN-TUBE RECEIVER, FOR WHICH WE ARE DESIGNING THE POWER TRANSFORMER, IS TO BE OPERATED FROM A 60 CYCLE A.C. 110 VOLT LIGHTING CIRCUIT AND THAT THE POWER TRANSFORMER IS TO BE OF THE "SHELL TYPE". THIS BEING THE CASE, WE DETERMINE THE TURNS PER VOLT BY USING THE

FORMULA: TURNS PER VOLT $= \frac{32}{\sqrt{\text{PRIMARY WATTAGE}}}$.

SINCE WE HAVE ALREADY CALCULATED OUR PRIMARY WATTAGE AS BEING 85 WATTS, THE TURNS PER VOLT FOR THIS PARTICULAR TRANSFORMER WILL WORK OUT AS FOLLOWS: TURNS PER VOLT $= \frac{32}{\sqrt{85}} = \frac{32}{9.2} = 3.48$.

IN ACTUAL PRACTICE, IT IS ADVISABLE TO SET THE TURNS PER VOLT FACTOR SLIGHTLY HIGHER RATHER THAN LOWER THAN THE VALUE FOUND BY CALCULATION. THAT IS TO SAY, IN ORDER TO AVOID FRACTIONAL TURNS SO AS TO SIMPLIFY WINDING, WE WILL SET OUR TURNS PER VOLT FACTOR TO THE NEXT WHOLE NUMBER OR 4. THIS MEANS THAT WE SHALL CONSTRUCT THE WINDINGS OF OUR TRANSFORMER ON THE BASIS OF 4 TURNS PER VOLT. ALTHOUGH THIS IS SLIGHTLY HIGHER THAN THE CALCULATED VALUE, IT IS SUFFICIENTLY CLOSE FOR PRACTICAL PURPOSES, WHILE AT THE SAME SIMPLIFYING THE DESIGN CONSIDERABLY AS WELL AS TO IMPROVE THE PERFORMANCE OF THE TRANSFORMER TO WHAT IT WOULD BE WITH A REDUCED TURNS PER VOLT FACTOR.

TABLE I

WIRE TABLE FOR POWER TRANSF. DESIGN

Size	Diameter		Area	Turns per In.	
B&S	Enameled	Double Cotton	Circ. Mils.	Enameled	Double Cotton
8	.1307	.1413	16510.	7.7	7.0
9	.1166	.1252	13090.	8.6	7.9
10	.1041	.1118	10380.	9.6	8.9
11	.0927	.1006	8234.	10.8	9.9
12	.0828	.0902	6530.	12.1	11.0
13	.0740	.0812	5178.	13.6	12.1
14	.0659	.0733	4107.	15.2	13.6
15	.0589	.0655	3257.	17.0	15.1
16	.0526	.0592	2583.	19.1	16.7
17	.0469	.0536	2048.	21.5	18.2
18	.0419	.0487	1624.	23.9	20.2
19	.0373	.0446	1288.	26.8	22.2
20	.0334	.0408	1022.	30.1	24.3
21	.0297	.0368	810.1	33.7	26.7
22	.0265	.0335	642.4	37.7	29.2
23	.0238	.0308	509.5	42.3	31.6
24	.0213	.0283	404.0	47.1	34.4
25	.0191	.0261	320.4	52.9	37.2
26	.0170	.0240	254.1	59.1	40.1
27	.0153	.0219	201.5	66.2	43.1
28	.0135	.0205	159.8	74.1	46.2
29	.0122	.0192	126.7	83.3	49.2
30	.0108	.0179	100.5	92.2	52.5
31	.0097	.0168	79.70	103.4	55.8
32	.0087	.0158	63.21	115.6	58.9
33	.0077	.0150	50.13	129.3	62.1
34	.0069	.0143	39.75	144.9	65.3
35	.0062	.0136	31.52	162.3	68.4
36	.0055	.0130	25.00	181.8	71.4
37	.0049	.0124	19.83	202.4	74.3
38	.0044	.0119	15.72	227.7	77.1
39	.0039	.0115	12.47	252.5	79.8
40	.0034	.0112	9.888	280.1	82.3

WE CAN NOW PROCEED BY CALCULATING THE EXACT NUMBER OF TURNS TO EMPLOY ON EACH OF THE WINDINGS, SIMPLY BY MULTIPLYING THE VOLTAGE AT WHICH EACH OF THE TRANSFORMER WINDINGS IS TO BE OPERATED BY THIS FACTOR OF 4.

THE TURNS REQUIRED FOR EACH WINDING

FOR EXAMPLE, SINCE THE VOLTAGE ACROSS THE PRIMARY WINDING IS TO BE 110 VOLTS, THE NUMBER OF TURNS TO BE USED IN THIS PARTICULAR WINDING WILL BE 110 X 4 = 440 TURNS. FOR THE 5 VOLT SECONDARY WINDING, WE WILL USE 5 X 4 = 20 TURNS AND FOR EACH OF THE 2.5 VOLT SECONDARY WINDINGS 2.5 X 4 = 10 TURNS.

ACCORDING TO THIS SAME METHOD OF CALCULATION, EACH HALF OF THE HIGH VOLTAGE SECONDARY WINDING MUST CONSIST OF 375 X 4 = 1500 TURNS. IN ADDITION, HOWEVER, WE MUST CONSIDER "REGULATION" IN RESPECT TO THIS WINDING. THAT IS, WHILE THE RECEIVER IS OPERATING, THE "B" CURRENT DRAWN BY IT AND THROUGH THE HIGH VOLTAGE SECONDARY VARIES CONSIDERABLY WHILE HANDLING SIGNAL VOLTAGES OF DIFFERENT INTENSITIES AND THIS IN TURN WILL AFFECT THE VOLTAGE AVAILABLE FROM OUR GIVEN HIGH VOLTAGE SECONDARY WINDING OF THE POWER TRANS-

FORMER. SO TO TAKE THIS CONDITION INTO ACCOUNT, WE ADD 5% OF THE NUMBER OF THE HIGH VOLTAGE WINDING TURNS TO THE VALUE OBTAINED THROUGH OUR PREVIOUS CALCULATION. THIS 5% IS AN AVERAGE VALUE, WHICH CAN BE EMPLOYED IN THE GENERAL TYPES OF POWER TRANSFORMERS USUALLY ENCOUNTERED IN PRACTICE.

WE THUS FIND THAT EACH HALF OF THE HIGH VOLTAGE SECONDARY WINDING FOR THE PARTICULAR TRANSFORMER UNDER OUR PRESENT CONSIDERATION SHOULD CONSIST OF 1500 TURNS + 1500 X .05 = 1575 TURNS. THE ENTIRE HIGH VOLTAGE SECONDARY WINDING WILL THEREFORE CONSIST OF 2 X 1575 OR 3150 TURNS.

WIRE SIZES NEEDED

WE CAN NOW PROCEED BY DETERMINING THE SIZE OF WIRE TO BE EMPLOYED FOR EACH OF THESE INDIVIDUAL WINDINGS. THE SIZE OF WIRE TO USE FOR ANY GIVEN WINDING WILL DEPEND ENTIRELY UPON THE AMOUNT OF CURRENT WHICH THE PARTICULAR WINDING IN QUESTION IS TO CARRY DURING THE COURSE OF NORMAL OPERATION. NATURALLY, IN ORDER TO AVOID AN EXCESSIVE GENERATION OF HEAT, WE MUST CHOOSE A WIRE SIZE SUFFICIENTLY LARGE SO AS TO CARRY THE REQUIRED CURRENT WITHOUT BECOMING TOO HOT. YET AT THE SAME TIME, WE MUST REMEMBER THAT THE LARGER THE WIRE-SIZE USED, THE GREATER WILL BE THE SPACE REQUIRED IN WHICH TO WIND A GIVEN NUMBER OF TURNS. WE MUST THEREFORE CHOOSE A WIRE SIZE WHICH IS MOST PRACTICAL FROM ALL POINTS OF VIEW AND PREVIOUS EXPERIENCE HAS PROVEN THAT SATISFACTORY RESULTS ARE OBTAINED FOR ALL PURPOSES, BY ALLOWING 1000 CIRCULAR MILS OF CONDUCTOR CROSS-SECTION FOR EACH AMPERE OF CURRENT TO BE CARRIED BY IT. THIS IS THE SAME AS SAYING THAT FOR EACH MILLIAMPERE OF CURRENT, A CONDUCTOR CROSS-SECTION OF 1 CIRCULAR-MIL SHOULD BE AVAILABLE.

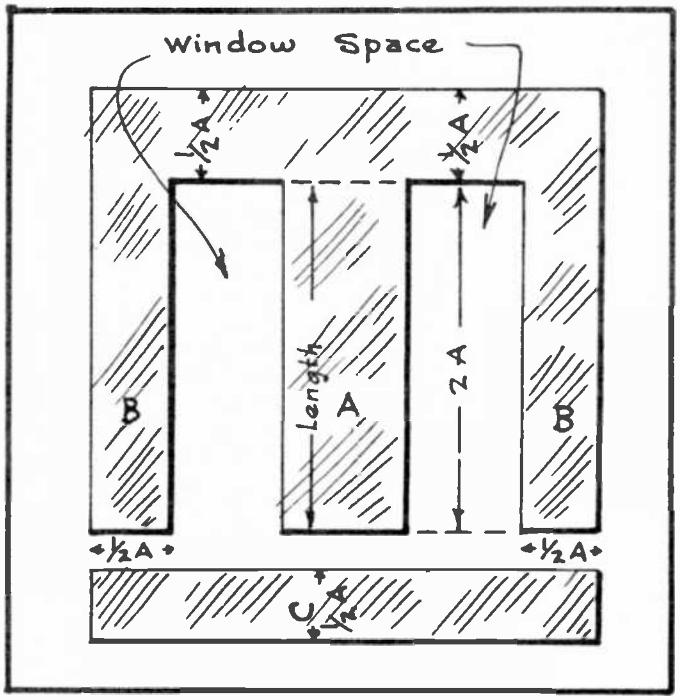

FIG. 5
The Core Laminations.

WITH THIS SIMPLE RULE IN MIND, WE FIND THAT FOR THE 2.5 VOLT SECONDARY WINDING "X" OF OUR TRANSFORMER AND WHICH IS TO CARRY 7 AMPS., WE MUST USE A WIRE-SIZE HAVING A CROSS-SECTIONAL AREA OF 7 X 1000 = 7000 CIRCULAR MILS. BY LOOKING IN THE COLUMN HEADED "AREA-CIRCULAR MILS" IN THE HANDY WIRE TABLE WHICH IS GIVEN YOU IN TABLE I OF THIS LESSON, YOU WILL FIND THAT A WIRE CORRESPONDING TO A CROSS-SECTIONAL AREA OF 7000 CIRCULAR MILS WILL BE BETWEEN A #11 AND #12 B&S GAUGE WIRE. WE THEREFORE, CHOOSE A STANDARD WIRE SIZE, WHICH IS THE FIRST SIZE LARGER IN RESPECT TO THE CROSS-SECTIONAL AREA WE WANT. IN OTHER WORDS, FOR THIS SECONDARY WINDING "X", WE WILL USE A #11 B&S SIZE COPPER WIRE.

IN LIKE MANNER, WE FIND THAT THE 2.5 VOLT SECONDARY WINDING "Y", WHICH

IS TO CARRY 3 AMPERES, MUST CONSIST OF A WIRE-SIZE OFFERING A CROSS-SECTIONAL AREA OF 3 X 1000 = 3000 CIRCULAR MILS. ACCORDING TO TABLE I, WE FIND THAT THE CLOSEST STANDARD WIRE-SIZE CORRESPONDING TO THIS VALUE IS A #15 B&S SIZE, SO THIS IS THE WIRE-SIZE WHICH WE WILL USE FOR THIS WINDING.

THE 5 VOLT SECONDARY WINDING WILL BE REQUIRED TO CARRY 2 AMPS. AND SO THE WIRE SIZE NEEDED IN THIS CASE WILL CORRESPOND TO A CROSS-SECTIONAL AREA OF 2 X 1000 = 2000 CIRCULAR-MILS. ACCORDING TO TABLE I, WE THUS CHOOSE THE NEAREST STANDARD SIZE OR A #17 B&S GAUGE.

EACH HALF OF THE HIGH VOLTAGE SECONDARY IS TO CARRY 100 MILLIAMPERES, THEREFORE, THE CROSS-SECTIONAL AREA FOR THE WIRE USED FOR THIS WINDING SHOULD BE 100 MA X 1 CIRCULAR-MIL = 100 CIRCULAR MILS AND SO FROM TABLE I, WE WILL CHOOSE A #30 B&S GAUGE WIRE FOR THIS WINDING. IF DESIRED, ONE COULD CHOOSE THE NEXT SIZE LARGER IN THIS CASE, IN ORDER TO ALLOW FOR A SLIGHT OVER-LOAD. THAT IS, A #29 B&S GAUGE WIRE COULD BE EMPLOYED IF PREFERRED.

OUR FINAL STEP IN REGARDS TO DETERMINING WIRE SIZES WILL BE TO FIND OUT THE SIZE NEEDED FOR THE PRIMARY WINDING, BUT IN ORDER TO BE ABLE TO DO THIS, WE MUST FIRST DO A LITTLE ADDITIONAL CALCULATION. TO BEGIN WITH, WE MUST CALCULATE THE CURRENT WHICH IS TO BE CARRIED BY THIS WINDING AND WE CAN DO THIS VERY READILY BY EMPLOYING "WATT'S LAW" IN THE FORM

$\text{CURRENT} = \frac{\text{WATTS}}{\text{VOLTS}}$. IN OTHER WORDS, SINCE THE PRIMARY WATTAGE OF OUR TRANSFORMER HAS ALREADY BEEN DETERMINED AS BEING 85.3 WATTS AND THE PRIMARY WINDING IS TO BE CONNECTED TO A 110 VOLT LIGHTING CIRCUIT, THEN THE APPROXIMATE CURRENT TO BE CARRIED BY THE PRIMARY WINDING UNDER NORMAL CONDITIONS WILL BE

$\frac{85.3}{110} = 0.775$ AMPERE.

THE CROSS-SECTION FOR THE WIRE TO BE USED FOR THE PRIMARY WINDING WILL THEREFORE BE 0.775 X 1000 OR 775 CIRCULAR-MILS. ACCORDING TO TABLE I, WE WILL THUS CHOOSE A CONDUCTOR OF A #21 B&S GAUGE.

CALCULATING THE REQUIRED CORE AREA

OUR FOLLOWING STEP WILL BE TO FIGURE OUT THE SIZE OF CORE TO USE FOR THE TRANSFORMER AND FOR THIS WE HAVE TWO HANDY AND EASILY APPLIED FORMULAR. HERE THEY ARE:

WHEN THE A.C. LIGHTING CIRCUIT IS OF THE 60 CYCLE TYPE, THEN THE CROSS SECTIONAL AREA OF THE CORE EXPRESSED IN SQUARE INCHES = VOLTS PER TURN X 7.5.

IF ON THE OTHER HAND, THE FREQUENCY OF THE A.C. LIGHTING CIRCUIT, ACROSS WHICH THE PRIMARY WINDING OF THE TRANSFORMER IS TO BE CONNECTED, IS OF THE 25 CYCLE TYPE, THEN THE CROSS-SECTIONAL AREA OF THE CORE EXPRESSED IN SQUARE INCHES = VOLTS PER TURN X 18.

THIS BRINGS US UP TO THE POINT WHERE WE MUST DETERMINE THE EXACT MEANING OF THE EXPRESSION "VOLTS PER TURN", AS USED IN THESE FORMULAS, AND THE RELATION WHICH THIS SAME EXPRESSION BEARS TO THE TERM "TURNS PER VOLT" WHICH WE HAVE ALREADY USED IN OUR PREVIOUS TRANSFORMER CALCULATIONS. FORTUNATELY, THIS HAPPENS TO BE A VERY SIMPLE MATTER BECAUSE THE "VOLTS PER TURN" IS MERELY EQUAL TO "ONE" DIVIDED BY THE "TURNS PER VOLT". FOR EXAMPLE, IF THE TURNS PER VOLT OF A CERTAIN TRANSFORMER IS 3, THEN THE VOLTS

PER TURN OF THIS SAME TRANSFORMER IS EQUAL TO 1/3.

NOW THEN, FOR THE PARTICULAR TRANSFORMER WHICH WE ARE DESIGNING, WE HAVE ALREADY FOUND THE TURNS PER VOLT TO BE 4. THEREFORE, THE VOLTS PER TURN IN THIS CASE WILL BE 1/4. THIS IS THE SAME AS SAYING 1 DIVIDED BY 4 AND SO BY COMPLETING THIS MATHEMATICAL PROCESS, WE FIND THE VOLTS PER TURN FOR OUR PRESENT USE TO BE 0.25.

WE ARE NOW READY TO CALCULATE THE CROSS-SECTIONAL AREA OF THE CORE FOR OUR TRANSFORMER AND SINCE THE UNIT IS TO BE OPERATED ON A 60 CYCLE A.C. SUPPLY, WE WILL USE THE FORMULA: AREA OF CROSS-SECTION = VOLTS PER TURN X 7.5. SUBSTITUTING OUR VALUE OF .25 FOR THE VOLTS PER TURN IN THIS FORMULA WE HAVE: AREA OF CROSSECTION = .25 X 7.5 = 1.875 SQUARE INCHES.

OUR COMPLETE DATA

WITH THIS CALCULATION FOR THE CORE TAKEN CARE OF, WE HAVE NOW CALCULATED THE BASIC DATA FOR THE CONSTRUCTION OF OUR POWER TRANSFORMER. ARRANGING THIS DATA IN TABULAR FORM FOR HANDY REFERENCE, WE HAVE:

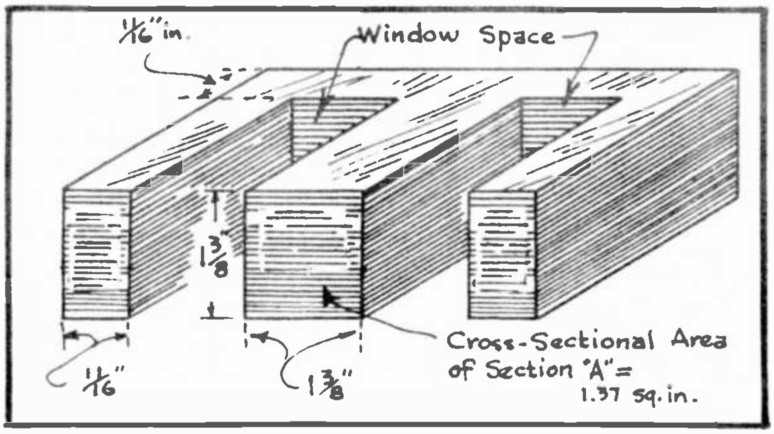

FIG. 6
Stack of E-Shaped Laminations.

CROSS-SECTIONAL AREA OF CORE = 1.875 SQUARE INCHES. PRIMARY WINDING = 440 TURNS OF #21 B&S WIRE. SECONDARY WINDING "X" = 10 TURNS OF #11 B&S WIRE. SECONDARY WINDING "Y" = 10 TURNS OF #15 B&S WIRE. THE 5-VOLT SECONDARY WINDING = 20 TURNS OF #17 B&S WIRE. HIGH VOLTAGE SECONDARY = 3150 TURNS (CENTER-TAPPED) OF #30 B&S WIRE.

PLANNING THE CORE CONSTRUCTION

FOR THE CONSTRUCTIONAL PART OF OUR WORK, WE SHALL BEGIN WITH THE LAYOUT OF THE CORE. SINCE THE CORE IS TO BE OF THE "SHELL-TYPE", WE WILL HAVE TO HAVE ONE GROUP OF "E" SHAPED STEEL LAMINATIONS AND A GROUP OF AN EQUAL NUMBER OF "I"-SHAPED STEEL LAMINATIONS AS SHOWN YOU IN FIG. 5.

TO FULFILL OUR DESIGN REQUIREMENTS UP TO THIS POINT, THE CENTER-LEG OR SECTION "A" OF OUR CORE MUST HAVE A CROSSECTIONAL AREA OF 1.875 SQUARE INCHES. THIS MEANS THAT IF WE DESIRE, WE CAN MAKE THE DIMENSION "A" IN FIG. 5 EQUAL TO $\sqrt{1.875}$ OR 1.37" IN THIS CASE AND USE A SUFFICIENT NUMBER OF LAMINATIONS SO THAT WHEN STACKED UP, THE PILE WILL BE 1.37" THICK. IN THIS WAY, WE WILL OBTAIN A SQUARE CROSS-SECTION AT "A" BEING 1.37" ON A SIDE AND HAVING A CROSS-SECTIONAL AREA OF 1.37 X 1.37 = 1.875 (APPROX.) SQUARE INCHES AS SHOWN IN FIG. 6. A DIMENSION OF 1.37" IS APPROXIMATELY EQUAL TO 1-3/8".

NOW IT IS NOT ALTOGETHER NECESSARY THAT THE CROSS-SECTION OF "A" BE SQUARE-SHAPED. FOR EXAMPLE, YOU CAN ALSO OBTAIN A CROSS-SECTIONAL AREA OF

1.875 SQUARE INCHES AT THIS POINT IF SECTION "A" IS 1" WIDE AND 1.875" THICK. THE RELATION BETWEEN THESE TWO DIMENSIONS REMAINS AS A CHOICE FOR THE DESIGNER, BEING PRIMARILY AFFECTED BY THE DESIRED OVERALL-SIZE AND GENERAL SHAPE OF THE COMPLETED TRANSFORMER, SO THAT IT WILL FIT INTO THE SPACE AVAILABLE ON THE CHASSIS. NEVERTHELESS, A SQUARE CROSS-SECTION IS MOST USED.

IT IS GENERALLY THE PRACTICE TO MAKE THE DIMENSION "B" AND "C" OF FIG. 5 ONE HALF THAT OF THE DIMENSION "A". IN OTHER WORDS, IF "A" IS CHOSEN AS 1⅜", THEN DIMENSIONS "B" AND "C" WILL BE 11/16 ".

FIGURING THE WINDOW-SPACE

THE AMOUNT OF ROOM ALLOTED FOR THE WINDOW-SPACE IN WHICH THE WINDINGS ARE TO BE INSTALLED WILL DEPEND ENTIRELY UPON THE AMOUNT AND SIZE OF THE WIRE AND INSULATION WHICH IT WILL BE NECESSARY TO PUT IN THIS SPACE FOR ANY GIVEN TRANSFORMER. THE SIMPLEST WAY IN WHICH TO FIGURE HOW MUCH SPACE IS NEEDED FOR THIS PURPOSE IS TO DRAW THE TRANSFORMER TO ACTUAL SIZE ON A PIECE OF PAPER AS THE DIMENSIONS DEVELOPE FROM THE SERIES OF CALCULATIONS WHICH ARE NOW GOING TO BE DESCRIBED.

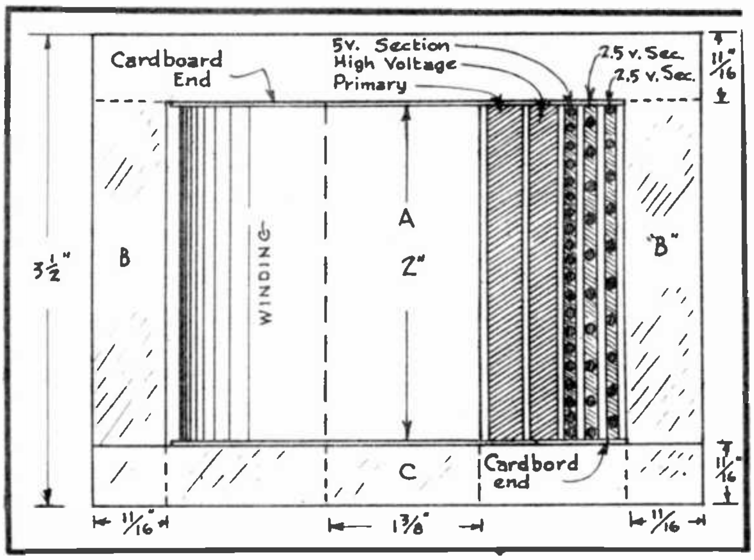

FIG. 7

Figuring the Remaining Core Dimensions.

FOR EXAMPLE, LET US SUPPOSE THAT WE HAVE DECIDED TO MAKE OUR TRANSFORMER 3½" WIDE. THIS HAPPENS TO BE A POPULAR DIMENSIONS AMONG FACTORY BUILT UNITS OF THIS POWER RATING. NOW THEN, IF THIS PARTICULAR DIMENSION IS CHOSEN, IT IS PERFECTLY CLEAR ACCORDING TO FIG. 7 THAT THE MAXIMUM LENGTH FOR SECTION "A" WILL BE 3½" - (11/16" + 11/16") = 3½" - 1⅜" = 2⅛". HOWEVER, THIS ENTIRE LENGTH CANNOT BE UTILIZED FOR WINDING PURPOSES DUE TO THE FACT THAT WE ARE GOING TO PROVIDE A CARDBOARD OR FIBER END WASHER AT EACH END OF THE WINDING. ASSUME EACH OF THESE WASHERS TO BE 1/16" THICK, THE TWO TOGETHER WILL OCCUPY ⅛" OF WINDING SPACE, THEREBY LEAVING US BUT 2⅛" - ⅛" = 2" FOR ACTUAL WINDING PURPOSES ALONG THE LENGTH OF THE CORE'S CENTER LEG. THIS DIMENSION IS CLEARLY SPECIFIED IN FIG. 7.

ANOTHER HANDY RULE WITH WHICH TO DETERMINE THE LENGTH OF THE WINDOW-SPACE IS TO MAKE IT EQUAL TO 1½ TO 2 TIMES THE DIMENSION "A" AS ILLUSTRATED BY THE DIMENSION 2A IN FIG. 5. THE WINDING LENGTH IS THEN MADE SLIGHTLY LESS THAN THIS DISTANCE (APPROXIMATELY ⅛" LESS) IN ORDER TO PERMIT THE FINISHED COIL WITH ITS END WASHERS TO FIT INTO THIS SPACE.

THE NEXT STEP WILL BE TO DETERMINE HOW MUCH SPACE IS NEEDED BETWEEN CENTER LEG "A" AND THE TWO OUTER LEGS OF OUR CORE "B", SO THAT ALL OF THE WINDINGS CAN BE ACCOMMODATED BY THIS WINDOW SPACE. IN FIGURING THIS DIMENSION, IT IS ONLY NECESSARY TO FIGURE IT FOR THE WINDOW SPACE ON ONE SIDE AS THE OTHER SIDE WILL BE EQUAL TO IT.

TO BEGIN WITH, WE MUST FIRST ALLOW FOR SOME INSULATION BETWEEN THE CENTER LEG OF THE CORE "A" AND THE PRIMARY WINDING. SINCE CARDBOARD AND TAPE ARE TO BE USED FOR THE THE INSULATION AT THIS POINT, WE WILL ALLOW A THICKNESS OF 1/8" FOR THIS PURPOSE.

THE NEXT STEP WILL BE TO FIGURE THE THICKNESS OF THE PRIMARY WINDING. WE ARE GOING TO USE 440 TURNS OF #21 B&S DOUBLE- COTTON COVERED WIRE FOR THIS PURPOSE AND ACCORDING TO TABLE I OF THIS LESSON, WE FIND THAT THIS PARTICULAR WIRE CAN BE WOUND 26.7 TURNS TO THE INCH. SINCE WE HAVE 2" AVAILABLE ON OUR CORE CONSTRUCTION FOR EACH LAYER OF WIRE, WE WILL BE ABLE TO GET (26.7 X 2) TURNS OF THIS WIRE PER LAYER. THUS WE HAVE 26.7 X 2=53.4 BUT WE WILL ESTIMATE THIS AT 53 TURNS PER LAYER.

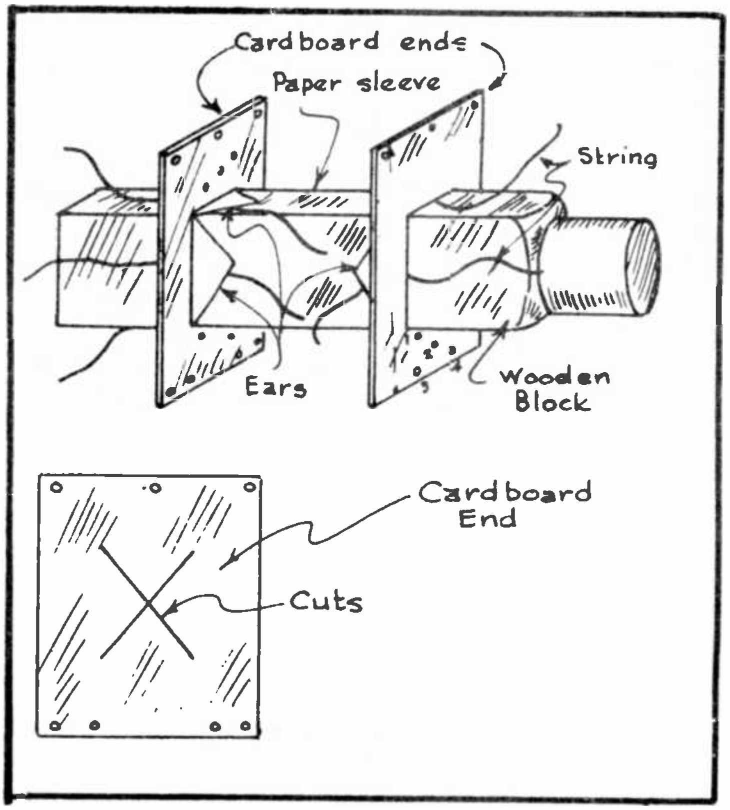

FIG. 8
The Winding Form.

THE TOTAL NUMBER OF PRIMARY TURNS REQUIRED, HOWEVER, IS 440 AND SINCE 53 TURNS CAN BE WOUND ON ONE LAYER, THE TOTAL NUMBER OF LAYERS NEEDED FOR THIS WINDING WILL BE 440 DIVIDED BY 53 OR 8.5 LAYERS. WE WILL ESTIMATE THIS VALUE AT 9 LAYERS.

NOW BY AGAIN CONSULTING TABLE I OF THIS LESSON, WE FIND THAT THE DIAMETER OF DOUBLE COTTON COVERED #21 B&S WIRE IS .0368". NINE LAYERS OF THIS WIRE WILL THEREFORE BE 9 X .0368" OR APPROXIMATELY .33 INCHES THICK.

THE HIGH VOLTAGE SECONDARY WINDING IS TO BE WOUND OVER THE PRIMARY BUT INSULATIVE TAPE WOUND 1/8" THICK SHOULD BE PROVIDED BETWEEN THESE TWO WINDINGS. FOR ALL SECONDARY WINDINGS, PLAIN ENAMELED COPPER WIRE MAY BE USED AND THE THICKNESS OF EACH WINDING MAY BE CALCULATED BY THE METHOD ALREADY DESCRIBED REGARDING THE PRIMARY WINDING. ALLOW A TOTAL OF 1/8" FOR INSULATIVE PAPER WHICH IS TO BE USED BETWEEN EACH LAYER OF THE HIGH-VOLTAGE SECONDARY WINDINGS.

ALTHOUGH WE HAVE SPECIFIED DOUBLE COTTON-COVERED WIRE FOR THE PRIMARY WINDING IN THIS PARTICULAR EXAMPLE, YET PLAIN ENAMELED WIRE CAN ALSO BE USED FOR THIS PURPOSE BUT UNDER SUCH CONDITIONS, INSULATIVE PAPER SHOULD BE PROVIDED BETWEEN EACH LAYER OF TURNS MAKING UP THIS WINDING.

AFTER YOU HAVE ADDED TOGETHER THE THICKNESS OF ALL THE WINDINGS, INCLUDING ALL INSULATION, YOU WILL HAVE THE DIMENSION FOR THE WINDOW SPACE BETWEEN THE CENTER CORE-LEG "A" AND THE TWO END-LEGS "B". IT IS BETTER TO ESTIMATE THE REQUIRED WINDOW SPACE TOO LARGE RATHER THAN TOO SMALL BECAUSE IF IT IS TOO LARGE, YOU CAN FILL IT WITH INSULATIVE TAPE WHILE ON THE OTHER HAND, IF THE WINDOW SPACE IS TOO SMALL, IT WILL BE IMPOSSIBLE TO ASSEMBLE THE CORE AFTER THE ENTIRE WINDING PROCESS HAS BEEN COMPLETED.

HAVING DETERMINED THIS WINDOW SPACE DIMENSION, IT IS A SIMPLE MATTER TO CALCULATE THE TOTAL LENGTH OF THE CORE'S "E" AND "I" SECTIONS. TO DO THIS, IT IS ONLY NECESSARY TO MULTIPLY THE WINDOW SPACE DIMENSION JUST DETERMINED BY 2 IN ORDER TO ALLOW FOR THE WINDOW SPACE ON BOTH SIDES OF THE CORE'S CENTER SECTION "A". TO THIS VALUE ADD THE DIMENSION "A" OF FIG. 5 AND TWICE THE DIMENSION "B". THIS ANSWER WILL BE THE OVER-ALL LENGTH OF THE CORE'S "I" AND "E" SECTIONS. THUS ALL DIMENSIONS FOR CUTTING THE STEEL LAMINATIONS TO THE PROPER SIZE HAVE BEEN DETERMINED.

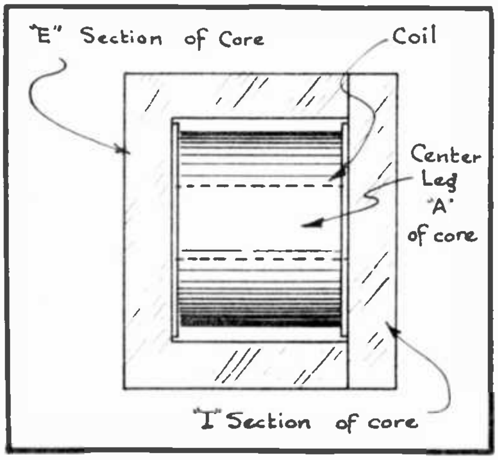

FIG. 9
Assembling the Core.

POSSIBLE CHANGES TO BE CONSIDERED

SHOULD AT ANY TIME THE LENGTH OF THE TRANSFORMER FIGURE OUT TO BE TOO GREAT IN PROPORTION TO ITS WIDTH SO AS TO BE IMPRACTICAL REGARDING ITS GENERAL SHAPE, THEN YOU CAN FIGURE ON USING A GREATER DIMENSION FOR THE WIDTH, OR ELSE TO MAKE DIMENSION "A" SMALLER AND INCREASING THE THICKNESS OF THE CORE ACCORDINGLY OR ELSE A COMBINATION OF BOTH THESE METHODS. BY DOING ALL OF THIS FIGURING ON PAPER BEFORE-HAND, YOU WILL BE ABLE TO FORESEE THE ACTUAL SHAPE AND SIZE OF THE COMPLETED TRANSFORMER AND THUS SAVE YOURSELF CONSIDERABLE TIME IN THE EVENT THAT ANY CHANGES IN THE ORIGINALLY CHOSEN DIMENSIONS ARE FOUND NECESSARY.

THE CORE LAMINATIONS

THE NUMBER OF LAMINATIONS WHICH ARE TO BE CUT FOR BOTH THE "E" AND "I" SECTIONS OF THE TRANSFORMER CORE WILL BE APPROXIMATELY EQUAL TO THE THICKNESS OF THE CORE DIVIDED BY THE THICKNESS OF THE LAMINATION STOCK (SHEETS) USED. FOR 60 CYCLE TRANSFORMERS, CORE MATERIAL .014" THICK IS USUALLY CONSIDERED BEST, WHEREAS SLIGHTLY THICKER CORE MATERIAL MAY BE USED FOR A 25-CYCLE TRANSFORMER. FOR HOME CONSTRUCTION, HOWEVER, IT WILL BE BEST TO USE CORE MATERIAL OF THE SAME THICKNESS FOR A 25 CYCLE TRANSFORMER AS WAS SPECIFIED FOR A 60 CYCLE UNIT. THIS CORE MATERIAL SHOULD PREFERABLY BE TRANSFORMER STEEL WHICH IS CAPABLE OF HANDLING A FLUX DENSITY OF APPROXIMATELY 50,000 LINES OF FORCE PER SQUARE INCH.

CONSTRUCTING THE TRANSFORMER

WITH ALL OF OUR CALCULATIONS COMPLETE, WE ARE NOW READY TO ACTUALLY PROCEED WITH THE CONSTRUCTIONAL WORK ON OUR TRANSFORMER. THE FIRST THING TO DO IN THIS RESPECT IS TO CONSTRUCT A FORM ON WHICH THE WINDINGS ARE TO BE PLACED. THE SIMPLEST METHOD OF DOING THIS IS TO SHAPE A PIECE OF WOOD SO THAT ITS CROSS-SECTION WILL CORRESPOND TO THE CROSS-SECTION OF THE TRANSFORMER CORE'S CENTER-LEG "A".

BUILDING A FORM

WRAP ONE LAYER OF ORDINARY THIN STRING AROUND THIS PIECE OF WOOD AND THEN WRAP A PIECE OF GOOD STIFF PAPER OVER THE STRING. (INSULATIVE PAPER, KNOWN TO THE INDUSTRY AS "FISH-PAPER", IS EXCELLENT FOR THIS PURPOSE). LEAVE THE ENDS OF THE STRING PROJECT OUT THROUGH THE EDGES OF THIS CARDBOARD SLEEVE, SO THAT THE STRING CAN BE EASILY RIPPED OUT AFTER THE WINDING IS COMPLETED IN ORDER TO ENABLE THE ENTIRE WINDING FORM TO BE EASILY REMOVED FROM THE WOOD BLOCK.

THE NEXT STEP IS TO MOUNT THE CARDBOARD OR FIBER ENDS ON THE WINDING FORM. THE SIZE OF THESE ENDS WILL BE GOVERENED BY THE SIZE OF THE CORE-SECTION AND WINDOW SPACE, WHEREAS THE DISTANCE BETWEEN THEM WILL BE GOVERNED BY THE DIMENSION NOTED AS 2" IN FIG. 7. CUT THESE AT THEIR CENTER SO THAT THEY CAN BE SLIPPED ONTO THE ENDS OF THE PAPER SLEEVE AS ILLUSTRATED IN FIG. 8, PROVIDING THE "EARS" AS SHOWN, SO THAT THEY WILL OVERLAP THE PAPER SLEEVE. INSULATION TAPE SHOULD THEN BE WRAPPED OVER THE PAPER SLEEVE IN TWO OR THREE LAYERS, FROM ONE CARDBOARD END TO ANOTHER.

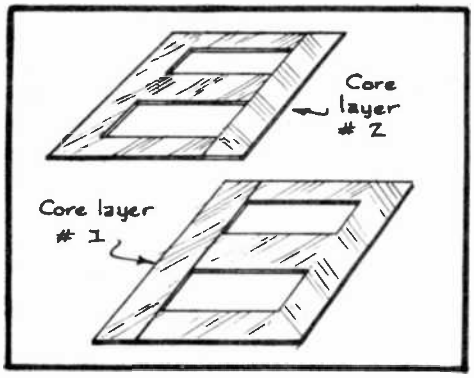

FIG. 10

Alternating Core Placement for Successive Layers.

WINDING THE PRIMARY

YOU CAN NOW PROCEED BY WINDING THE PRIMARY WINDING UPON THE FORM. THIS WINDING SHOULD BE WOUND EVENLY WITH ALL TURNS SIDE BY SIDE (THAT IS, NOT SPACE WOUND). IF THE WINDING IS DONE BY HAND, THE TASK WILL BE A TEDIOUS ONE BECAUSE IN ADDITION TO NEATLY WINDING THE COIL, IT IS ALSO NECESSARY TO KEEP AN ACCURATE COUNT OF THE NUMBER OF TURNS APPLIED. HOWEVER, THE WORK CAN BE SIMPLIFIED BY MOUNTING THE WOODEN FORM BLOCK IN A LATHE TO BE ROTATED AND SO THAT THE OPERATOR NEED ONLY FEED THE WIRE ONTO THE FORM AND KEEP TRACK OF THE NUMBER OF TURNS. TURN INDICATORS ARE ALSO AVAILABLE WHICH CAN BE ATTACHED TO INDICATE THE NUMBER OF REVOLUTIONS COMPLETED BY THE WINDING FORM SO THAT THE OPERATOR CAN TELL AT A GLANCE THE NUMBER OF TURNS BEING APPLIED.

FOR THIS WINDING WORK, ONE CAN ALSO CONSTRUCT A HAND WINDING - JIG ALONG THE SAME LINES AS PRESCRIBED FOR WINDING R.F. TRANSFORMERS IN ONE OF YOUR PREVIOUS LESSONS, ONLY THAT IN THIS PARTICULAR CASE, THE ARRANGEMENT WILL HAVE TO BE SUCH AS TO PERMIT THE ENTIRE WINDING FORM TO BE ROTATED.

REMEMBER, THAT IF PLAIN ENAMEL COVERED WIRE IS USED FOR THE PRIMARY

WINDING, THEN A LAYER OF THIN INSULATION PAPER WILL HAVE TO BE PROVIDED BETWEEN EACH LAYER OF WINDING COMPRISING THE PRIMARY COIL. IF COTTON COVERED ENAMEL WIRE IS USED, THEN THIS ADDITIONAL INSULATION IS NOT NECESSARY.

AFTER COMPLETING THE PRIMARY WINDING, A LAYER OF "EMPIRE CLOTH" SHOULD BE WRAPPED OVER IT. EMPIRE CLOTH IS A SPECIAL TYPE OF TREATED INSULATION CLOTH, WHICH IS AN EXCELLENT INSULATOR AND CAPABLE OF WITHSTANDING CONSIDERABLE VOLTAGE.

THE "STATIC-SHIELD"

TO AVOID THE TRANSFER OF STATIC AND POWER LINE NOISES FROM THE LIGHTING CIRCUIT INTO THE RECEIVER, IT IS ADVISABLE TO SURROUND THE PRIMARY WINDING WITH A "STATIC SHIELD". THIS STATIC SHIELD CONSISTS MERELY OF A THIN SHEET OF COPPER, WHOSE WIDTH IS EQUAL TO THE LENGTH OF THE WINDING FORM. THIS COPPER SHEET SHOULD BE WRAPPED OVER THE INSULATED PRIMARY WINDING AND CUT TO SUCH A LENGTH THAT ITS ENDS WILL NOT MEET OR TOUCH. SOLDER A WIRE TO THIS COPPER SHEET, LEAVING ITS END FREE SO THAT IT CAN LATER BE GROUNDED TO THE TRANSFORMER CORE.

WINDING THE HIGH-VOLTAGE SECONDARY

PLACE ANOTHER LAYER OF EMPIRE CLOTH OVER THIS STATIC SHIELD AND THEN APPLY THE SECONDARY WINDING. BE SURE TO INSULATE EACH LAYER OF SECONDARY WINDING WITH EMPIRE CLOTH OR A THIN PIECE OF INSULATION PAPER AND DON'T FORGET TO PROVIDE A LEAD FOR THE CENTER TAP OF THIS WINDING. FOR ALL WINDINGS, LEAVE THE THE END LEADS OF SUFFICIENT LENGTH SO THAT THEY CAN LATER BE CONVENIENTLY CONNECTED TO SOLDERING LUGS, AT WHICH TIME THEY CAN BE TRIMMED TO THE PROPER LENGTH. ALSO SLIP A SLEEVE OF SPAGHETTI TUBING OVER THE LENGTH OF EACH OF THE PRIMARY AND HIGH VOLTAGE LEADS WHICH ARE TO BE USED ON THE FINISHED TRANSFORMER.

AFTER THE HIGH VOLTAGE SECONDARY WINDING IS APPLIED, WRAP ANOTHER LAYER OF EMPIRE CLOTH OVER IT AND THEN WIND EACH OF THE LOW VOLTAGE WINDINGS IN TURN OVER THE HIGH VOLTAGE SECONDARY, USING EMPIRE CLOTH INSULATION BETWEEN EACH OF THE WINDINGS.

THE OUTER SURFACE OF THE COIL CAN BE TAPED RIGIDLY SO AS TO HOLD THE WINDINGS IN PLACE FIRMLY AND THE END LEADS OF THE COIL CAN THEN BE SOLDERED TO TERMINAL LUGS WHICH ARE FASTENED TO THE PAPER OR FIBER END PIECES OF THE COIL IN THE MANNER AS DONE ON THE TRANSFORMER AS ILLUSTRATED IN FIG. 1 OF THIS LESSON.

WITH THE COIL ITSELF THUS COMPLETED, THE STRING CAN BE RIPPED OUT FROM UNDERNEATH THE WINDING FORM, SO THAT THE ENTIRE COIL, TOGETHER WITH ITS FORM, CAN BE PULLED OFF THE WOODEN WINDING BLOCK.

MANUFACTURERS GENERALLY SOAK THE COMPLETED COIL IN HOT INSULATING VARNISH FOR ABOUT 12 HOURS UNTIL THE ENTIRE UNIT IS THOROUGHLY SOAKED. AFTER THIS PROCESS, THE COIL IS BAKED IN AN OVEN AT A LOW TEMPERATURE FOR TWO OR THREE HOURS SO THAT THE VARNISH BECOMES DRY AND HARD.

ASSEMBLING THE CORE

THE NEXT STEP IS TO ASSEMBLE THE CORE AND FIG. 9 SHOWS YOU HOW

THIS IS DONE. NOTICE HERE THAT AN "E"-SHAPED SECTION OF LAMINATION IS SLIPPED THROUGH THE COIL FROM THE LEFT SO THAT THE CENTER LEG OR SECTION "A" OF THIS PIECE OF LAMINATION PASSES THROUGH THE OPENING PROVIDED IN THE CENTER OF THE COIL. AN "I" SECTION OF LAMINATION IS THEN PLACED ON THE RIGHT SIDE OF THE COIL, SO THAT IT TOUCHES THE EXTREMETIES OF THE "E" SECTION.

FOR THE NEXT LAYER OF THE LAMINATED CORE, INSERT THE "E" SECTION THROUGH THE COIL FROM THE RIGHT SIDE AND PLACE THE "I" SECTION AT THE LEFT ETC. CONTINUE BUILDING UP THE CORE IN THIS MANNER, THUS ALTERNATING THE PLACEMENT OF THE CORE SECTIONS UNTIL THE ENTIRE CORE OPENING IN THE COIL IS FILLED UP AND THE REQUIRED CORE THICKNESS IS OBTAINED.

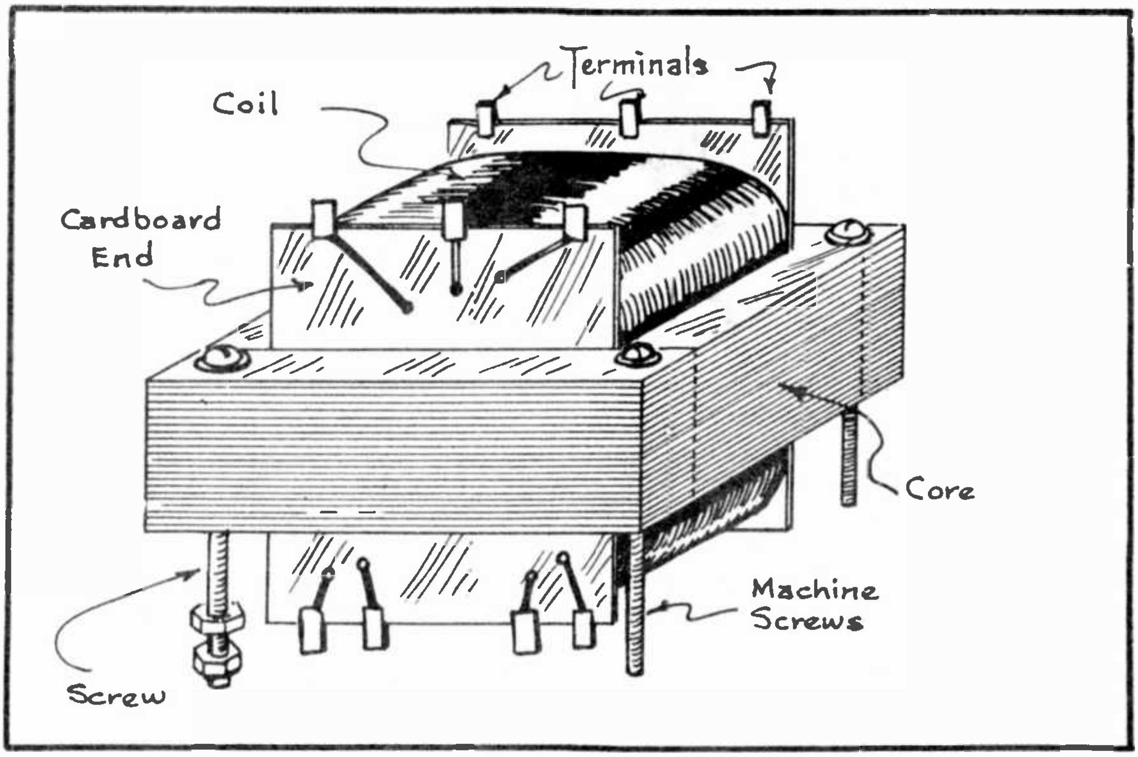

FIG. 11
The Completed Transformer.

FIG. 10 MORE CLEARLY ILLUSTRATES HOW THE POSITION OF THE "E" AND "I" LAMINATION SECTIONS OF THE CORE ARE ALTERNATED FOR EACH LAYER OF THE CORE, AS THE STOCK IS PILED UP. TO SPEED UP THIS PROCESS OF BUILDING UP THE CORE, MOST MANUFACTURES HAVE ADOPTED THE PRACTICE OF INSERTING 4 OR 5 CORE LAMINATIONS OF SIMILAR SECTION AT A TIME FROM EACH SIDE OF THE COIL INSTEAD OF ONLY ONE. IN OTHER WORDS, THE PROCESS OF LAMINATION INSERTION IS ONLY REVERSED AT INTERVALS OF 4 OR 5 LAYERS INSTEAD OF AT EACH SUCCESSIVE LAYER. ALTHOUGH THIS PRACTICE IS NOT THEORITICALLY AS GOOD AS WHEN ALTERNATING THE INSERTIONS FOR EACH SUCCESSIVE LAYER, YET NO NOTICEABLE INEFFICIENCY IS EVIDENT FROM A PRACTICAL STANDPOINT.

THE STATIC SHIELD CAN BE GROUNDED BY LAYING THE FREE END OF ITS LEAD BETWEEN CORE LAMINATIONS SO THAT IT WILL BECOME COMPRESSED BETWEEN THE LAMINATIONS AND THUS BE FIRMLY HELD IN PLACE. IT IS OF COURSE NECESSARY THAT THIS GROUNDING WIRE BE CLEAN AT THE POINT WHERE IT CONTACTS THE

CORE MATERIAL, SO THAT A GOOD GROUND CONNECTION WILL BE OBTAINED.

WHEN ALL OF THE CORE LAMINATIONS HAVE BEEN PLACED INTO POSITION, HOLES CAN BE DRILLED THROUGH THE ENTIRE STACK AT EACH OF THE FOUR CORNERS AND MACHINE SCREWS WITH NUTS EMPLOYED FOR COMBINING THE CORE LAMINATIONS INTO ONE RIGID AND COMPACT UNIT. THIS COMPLETED TRANSFORMER IS ILLUSTRATED IN FIG. 11.

SOMETIMES, THE TRANSFORMER IS LEFT IN AN OPEN CONDITION WHILE IN OTHER INSTANCES, IT IS ENCLOSED IN A METAL CONTAINER WITH EXTERNAL LEAD WIRES SOLDERED TO ITS TERMINAL LUGS.

EXAMINATION QUESTIONS

LESSON NO. 47

1. - THE SECONDARY LOAD OF A CERTAIN POWER TRANSFORMER IS AS FOLLOWS: 350 VOLTS AT 95 MA; 2.5 VOLTS AT 10 AMPERES, AND 5 VOLTS AT 2 AMPERES. THE TRANSFORMER IS 90% EFFICIENT. HOW MUCH PRIMARY CURRENT WILL BE DRAWN FROM A 110-VOLT A-C LINE UNDER FULL LOAD?

2. - IF A CERTAIN SHELL-TYPE POWER TRANSFORMER IS TO HAVE A PRIMARY WATTAGE RATING OF 80 WATTS AND IS TO BE OPERATED OFF A 60-CYCLE, 110-VOLT A-C SUPPLY, HOW MANY TURNS-PER-VOLT WOULD YOU USE FOR THE PRIMARY AND LOW-VOLTAGE SECONDARY WINDINGS?

3. - WHAT IS THE DIFFERENCE IN THE MEANING BETWEEN THE TWO EXPRESSIONS "TURNS-PER-VOLT" AND "VOLTS-PER-TURN"?

4. - IF A CERTAIN SECONDARY WINDING OF A POWER TRANSFORMER IS TO OFFER A VOLTAGE OF 5 VOLTS AND YOU HAVE ALREADY DETERMINED THE "TURNS-PER-VOLT FACTOR" TO BE 5, HOW MANY TURNS OF WIRE WOULD YOU USE FOR THIS 5-VOLT WINDING?

5. - A CERTAIN TRANSFORMER WINDING IS EXPECTED TO CARRY 80 MA. WHAT SIZE OF WIRE MAY BE USED FOR THIS WINDING?

6. - EXPLAIN BRIEFLY HOW THE WINDOW-SPACE OF A POWER TRANSFORMER IS DETERMINED.

7. - IF YOU HAVE DETERMINED THAT A "TURNS-PER-VOLT FACTOR" OF 3 IS TO BE USED FOR A GIVEN 60-CYCLE TRANSFORMER, WHAT CROSS-SECTIONAL AREA WOULD YOU USE IN THE CONSTRUCTION OF THE CORE?

8. - WHY IS A "STATIC SHIELD" USED IN A POWER TRANSFORMER, AND HOW IS IT INSTALLED IN THE UNIT?

9. - EXPLAIN BRIEFLY HOW YOU WOULD WIND TRANSFORMER COILS.

10. - HOW ARE THE VARIOUS WINDINGS OF A POWER TRANSFORMER GENERALLY INSULATED?

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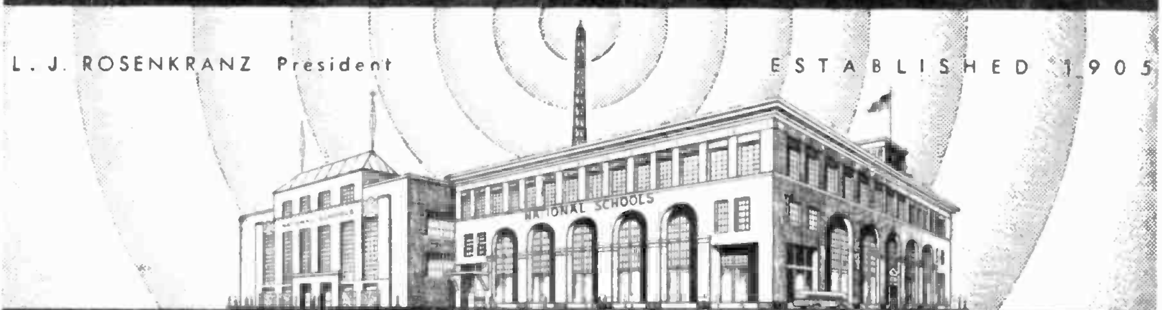

NATIONAL SCHOOLS * LOS ANGELES 37, CALIF.

LESSON NO. 48

AUTOMATIC FREQUENCY CONTROL

The highly selective properties of the superheterodyne receiver make it necessary that this receiver be tuned to absolute resonance with the signal being received. Inaccurate tuning causes the sound, as reproduced by the loud-speaker, to be distorted -- the extent of distortion depending upon how much the receiver is detuned from the point of absolute resonance. Obviously, there is only one way in which to prevent distortion due to this cause, and that is to tune the receiver to exact resonance with the signal being received. And, since the listener cannot be depended upon to do this, engineers have developed a system for accomplishing it automatically by using a principle known as AUTOMATIC FREQUENCY CONTROL, or as it is more commonly referred to, AFC.

Receivers so equipped need not be tuned with the same care as do receivers not so equipped. In fact, AFC compensates for errors made in selecting a desired station manually to such an extent that if the receiver is detuned by as much as 10 kilocycles toward either side of the carrier frequency, the signal will still be received with perfect fidelity. Incorporating AFC into the circuit thus makes it possible

FIG. 1
TO SUCCEED AS A LABORATORY TECHNICIAN REQUIRES THOROUGH TRAINING SUCH AS YOU ARE RECEIVING

to adjust a receiver quickly to within a few degrees of the correct dial-setting for the desired station and yet be assured of perfect tuning despite the fact that the dial-setting does not coincide exactly with the station frequency.

AFC should not be confused with the automatic tuning systems about which you studied in a previous lesson. While AFC does simplify the design of such systems by reducing the tolerance required in the setting of the variable condenser, or the tuning of the substitution tuned circuits, it should be borne in mind that it is a separate system and functions apart and independently of the automatic tuning arrangements previously described.

It is to be understood that automatic frequency control is applied to superheterodyne circuits only, and that its application is quite limited in commercial receivers of this type. The chief reasons why automatic frequency control is not used more extensively in commercial receivers are that it is a costly feature to incorporate in competitive lines of receivers, it is somewhat difficult to adjust, the adjustments are easily disturbed, and the system is rather complex as to the circuits involved. However, even though AFC is not especially popular, it is nevertheless being used on some of the high-priced receivers.

THE BASIC PRINCIPLES OF AFC

The purpose of AFC is to vary the frequency of the receiver's oscillator circuit (over a certain range) so that the frequency-difference or beat between the frequency generated by the receiver oscillator and the signal frequency will always be within a few cycles of the intermediate frequency of the receiver. This will then automatically take care of any improper tuning adjustment, oscillator drift, tracking inaccuracies, etc., and also makes possible more accurate tuning of push-button receivers.

Two distinct circuits make AFC possible -- these two sections of the system are known as the DISCRIMINATOR and the FREQUENCY CONTROL circuits.

PURPOSE OF THE DISCRIMINATOR: The purpose of the discriminator is to convert changes in intermediate frequency, caused by detuning, into voltage variations. That is, if the intermediate frequency resulting from the incoming signal is higher than the i-f to which the receiver is peaked, the discriminator must produce a d-c voltage of a given polarity (usually positive). On the other hand, if the resulting i-f is lower than the intermediate-frequency setting of the receiver, the discriminator must produce a d-c voltage of opposite polarity. The value or magnitude of this voltage, in either direction, is controlled by the extent of detuning.

PURPOSE OF THE FREQUENCY-CONTROL CIRCUIT: The frequency-control circuit alters the frequency to which the receiver's oscillator is tuned, in accordance with the extent of detuning. The frequency-control circuit must therefore be arranged so that voltage variations in one direction, as produced by the discriminator, tend to increase the frequency of the oscillator, while voltage variations in the opposite direction tend to decrease the frequency of the oscillator.

The Discriminator

As we have just mentioned, the purpose of the discriminator is to change any deviations from the resonant i-f into d-c control voltages. In other words, it is required to develop a d-c control voltage of varying magnitude and polarity, in accordance with the degree of detuning; this d-c control voltage is then applied to the oscillator control stage in such a way as to correct any detuning automatically by establishing proper operating conditions.

HOW RECTIFICATION IS OBTAINED

Inasmuch as the discriminator in an AFC system is essentially a rectifier circuit, let us first briefly review the manner in which a d-c voltage may be produced by a simple rectifier which receives its a-c exciting voltage from a tuned circuit. The diode detector of a superheterodyne receiver is typical of such a circuit and is therefore used for illustrative purposes at this time. Such a circuit is illustrated at (A) of Fig. 2, where you will observe that an ordinary i-f transformer is coupled to a diode.

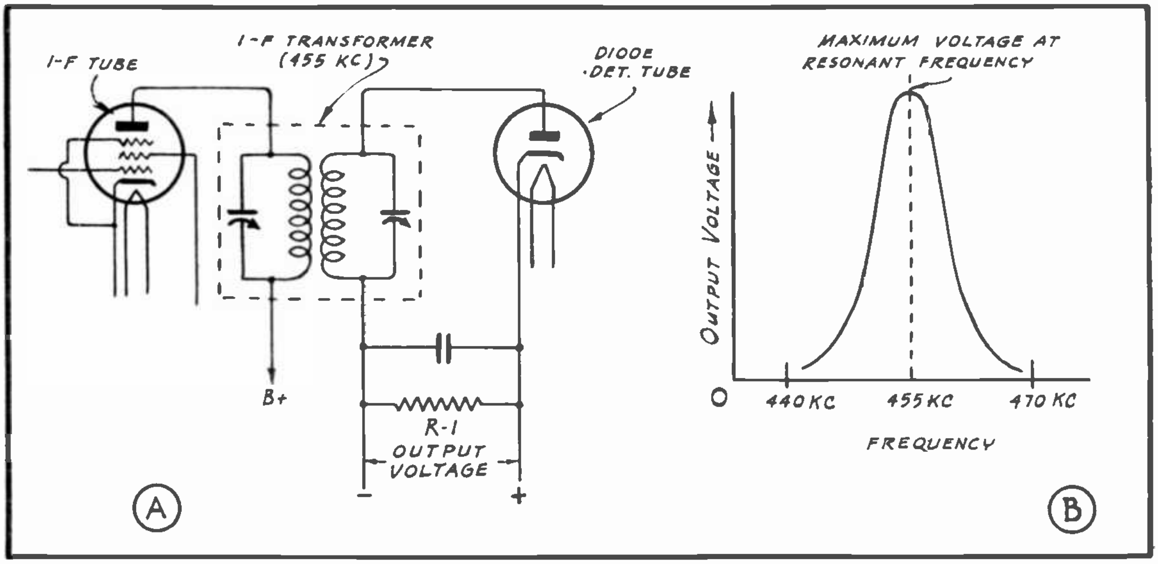

FIG. 2
TUNED RECTIFIER CIRCUIT AND RESULTANT RESONANCE CURVE

In our analogy of this circuit's operation, let us assume that the i-f transformer is tuned to 455 kc, and that the input-frequency is varied from 440 to 470 kc. Because of the selective properties of the i-f transformer's primary and secondary circuits, the rectified d-c output voltage produced across the diode load resistor R-1 will vary as a result of the change in the signal voltage input. The greatest output d-c voltage will be produced when the frequency of the input signal is <u>equal</u> to the frequency to which this transformer is tuned. This transformer is tuned to 455 kc because this is the frequency at which the input voltage to the rectifier is at a maximum.

Now, if the input-frequency (i-f signal) is varied toward either side of 455 kc, the value of the resulting d-c voltage output will decrease. Therefore, if the rectified voltage is plotted against the input frequency, a resonance curve similar to the one shown at (B) of Fig. 2 will be obtained. Observe closely how the d-c voltage decreases rapidly on both sides of the resonant frequency.

As was mentioned earlier in this lesson, we are interested primarily in the polarity and magnitude of this d-c voltage as caused by variations in the input frequency. Referring again to the curve shown at (B) in Fig. 2, you will note that a simple circuit of this type makes no distinction between frequencies which are above or below the resonant frequency. That is, by applying this curve to the circuit shown at (A) of the same illustration, you will find that the polarity of the rectified output voltage remains the same regardless of whether the i-f signal is above, below or at resonance with the frequency to which the i-f amplifier of the receiver has been peaked. Consequently, the circuit arrangement shown at (A) is not suited in its present form for controlling the oscillator frequency in an AFC system.

BASIC DISCRIMINATOR CIRCUIT

The discriminator circuit shown in Fig. 3 was developed to produce rectified voltages whose polarities differ in accordance as to whether the i-f resulting from the incoming signal is above or below the frequency to which the receiver's i-f amplifier has been peaked. This circuit comprises two tuned input (secondary) circuits, one of which is tuned to a frequency above the i-f peak and the other to a frequency below the i-f peak by an equal amount. These two tuned circuits are in effect dual secondary circuits that are coupled to a common primary tuned circuit which is located symmetrically between them, and which is tuned to the same frequency to which the other i-f transformers of the receiver have been peaked.

Let us now see how the introduction of these two tuned secondary circuits provides a means for discriminating between frequencies which are below the i-f resonance peak and those which are above the i-f resonance peak.

CIRCUIT OPERATION AT RESONANCE: The operation of the circuit at this time is illustrated in Fig. 4. First, observe that each diode in

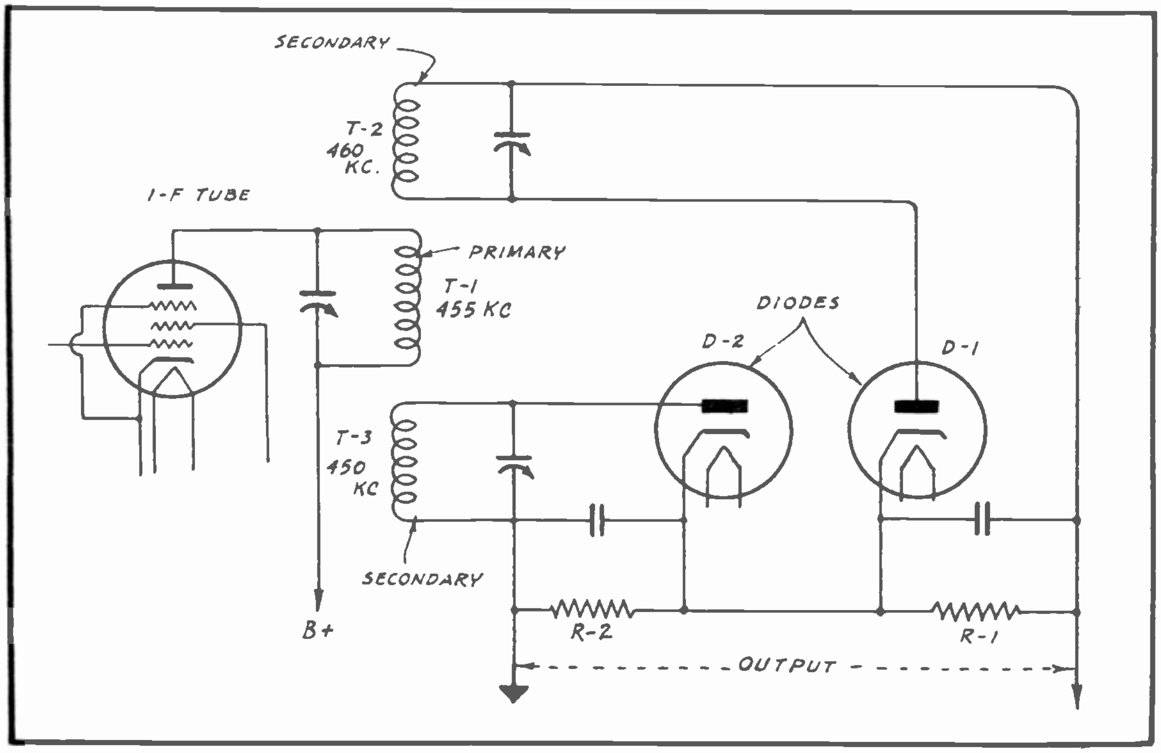

FIG. 3
BASIC "SIDE-FREQUENCY" OR "SIDE-CIRCUIT" DISCRIMINATOR

Fig. 4 has its own input winding and that each diode is therefore independent of the other. In other words, each diode forms a complete but independent rectifying system. Another important fact is that the two diodes are so connected that when a d-c voltage appears across R-1 and another voltage across R-2, as a result of simultaneous rectification, these two d-c voltages are of such polarity as to oppose each other. This will become more apparent when you have studied the following paragraphs.

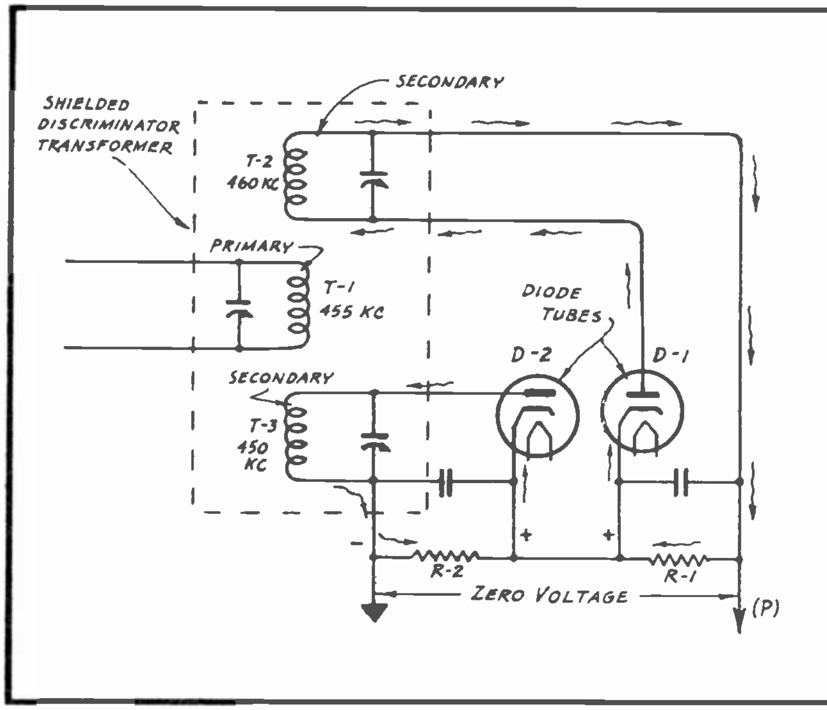

FIG. 4
OPERATION OF THE CIRCUIT AT RESONANCE

When the signal intermediate-frequency is exactly equal to the resonant i-f (455 kc), voltage of equal magnitude will be induced in windings T-2 and T-3 as they are each detuned from the primary winding by an equal amount (5 kc). Therefore, an i-f signal voltage of equal magnitude is also applied to each of the diodes, causing each of the tubes to pass the same value of current and thereby produce equal values of rectified d-c voltage across the cathode load resistors R-1 and R-2. However, these two d-c voltages will oppose each other, causing the net voltage across the complete load circuit to have a value of zero, and point P a potential equal to that of the chassis (ground).

CIRCUIT OPERATION AT FREQUENCIES ABOVE RESONANCE: Now, let us suppose that the receiver is detuned slightly above the point of resonance. At this time, the resulting signal i-f will more nearly approach the value to which winding T-2 is tuned, while at the same time being farther removed from the frequency to which winding T-3 is tuned. Therefore, more voltage will be induced in T-2 than in T-3 and a greater current will flow through diode D-1 than through diode D-2. This, in turn, will cause a greater voltage-drop to appear across R-1 than across R-2, as pointed out in Fig. 5.

Let us assume, for example, that as a result of the variation in the amplitude of signal voltage applied to the two tuned circuits, the d-c voltage across R-1 is 20 volts while that across R-2 is 8 volts as shown in Fig. 5. Because of the opposing polarities, a differential d-c voltage of 12 (20 - 8 = 12) now exists between ground and point P, the latter being 12 volts negative with respect to ground.

CIRCUIT OPERATION AT FREQUENCIES BELOW RESONANCE: When the receiver is detuned below the point of resonance, the resulting signal i-f will approach the frequency to which winding T-3 is tuned, causing a greater

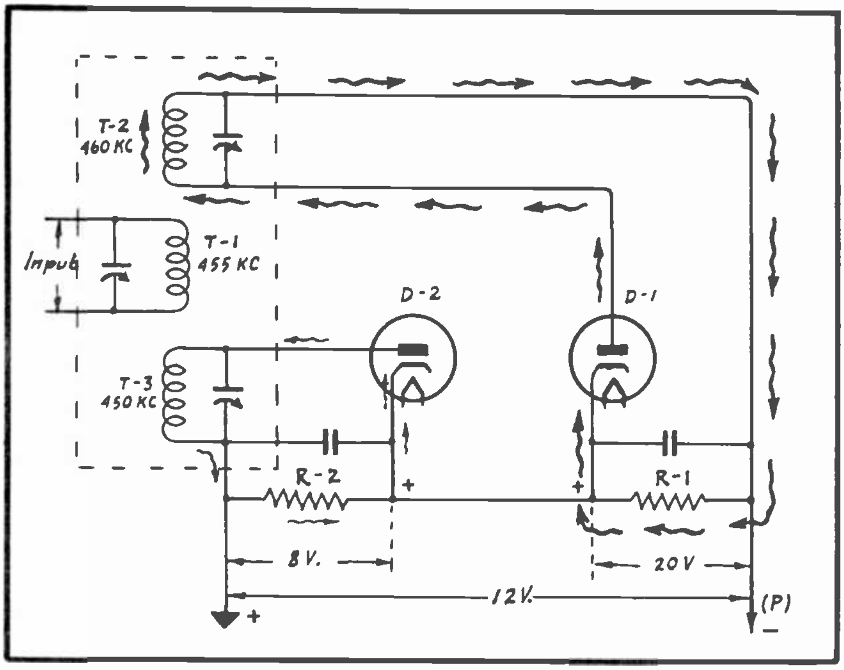

FIG. 5
OPERATION OF THE CIRCUIT AT FREQUENCIES ABOVE RESONANCE

voltage to be induced in this winding than in T-2. This results in a greater current flow through diode D-2 than through diode D-1, and so a greater voltage-drop will appear across R-2 than across R-1, as pictured in Fig. 6.

To better illustrate this point, let us assume that the rectified d-c voltage across R-1 is 8 volts and that across R-2 is 20 volts. Because of the relative values and polarities, the net voltage again is 12 volts, but this time the final voltage at P is positive with respect to ground as shown in Fig. 6. That is, the final voltage now assumes the polarity of the voltage appearing across R-2, because the latter is the greater of the two combined voltages. Thus, we have a means for securing d-c control voltages whose polarity depends upon whether the signal i-f is above or below the frequency to which the receiver's i-f transformers have been peaked. Furthermore, the magnitude of this discriminator's d-c voltage depends upon how far the signal i-f is removed from the i-f to which the receiver is peaked.

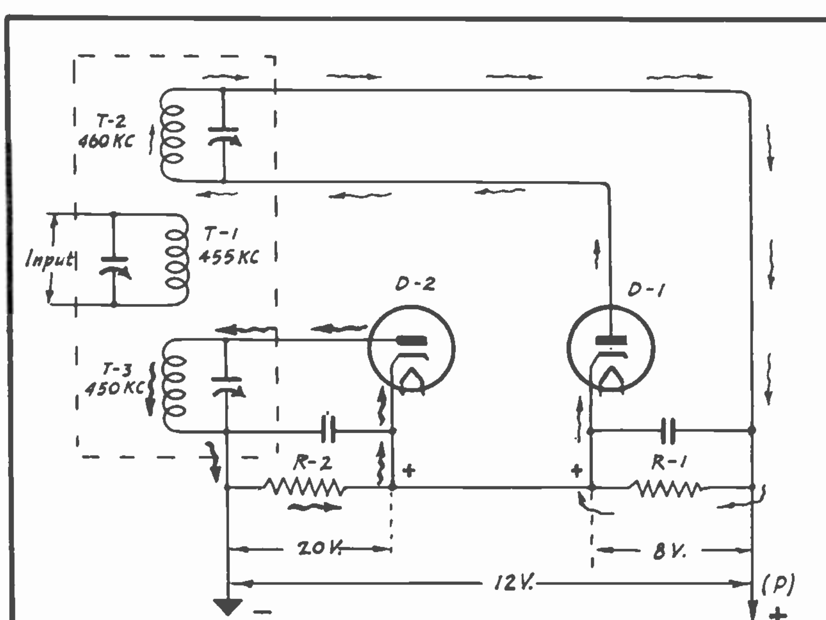

FIG. 6
OPERATION OF THE CIRCUIT AT FREQUENCIES BELOW RESONANCE

HOW CURVES ILLUSTRATE DISCRIMINATOR ACTION

To further analyze the action which takes place in this circuit let us consider a case where the discriminator is coupled to a receiver's i-f amplifier that is peaked at 455 kc, that the upper secondary winding T-2 is tuned to 460 kc, while the lower secondary winding T-3 is tuned to 450 kc. The two secondary circuits are thus tuned respectively 5 kc above and 5 kc below the resonant i-f peak of 455 kc, as pointed out in Figs. 3 to 6.

With this point clearly in mind, let us now turn our attention to the two frequency curves shown at (A) in Fig. 7. These curves represent the frequency response of the two secondary windings, individually. Obviously, the maximum voltage is induced in the upper tuned circuit (T-2) when the signal frequency in the i-f amplifier is 460 kc, whereas the maximum voltage is induced in the lower tuned circuit (T-3) when the signal frequency is 450 kc. The voltage across each secondary circuit falls off on either side of the two resonant frequencies.

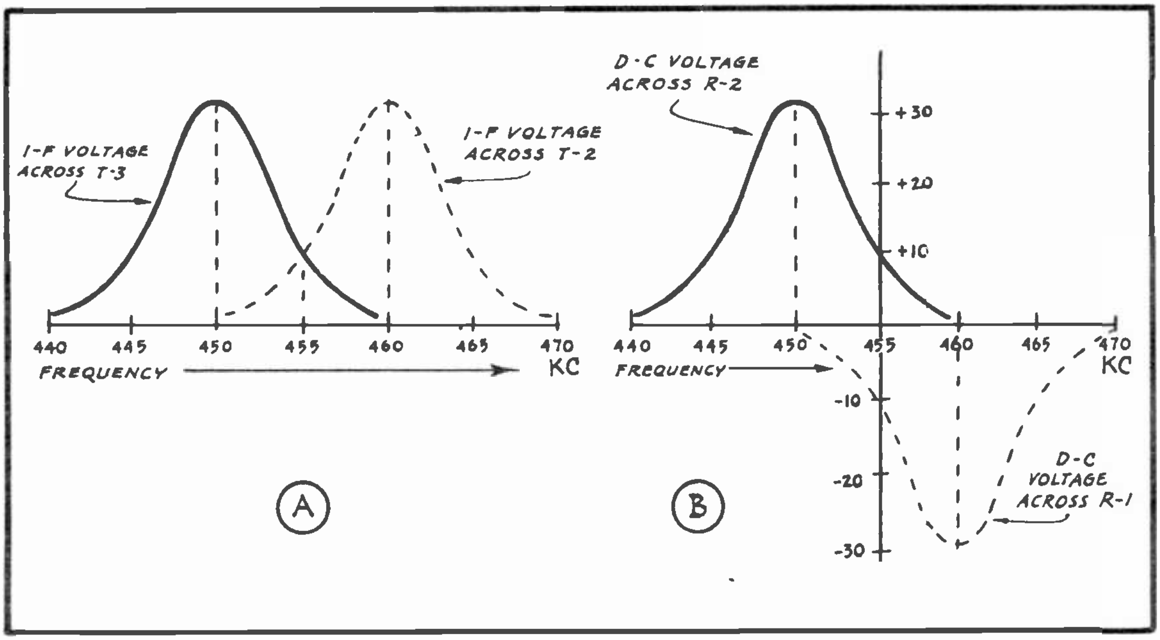

FIG. 7
FREQUENCY-RESPONSE CURVES OF "SIDE-CIRCUIT" DISCRIMINATOR

Continuing our study of these curves, we find that the rectified voltage produced across the diode load resistors, R-1 and R-2, follows the same variations as does the i-f voltage across the two tuned circuits. However, because of the differentially-connected circuit, the voltages are opposite in polarity and, consequently, the net voltage produced at the high end of R-1 (P) with respect to ground, is equal to the arithmetical difference between the voltages appearing across R-1 and R-2, individually.

Because of the fact that the voltages across R-1 and R-2 are opposite in sign, we can represent the individual voltages produced across R-1 and R-2 by the two curves shown at (B) of Fig. 7, where one curve is drawn above the horizontal reference line and the other below it. For any given frequency represented along the horizontal axis, the corresponding d-c voltage produced across R-2 is represented by the solid-line curve, while the d-c voltage developed across R-1 is represented by the dotted-line curve. The former is shown above the axis because the voltage across R-2 is positive, while that across R-1 is negative and is therefore shown below the horizontal axis.

We are interested only in the net voltage of point P with respect to ground, which is also that voltage produced across R-1 and R-2 combined. This voltage can be determined easily by adding algebraically the two individual voltages at any given frequency in graph (B) of Fig. 7. In other words, if we wish to find the voltage between P and ground in the circuits shown in Figs. 3 to 6 inclusive for any one value of input frequency, it is only necessary to combine the voltages which are present across R-1 and R-2 for that particular frequency. This has been done in Fig. 8, resulting in an S-shaped curve which is characteristic of all discriminator circuits.

Notice, also, in Fig. 8 that the combination-curve can be obtained by combining the voltage values of the two curves for any given frequency at (B) of Fig. 7. For example, at the 455 kc point, the voltage values of +10 and -10 result in a net value of zero, which also appears at the 455 kc point in Fig. 8.

EFFECT OF STAGGERED TUNED CIRCUITS

Further analysis of the S-shaped characteristic curve in Fig. 8 will disclose the following facts:

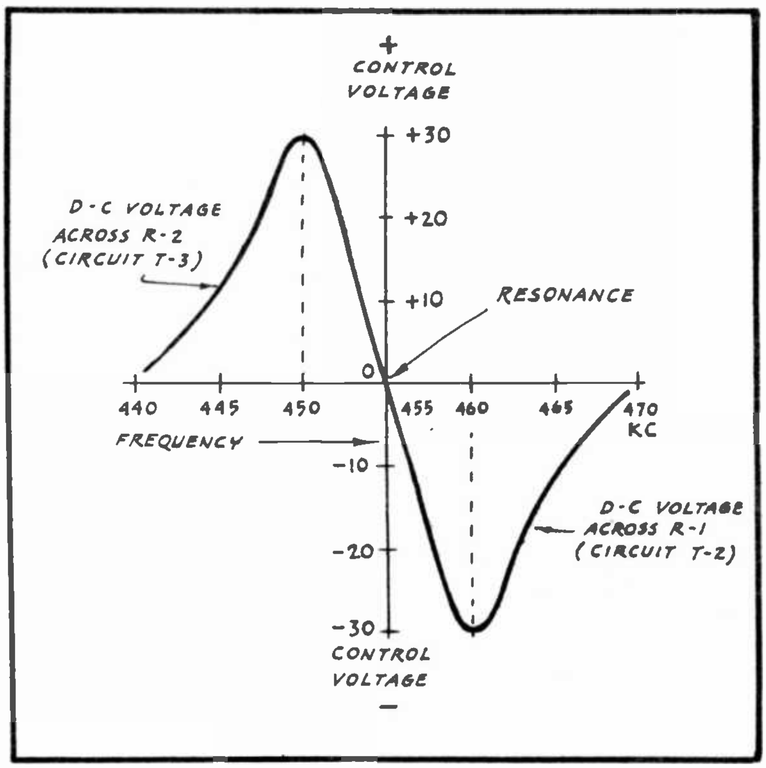

FIG. 8
OUTPUT CONTROL-VOLTAGE AT ONE PARTICULAR FREQUENCY

Should the variable frequency input to circuit T-1 in Fig. 3 extend over a range of from 440 to 470 kc, we find in Fig. 8 that at frequencies between 440 kc and 450 kc, the presence of circuit T-2 has practically no effect on the net voltage appearing across the d-c output terminals of the discriminator because practically no rectified voltage is produced across R-1 at this time. Therefore, this part of the curve in Fig. 8 is essentially the sole member of the complete curve at this time.

However, as the input frequency to T-1 is increased above 450 kc, a voltage begins to appear across R-1, and at the same time, the voltage produced across R-2 begins to decrease, because the applied frequency is moving further away from the resonant frequency of T-3. As a result of this decrease in positive voltage across R-2, and the increase in the negative voltage across R-1, a point is reached midway between the two resonant frequencies of T-2 and T-3 (455 kc) where the voltage across R-1 becomes equal to that across R-2.

Therefore, at a frequency of 455 kc, the net voltage produced across the combined load resistance is zero, as shown in Fig. 8. In other words, at a frequency midway between the two staggered frequencies of the secondary windings, which frequency is also equal to the peaked intermediate frequency of the receiver, the net control voltage of the AFC system's discriminator is zero.

In a similar manner, if we combine the voltages across R-1 and R-2 for frequencies between 455 kc and 470 kc, represented by the curves shown at (B) in Fig. 7, we arrive at the lower half of the S-shaped curve in Fig. 8. You will here note that the variation of the net control voltage is essentially the same on both sides of the correct i-f peak. This is to be expected because the individual resonant curves shown at (A) and (B) of Fig. 7 are quite symmetrical.

In addition to producing a zero control voltage when the receiver is resonated to the signal, we also find that the circuit distinguishes between a signal which comes through the i-f amplifier at a frequency below the i-f peak, and one which comes through the i-f amplifier at a frequency above the i-f peak. As you have learned from studying the curve in Fig. 8, it does this by producing a positive control voltage in the one case, and a negative control voltage in the other case. Furthermore, the magnitude of the control voltage depends upon the extent to which the signal frequency departs from the correct or absolute resonance value. Fig. 8 shows clearly that the greater the degree of detuning -- that is, the greater the deviation of the i-f signal input from the correct value of the i-f resonance peak -- the greater is the amount of control voltage produced.

Because of its simplicity, the discriminator just described is by far the easiest of the discriminator circuits to understand, and therefore serves well to illustrate the basic principles of the system. A clear understanding of this circuit will enable you to understand more easily the operation of the more complex discriminator circuits as used in commercial receivers, which will now be explained.

You will also no doubt be interested to know that the so-called "side-frequency" or "side-circuit" discriminator, just described, is used as a frequency deviation indicator in radio stations to show when the transmitter is not working on its assigned carrier frequency. Indicators such as these will be dealt with later in the course.

PHASE-SHIFTING DISCRIMINATOR

A typical phase-shifting discriminator circuit, as used in practically all modern receivers employing AFC, is shown in Fig. 9. The chief difference between the

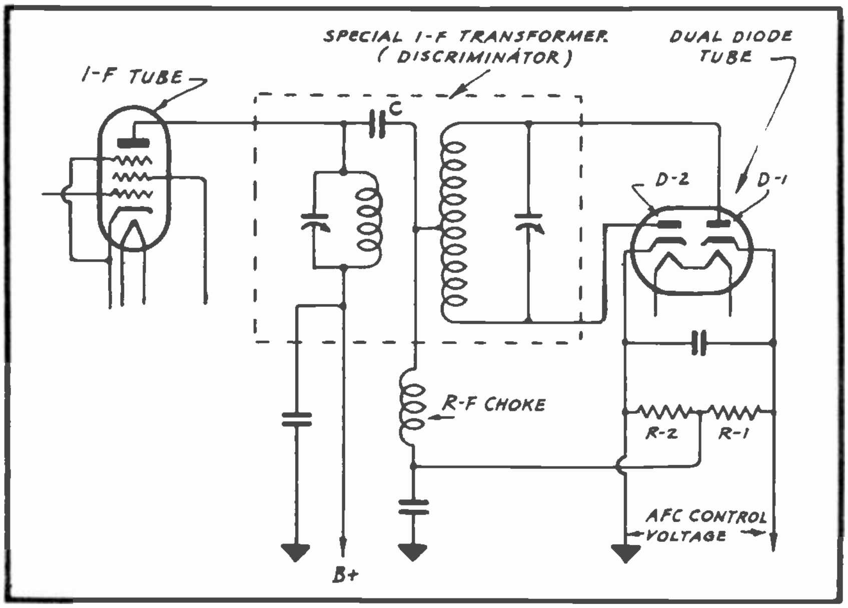

FIG. 9
PHASE-SHIFTING DISCRIMINATOR CIRCUIT

circuit previously shown and that appearing in Fig. 9, is that the latter makes possible the elimination of two tuned circuits in the secondary section of the discriminator's i-f transformer. Instead, a transformer with a center-tapped secondary is used. With the latter exception, this discriminator transformer is similar to the other i-f transformers in the receiver.

You will also observe in Fig. 9 that a dual diode is used and that the plate-end of the primary is coupled to the secondary center-tap by means of condenser C, so that in addition to the usual magnetic coupling between the coils, the primary circuit is also coupled to the center-tap of the secondary coil electrostatically. Thus, coupling between the primary and secondary is accomplished in two ways.

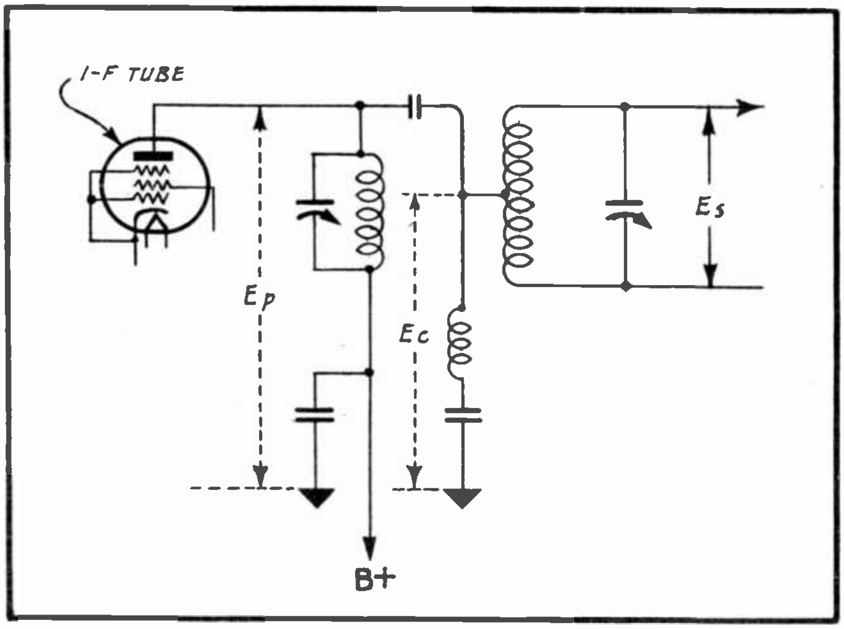

FIG. 10
VOLTAGE TRANSFER THROUGH CAPACITIVE AND INDUCTIVE COUPLING

CIRCUIT ACTION AT RESONANCE: The operation of this circuit depends on the fact that the voltage transmitted through the coupling condenser (E_c in Fig. 10) and the induced secondary voltage, E_s, are 90° out-of-phase at the resonant frequency, and that the phase angle varies as the frequency changes. The choice of the proper circuit constants (inductance, resistance, and capacitive values) establishes this phase relationship.

By referring to Fig. 11 it will be observed that the circuit is arranged so that a resultant voltage ($E_1 + E_c$) is applied to one diode -- this resultant voltage is the vector sum of the voltage E_c that is transmitted through the condenser and one-half of the total secondary voltage produced by induction (E_1). Similarly, a resultant voltage ($E_2 + E_c$) is applied to the other diode -- this is the vector sum of the voltage E_c and the other half of the total induced secondary voltage (E_2).

In Fig. 12 is shown a vector diagram, illustrating the phase relations of the several voltages when the applied voltage is at the resonant frequency. Notice particularly that we have a 90-degree phase relation between the voltage, E_c, and the induced secondary voltages, E_1 and E_2, at this time and that when such is the case the resultant r-f voltages $E_1 + E_c$ and $E_2 + E_c$, as applied to the two diodes of the discriminator tube, are of equal magnitude.

It thus follows that if equal r-f voltages appear between the plate of each diode and ground, equal currents will flow through diodes D-1 and D-2, and equal d-c voltages will therefore appear across the

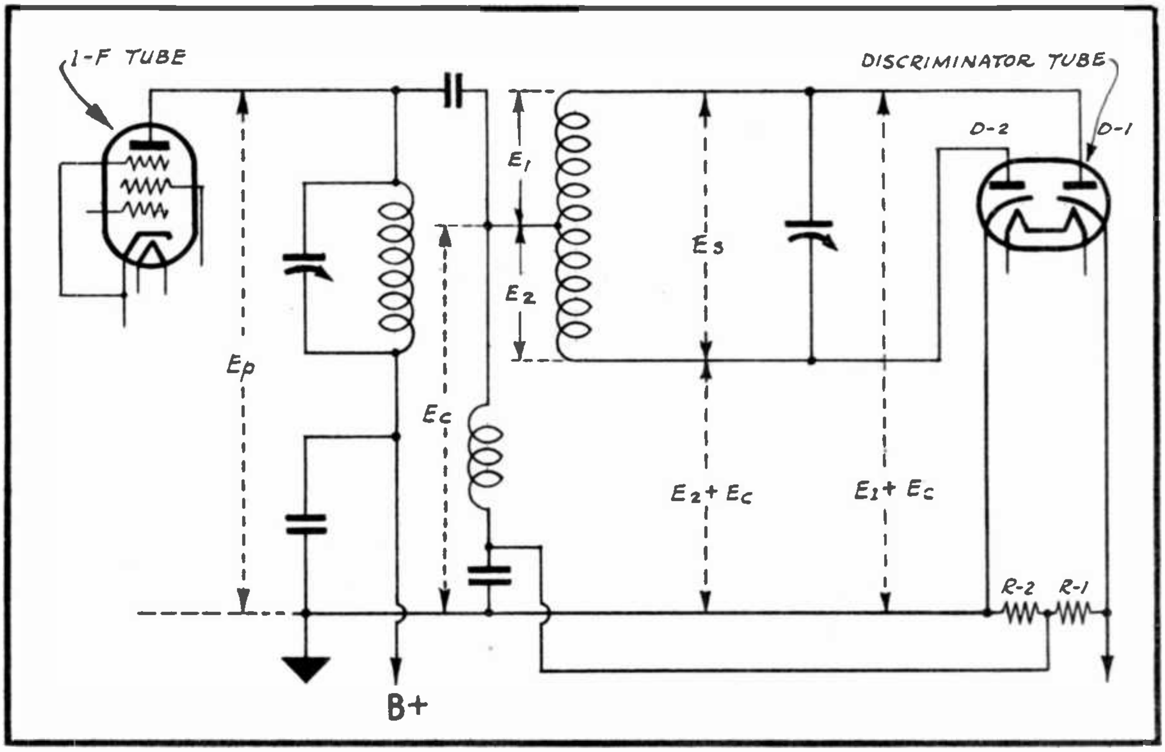

FIG. 11
DISTRIBUTION OF EXCITING VOLTAGE IN PHASE-SHIFTING DISCRIMINATOR CIRCUIT

output load resistors R-1 and R-2 at resonance, as shown in Fig. 13. It is to be noted that points "N" and "P" in Fig. 13 will be positive with respect to the center-tap between the two load resistors. Therefore, the total d-c voltage from point "P" to "N" across the two resistors will be zero, and consequently, no AFC control voltage will be developed when the incoming i-f signal is at the resonance frequency to which the i-f transformer of the AFC discriminator has been peaked.

CIRCUIT ACTION BELOW RESONANCE: We have just seen what occurs during conditions of resonance. Let us now see what occurs when the frequency of the incoming signal is below the resonant point of this discriminator circuit.

Under such a condition, the angle of lag of the inductive circuits decreases while the angle of lead of the capacitive circuits increases,

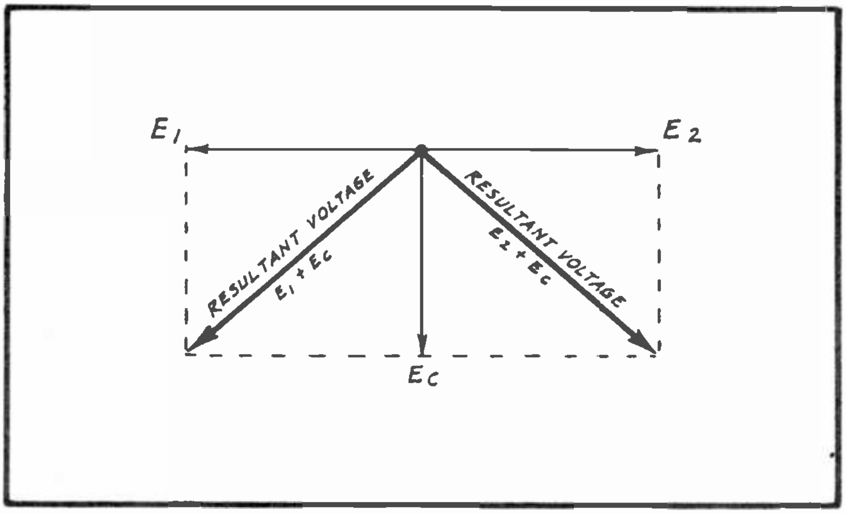

FIG. 12
VECTOR DIAGRAM OF VOLTAGES WHEN APPLIED VOLTAGE IS AT THE RESONANT FREQUENCY

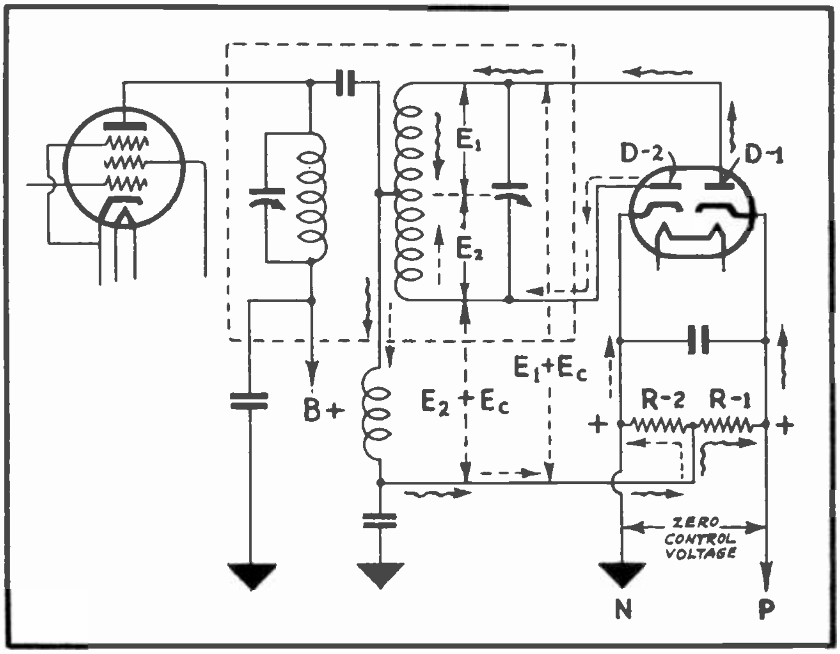

FIG. 13
OPERATION OF THE CIRCUIT AT RESONANCE

the result being a phase angle between the transformer secondary voltages and voltage E_c of other than 90 degrees, as shown by the vector diagram appearing in Fig. 14.

Here it will be observed that while the values of Ec, E_1 and E_2 may still be the same, the phase angle between E_c and the values E_1 and E_2 is such that the resultant voltage value, $E_1 + E_c$, is greater than $E_2 + E_c$. Therefore, a greater r-f voltage will be applied to diode D-1 than to diode D-2 and more current will flow through diode D-1. This results in the rectified d-c voltage appearing across the load resistor R-1 in Fig. 15 being greater than that appearing across resistor R-2. Also, since point "P" will now be positive with respect to the center-tap between the resistors, the resulting d-c voltage appearing across R-1 and R-2 combined will be a positive AFC control voltage.

CIRCUIT ACTION ABOVE RESONANCE: When the intermediate frequency resulting from the incoming signal is higher than the resonant AFC frequency, the angle of lag of the inductive circuits increases while the angle of lead of the capacitive circuits decreases and the phase relation swings to the opposite side of the 90-degree position, as pictured in Fig.16. When this occurs the resultant voltage value $E_2 + E_c$ will be greater than that of $E_1 + E_c$. Therefore, a greater r-f voltage will be applied to diode D-2 than to diode D-1, caus-

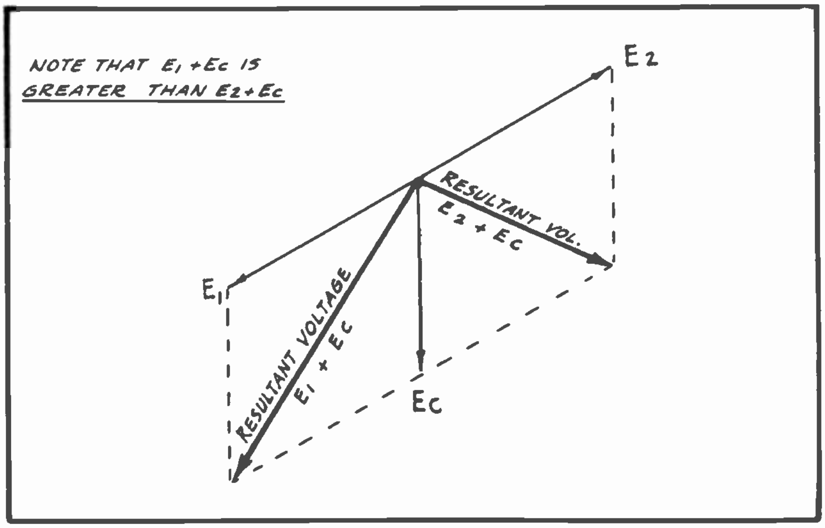

FIG. 14
VECTOR DIAGRAM OF VOLTAGES WHEN APPLIED VOLTAGE IS AT A FREQUENCY BELOW RESONANCE

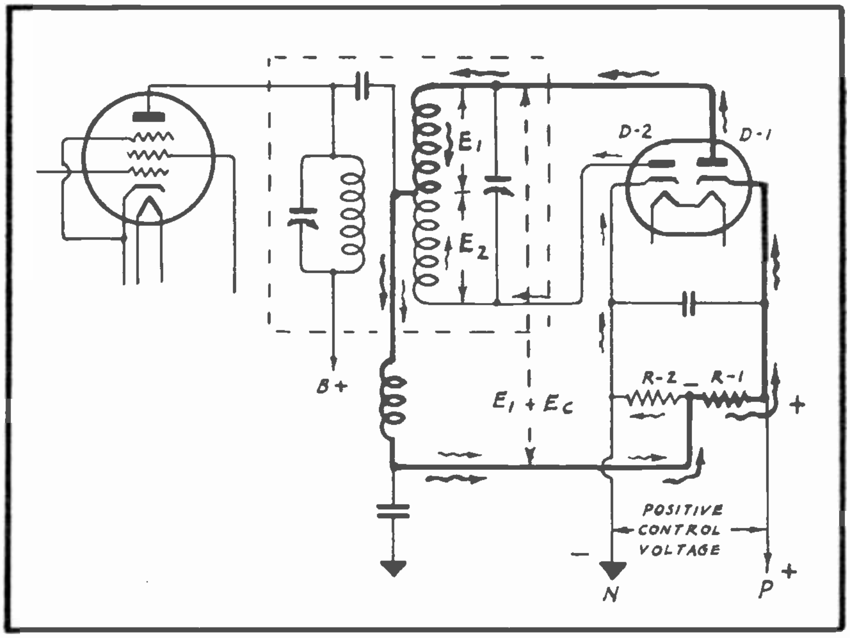

FIG. 15
OPERATION OF THE CIRCUIT AT FREQUENCIES BELOW RESONANCE

ing more current to flow through diode D-2 and thereby developing a greater voltage across diode resistor R-2, than across R-1. (See Fig.17.) Also, since the center-tap connection of the two resistors (R-1 and R-2) will now be negative with respect to ground or "N", this negative voltage will overcome the voltage produced by the diode D-1, resulting in a negative AFC control voltage across points P and N in Fig. 17.

In our discussion, we have considered only three representative cases, namely, when the signal is at the resonant frequency, above the resonant frequency, and below the resonant frequency, and for a standard intermediate frequency. However, for other values of intermediate frequency, the action of the discriminator circuit is basically the same, with the exception that the secondary voltage produced by induction will lag or lead with respect to the voltage Ec transmitted through the coupling condenser by a varying number of degrees in accordance with how far the signal i-f is removed from the frequency to which the discriminator circuit has been peaked.

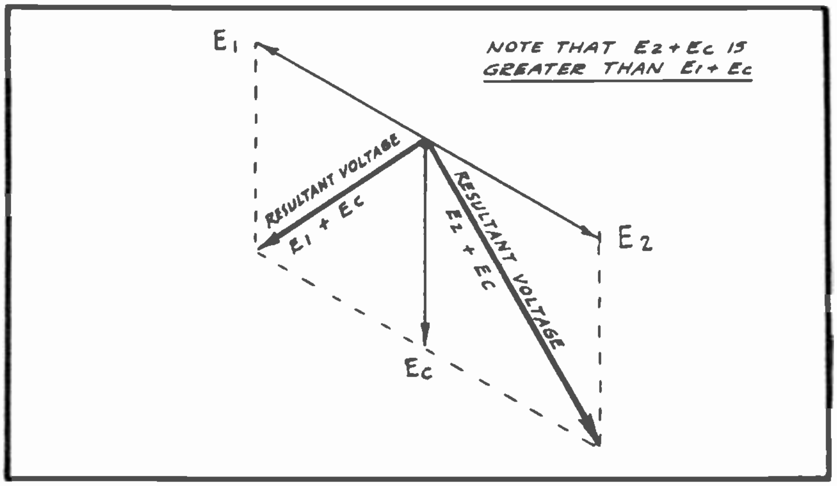

FIG. 16
VECTOR DIAGRAM OF VOLTAGES WHEN APPLIED VOLTAGE IS AT A FREQUENCY ABOVE RESONANCE

IMPORTANCE OF SECONDARY TUNING

From your study of the discriminator circuit just explained, you can readily see that it is the tuning of the secondary circuit which determines the polarity and magnitude of the AFC control voltage developed by the entire discriminator system. The tuning of the transformer's primary circuit is of relative unimportance, in that the phase of the voltages involved is unaffected by the tuning of this winding.

While it is true that the primary winding does not affect the phase of the currents or voltages induced in the balanced rectifier network of the discriminator, it does, however, affect the magnitude of the voltage which is fed to the discriminator. Therefore, improper tuning of the primary winding will reduce the AFC voltage which ultimately reaches the discriminator tube. In other words, the setting of the trimmer condenser across the secondary winding, controls the frequency at which zero voltage is obtained at the output of the discriminator, while the setting of the trimmer across the primary winding determines the amplitude of the voltage peaks, as well as the symmetry of the AFC control voltages.

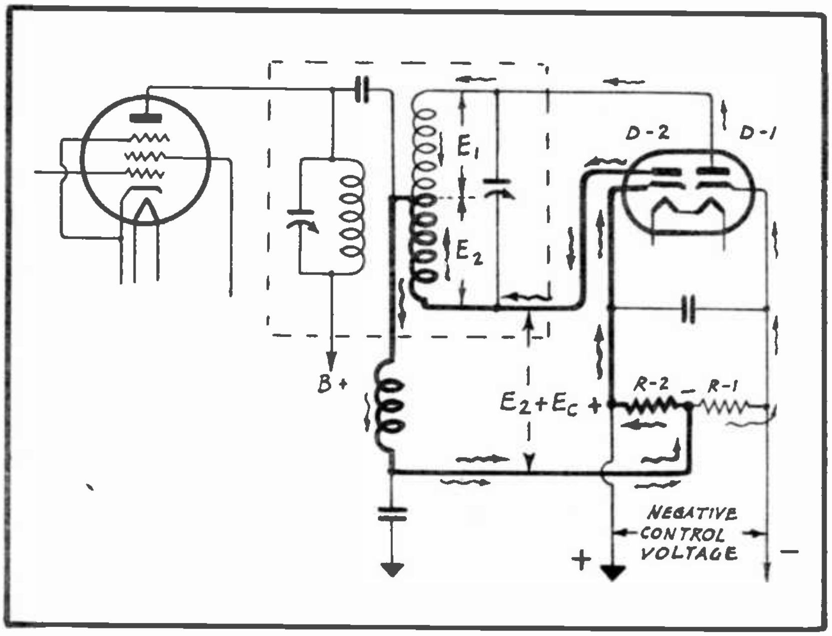

FIG. 17
OPERATION OF THE CIRCUIT AT FREQUENCIES ABOVE RESONANCE

The Frequency-Control Circuit

We have just discussed the discriminator, and learned that this portion of the AFC system produces a d-c voltage which varies in magnitude and polarity in accordance with whether or not the receiver's oscillator is tuned accurately to the signal frequency. This voltage was referred to as the control voltage, or AFC voltage. We are now ready to study the circuit which receives this control voltage and automatically controls the oscillator frequency so as to keep the receiver tuned correctly at all times while receiving a station.

To accomplish this -- that is, to provide some way of either increasing or decreasing the receiver's oscillator frequency without changing the position of the gang tuning condenser -- we connect an imaginary inductance across the oscillator coil in such manner that the value of the imaginary inductance can be made either larger or smaller by means of the discriminator AFC voltage. This imaginary inductance takes the form of a FREQUENCY-CONTROL TUBE, used in the circuit diagrammed in Fig. 18.

HOW THE FREQUENCY-CONTROL TUBE ACTS AS AN INDUCTANCE

In order for the frequency-control tube to act as an imaginary inductance in shunt with the oscillator secondary tuning coil L, in

Fig. 18, it must cause a lagging current to flow through this coil. That is, this current must lag with respect to the oscillator voltage already established across the coil, since this is exactly what would happen if an inductance were connected in shunt with the coil.

In an earlier lesson treating with a-c theory you learned that current in a condenser leads the voltage by 90 degrees, and that the current in an inductance lags behind the voltage by 90 degrees. You also learned that when two inductances are connected in parallel, the resultant inductance is always less than that of the lower of the two inductances.

With these points in mind, let us return to the circuit illustrated in Fig. 18 where the frequency-control tube is shown as being connected across the secondary tuning coil L. In beginning this analogy, we will assume that no a-c excitation voltage is applied to the tube's grid. In this case, the tube would act as a definite resistance or impedance connected in parallel with coil L, and its resistance value in the circuit would depend on its grid-bias voltage. (The more positive the bias voltage, the less will be the resistance value of the tube.) The tube connections being such, it is apparent that it will draw current from coil L, and that this current will be in phase with the oscillator voltage due to the tube acting as a resistance.

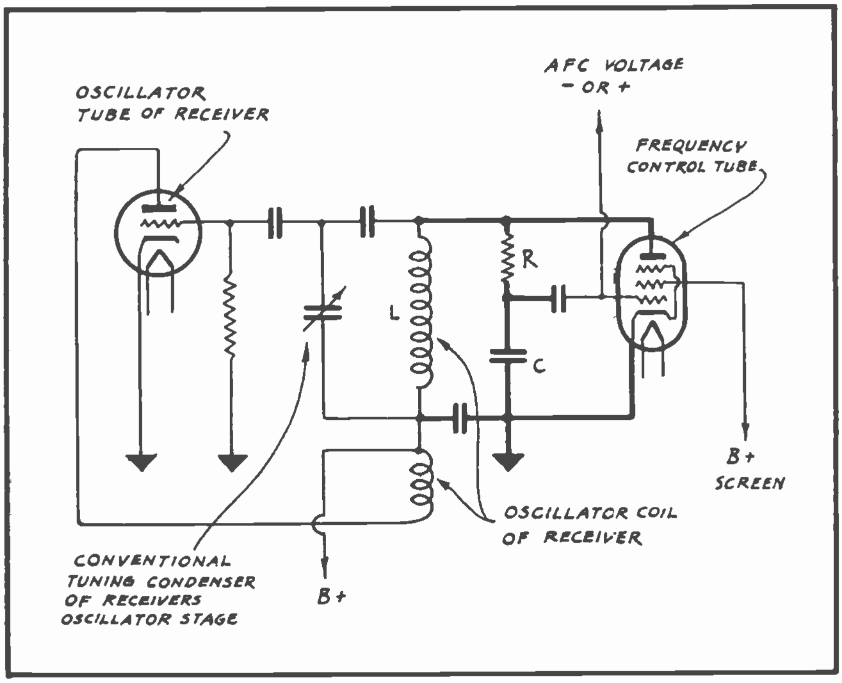

FIG. 18
BASIC FREQUENCY-CONTROL CIRCUIT

Referring to Fig. 18, you will observe that a resistance R and a capacity C are connected in series and are connected together across the oscillator coil L. The values for R and C are so chosen that the resistance of R is greater than the reactance of C, thereby causing this combination to have a power factor of practically 1 (unity). Therefore, this resistor-condenser combination appears to the oscillator coil L and the oscillator voltage source as a pure resistance load, and the current through R and C is therefore nearly in phase with the oscillator voltage. Although the current through condenser C is nearly in phase with the oscillator voltage across coil L, it is also true that the voltage appearing across a condenser lags behind the current flowing through it by 90 degrees. Therefore, the voltage appearing across condenser C is lagging by nearly 90 degrees with respect to the oscillator coil voltage. This voltage appearing across C is applied to the control grid of the frequency-control tube.

With a correct bias voltage applied to the tube, the a-c component of plate current will be in phase with the grid voltage -- that is, peak plate current values will occur simultaneously with peak grid voltage. This means that the plate current will lag with respect to the voltage across coil L by nearly 90 degrees, thereby causing the tube to act in the same manner as though another inductance were connected in parallel with L. The tube can thus be said to function as an "imaginary inductance."

HOW THE CONTROL VOLTAGE AFFECTS THE INDUCTANCE

Since the plate current of the frequency-control tube draws a lagging current with respect to the oscillator voltage appearing across L, and since the plate current can be varied by varying the bias voltage applied to the tube, it follows that the tube's inductive effect upon the oscillator coil L can also be varied by altering the tube's bias voltage. The AFC voltages furnished by the discriminator are used to supply this bias voltage.

Therefore, by employing the discriminator's output voltage to alter the grid bias voltage of the frequency-control tube, the effective inductance value of the receiver's oscillator tuning circuit can be varied also and the frequency of this circuit thus changed accordingly.

Essentially, these are the basic principles underlying automatic frequency control systems. Now that you have a general understanding of the theory involved, you are ready to examine the application of this system as used in a typical commercial receiver.

COMMERCIAL APPLICATION OF AFC

The AFC system used by one well known receiver manufacturer is illustrated in Fig. 19. A close examination of the discriminator circuit will disclose it to be essentially the same as that described in connection with Fig. 9. Of course, the complete diode load circuits appearing in Fig. 19 differ somewhat from those used in circuits previously discussed but this is to be expected because Fig. 19 also includes the a-v-c and audio circuits.

<u>THE DISCRIMINATOR CIRCUIT</u>: One modification of the discriminator network appearing in Fig. 19 is the use of the resistance-capacity filter, comprising the 50,000-ohm resistor (R) and the two .0001 mf condensers in the common lead which joins the input and output circuits of the discriminator tube. The purpose of this filter is to keep the i-f voltages and currents out of the diode load resistor circuit. You will notice that the audio voltages are secured from the junction point of the load resistors R-1 and R-2, which is in the rectified section of the detector circuit wherein the audio component is also present.

From previous instruction given you relative to diode detection, you will realize that a d-c voltage is also available at this point for a-v-c purposes. Therefore, in addition to supplying the AFC and a-f voltages, this discriminator tube is also used to furnish a-v-c voltage. Essentially, the a-v-c and a-f circuits do not affect the AFC action.

There is also another difference between the discriminator load circuit used in Fig. 19 and the basic circuit described previously. Normally, the one end of the discriminator load circuit (N) is returned to ground, as shown in Fig. 9. However, in the circuit diagrammed in Fig. 19, this point is bypassed to ground through a 10-mf condenser and returned to a point on the voltage divider which is three volts negative with respect to ground. This connection is made through

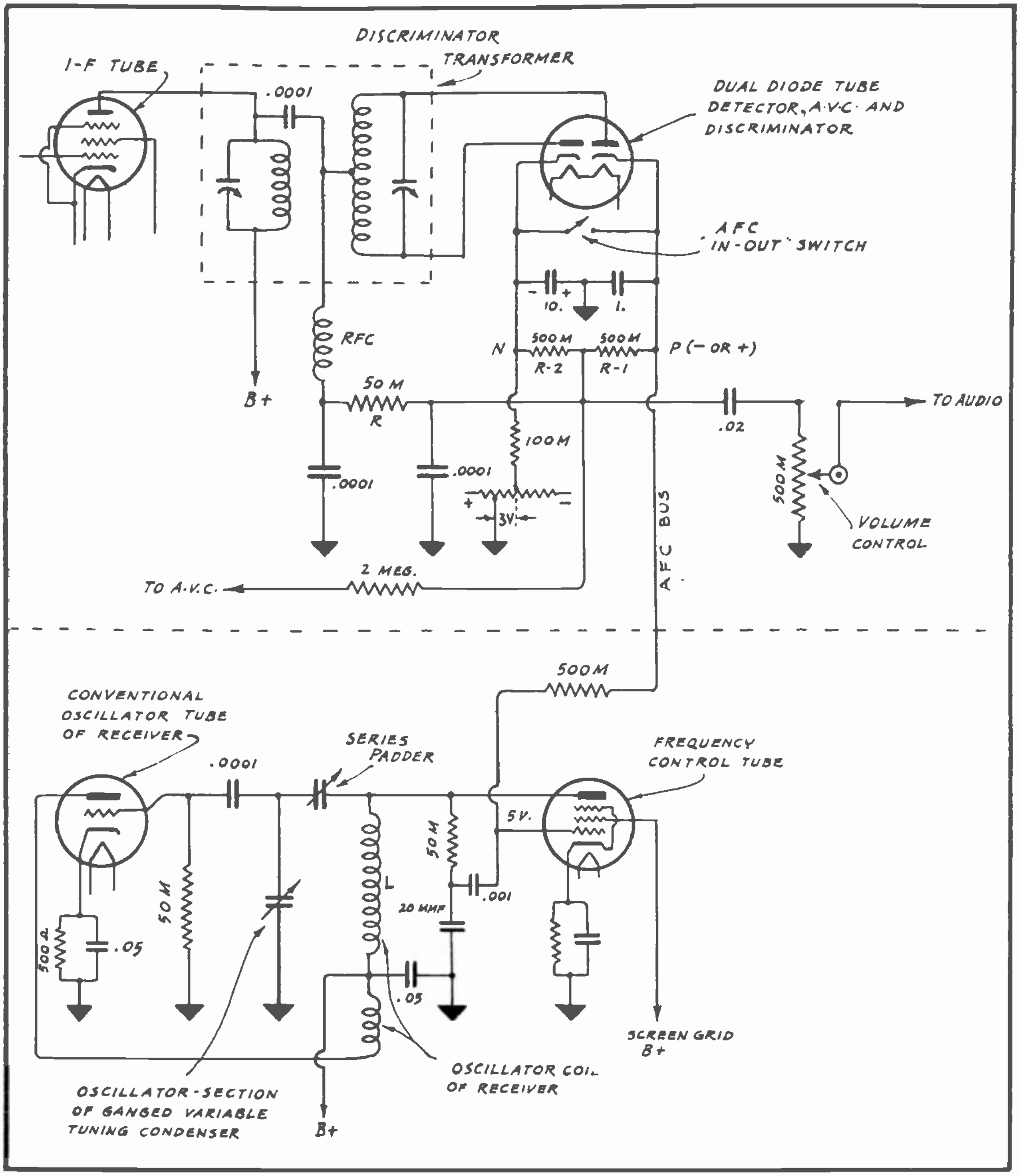

Fig. 19
AFC system as employed in a Typical Commercial Superheterodyne Receiver

a 100,000-ohm filter resistor, which, in conjunction with the 10-mf condenser, acts to prevent any hum or audio voltages from being fed into the discriminator circuit. As a result of this connection, the entire discriminator circuit is placed at a potential of 3 volts below ground. In this way an initial bias is fed to the grids of the tubes which are controlled through the a-v-c bus, so that it is unnecessary to use individual cathode resistors and bypass condensers for each controlled tube. Instead, the cathodes of the controlled tubes are connected directly to ground.

The "hot"side of R-1 (P in Fig.19) is bypassed to ground through a 1-mf condenser. This condenser serves a two-fold purpose: first, it prevents hum and audio voltages from being fed to the oscillator control tube, and in addition, increases the time-constant of the AFC circuit so that the action of the a-v-c system will precede that of the AFC system.

A switch for shorting out the AFC action is incorporated in the circuit. When this switch is closed, the cathodes of the two diodes are joined together, so that essentially, the discriminator circuit becomes a conventional full-wave rectifier circuit. Note that under this condition, the two diode loads are in parallel with each other and that no AFC voltage is generated for this reason. However, the audio and a-v-c voltages are still produced just as they would be in the case of a conventional full-wave rectifier circuit.

THE CONTROL-TUBE CIRCUIT: Let us now turn our attention to the frequency-control circuit appearing in the lower section of Fig. 19. In studying this portion of the AFC system, you will find that the control circuit used in this receiver is similar to that shown in the basic diagram illustrated in Fig. 18. Note, especially, that the phase-shifting network consists of a 50,000-ohm resistor and a 20-mmf condenser. The .001-mf condenser in series with the control grid does not play any part in phase-shifting because of its large value. Its sole purpose is to prevent the d-c plate voltage from reaching the grid of the control tube.

THE COMPLETE CIRCUIT ACTION: Referring again to Fig. 19, let us assume that the receiver is in operation and that its oscillator is generating the correct frequency to produce an i-f signal equal to the resonant intermediate frequency to which the i-f stages of the receiver have been peaked. Under such a condition, there is no need of any further tuning adjustment. At this time, the differential voltage developed across the rectifier output load resistors, R-1 and R-2, is zero and, therefore, there is no effect upon the control tube and oscillator circuit.

However, if the receiver is so tuned that the resulting i-f is lower than the i-f to which the receiver has been adjusted, then end "P" of R-1 becomes positive with respect to ground. This positive potential is applied to the control grid circuit of the frequency-control tube as a positive bias, causing the frequency-control tube to draw more plate current and thereby decrease the effective inductance of oscillator coil L. This in turn causes the oscillator frequency to increase and thereby also increases the abnormally low i-f signal frequency until it equals the i-f frequency to which the receiver has been resonated.

If the receiver is detuned so that the resulting i-f signal is higher than the i-f to which the circuits have been resonated, point "P" becomes negative with respect to ground, which applies a negative bias to the frequency-control tube and causes the latter to draw less plate current. The oscillator coil's effective inductance is therefore increased accordingly and in turn decreases the oscillator frequency until it is correct to produce the intermediate frequency to which the receiver circuits have been resonated.

The action finally stops in either case, with about one volt of differential voltage actually remaining across the load resistors, R-1 and R-2. This action of correcting the frequency is quite rapid, taking place in less than one second of time.

How to Align Receivers that are Equipped with AFC

With the fundamental principles of a typical AFC system well in mind, let us now turn our attention to the alignment of a typical receiver equipped with such a system, in accordance with the theory of operation that we have discussed in this lesson.

First, the i-f transformers of the set should be carefully aligned to the frequency specified by the manufacturer. (It is good practice to permit the receiver to warm up thoroughly before making any adjustments, so as to allow for any probable changes in inductance or capacity values due to thermal expansion.)

A service (test) oscillator should be connected to the first detector or mixer tube,or to the first i-f stage, and tuned to the exact i-f frequency of the set,as determined by the peak indication of an output meter or other indicating device. A vacuum-tube-voltmeter should be connected across the discriminator output control voltage line. That is, from point "P" in Fig. 19 to ground. (Note: The operating principles of vacuum-tube-voltmeters are explained in another lesson.)

The adjusting screw of the trimmer condenser which is connected across the secondary winding of the AFC (discriminator) i-f transformer should then be backed out until the plates of this condenser are nearly open. This is done in order to insure ease of aligning the primary trimmer. (Practically no change would result if the secondary condenser happened to be set for zero discriminator voltage,regardless of the amount of adjusting that was given the primary trimmer. Thus an inaccurate setting would result.)

This done, adjust the primary trimmer condenser for maximum discriminator voltage, either positive or negative. Then adjust the secondary trimmer for exactly zero voltage across the discriminator output. That is, across terminals P and N in Fig. 19, or across the load resistors R-1 and R-2.

The adjustment of the trimmer condenser that is connected across the secondary winding of the discriminator's i-f transformer is critical in most receivers so equipped, and must not be attempted without having available the proper testing equipment. The reason for this is that there are three points at which zero discriminator voltage is obtained; namely, when the trimmer's adjusting screw is turned all the way out; when it is turned all the way in,and at its mid-position. The latter is the correct point for adjustment, as at this point a slight change in adjustment causes a rapid change in discriminator voltage.

After the zero voltage setting is made, the test oscillator frequency should be varied until the maximum positive and maximum negative discriminator voltages are developed, and the vacuum-tube-voltmeter readings noted. These readings should be nearly the same. A wide discrepancy in the readings will indicate misalignment of the primary trimmer. In such case, the primary trimmer should be readjusted slightly until equal readings on the vacuum-tube-voltmeter are obtained. Do not readjust the secondary trimmer to make them equal, since this would cause zero voltage to be developed at some frequency other than the resonant i-f peak, and thus cause the receiver to detune every station signal when the AFC system is functioning.

PERFORMANCE TESTS

The performance of the entire AFC system can be checked as follows: Tune-in a local station with the AFC switch in the "off" position. Then detune the receiver from resonance a definite amount, say

8 kilocycles. Then turn the AFC control switch to the "on" position. The AFC system should now "lock in" and automatically tune the receiver to exact resonance. Repeat the same test with the receiver dial set at 8 kilocycles toward the opposite side of resonance, and notice if the AFC again locks-in and automatically tunes the set to resonance.

The AFC should control tuning an equal amount from either side of resonance, when properly aligned. Also, when tuning the receiver to resonance on a weak signal with the AFC control switch in the "off" position, turning the AFC control to the "on" position should not cause the set to be detuned. If it does, the AFC control adjustments are not properly aligned.

EXAMINATION QUESTIONS

LESSON NO. 48

1. - What is the net voltage across the output or load circuit of the discriminator when the signal intermediate-frequency is exactly equal to the frequency to which the receiver's i-f amplifier has been peaked?

2. - Does the discriminator provide an a-c or d-c control-voltage at its output terminals? Explain.

3. - In a phase-shifting discriminator, is the induced secondary voltage 90° out-of-phase with the voltage transmitted through the coupling condenser <u>at</u> the resonant frequency, <u>below</u> the resonant frequency, or <u>above</u> the resonant frequency?

4. - How does the frequency-control tube in an AFC system act so as to affect the tuning of the receiver's oscillator circuit?

5. - What is the purpose of the discriminator in an AFC system?

6. - How does adjustment of the primary circuit's tuning affect the performance of the discriminator circuit?

7. - How does adjustment of the secondary circuit's tuning affect the performance of the discriminator circuit?

8. - What is the purpose of the frequency-control circuit in an AFC system?

9. - How can you determine whether or not the AFC system in a receiver is operating?

10. - Explain briefly how you would align a receiver that is equipped with AFC.

Practical Technical Training In
RADIO·TELEVISION
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LESSON NO. 49

METERS AS USED IN RADIO

UP TO THIS TIME, ALL OF OUR DISCUSSIONS ON METERS HAVE APPLIED TO THEIR USE RATHER THAN TO THEIR CONSTRUCTION AND OPERATING PRINCIPLES. SO, IN THIS LESSON WE ARE GOING TO CONSIDER METERS, THEMSELVES, IN DETAIL.

THE SIMPLEST WAY TO DEMONSTRATE THE FUNDAMENTAL OPERATING PRINCIPLE OF ELECTRIC METERS IS BY MEANS OF A RATHER CRUDE GALVANOMETER, WHICH CAN EASILY BE BUILT FOR EXPERIMENTAL PURPOSES.

THE SIMPLE GALVANOMETER

THIS HOME-MADE GALVANOMETER IS SHOWN IN FIG. 2, WHERE YOU WILL NOTE THAT SEVERAL TURNS OF SMALL WIRE ARE WRAPPED AROUND A POCKET COMPASS. THE COMPASS NEEDLE HAS A NATURAL TENDENCY TO POINT IN A NORTH-AND-SOUTH DIRECTION, DUE TO THE EFFECT OF THE EARTH'S MAGNETIC LINES OF FORCE UPON IT.

FIG. 1
ACCURATE TESTING IS ESSENTIAL IN RADIO

NOW, SHOULD WE CONNECT THE WINDING OF THIS SIMPLE GALVANOMETER IN SERIES WITH A RHEOSTAT AND A BATTERY AS IN FIG.2, THEN A CERTAIN AMOUNT OF BATTERY CURRENT WILL FLOW THROUGH THE WINDING. THIS FLOW OF CURRENT THROUGH THE WINDING WILL PRODUCE A MAGNETIC FIELD AROUND THE COMPASS, WHICH WILL EXERT ITS INFLUENCE UPON THE NEEDLE IN SUCH A WAY AS TO CAUSE THE NEEDLE TO DEVIATE FROM ITS NORMAL NORTH-AND-SOUTH POSITION. THEN, BY REGULATING THE AMOUNT OF RESISTANCE IN THE CIRCUIT, THE CURRENT FLOW WILL RESPOND ACCORDINGLY AND WILL THUS VARY THE AMOUNT OF MOTION OF THE MAGNETIZED NEEDLE; THAT IS, THE GREATER THE CURRENT FLOW, THE GREATER WILL BE THE DEVIATION OF THE NEEDLE. HENCE, SHOULD THE BATTERY CONNECTIONS NOW

BE REVERSED, SO THAT THE CURRENT WILL FLOW THROUGH THE WINDING IN AN OPPOSITE DIRECTION, THEN THE MAGNETIC LINES OF FORCE SET UP AROUND THE COIL WILL ALSO BE REVERSED, THEREBY CAUSING THE NEEDLE TO SWING IN THE OPPOSITE DIRECTION.

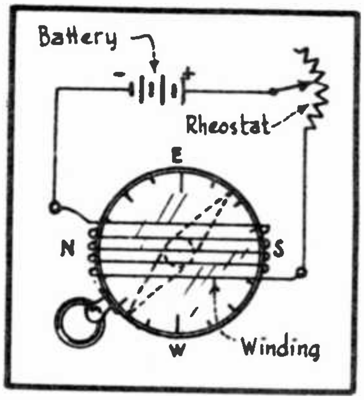

FIG. 2
A Simple Galvanometer.

WHEN WINDING THE COIL FOR SUCH A GALVANOMETER, IT IS ADVISABLE TO WIND THE COIL PARALLEL TO THE MAGNETIZED NEEDLE, WHEN THE NEEDLE IS AT REST AND IN ITS NORMAL POSITION. IN THIS WAY, THE MAGNETIC FIELD, PRODUCED BY THE CURRENT FLOW THROUGH THE WINDING, WILL ACT AT RIGHT ANGLES TO THE EARTH'S MAGNETIC FIELD AND THUS PROVIDE A BETTER POISED INSTRUMENT. THEN TOO, BY INCREASING THE NUMBER OF TURNS ON THE WINDING, THE ARRANGEMENT WILL BE MADE MORE SENSITIVE.

SO YOU SEE, EVEN A SIMPLE GALVANOMETER AS THIS WILL INDICATE THE PRESENCE OF AN ELECTRIC CURRENT AND NOT ONLY THIS, BUT IT WILL ALSO INDICATE THE DIRECTION IN WHICH THE CURRENT IS FLOWING. WITH THIS BASIC PRINCIPLE IN MIND, LET US NOW CONTINUE WITH A STUDY OF METERS, SUCH AS ARE USED IN EVERYDAY RADIO AND ELECTRICAL PRACTICE.

THE "PLUNGER-TYPE" AMMETER

THE INTERNAL CONSTRUCTION OF A "PLUNGER-TYPE" AMMETER IS SHOWN IN FIG. 3. IN THIS CASE, AN INDICATING NEEDLE IS PIVOTED AT ITS UPPER END, SO THAT ITS LOWER END IS FREE TO SWING ACROSS A CALIBRATED DIAL OR SCALE. A SOFT IRON PLUNGER OR ARM IS FASTENED TO THE INDICATING NEEDLE AND ONE END OF THIS PLUNGER IS SURROUNDED BY A COIL OF WIRE, WHOSE DIAMETER IS LARGE ENOUGH TO PERMIT THE PLUNGER TO PASS UP THROUGH THE CENTER OF THE COIL WITHOUT TOUCHING IT.

THE INSTRUMENT IS SO BALANCED THAT THE INDICATING NEEDLE NORMALLY RESTS OVER THE ZERO MARK OF THE SCALE. NOW IF THE METER TERMINALS ARE CONNECTED IN SERIES WITH A CIRCUIT, WHICH IS CARRYING A DIRECT CURRENT, THEN THIS CURRENT WILL FLOW INTO ONE METER TERMINAL, THROUGH THE METER COIL AND THENCE TO THE OTHER METER TERMINAL AND BACK TO THE CIRCUIT. THIS SAME CURRENT, WHILE FLOWING THROUGH THE METER COIL, WILL CAUSE A MAGNETIC FIELD TO BUILD UP AROUND THE COIL, WHICH WILL PULL THE IRON PLUNGER UP INTO THE CENTER OF THE COIL. WE CALL THIS, "SOLENOID ACTION" AND THE METER COIL AND IRON PLUNGER IN THIS CASE CONSTITUTE A SOLENOID.

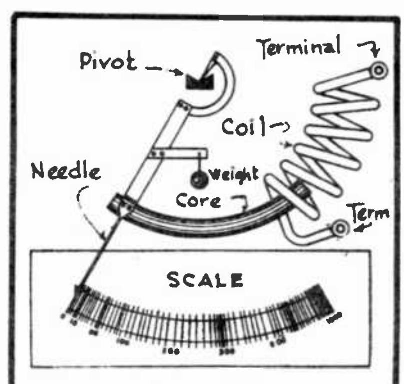

FIG. 3
The "Plunger Type" Ammeter.

SINCE THE PLUNGER IN FIG. 3 IS NOW BEING PULLED TOWARD THE RIGHT, IT PULLS THE PIVOTED NEEDLE WITH IT, THUS CAUSING THE INDICATOR TO SWING ACROSS THE SCALE. THE GREATER THE CURRENT FLOW THROUGH THE METER COIL, THE GREATER WILL BE THE DEFLECTION OF THE INDICATING NEEDLE AND SINCE THE MOVEMENT OF THE NEEDLE VARIES WITH THE CURRENT FLOW, IT IS OBVIOUS THAT

BY PROPERLY CALIBRATING THE SCALE, A MEANS IS PROVIDED WHEREBY THE CURRENT FLOW THROUGH THE METER COIL CAN BE MEASURED.

THE SMALL WEIGHT WHICH IS CONNECTED TO THE INDICATING NEEDLE ACTS AS A COUNTERWEIGHT AND IN THIS WAY AIDS IN CONTROLLING THE ACTION OF THE PLUNGER.

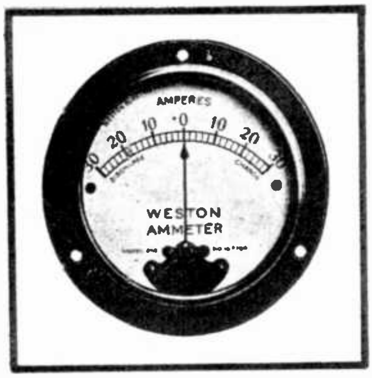

FIG 4
The Magnetic Vane Type Ammeter.

THE "MAGNETIC VANE" TYPE METER

IN FIG. 4, YOU WILL SEE AN AMMETER OF THE "MAGNETIC VANE" TYPE, WHICH IS ALSO KNOWN AS THE "POLARIZED VANE" TYPE. METERS AS THIS ARE QUITE COMMON AND THEY ARE GENERALLY USED FOR PORTABLE PURPOSES, WHERE LABORATORY ACCURACY IS NOT REQUIRED. THIS IS THE SAME TYPE METER, WHICH IS MOUNTED ON THE INSTRUMENT PANEL OF MOST AUTOMOBILES AND IT IS AN INEXPENSIVE TYPE METER.

THE INTERNAL CONSTRUCTION OF THE MAGNETIC VANE TYPE AMMETER IS SHOWN IN FIG. 5. HERE A PIECE OF SOFT IRON (THE VANE) IS MOUNTED ON A PIVOT BETWEEN THE POLES OF A HORSESHOE MAGNET, WHICH IS A PERMANENT MAGNET. THE VANE TENDS TO REST IN A HORIZONTAL POSITION OR TO STAY IN LINE WITH THE POLES OF THE PERMANENT MAGNET, SO AS TO ACT AS A PATH FOR THE LINES OF FORCE GOING FROM THE NORTH POLE OVER TO THE SOUTH POLE. THE NEEDLE AT THIS TIME POINTS TO ZERO ON THE SCALE.

A COIL OF HEAVY COPPER WIRE SURROUNDS THE METER NEEDLE AT A POINT SLIGHTLY ABOVE THE VANE. THIS COIL IS QUITE LARGE IN DIAMETER SO AS NOT TO INTERFERE WITH THE MOTION OF THE NEEDLE. THE METER TERMINALS ARE CONNECTED TO THE ENDS OF THIS COIL AND BY CONNECTING THESE METER TERMINALS IN SERIES WITH A D.C. CIRCUIT, CURRENT WILL FLOW THROUGH THE METER COIL.

LET US ASSUME THAT THE DIRECTION OF CURRENT FLOW THROUGH THE METER COIL IS SUCH AS TO PRODUCE A NORTH POLE AT THE LOWER END OF THE COIL. THIS BEING THE CASE, THE TOTAL NORTH POLE EFFECT WILL THEN BE DIVIDED AND WILL NO LONGER BE STRAIGHT TO THE RIGHT OF THE VANE BUT SLIGHTLY ABOVE IT. THIS SLIGHT UPWARD SHIFT IN THE TOTAL OR EFFECTIVE NORTH POLE WILL CAUSE THE PIVOTED VANE TO TURN COUNTER CLOCKWISE BY A DEFINITE AMOUNT BECAUSE IT ALWAYS TENDS TO ALIGN ITSELF BETWEEN THE NORTH AND SOUTH POLES. THIS CHANGE IN THE VANE'S POSITION WILL CAUSE THE INDICATING NEEDLE TO SWING ACROSS THE DIAL TOWARD THE LEFT OR "DISCHARGE" SIDE OF THE SCALE. THE GREATER THE CURRENT FLOW THROUGH THE COIL, THE GREATER WILL BE THE EFFECT UPON THE MAGNETIC FIELD AND THE GREATER WILL BE THE DEFLECTION OF THE NEEDLE.

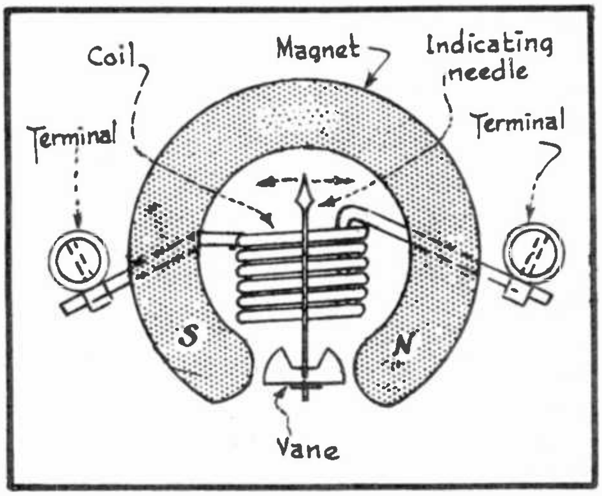

FIG. 5
Contruction of the Vane Type Ammeter.

SHOULD THE CURRENT BE SENT THROUGH THE COIL OF FIG.5 IN THE OPPOSITE DIRECTION, THEN THE LOWER

END OF THE COIL WILL BECOME A SOUTH POLE, THEREBY CAUSING THE TOTAL OR EFFECTIVE SOUTH POLE TO SHIFT SLIGHTLY TOWARD THE UPPER LEFT OF THE VANE AND THIS WILL SWING THE VANE ABOUT ITS PIVOT IN A CLOCKWISE DIRECTION, SO THAT THE METER NEEDLE WILL NOW REGISTER ON THE CHARGE SIDE OF THE SCALE. THIS METER IS ONLY SUITABLE FOR USE WHEN TESTING IN A D.C. CIRCUIT.

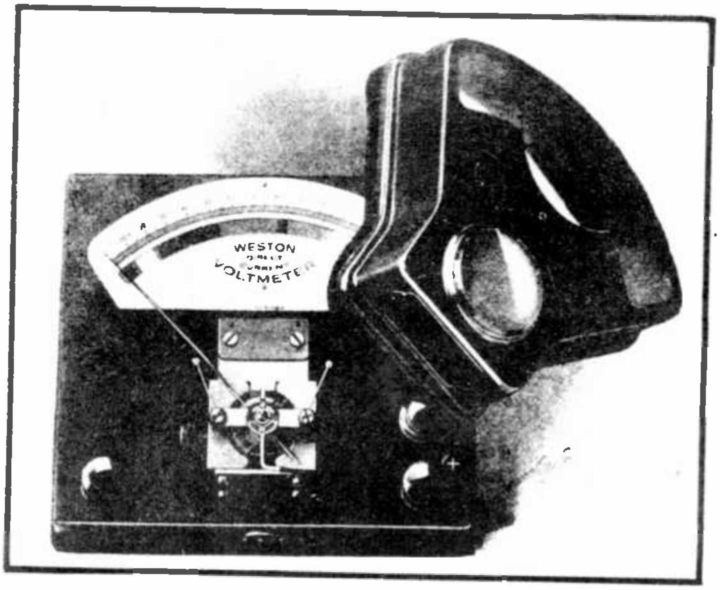

FIG. 6
The Moving Coil Type Meter.

THE "MOVING-COIL" TYPE METER

A MOVING COIL OR D'ARSONVAL TYPE D.C. VOLTMETER IS SHOWN YOU IN FIG. 6, WITH ITS COVER REMOVED, SO THAT YOU MAY CLEARLY SEE ITS INTERNAL WORKING PARTS. METERS OF THE MOVING COIL TYPE ARE THE MOST ACCURATE OF ALL THOSE SHOWN YOU SO FAR AND IT IS THE TYPE USED IN MAKING PRECISE MEASUREMENTS. IN FIG. 7, YOU WILL SEE THE PRINCIPLES OF CONSTRUCTION OF THIS TYPE OF METER. THIS METER IS REALLY NOTHING MORE THAN A SMALL ELECTRIC MOTOR, ONLY THAT ITS ARMATURE IS PREVENTED FROM COMPLETING A FULL REVOLUTION.

NOTICE IN FIG. 7 THAT WE HAVE A PERMANENT MAGNET OF THE HORSESHOE TYPE AND THAT A COIL OF WIRE IS MECHANICALLY SUPPORTED IN JEWELLED BEARINGS SO THAT IT IS FREE TO TURN BETWEEN THE POLE PIECES OF THE MAGNET—THE WINDING ASSEMBLY THUS BECOMING A SMALL MOTOR ARMATURE. THE LOWER END OF THE INDICATING NEEDLE IS FASTENED TO THE ARMATURE AND A LIGHT SPRING AT EACH END OF THE ARMATURE NORMALLY HOLDS THE ARMATURE IN THE POSITION AT WHICH THE NEEDLE POINTS TO ZERO ON THE SCALE. VERY OFTEN, THESE SPRINGS SERVE AS ELECTRICAL CONDUCTORS BETWEEN THE METER TERMINALS AND THE METER COIL.

THE OPERATING PRINCIPLE OF THIS EXTENSIVELY USED METER IS ILLUSTRATED SOMEWHAT CLEARER IN FIGS. 8 AND 9.

IN FIG. 8 THE INSTRU-

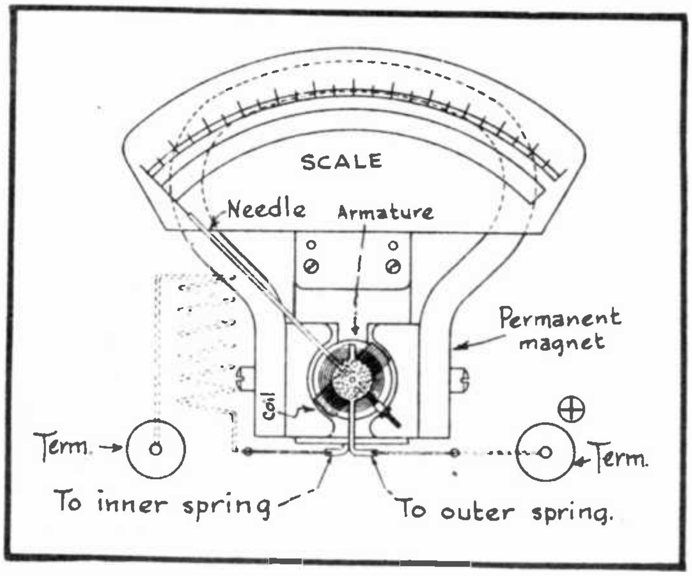

FIG. 7
Construction of the Moving Coil Meter.

MENT IS SHOWN AT REST AND AT WHICH TIME NO CURRENT IS FLOWING THROUGH ITS WINDING. CONDITIONS BEING SUCH, THE MAGNETIC FIELD, AS ESTABLISHED BY THE PERMANENT MAGNET, WILL FLOW HORIZONTALY FROM LEFT TO RIGHT AND THE SPRINGS WILL HOLD THE ARMATURE COIL IN THE POSITION AS HERE ILLUSTRATED, SO THAT THE INDICATING NEEDLE WILL POINT TO THE ZERO MARK OF THE SCALE.

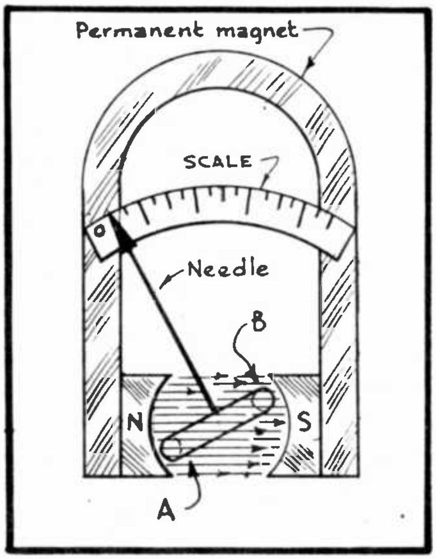

FIG. 8
The Meter at Rest.

NOW THEN, IF THE TERMINALS OF THIS METER ARE CONNECTED TO AN ELECTRICAL CIRCUIT SO THAT CURRENT THEREFROM FLOWS IN ON SIDE "B" OF THE ARMATURE WINDING AND OUT ON SIDE "A" OF THIS SAME WINDING, WE FIND THAT LINES OF FORCE WILL BE ESTABLISHED AROUND THIS WINDING. THESE LINES OF FORCE WILL ENCIRCLE SIDE "A" IN A COUNTER-CLOCKWISE DIRECTION AND SIDE "B" IN A CLOCKWISE DIRECTION.

THESE ENCIRCLING FIELDS WILL REACT WITH THE MAIN MAGNETIC FIELD IN SUCH A MANNER THAT THE LINES OF FORCE OF THE ENCIRCLING FIELD WILL OPPOSE THOSE OF THE MAIN FIELD AT THE REGION BELOW SIDE "B" OF THE ARMATURE, RESULTING IN A WEAKENING OF THE COMBINED FIELD AT THIS POINT. AT THE SAME TIME, WE FIND THAT AT THE UPPER SIDE OF "B", THE ENCIRCLING LINES OF FORCE ACT IN THE SAME DIRECTION WITH THOSE OF THE MAIN FIELD AND THEREFORE CAUSE A STRENGTHENING OF THE COMBINED FIELD AT THIS POINT. THIS IS ILLUSTRATED IN FIG. 9.

IN LIKE MANNER, THE COMBINED FIELD AT THE UPPER REGION OF SIDE "A" IS WEAKENED WHILE THE LOWER REGION OF SIDE "A" IS STRENGTHENED. THERE IS A NATURAL TENDENCY FOR THE WINDING TO BE FORCED FROM THE STRONGER REGIONS OF THE MAGNETIC FIELD INTO THE WEAKER REGIONS AND FOR THIS REASON, THE ARMATURE ROTATES ABOUT ITS AXIS IN A CLOCKWISE DIRECTION AS SHOWN IN FIG. 9.

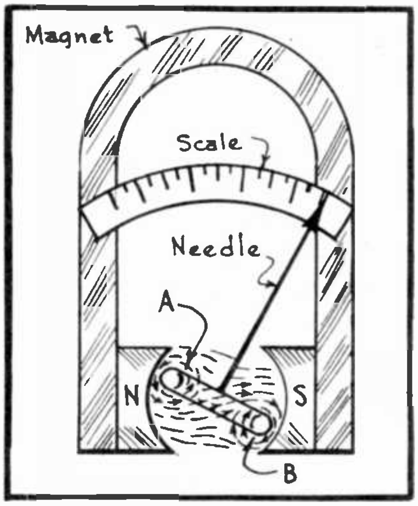

FIG. 9
Full-scale Deflection.

THIS MOTION OF THE METER COIL WILL CAUSE THE INDICATING NEEDLE TO SWING ACROSS THE SCALE TOWARDS THE RIGHT AND THIS NEEDLE DEFLECTION WILL BE PROPORTIONAL TO THE AMOUNT OF MOVEMENT OF THE COIL, WHICH IN TURN DEPENDS UPON THE QUANTITY OF CURRENT FLOWING THROUGH IT OR TO THE VOLTAGE IMPRESSED ACROSS IT. THE INSTANT THAT CURRENT FLOW THROUGH THE COIL IS INTERRUPTED, THE SPRINGS WILL RESTORE THE NEEDLE TO ITS ZERO READING. THIS TYPE OF METER IS ONLY SUITABLE FOR USE ON D.C. CIRCUITS.

THE MOVING COIL, TOGETHER WITH ITS SPRINGS AND INDICATING NEEDLE, ARE SHOWN YOU IN FIG. 10. IN THIS SAME ILLUSTRATION YOU ARE SHOWN ANOTHER POINT OF INTEREST, NAMELY THE USE OF A SOFT IRON CORE WHICH IS CEN-

TRALLY LOCATED BETWEEN THE POLE PIECES OF THE PERMANENT MAGNET AND A-ROUND WHICH THE MOVING COIL OSCILLATES.

THE OBJECT FOR USING THIS IRON CORE IS TO PROVIDE AN EASY PATH FOR THE PERMANENT MAGNET'S LINES OF FORCE BETWEEN THE POLE PIECES AND WHICH AT THE SAME TIME AIDS TO PREVENT LOSS OF MAGNETISM.

WITH THE CORE CENTRALLY LOCATED AS PICTURED AT THE LOWER LEFT OF FIG. 10, ONLY A SMALL AIR GAP IS ALLOWED BETWEEN THE CORE AND THE POLE PIECES AND THROUGH WHICH THE COIL IS FREE TO MOVE WITHOUT TOUCHING EITHER THE CORE OR THE POLE PIECES.

THE DIFFERENCE BETWEEN A VOLTMETER AND AN AMMETER

NO DOUBT, YOU ARE NOW BEGINNING TO WONDER AS TO WHAT THE DIFFERENCE REALLY IS BETWEEN A VOLTMETER AND AN AMMETER. THE OPERATING PRINCIPLES OF BOTH THESE INSTRUMENTS ARE FUNDAMENTALLY THE SAME AND IF YOU ARE FAMILIAR WITH THE OPERATION OF ONE, YOU ARE ALSO FAMILIAR WITH THE OPERATION OF THE OTHER. THE MAIN DIFFERENCE BETWEEN A VOLTMETER AND AN AMMETER IS THAT THE WINDING WITHIN THE AMMETER IS OF LOW RESISTANCE. THAT IS, THE WIRE USED FOR THIS PURPOSE IS LARGE IN SIZE AND CONSISTS OF BUT A FEW TURNS, THEREBY PERMITTING THE PASSAGE OF CONSIDERABLE CURRENT. IN THIS WAY, THE AMMETER OFFERS COMPARATIVELY LOW RESISTANCE TO THE CIRCUIT WITH WHICH IT IS CONNECTED IN SERIES WHILE TAKING A READING.

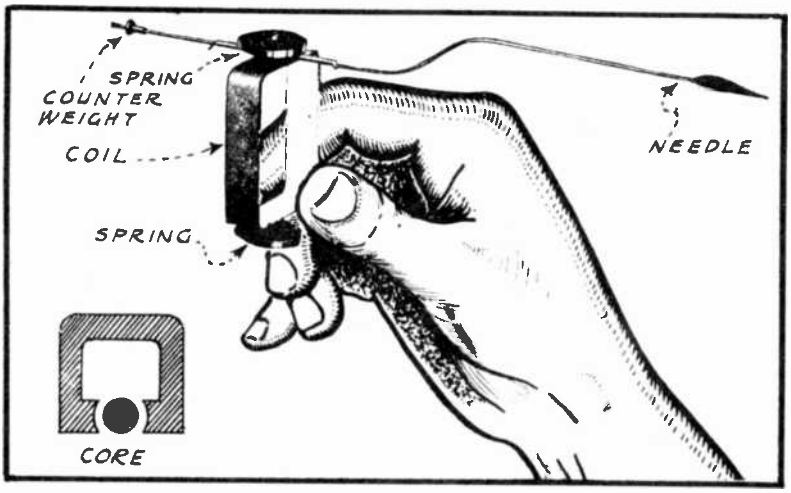

FIG. 10

Constructional Details of the Moving Coil.

THE VOLTMETER, ON THE OTHER HAND, HAS A HIGH INTERNAL RESISTANCE BECAUSE ITS WINDING IS MADE UP OF A GREAT MANY TURNS OF VERY SMALL WIRE. THIS BEING THE CASE, IT IS OBVIOUS THAT WHEN A VOLTMETER IS CONNECTED ACROSS A CIRCUIT FOR MEASURING PURPOSES, IT DRAWS BUT VERY LITTLE CURRENT FROM THE CIRCUIT, IN ORDER TO ACTUATE THE NEEDLE. IN FACT, THE HIGHER THE INTERNAL RESISTANCE OF THE VOLTMETER, THE GREATER WILL BE ITS DEGREE OF ACCURRACY AND HIGH GRADE D.C. VOLTMETERS FOR RADIO PURPOSES GENERALLY HAVE AN INTERNAL RESISTANCE OF ABOUT 1000 OHMS PER VOLT, WHICH MEANS THAT A METER WITH A 250 VOLT SCALE HAS AN INTERNAL RESISTANCE OF 250,000 OHMS.

THE OTHER BIG DIFFERENCE BETWEEN A VOLTMETER AND AN AMMETER IS OF COURSE THE FACT THAT THE SCALE OF THE VOLTMETER HAS BEEN CALIBRATED TO READ VOLTAGE, WHILE THE SCALE OF THE AMMETER HAS BEEN CALIBRATED TO READ THE AMPERAGE.

IT IS NOW THE PRACTICE TO CONSTRUCT THE MOVEMENT OF HIGH GRADE D.C.

VOLTMETERS EXACTLY THE SAME AS USED IN MILLIAMMETERS. THAT IS, THE MOVING COIL IN BOTH CASES ACTUALLY CONTAINS ONLY A FEW OHMS OF RESISTANCE AND IS SO SENSITIVE THAT A CURRENT FLOW OF ONE MILLIAMPERE OR LESS FLOWING THROUGH IT IS SUFFICIENT TO CAUSE THE INDICATING NEEDLE TO SWING ACROSS THE ENTIRE SCALE. THEN TO USE THIS INSTRUMENT AS A VOLTMETER, IT IS ONLY NECESSARY TO ADD SUFFICIENT RESISTANCE IN SERIES WITH THE MOVING COIL SO THAT ONLY A SMALL CURRENT WILL FLOW THROUGH THE COIL EVEN WHEN THE METER TERMINALS ARE CONNECTED ACROSS A SOURCE OF HIGH VOLTAGE. SUCH RESISTANCE UNITS ARE MOUNTED INSIDE OF THE METER CASE.

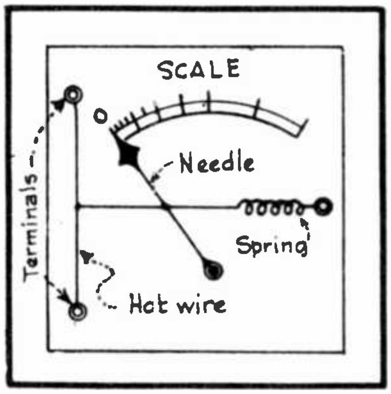

FIG. 11.
Principle of the Hot-wire Ammeter.

IN LIKE MANNER, MANY AMMETERS ARE IN REALLITY MILLIAMMETERS CALIBRATED IN "AMPERES" BUT THE MOVING COIL RECEIVES ONLY A SMALL FRACTION OF THE CURRENT BEING MEASURED. THIS IS ACCOMPLISHED THROUGH BYPASSING A DEFINITE PORTION OF THE TOTAL CURRENT AROUND THE MOVING COIL THROUGH A SHUNT.

ALL OF THESE DETAILS WILL APPEAR CLEARER TO YOU AS YOU CONTINUE WITH THIS LESSON. HOWEVER, BEFORE GOING INTO THIS WORK LET US FIRST STUDY THE HOT-WIRE TYPE METERS.

THE "HOT-WIRE" METER

WHEN DEALING WITH ALTERNATING CURRENTS, WHOSE FREQUENCY IS VERY HIGH, SUCH AS THE ELECTRICAL OSCILLATIONS OCCURRING AT RADIO FREQUENCIES, THEN WE MUST DEPART FROM THE MAGNETIC PRINCIPLES IN METER CONSTRUCTION. THAT IS, FOR TAKING MEASUREMENTS IN HIGH FREQUENCY CIRCUITS, IT IS BETTER TO USE SOME METER OPERATING PRINCIPLE WHICH DOES NOT DEPEND UPON MAGNETIC ACTION TO ACTUATE THE NEEDLE. MOST METERS FOR HIGH FREQUENCY USE THEREFORE DEPEND UPON THE HEATING EFFECT OF AN ELECTRIC CURRENT FLOWING THROUGH A CONDUCTOR AND WE GENERALLY CLASSIFY METERS AS THIS AS BEING OF THE "THERMO" TYPE.

IN FIG. 11 YOU ARE SHOWN THE BASIC CONSTRUCTIONAL FEATURES OF AN AMMETER, WHICH CAN BE USED FOR TAKING MEASUREMENTS IN CIRCUITS OPERATING AT RADIO FREQUENCIES. THE METER HERE SHOWN CAN ALSO BE CLASSIFIED AS A "HOT WIRE" AMMETER. IN THIS CASE, A SPECIAL WIRE, WHICH IS MADE OF NON-OXIDIZABLE METAL, HAVING A LOW TEMPERATURE COEFFICIENT, IS CONNECTED ACROSS THE TWO METER TERMINALS INSIDE OF THE METER BODY. THE TENSION OF THIS HEATING WIRE AND THE TENSION OF THE SPRING ARE SO BALANCED WITH EACHOTHER THAT THE METER NEEDLE NORMALLY LINES UP WITH THE ZERO MARK ON THE SCALE.

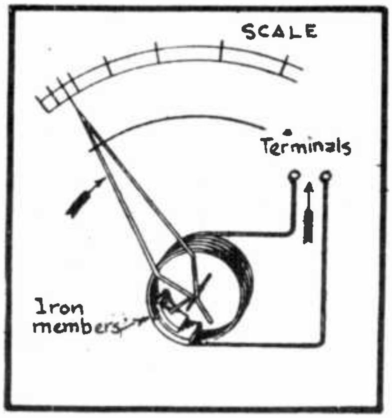

FIG.12
The A.C. Voltmeter.

NOW IF THE TERMINALS OF THIS AMMETER ARE PROPERLY CONNECTED INTO A CIRCUIT CARRYING HIGH FREQUENCY CURRENTS, THE HEATING WIRE WILL BE CONNECTED IN SERIES WITH THIS CIRCUIT, SO THAT ALL OF THESE HIGH FREQUENCY CURRENTS MUST FLOW THRU

IT. IT IS A WELL KNOWN FACT THAT CURRENT FLOW THROUGH A CONDUCTOR PRODUCES HEAT AND THIS HEATING EFFECT IS PROPORTIONAL TO THE SQUARE OF THE CURRENT AND TO THE RESISTANCE OFFERED BY THE CONDUCTOR.

THE HEAT PRODUCED BY THE FLOW OF THE HIGH FREQUENCY CURRENTS THRU THE HEATING WIRE, CAUSES THE WIRE TO EXPAND OR BECOME LONGER AND IN DOING SO, ADDITIONAL SLACK IS INTRODUCED INTO IT AND THIS WILL PERMIT THE SPRING TO PULL THE INDICATING NEEDLE TOWARD THE RIGHT, THUS INDICATING THIS CURRENT FLOW ON A PROPERLY CALIBRATED SCALE. THIS DEFLECTION OF THE NEEDLE WILL INCREASE WITH AN INCREASE IN CURRENT FLOW, DUE TO THE ADDITIONAL SLACK, WHICH IS INTRODUCED INTO THE HEATING WIRE.

MOVABLE-IRON A.C. METERS

FOR TAKING MEASUREMENTS IN RADIO CIRCUITS THROUGH WHICH ALTERNATING CURRENTS OF A 50 OR 60 CYCLE FREQUENCY FLOW, THE MOVABLE-IRON TYPE METER IS BEING MOST USED. THE INTERNAL CONSTRUCTION OF SUCH A METER IS ILLUSTRATED IN FIG. 12.

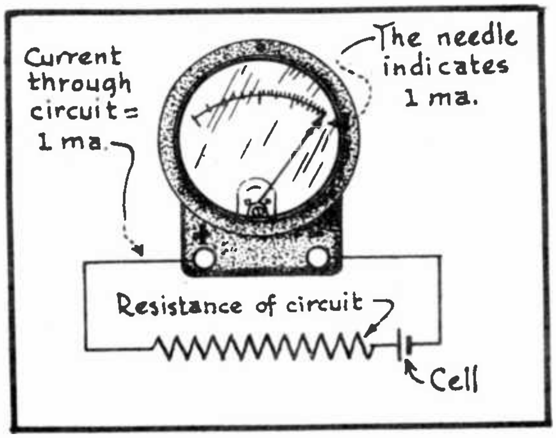

FIG. 13
Milliammeter Reading "Full-scale".

AS YOU WILL OBSERVE, A COIL OF INSULATED WIRE IS LOCATED WITHIN THE HOUSING OF THIS INSTRUMENT AND THE ENDS OF THIS COIL ARE CONNECTED TO THE TERMINALS OF THE METER.

THE INDICATING NEEDLE IS FASTENED TO A SHAFT OR AXIS WHICH IS SUPPORTED IN SAPHIRE JEWEL BEARINGS. A SMALL CURVED PIECE OF IRON, (THE ARMATURE) IS ALSO FASTENED TO THE CENTER SHAFT THROUGH AN ARM AND THIS ARMATURE RESTS DIRECTLY IN FRONT OF ANOTHER SIMILARLY SHAPED PIECE OF IRON WHICH IS ATTACHED TO THE COIL AND WHICH REMAINS STATIONARY.

UPON PASSING CURRENT THROUGH THE COIL, THE TWO PIECES OF IRON BECOME MAGNETIZED, BUT SINCE BOTH PIECES OF IRON ARE LOCATED ON THE SAME SIDE OF THE COIL, THEY WILL HAVE THE SAME POLARITY. THIS MEANS THAT THERE WILL BE A REPELLING FORCE BETWEEN THEM BECAUSE LIKE MAGNETIC POLES REPEL.

THE COIL AND ITS IRON MEMBER ARE FIXED AND THEREFORE THE ARMATURE WILL BE REPELLED AND THEREBY CAUSE THE INDICATING NEEDLE TO ROTATE CLOCKWISE ON ITS AXIS AND THUS SWING THE INDICATING NEEDLE TOWARDS THE RIGHT ACROSS ITS SCALE. AS SOON AS THE CURRENT FLOW STOPS, A SPRING RETURNS THE MOVEMENT TO ITS NORMAL POSITION SO THAT THE NEEDLE COINCIDES WITH THE ZERO MARK OF THE SCALE.

IT REQUIRES BUT LITTLE CURRENT TO OPERATE THIS MECHANISM AND FOR MEASURING HIGHER VOLTAGES IT IS THE PRACTICE TO INCLUDE A RESISTOR IN SERIES WITH THE METER WINDING IN ORDER TO LIMIT THE CURRENT FLOW.

A SMALL AND VERY LIGHT VANE IS ALSO ATTACHED TO THE MOVING PART OF THE INSTRUMENT. THIS VANE MOVES BACK AND FORTH IN A SEALED AIR CHAMBER WHENEVER THE INDICATOR MOVES AND IN THIS WAY OFFERS A CERTAIN AMOUNT OF

RESISTANCE OR DAMPING EFFECT TOWARDS THE MOVEMENT. THIS PERMITS THE NEEDLE TO COME TO A STATIONARY POSITION IMMEDIATELY AFTER ITS INITIAL DEFLECTION.

THIS MOVING-IRON PRINCIPLE CAN BE APPLIED TO EITHER AN AMMETER OR VOLTMETER OF THE A.C. TYPE.

STILL OTHER TYPES OF METERS ARE AVAILABLE TO THE ELECTRICAL INDUSTRY BUT THOSE SHOWN YOU WILL FAMILIARIZE YOU WITH THE OPERATING PRINCIPLES OF THE MOST POPULAR TYPES OF METERS, SUCH AS YOU ARE CALLED UPON TO USE IN YOUR RADIO WORK. THE NEXT STEP THEN, WILL BE TO SHOW YOU THE MANY DIFFERENT WAYS IN WHICH YOU CAN USE METERS. OF COURSE, YOU HAVE BEEN SHOWN TIME AFTER TIME HOW TO CONNECT AMMETERS IN SERIES WITH THE CIRCUIT UNDER TEST AND VOLTMETERS ACROSS THE CIRCUIT UNDER TEST. WE ARE THEREFORE TAKING IT FOR GRANTED THAT YOU HAVE A PERFECT UNDERSTANDING OF THIS SUBJECT AND FOR THIS REASON WILL NOT SPEND THE PRESENT TIME IN REVIEWING PREVIOUS SUBJECT MATTER. IF, HOWEVER, YOU HAVE FORGOTTEN SOME OF THESE IMPORTANT POINTS, IT IS MOST ADVISABLE THAT YOU GLANCE OVER THE EARLIER LESSONS REGARDING METER CONNECTIONS, BEFORE CONTINUING WITH THE STUDY TO FOLLOW.

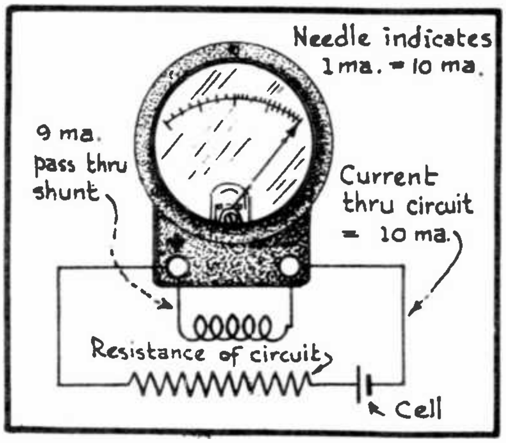

FIG. 14
Measuring 10 Ma. With a Meter of only 1 Ma. Range.

CONDITIONS FREQUENTLY ARISE WHERE THE RADIO EXPERT FINDS IT NECESSARY TO CHANGE THE SCALE OF HIS VOLTMETERS AND AMMETERS, THEREBY MAKING THEM SUITABLE FOR TESTS ON VARIOUS DIFFERENT CIRCUITS. BY PROPERLY ARRANGING THINGS, IT IS POSSIBLE TO USE A SINGLE METER AS A UNIVERSAL METER, THEREBY DOING AWAY WITH THE NEED FOR A WHOLE STRING OF EXPENSIVE METERS.

THE USE OF AMMETER SHUNTS

IN FIG. 13, FOR EXAMPLE, WE HAVE A MILLIAMMETER, WITH A FULL SCALE READING OF 1 MILLIAMPERE, CONNECTED IN A CIRCUIT IN WHICH JUST EXACTLY 1 MILLIAMPERE IS FLOWING. UNDER THESE CONDITIONS, IT IS OBVIOUS THAT 1 MILLIAMPERE WILL FLOW THROUGH THE METER WINDING BECAUSE IT IS CONNECTED IN SERIES WITH THE CIRCUIT AND SINCE THE METER HAS ORIGINALLY BEEN CALIBRATED BY THE MANUFACTURER TO READ 1 MILLIAMPERE WHEN 1 MILLIAMPERE IS FLOWING THROUGH ITS COIL, WE WILL FIND THE METER READING FULL SCALE AT THIS TIME. THAT IS, THE NEEDLE IS AT ITS MAXIMUM POSITION, READING 1 MILLIAMPERE.

SHOULD WE WISH TO USE THIS SAME METER TO MEASURE THE CURRENT FLOW THROUGH A CIRCUIT, WHICH WE KNOW BEFORE-HAND AS CARRYING MORE THAN 1 MILLIAMPERE, THEN WE MUST USE A SHUNT WITH THE METER. IN FIG. 14, FOR EXAMPLE WE HAVE A CIRCUIT, THROUGH WHICH 10 MA. ARE FLOWING, AND IF WE SHOULD SIMPLY CONNECT THE ORIGINAL METER IN SERIES WITH THIS CIRCUIT, THE METER WOULD BE INJURED BECAUSE ITS MAXIMUM RANGE IS ONLY ONE-TENTH OF THAT REQUIRED FOR THIS CIRCUIT.

IT IS, HOWEVER, POSSIBLE TO USE THIS SAME METER IN THE CIRCUIT OF

FIG. 14, PROVIDED THAT WE ONLY PERMIT 1 MILLIAMPERE TO FLOW THROUGH THE METER COIL AND BY-PASS THE BALANCE AROUND THE METER BY MEANS OF A SUITABLE SHUNT. IF 10 MA. ARE FLOWING THROUGH THE CIRCUIT OF FIG. 14 AND WE ARE ONLY ALLOWED TO PASS ONE MA. THROUGH THE METER COIL, THEN IT IS APPARENT THAT 9 MA. MUST BE PASSED BY THE METER SHUNT. THE QUESTION NOW ARISES AS TO THE RESISTANCE VALUE OF THE SHUNT, WHICH SHOULD BE USED IN THIS CASE.

LET US ASSUME THAT THIS METER HAS AN INTERNAL RESISTANCE OF 27 OHMS. SINCE THE SAME POTENTIAL EXISTS ACROSS THE METER AND SHUNT AND THE SHUNT HAS TO CARRY 9 TIMES AS MUCH CURRENT AS THE METER, THEN IT IS PERFECTLY LOGICAL THAT THE RESISTANCE VALUE OF THE SHUNT MUST BE JUST 1/9 OF THE METER'S INTERNAL RESISTANCE OR 3 OHMS (1/9 X 27 OHMS = 3 OHMS).

BY CONNECTING A SHUNT OF THIS SIZE ACROSS THE METER TERMINALS, THE RANGE OF THE METER HAS BEEN INCREASED TO 10 TIMES ITS FORMER VALUE AND THE NEEDLE WILL REGISTER 1 MILLIAMPERE WHEN THERE ARE ACTUALLY 10 MILLIAMPERES FLOWING THROUGH THE CIRCUIT. THIS MEANS THAT ALL THAT IS NECESSARY IS TO MULTIPLY THE METER READING BY 10, IN ORDER TO DETERMINE THE CORRECT VALUE. THAT IS, IF THE METER NOW READS .5 MILLIAMPERES, THERE ARE ACTUALLY 5 MILLIAMPERES FLOWING, A READING OF .25 MA. WOULD NOW BE INTERPRETED AS 2.5 MA. ETC.

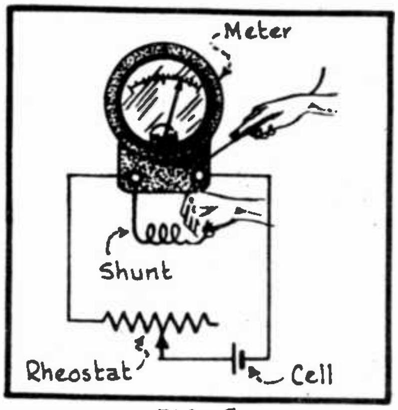

FIG. 15
Making the Shunt.

FOR THE SHUNT, YOU MAY USE ANY KIND OF WIRE, WHOSE RESISTANCE PER UNIT LENGTH IS KNOWN AND WHICH WILL CARRY THE REQUIRED CURRENT WITHOUT HEATING SUFFICIENTLY TO MATERIALLY INCREASE ITS RESISTANCE. MANGANIN AND GERMAN SILVER ARE FREQUENTLY USED FOR THIS PURPOSE AND IT IS ADVISABLE TO WIND THE WIRE SHUNT ON A PORCELAIN TUBE OR SOME OTHER SUITABLE SUBSTANCE.

THE EXPLANATION, AS JUST GIVEN, WILL ENABLE YOU TO CLEARLY SEE JUST EXACTLY HOW A SHUNT WORKS WITH THE METER, IN ORDER TO BRING ABOUT THE REQUIRED RESULTS BUT IN PRACTICE IT IS NOT EVEN NECESSARY TO DO ANY CALCULATING, IN ORDER TO CHANGE THE SCALE OF SUCH A MILLIAMMETER OR EVEN AN AMMETER FOR THAT MATTER.

DETERMINING THE SIZE OF SHUNT IN PRACTICE

THE EASIEST WAY TO CHANGE THE SCALE OF AN AMMETER OR MILLIAMMETER BY MEANS OF SHUNTS IS TO USE THE "CUT AND TRY" METHOD. TO CHANGE THE RANGE OF A MILLIAMMETER FROM 1 MA. TO 10 MA. BY THIS METHOD, YOU WOULD CONNECT THE METER IN SERIES WITH A CELL AND HIGH RESISTANCE RHEOSTAT AS SHOWN IN FIG. 15 AND THEN ADJUST THE RHEOSTAT SO THAT THE ORIGINAL METER READS FULL SCALE OR 1 MILLIAMPERE. THIS DONE, CONNECT A PIECE OF SHUNT WIRE ACROSS THE METER TERMINALS AND ADJUST ITS LENGTH UNTIL THE METER READING IS REDUCED TO .1MA. THIS THEN IS THE SIZE SHUNT REQUIRED TO INCREASE THE RANGE OF THE METER TO TEN TIMES ITS ORIGINAL VALUE. TO DOUBLE THE RANGE, ADD ENOUGH SHUNT WIRE TO MAKE THE METER READ HALF OF THE FULL SCALE AND MULTIPLY THE READINGS BY TWO ETC.

YOU CAN TAKE ANY SIZE AMMETER YOU CHOOSE AND BY THIS MEANS INCREASE ITS RANGE TO ANY REASONABLE EXTENT. THE METER, WHICH WE HAVE USED AS THE

EXAMPLE IN OUR DISCUSSION, CAN HAVE ITS RANGE INCREASED EVEN TO 100 AND 500 MILLIAMPERES, SIMPLY BY REDUCING THE RESISTANCE OF THE SHUNT TO THE PROPER VALUE. WHEN USING THE 100 MILLIAMPERE SCALE, THE READINGS WILL HAVE TO BE MULTIPLIED BY 100 AND WHEN USING THE 500 MILLIAMPERE SCALE, THE READINGS WILL HAVE TO BE MULTIPLIED BY 500.

BUILDING A MILLIAMMETER WITH 4 RANGES

THE EASIEST WAY TO DETERMINE THE SHUNT FOR THE HIGHER SCALES IS BY MEANS OF THE SYSTEM ILLUSTRATED IN FIG. 16. FOR EXAMPLE, TO PROVIDE A 10-100 AND 500 MILLIAMPERE SCALE ON THE AMMETER, WHOSE MAXIMUM RANGE IS 1 MILLIAMPERE, YOU WOULD FIRST DETERMINE THE SIZE SHUNT TO USE FOR THE 10 MILLIAMPERE SCALE AS ALREADY DESCRIBED. THIS SAME SHUNT FOR THE 10 MILLIAMPERE SCALE CAN ALSO BE USED FOR THE 100 AND 500 MILLIAMPERE SCALES BY TAKING OFF TAPS AT THE PROPER POINTS.

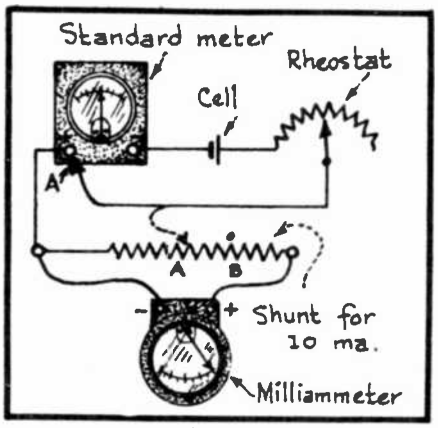

FIG.16
Calibrating the higher Milliammeter Scales.

TO DETERMINE THE LOCATION OF THESE TAPS, CONNECT THE SHUNT FOR THE 10 MILLIAMPERE SCALE ACROSS THE 0 TO 1 MA. METER, AS SHOWN IN FIG. 16. THEN PROVIDE YOURSELF WITH A MILLIAMMETER, WHICH IS ALREADY CALIBRATED TO TAKE READINGS UP TO 500 MILLIAMPERES, AND USE THIS AS YOUR "STANDARD METER." TO LOCATE THE 500 MILLIAMPERE TAP ON THE 10 MA. SHUNT, CONNECT THE STANDARD METER IN SERIES WITH A CELL AND RHEOSTAT, WITH CONTACT POINT "A" TOUCHING THE (+) SIDE OF THE STANDARD METER.

NOW ADJUST THE RHEOSTAT UNTIL THE STANDARD METER READS JUST EXACTLY 500 MILLIAMPERES. THEN GRADUALLY MOVE CONTACT "A" TOWARDS THE RIGHT ALONG THE 10 MA. SHUNT UNTIL YOU LOCATE THE POINT AT WHICH THE METER TO BE CALIBRATED READS EXACTLY FULL SCALE OR 1 MILLIAMPERE. THE TAP ON THE SHUNT FOR THE 500 MILLIAMPERE SCALE IS TO BE MADE AT THE POINT NOW OCCUPIED BY CONTACT "A".

WITH THE TAP MADE AT THIS POINT, PUT CONTACT "A" BACK ON THE (+) TERMINAL OF YOUR STANDARD METER AND ADJUST THE RHEOSTAT UNTIL THE STANDARD METER READS 100 MILLIAMPERES. AGAIN MOVE YOUR CONTACT POINT ALONG THE 10 MA. SHUNT TOWARDS THE RIGHT UNTIL THE METER TO BE CALIBRATED READS JUST EXACTLY FULL SCALE. YOUR CONTACT POINT WILL NOW BE AT "B" AND THIS IS WHERE THE TAP MUST BE MADE SO THAT YOUR METER WILL READ PROPERLY UP TO 100 MILLIAMPERES. THE FINISHED METER WITH ITS CONNECTIONS FOR THE DIFFERENT SCALES THUS MADE IS SHOWN IN FIG. 17.

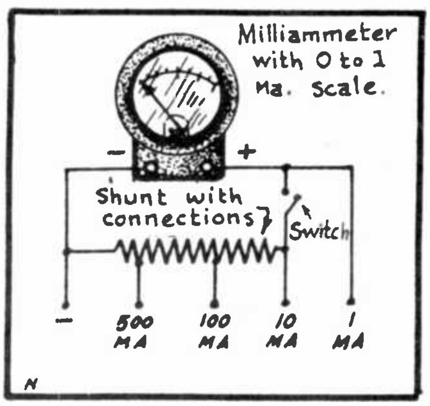

FIG. 17
A Milliammeter With Four Ranges.

BY USING THE (-) AND 1 MA. TERMINALS OF THE METER IN FIG. 17, WITH THE SWITCH OPEN, THE METER WILL READ ON ITS OWN SCALE UP TO A MAXIMUM OF 1 MA. BY CLOSING THE SWITCH AND USING THE (-) AND 10 MA. TERMINAL, THE READINGS MUST BE MULTIPLIED BY 10 AND THE MAXIMUM READING IN THIS CASE WILL BE 10 MA. THE 100 MA. SCALE IS USED WHEN THE METER CONNECTIONS ARE MADE AT THE (-) AND 100 MA. TERMINALS AND THE READINGS WILL HAVE TO BE MULTIPLIED BY 100, ETC.

THE USE OF MULTIPLIERS

THE RANGE OF VOLTMETERS CAN ALSO BE INCREASED AND FOR THIS WE USE MULTIPLIERS. WHILE THE AMMETER SHUNT BY-PASSED THE BULK OF THE CURRENT SO AS TO PREVENT IT FROM FLOWING THROUGH THE METER, THE MULTIPLIER, ON THE OTHER HAND, SERVES AS AN ADDITIONAL RESISTANCE IN SERIES WITH THE CIRCUIT SO AS TO PREVENT TOO MUCH CURRENT FROM FLOWING THROUGH ITS WINDING.

IN FIG. 18, FOR EXAMPLE, WE HAVE DOUBLED THE RANGE OF A VOLTMETER, SO THAT THIS 0 TO 250 VOLT METER CAN READ VOLTAGES UP TO 500 VOLTS. TO DOUBLE THE RANGE OF A VOLTMETER, WE MUST USE A MULTIPLIER, WHOSE RESISTANCE IS THE SAME AS THAT OF THE RESISTANCE WITHIN THE METER. THAT IS, IF THE METER IS RATED AS HAVING AN INTERNAL RESISTANCE OF 1000 OHMS PER VOLT, THEN IF ITS MAXIMUM RANGE IS 250 VOLTS, ITS INTERNAL RESISTANCE WILL BE 250,000 OHMS.

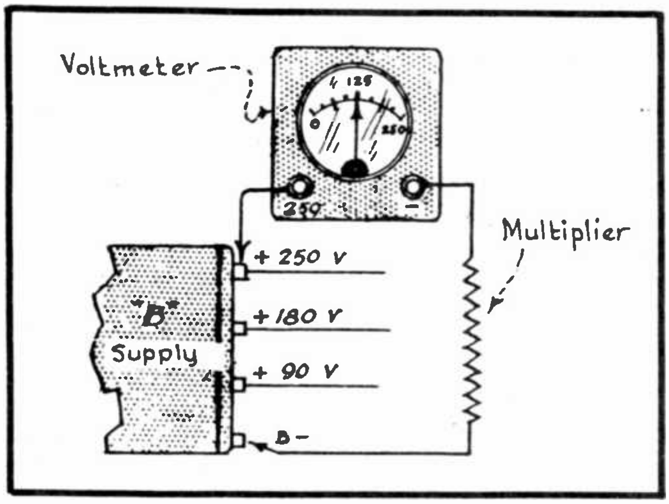

FIG. 18
Using a Multiplier.

BY DOUBLING THE RANGE OF THE VOLTMETER IN THIS WAY, THE NEEDLE WILL JUST READ EXACTLY ONE-HALF THE ACTUAL OR TRUE VALUE. TO PUT IT ANOTHER WAY - WHEN USING THE 250,000 OHM MULTIPLIER IN THIS CASE, WE MUST MULTIPLY THE INDICATED READING BY 2, IN ORDER TO DETERMINE THE ACTUAL OR TRUE VALUE.

SHOULD WE CARE TO INCREASE THE RANGE OF THE VOLTMETER IN FIG. 18 UP TO 750 VOLTS, THEN WE MUST USE A MULTIPLIER HAVING A RESISTANCE OF 500,000 OHMS AND TO INCREASE THE RANGE OF THIS SAME METER UP TO 1000 VOLTS, THE MULTIPLIER TO BE USED MUST HAVE A RESISTANCE OF 750,000 OHMS. THESE MULTIPLIER VALUES ARE FOUND IN THE FOLLOWING WAY: TO DOUBLE THE RANGE OF A VOLTMETER, THE METER RESISTANCE MUST BE DOUBLED. THAT IS, IF THE METER HAS AN INTERNAL RESISTANCE OF 250,000 OHMS, THIS MUST BE INCREASED TO 500,000 OHMS BUT SINCE 250,000 OHMS IS ALREADY PROVIDED INSIDE OF THE METER, AN ADDITIONAL RESISTANCE OF ONLY 250,000 OHMS MUST BE ADDED IN THE FORM OF A MULTIPLIER, SO AS TO BRING THE TOTAL METER RESISTANCE UP TO 500,000 OHMS.

TO TRIPLE THE RANGE OF A VOLTMETER, THE METER RESISTANCE MUST ALSO BE TRIPLED. MEANING THAT IF THE INTERNAL RESISTANCE OF THE METER IS 250,000 OHMS. THIS MUST BE INCREASED TO 3 TIMES THIS AMOUNT OR TO 750,000 OHMS. SINCE 250,000 OHMS OF THIS AMOUNT IS ALREADY INCLUDED WITHIN THE METER, THE MULTIPLIER MUST HAVE A RESISTANCE OF ONLY 750,000 OHMS MINUS 250,000 OR 500,000 OHMS. THE METER CAN NOW BE USED UP TO 750 VOLTS BUT THE READINGS INDICATED BY THE NEEDLE AT THIS TIME MUST ALL BE MULTIPLIED BY 3, IN ORDER TO DETERMINE THE TRUE VALUE.

YOU CAN FIGURE OUT ALL KINDS OF MULTIPLIER VALUES IN THIS WAY. MOST VOLT METERS HAVE THEIR "OHMS PER VOLT" RATING PRINTED ON THEIR DIAL OR ELSE THIS RATING IS SUPPLIED WITH THE LITERATURE FURNISHED BY THE MANUFACTURER AT THE TIME THE METER IS BOUGHT.

"LAYING-OUT" A 3 RANGE VOLTMETER

GENERALLY, IT IS CONVENIENT TO MOUNT A VOLTMETER IN A BOX, HAVING ITS FACE FLUSH WITH A NEAT PANEL. VARIOUS MULTIPLIERS CAN BE CONNECTED UP INSIDE THE BOX AND THEN ATTACHED TO DIFFERENT TERMINALS ON THE METER BOX. IN THIS WAY, A SINGLE-SCALE VOLT METER CAN BE TRANSFORMED INTO ONE HAVING TWO, THREE OR FOUR RANGES ETC. FIG. 19 SHOWS YOU HOW THIS CAN BE DONE.

IN FIG. 19, WE HAVE A VOLTMETER, WHOSE MAXIMUM RANGE IS 50 VOLTS BUT WE HAVE MOUNTED IT IN A BOX AND INCREASED ITS RANGE UP TO 250 AND 500 VOLTS THROUGH THE USE OF MULTIPLIERS, THUS CONVERTING IT INTO A THREE-RANGE INSTRUMENT. TO DO THIS, WE MOUNT FOUR TERMINALS IN A ROW ALONG THE PANEL, MARKING THEM AS (-), (500), (250) AND (50).

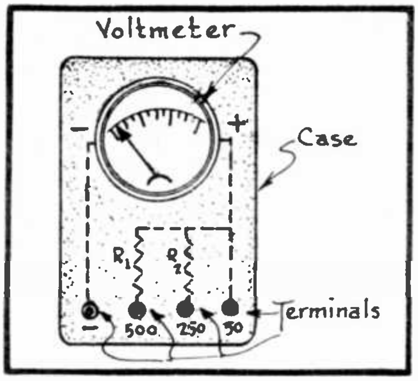

FIG. 19
A Multi-range Voltmeter.

THEN INSIDE OF THE BOX, WE CONNECT ONE (-) TERMINAL DIRECTLY TO THE (-) TERMINAL OF THE METER BY MEANS OF A PIECE OF INSULATED COPPER WIRE. THE "50" TERMINAL IS CONNECTED DIRECTLY TO THE (+) TERMINAL OF THE METER INSIDE THE BOX AND BY USING THE (-) AND "50" TERMINALS FOR OUR CIRCUIT TESTS, WE WILL BE USING THE METER IN ITS ORIGINAL FORM. THAT IS, ITS RANGE WILL NOW BE 50 VOLTS AND WE READ THE SCALE JUST AS IT IS.

THE 250 VOLT RANGE IS PROVIDED BY CONNECTING THE RESISTOR (MULTIPLIER) R_2 IN SERIES WITH THE "250" TERMINAL AND THE (+) METER TERMINAL AND THE 500 VOLT RANGE IS PROVIDED BY CONNECTING THE MULTIPLIER R_1 IN SERIES WITH THE "500" TERMINAL AND THE (+) METER TERMINAL. THE VALUES FOR THESE MULTIPLIERS ARE CALCULATED IN EXACTLY THE SAME WAY AS ALREADY DESCRIBED. YOU NOW HAVE A NEAT MULTI-RANGE VOLTMETER, WITH ALL WIRING, MULTIPLIERS ETC. CONCEALED WITHIN THE BOX.

TO USE THE 250 VOLT SCALE IN FIG. 19, THE INDICATED READINGS WILL HAVE TO BE MULTIPLIED BY 5 AND WHEN THE 500 VOLT RANGE IS USED, THEY WILL HAVE TO BE MULTIPLIED BY 10, IN ORDER TO DETERMINE THE TRUE VALUE.

CONVERTING A MILLIAMMETER TO A VOLTMETER

ANOTHER FAVORITE TRICK OF THE RADIO INDUSTRY IS TO CONVERT A MILLIAMMETER INTO A VOLTMETER, SO THAT IT CAN BE USED FOR BOTH PURPOSES. THIS IS ALSO DONE QUITE EASILY AND WE ACCOMPLISH THIS BY CONNECTING A RESISTOR IN SERIES WITH THE MILLIAMMETER.

THE VALUE FOR THIS SERIES RESISTOR IS DETERMINED IN THE FOLLOWING WAY: DIVIDE THE NUMBER REPRESENTING THE DESIRED VOLTAGE RANGE BY THE CURRENT RATING OF THE METER EXPRESSED IN AMPERES AND THE RESULT WILL BE THE OHM-RATING OF THE SERIES RESISTOR REQUIRED FOR THIS VOLTAGE RANGE. FOR EXAMPLE, LET US SUPPOSE THAT YOU HAVE A MILLIAMMETER WITH A SCALE READING OF 0 TO 1 MILLIAMPERES. IN ORDER TO CONVERT THIS INSTRUMENT INTO A VOLTMETER, HAVING A RANGE OF 0 TO 10 VOLTS, WE DIVIDE 10 BY .001 AMPERE (1 MILLIAMPERE), WHICH GIVES US AN ANSWER OF 10,000 OHMS ($R = \frac{E}{I}$) AS THE VALUE FOR

THE REQUIRED RESISTOR.

SO BY CONNECTING A 10,000 OHM RESISTOR IN SERIES WITH THIS MILLIAMMETER, WE CAN USE IT AS A VOLTMETER WITH A RANGE OF 0 TO 10 VOLTS AND EACH MILLIAMPERE DIVISION ON THE SCALE WILL BE READ AS 1 VOLT.

TO CONVERT THIS SAME MILLIAMMETER INTO A VOLTMETER WITH A RANGE OF 0 TO 100 VOLTS, WE DIVIDE 100 VOLTS BY .001 AMPERE, WHICH GIVES US 100,000 OHMS AS THE VALUE FOR THE SERIES RESISTOR AND EACH MILLIAMPERE DIVISION ON THE SCALE WOULD NOW BE INTERPRETED AS 10 VOLTS. TO INCREASE THE RANGE UP TO 200 VOLTS, A 200,000 OHM RESISTOR SHOULD BE USED ($R = \frac{E}{I} = \frac{200}{.001} = 200,000$ OHMS) AND EACH DIVISION ON THE SCALE WILL BE INTERPRETED AS 20 VOLTS.

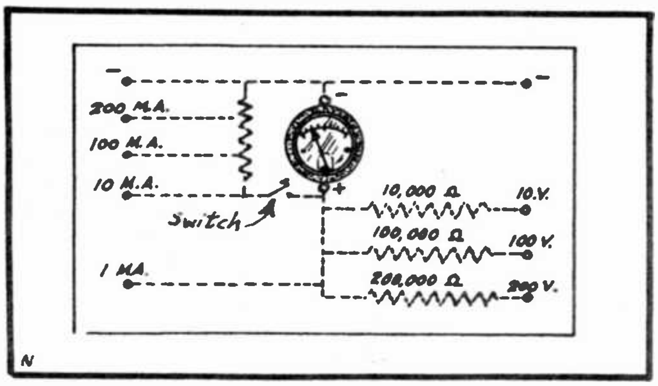

FIG. 20

Combination Milliammeter-Voltmeter.

AS YOU WILL NO DOUBT HAVE NOTICED FROM THIS EXPLANATION, WE ARE NOT TAKING INTO ACCOUNT THE INTERNAL RESISTANCE OF THE MILLIAMMETER'S MOVING COIL WHEN CALCULATING THE VALUE OF THE SERIES RESISTOR WHICH IS USED WHEN CONVERTING IT TO A VOLTMETER. FOR THE HIGHER VOLTMETER RANGES, THIS WILL NOT AFFECT THE ACCURACY OF THE INSTRUMENT TO ANY MARKED DEGREE BECAUSE THE SERIES RESISTOR VALUE IS SO VERY GREAT COMPARED TO THE METER'S INTERNAL RESISTANCE.

SHOULD THE INTENDED VOLTMETER RANGE BE LESS THAN 10 VOLTS, THEN THE RESISTOR VALUE THUS CALCULATED SHOULD BE CONSIDERED AS BEING THE INTERNAL RESISTANCE OF THE MILLIAMMETER ITSELF PLUS THE "VOLTAGE" SERIES RESISTOR VALUE. THE TRUE VALUE FOR THE "VOLTAGE" SERIES RESISTOR WILL THEN BE THE RESISTANCE VALUE THUS OBTAINED MINUS THE METER'S INTERNAL RESISTANCE.

A COMBINATION MILLIAMMETER-VOLTMETER

IN FIG. 20, YOU WILL SEE HOW A MILLIAMMETER WITH A RANGE OF 0 TO 1 MA. CAN BE MOUNTED IN A NEAT BOX AND USED BOTH AS A VOLTMETER AND A MILLIAMMETER, IN ADDITION TO HAVING A MILLIAMMETER RANGE OF 1-10-100, AND 200 MILLIAMPERES AND A VOLTMETER RANGE OF 10-100 AND 200 VOLTS. THE VOLTMETER TERMINALS ARE PLACED ALONG THE RIGHT EDGE OF THE BOX AND THE MILLIAMMETER TERMINALS ALONG THE LEFT EDGE. THE SWITCH MUST BE OPEN WHEN USING THE 1 MA. SCALE OR ANY OF THE VOLTAGE SCALES.

VARIOUS SIMILAR ARRANGEMENTS CAN BE WORKED OUT AND THE RESISTANCES CALCULATED FOR THE PARTICULAR METERS USED IN THE MANNER ALREADY SHOWN YOU IN THIS LESSON.

RESISTANCE RATING OF VOLTMETERS

AS YOU ALREADY KNOW, VOLTMETERS IN ADDITION TO BEING RATED ACCORDING TO THEIR VOLTAGE RANGE, ARE ALSO RATED AS TO THEIR INTERNAL RESISTANCE. THIS INTERNAL RESISTANCE IS EXPRESSED AS BEING A CERTAIN NUMBER OF OHMS FOR EACH VOLT REPRESENTED ON ITS DIAL SCALE. FOR INSTANCE, YOU WILL FIND VOLTMETERS HAVING A RESISTANCE RATING OF 300 OHMS PER VOLT, 500 OHMS PER

VOLT, 1000 OHMS PER VOLT ETC. FURTHERMORE, THE HIGHER THE OHMS PER VOLT RATING OF THE METER, THE GREATER WILL BE ITS DEGREE OF ACCURRACY BECAUSE IT WILL DRAW LESS CURRENT FROM THE CIRCUIT ACROSS WHICH A MEASUREMENT IS BEING TAKEN.

NOW THEN, SINCE A VOLTMETER HAVING A HIGH INTERNAL RESISTANCE TAKES VERY LITTLE CURRENT FROM THE LINE, IT STANDS TO REASON THAT THE METER ITSELF MUST BE VERY SENSITIVE, THAT IS, IT MUST REQUIRE VERY LITTLE CURRENT IN ORDER TO MOVE ITS COIL AND INDICATING NEEDLE OVER ITS DIAL FOR A FULL-SCALE DEFLECTION. THIS MEANS THAT EITHER THE PERMANENT MAGNET MUST BE STRONGER THAN IN THE USUAL METER OR ELSE MORE TURNS OF WIRE MUST BE WOUND ON THE MOVING COIL IN ORDER TO OBTAIN THE SAME AMPERE-TURN EFFECT AT A SMALLER VALUE OF AMPERES. THE LATTER METHOD IS USED IN THE CONSTRUCTION OF HIGH RESISTANCE VOLTMETERS AS EMPLOYED IN RADIO WORK. IN THIS CASE, THE MOVING COIL CONSISTS OF SEVERAL LAYERS OF VERY THIN COPPER WIRE IN ORDER TO PRODUCE THE NECESSARY FIELD STRENGTH.

THIS LEADS US UP TO ANOTHER POINT AND THAT IS THAT IT IS NOT POSSIBLE TO MAKE A HIGH RESISTANCE VOLTMETER OF THE SAME RANGE FROM AN ORDINARY OR CHEAP LOW RESISTANCE VOLTMETER BY SIMPLY CONNECTING ADDITIONAL RESISTANCE IN SERIES WITH ITS COIL. THE REASON FOR THIS IS OBVIOUS WHEN WE CONSIDER THE FACT THAT A LOW RESISTANCE METER REQUIRES CONSIDERABLE CURRENT IN ORDER TO OBTAIN A FULL SCALE DEFLECTION AND THIS MEANS THAT IF ADDITIONAL RESISTANCE IS USED, THE CURRENT THROUGH THE METER WILL BE REDUCED AND THIS IN TURN WILL REDUCE THE SCALE DEFLECTION. SO REMEMBER NOW THAT HIGH RESISTANCE VOLTMETERS ARE BUILT ESPECIALLY FOR THE PURPOSE, MORE SENSITIVE THAN THE LOW RESISTANCE TYPE AND THAT IT ISN'T PRACTICAL TO BUY CHEAP LOW RESISTANCE VOLTMETERS WITH THE EXPECTATION OF "RE-VAMPING" THEM INTO ACCURATE HIGH RESISTANCE UNITS BY MEANS OF SERIES RESISTORS.

IN THE FOLLOWING LESSON, YOU ARE GOING TO CONTINUE YOUR STUDY OF RADIO TESTING EQUIPMENT BY LEARNING ABOUT THERMO-COUPLE METERS, COPPER-OXIDE METERS AND OHMMETERS. ALL OF THESE INSTRUMENTS ARE EXTENSIVELY USED IN RADIO PRACTICE AND SO IT IS IMPORTANT THAT YOU BECOME THOROUGHLY FAMILIAR WITH THEM.

EXAMINATION QUESTIONS

LESSON NO. 49

Success hinges on loyalty. Be true to your art, your business, your employer, your "house." Loyalty is for the one who is loyal. It is a quality woven through the very fabric of one's being, and never a thing apart.

1. - DESCRIBE THE MOVING COIL TYPE METER MOVEMENT.

2. - DESCRIBE THE "HOT-WIRE" METER.

3. - DESCRIBE THE MOVABLE-IRON TYPE A.C. METER.

4. - WHAT ARE THE ESSENTIAL DIFFERENCES BETWEEN A D.C. AMMETER AND A D.C. VOLTMETER?

5. - EXPLAIN WHY SHUNTS ARE SOMETIMES USED IN CONJUNCTION WITH AMMETERS OR MILLIAMMETERS.

6. - IF YOU SHOULD HAVE A VOLTMETER WITH A MAXIMUM RANGE OF 300 VOLTS AND AN INTERNAL RESISTANCE OF 1000 OHMS PER VOLT, WHAT VALUE OF MULTIPLIER RESISTOR WOULD YOU USE TO INCREASE THE RANGE OF THIS METER UP TO 900 VOLTS? HOW WOULD YOU READ THIS METER AFTER INCREASING ITS RANGE IN THIS WAY?

7. - IF YOU SHOULD HAVE A D.C. MILLIAMMETER WITH A 0 TO 1 MA. RANGE AND HAVING AN INTERNAL RESISTANCE OF 27 OHMS, HOW WOULD YOU CONVERT THIS INSTRUMENT INTO A D.C. VOLTMETER WITH A MAXIMUM RANGE OF 500 VOLTS?

8. - HOW WOULD YOU INCREASE THE RANGE OF A MILLIAMMETER HAVING A FULL SCALE READING OF 1 MA. SO THAT READINGS UP TO 10 MA. MAY BE TAKEN? (NOTE: INTERNAL RESISTANCE OF METER IS 27 OHMS).

9. - EXPLAIN HOW YOU COULD INCREASE THE RANGE OF A MILLIAMMETER WITHOUT RESORTING TO CALCULATION.

10. - DRAW A COMPLETE CIRCUIT DIAGRAM OF A COMBINATION MULTI-RANGE D.C. MILLIAMMETER AND D.C. VOLTMETER.

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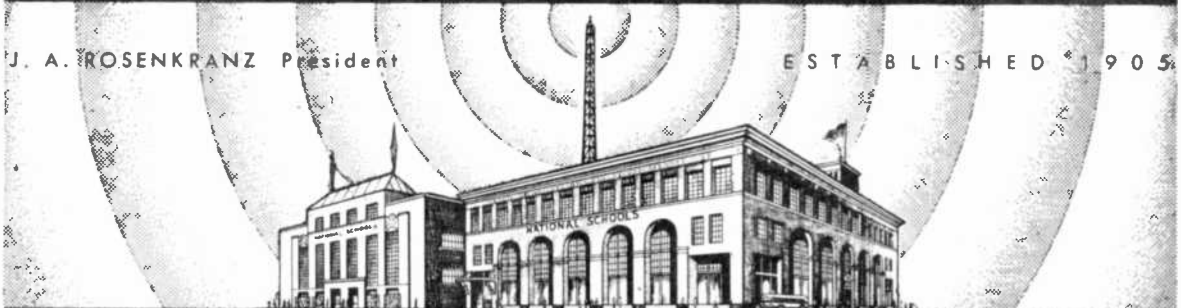


NATIONAL SCHOOLS ★ LOS ANGELES 37, CALIF.

LESSON NO. 50

MULTITESTERS

In this lesson, you are going to continue your study of radio service equipment by learning about thermocouple meters, rectifier type meters and combination instruments commonly known as "multitesters".

The knowledge of the various kinds of testing equipment that you are acquiring from the study of this and the lessons immediately following will enable you to use such apparatus to the best possible advantage. In addition, the information being presented at this time will be valuable in the event that you wish to construct similar testing units for your own use.

THERMOCOUPLE METERS

Thermocouple meters, as their name implies, utilize the effect of heat to actuate their movement; but this is accomplished in a different manner than in the so-called "hot-wire" instruments described in the previous lesson.

It can be shown that when two unlike metals are joined by being welded or clamped together and heat is applied to this juncture, the resulting increased velocity of the electrons (sometimes called "thermal agitation") causes an interchange of electrons to take place between the two metals. One of the metals, usually the better conductor, will deliver more electrons than it receives; thus setting up a difference of potential or electromotive force.

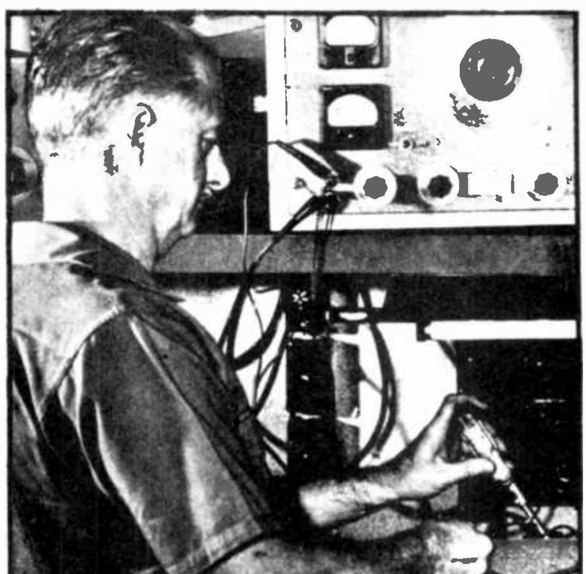


FIG. 1
TECHNICIAN USING PRECISION INSTRUMENTS TO ADJUST ELECTRONIC CIRCUIT

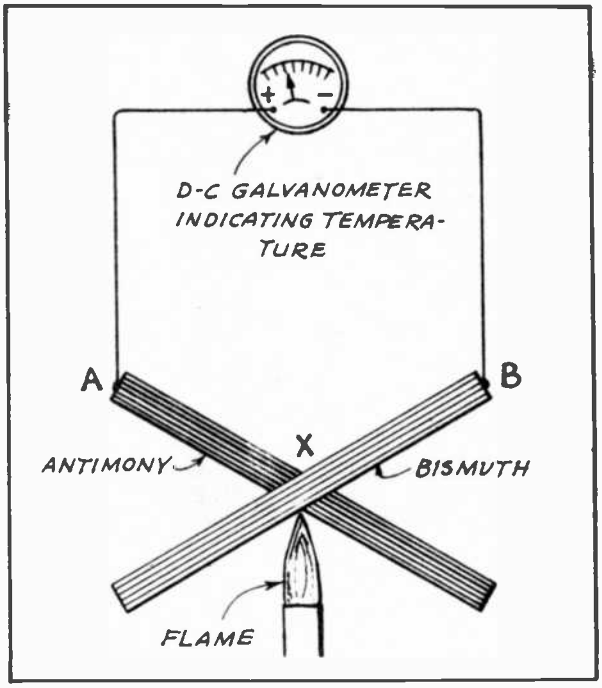


FIG. 2
PRINCIPLE OF THE THERMOCOUPLE

In Fig. 2, we show a bismuth bar joined at "X" to a bar of antimony. A sensitive galvanometer of the moving coil type, with which you are already familiar, is shown connected between the antimony at "A" and the bismuth at "B". If any heat be applied at the junction "X", a deflection of the galvanometer needle will be observed which is nearly proportional to the difference in temperature between the hot junction "X" and the cool junctions in the galvanometer circuit at "A" and "B". It is important that connections "A" and "B" remain cool with respect to "X".

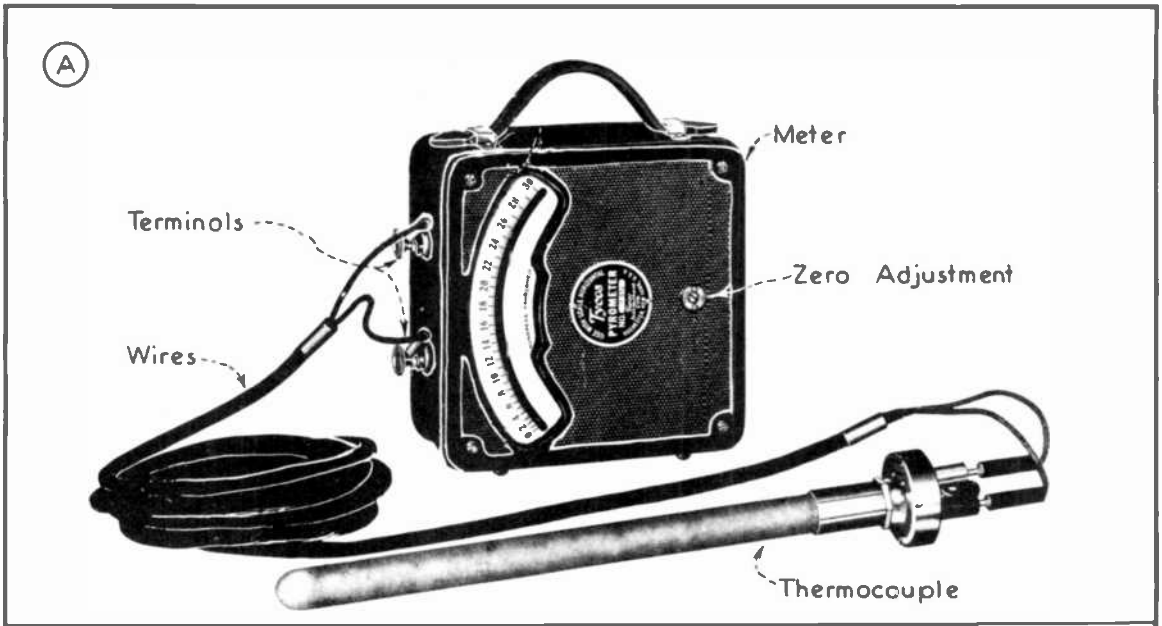
An increase in the temperature of the thermocouple will cause a corresponding increase in the deflection of the meter needle, so that it is possible to calibrate the meter scale in Fahrenheit or Centigrade degrees and thus measure temperatures which are beyond the range of an ordinary thermometer. Such instruments are known as pyrometers.

At (A) in Fig. 3 is shown a portable pyrometer, while (B) of Fig. 3 illustrates the electrical connections of a pyrometer for indicating blast furnace temperatures. A special compensator takes care of any change of temperature which may occur at the cold end of the two active metals. For extremely high temperatures platinum and rhodium alloy are used instead of antimony and bismuth.

In the thermocouple meter shown in Fig. 4 the heat is produced at junction "X" by sending an electric current, either d-c or a-c, through the metal bars from "C" to "D". Both antimony and bismuth have a high resistivity so that when current is sent through this path heat is developed which from Watt's Law ($W = I \times E = I^2 \times R$) is proportional to the square of the current. The scale on the meter in this case is calibrated to indicate the value of the current which is doing the heating.

Since the operation of the thermocouple meter depends upon heating, and is not influenced by the frequency of the current being measured, this type of instrument is better for measurements of alternating currents of varying frequencies than any type in which the measured current must pass through a coil. The inductive reactance of the coil would increase with frequency which would require separate calibration at each frequency to be measured. Furthermore, the by-passing effect of the distributed capacitance between coil turns makes such a movement unsuitable for use at the higher radio frequencies. These reactance effects are negligible in the short, straight or curved path followed by the current which is being measured in the thermocouple meter.

"Burning up" of the thermocouple, caused by a current overload, is the most common trouble encountered in this type of instrument. As a rule, this does no harm to the movement of the meter because the current of the circuit does not flow through it. Consequently, to remedy a "burn-out" in this case, it is only necessary to replace the thermocouple with a new one; and to adjust the calibrating resistor (Fig. 5) to match the new thermocouple.



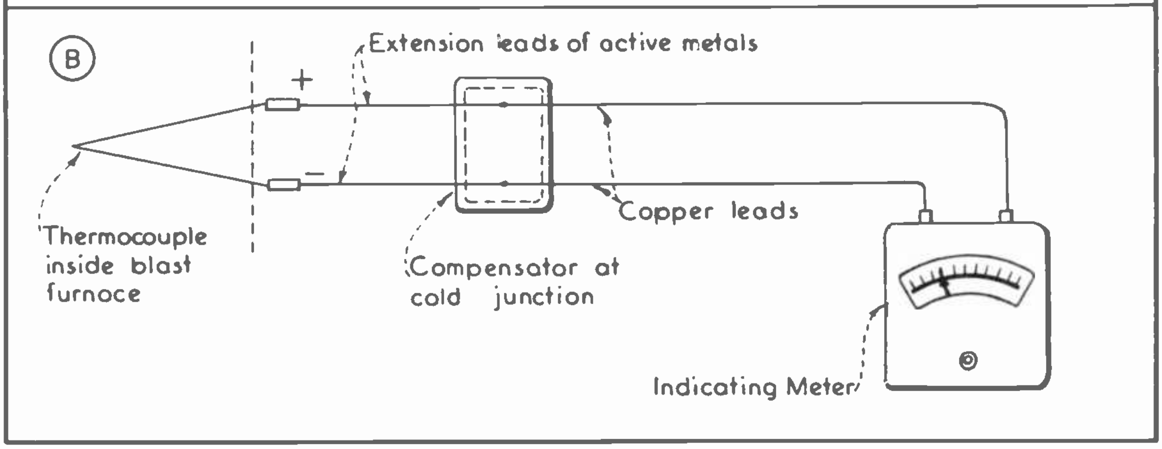


FIG. 3
PYROMETER AND APPLICATION

By adding a multiplier resistor in series with the heating element of the thermocouple and by recalibrating the scale, it is possible to use the instrument to measure r-f voltage as well as r-f current.

The majority of thermocouple meters are designed so that the d-c voltage across the moving coil for full-scale deflection is from about 15 to 25 millivolts. The small calibrating resistor which is connected in series with the moving coil of the instrument and the thermocouple is of such value as to provide the correct calibration of the instrument; that is, it causes full-scale deflection of the needle at the voltage specified above. Fig. 5 shows the relation between the calibrating resistor and moving coil.

COMPOUND THERMOCOUPLE METER

The principle of construction illustrated in Fig. 5 is used only in such cases where the current to be measured does not exceed one-half ampere.

Instruments capable of handling greater load currents are constructed somewhat as illustrated in Fig. 6. Here, the two dissimilar metals of the thermocouple are connected in parallel with respect to the r-f path or external circuit, but in series with respect to the

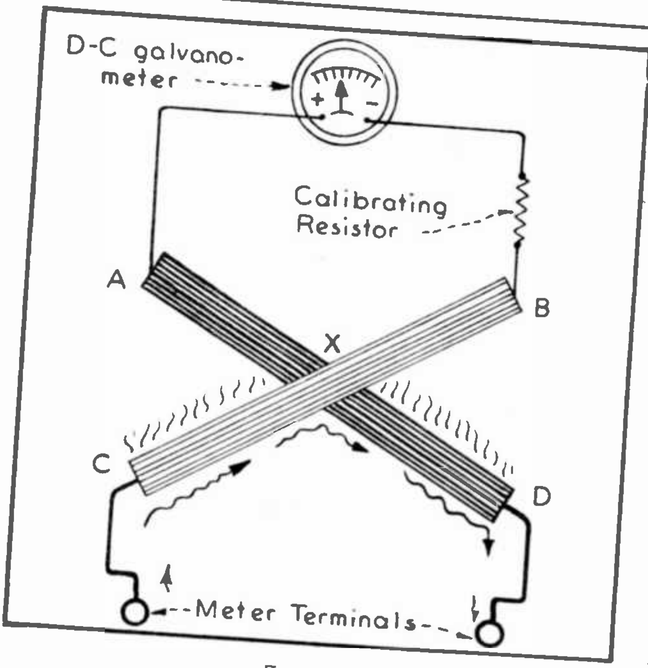


FIG. 4
THERMOCOUPLE HEATED
BY CURRENT FLOW

direct current which is caused to flow by the emf generated by the thermal-electric effect in the thermocouple.

Upon studying Fig. 6 closely, you will see that one of the metals of the thermocouple is shaded a bold black, while the other is not shaded. The metals frequently used for this purpose are manganin and a special alloy known as "Advance" wire.

APPLICATION OF HEATER WIRE IN THERMOCOUPLE METERS

Another form of construction sometimes employed in thermocouple meters is illustrated in Fig. 7. In this case, a special heater wire is connected in series with the circuit in which the measurement is being made. The flow of r-f current through this wire heats it, which heat is applied by direct contact to the point of junction of the two dissimilar metals comprising the thermocouple.

The meter is connected across the ends of the thermocouple the same as in the examples previously described, so that the direct current resulting from the heated junction point will flow through the meter winding and actuate the movement.

RECTIFIER-TYPE METERS

A-C meters, in general, are more sluggish in operation than are d-c meters; and they "absorb" considerably more power from the circuit in which the measurement is being made for energizing the movement of the instrument. This is an important factor when making radio measurements, because very often more power is required to swing the meter's needle than is available in the circuit being checked.

The advantage of low current drain in sensitive d-c instruments can be retained for measuring small a-c voltages and currents by using a suitable sensitive D'Arsonval (moving coil) type instrument in conjunction with a rectifier. Most of the a-c voltmeters used in ordinary radio service work employ this principle. With this arrangement, the a-c voltage to be measured is rectified and the resulting d-c is applied to the d-c instrument.

CRYSTAL RECTIFIER

There are several methods whereby we can rectify a-c voltages for measuring purposes. One is by using a crystal rectifier of the same type as employed for radio detection, in the manner illustrated in Fig. 8. Such crystals, however, are generally too unstable in operation and need to be adjusted quite often. They are also subject to "burn-out" at comparatively low current values.

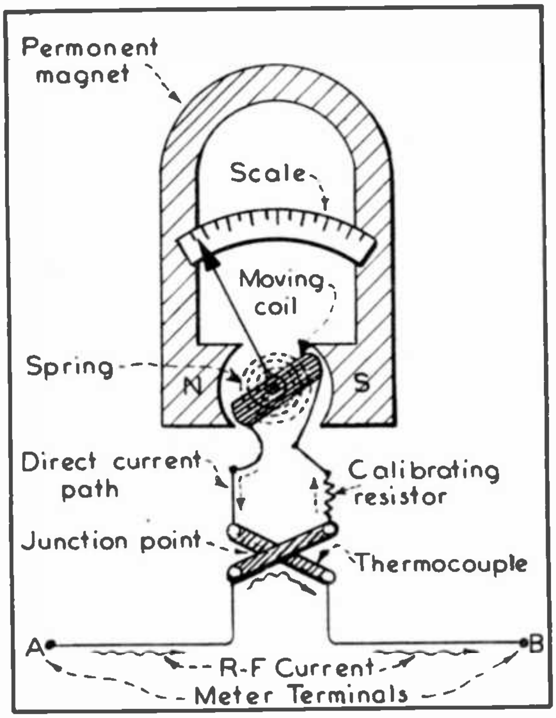


FIG. 5
THERMOCOUPLE METER

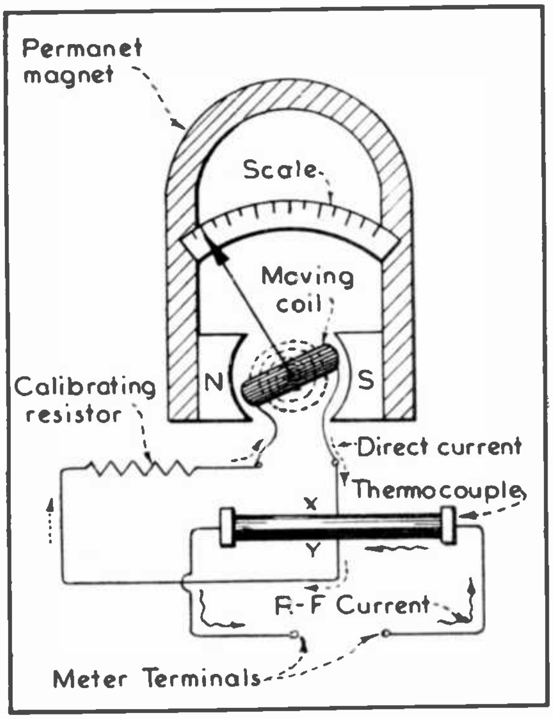


FIG. 6
COMPOUND THERMOCOUPLE METER

TUBE RECTIFIER

A second method of securing rectification is to employ a vacuum-tube rectifier as shown in Fig. 9. Here, a small-size duo-diode of the type used as a detector in radio receivers is being utilized as a half-wave meter rectifier. Thus, when a-c voltages are impressed across the

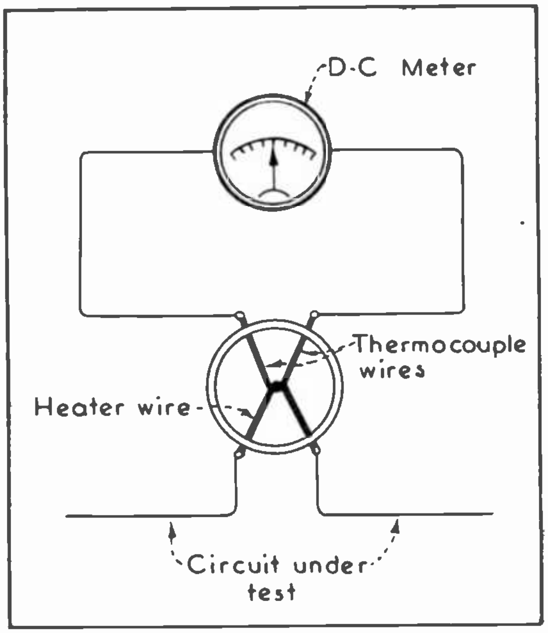


FIG. 7
HEATER WIRE APPLIED TO THERMOCOUPLE

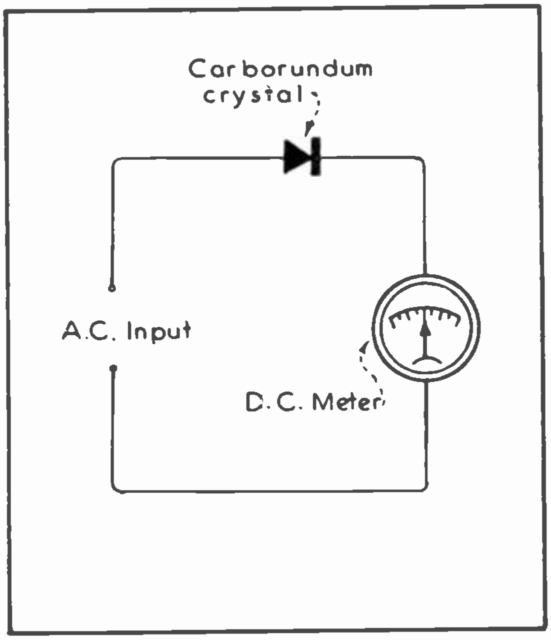


FIG. 8
METER WITH CRYSTAL RECTIFIER

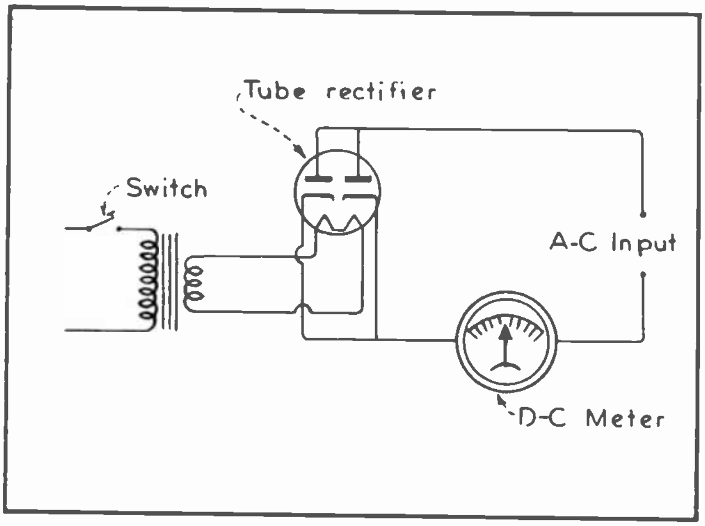


FIG. 9
TUBE RECTIFIER FOR D-C METER

terminals marked "A-C Input," only d-c can pass through the meter; but the scale of the meter is calibrated in a-c voltage values that are capable of causing a current flow of the intensity conforming to the "swing" of the needle.

COPPER-OXIDE RECTIFIER

A third method of rectification consists of employing a copper-oxide rectifier as illustrated in Fig. 10. This type of rectifier is most used in radio for measuring ordinary a-c voltages because of its ruggedness, sensitivity and unvarying electrical characteristics.

The main disadvantage of rectifier type meters is that they indicate average values instead of effective values. This introduces an inaccuracy in readings which becomes apparent when the voltage to be measured has a distorted wave form. However, since the wave form of most voltages encountered in a radio receiver or amplifier closely approximate sine waves, we find that for practical purposes distortion due to the rectifier, and its consequent error, will be negligible. Obviously, the scale of the meter is calibrated so as to compensate for any effect that the rectifier might have on the operation of the instrument.

Copper-oxide rectifiers have considerable capacitance which causes a change in the deflection of the needle across the scale as the frequency of the voltage to be measured is varied. The effect of this capacity is not great at low frequencies; but above three thousand cycles, the error caused by it is more pronounced. This is not as serious an objection as it appears to be at first glance, because a-c voltage measurements in ordinary radio service work seldom require absolute accuracy at frequencies above standard commercial frequencies (50-60 cycles per second). Other types of instruments are used where greater accuracy is required. Momentary overloads of three to ten times the normal voltage rating do not injure a copper-oxide rectifier, thus reducing to a minimum the danger of damaging the unit by this means.

Since the copper-oxide rectifiers used in connection with meters are required to handle only very low current values, such rectifiers can be manufactured in small sizes so as to take up little space in the testing instrument. Typical examples of copper-oxide rectifiers for meter use are shown in Fig. 11. The miniature type at (A) converts d-c meters drawing less than 5 ma to a-c instruments; the one at (B) is suitable for use with meters drawing not more than 20 ma; while the heavy-duty" type at (C) will safely pass 30 ma.

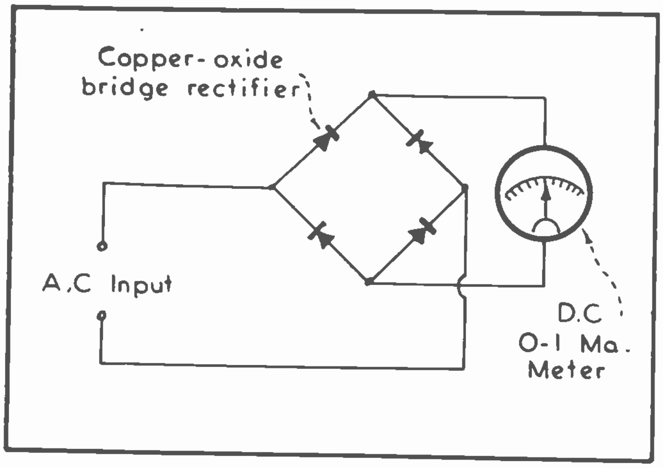


FIG. 10
APPLICATION OF COPPER-OXIDE METER RECTIFIER

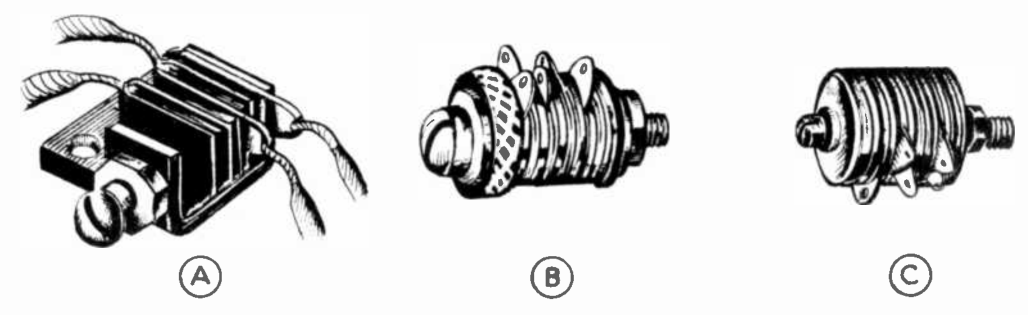


FIG. 11
COPPER-OXIDE METER RECTIFIERS

COMBINATION AC-DC METERS

In radio, it is common practice to use a single meter for measuring d-c current, d-c voltage and a-c voltage. The diagram in Fig. 12 shows how this can be done.

The meter used in this case is basically a d-c milliammeter, with a range of 0 to 1 ma. That is, the indicating needle of this meter will be swung completely across the scale when a current of 1 milliampere flows through the moving coil.

Switch #1 is a double-pole single-throw type, both pole sections being operated simultaneously by a single control button or lever. Its purpose is to connect the rectifier into the meter circuit when a-c voltages are to be measured, and to disconnect it when d-c readings are to be taken.

D-C VOLTAGE MEASUREMENT

To measure d-c voltages open switches #1 and #3, and close #2. Connect one test lead to the (-) d-c volts terminal and the other test lead to one of the other d-c volts terminals, in accordance with the range of voltage that must be covered in order to make a particular measurement. For instance, to read values of emf up to 5 volts, use the (-) and "5" terminals in the D-C VOLTS terminal-group. To read values up to 25 volts, insert the test leads into the (-) and "25" terminals of the D-C VOLTS terminal-group, etc.

No doubt, you are by this time interested in knowing why resistors R-1 and R-2 have been incorporated in this section of the tester. R-1 is of such value as to make the meter resistance equal to 300 ohms, thus serving as a basic calibrating resistance for the instrument around which all of the other resistor values are calculated so that full-scale deflection will be obtained when 1 ma flows through the meter, regardless of whether the d-c voltage, a-c voltage or d-c milliampere section of the instrument is being used at the time.

Resistor R-2 having a value of 4,700 ohms, and being connected in series with the meter resistance of 300 ohms, places a total resistance of 5,000 ohms in series with the (-) and "5" d-c volts terminals; thus limiting the current flow through the meter coil to 1 ma when 5 volts is applied across these two terminals. The other resistors in this terminal-group are the usual multipliers for increasing the d-c voltage range of the instrument, and with which you are already familiar so that no more need be said about them at this time.

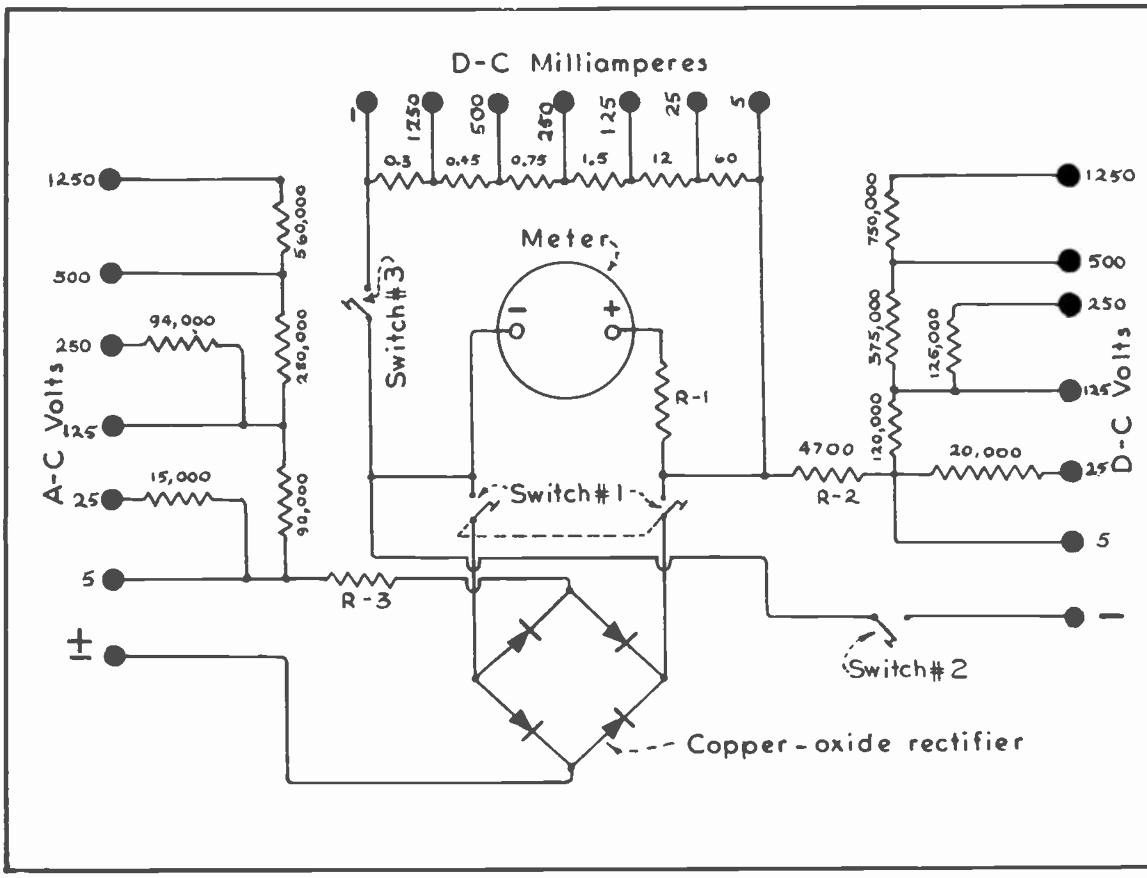


FIG. 12
COMBINATION D-C MILLIAMMETER, D-C VOLTMETER AND A-C VOLTMETER

D-C CURRENT MEASUREMENT

To use the d-c milliampere scale, open switches #1 and #2; and close switch #3. To read current values up to 5 ma, insert the test leads into the (-) and "5" terminals of the D-C MILLIAMPERES terminal-section. This places the complete series connected group of resistors at these terminals in shunt with the meter so that 1 ma will pass through the coil of the meter and 4 ma through the shunting resistor network, when current values up to 5 ma are being measured. You will observe in Fig. 12 that when terminals corresponding to higher current values are used, the shunting resistance between the terminals is decreased so that a greater percentage of the total current flow passes through the shunt path, and never more than 1 ma through the meter coil.

Notice, particularly, how the opening of switch #1 disconnects the rectifier from the circuit when the d-c volt and d-c milliampere scales of the instrument are being employed.

A-C VOLTAGE MEASUREMENT

To measure a-c voltages, open switches #2 and #3, and close switch #1. So doing, disconnects the d-c volt and d-c milliampere sections of the instrument from the meter; and connects the rectifier into the circuit, between the A-C VOLTS terminal-group and the meter. Therefore, when a-c voltages are applied across one pair of terminals of the rectifier, a d-c voltage will appear across the other pair of terminals, thereby causing a direct current to flow through the meter coil for actuating the meter.

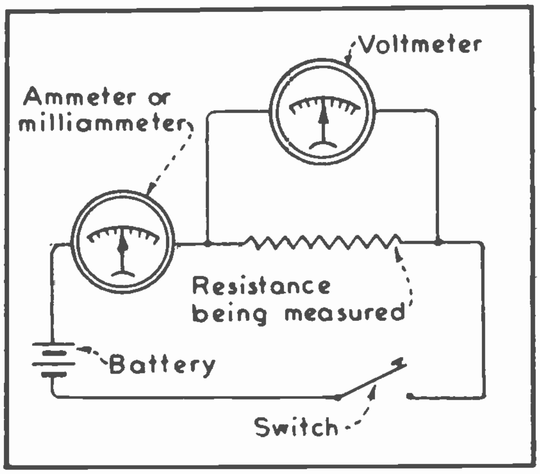


FIG. 13
VOLTMETER-AMMETER METHOD OF MEASURING RESISTANCE

Resistor R-3 is a calibrating resistor of such value as to match the rectifier so that 1 ma of direct current will flow through the meter winding and swing the needle all the way across its scale to indicate 5 volts when 5 volts a-c is applied across the (±) and "5" terminals of the "A-C VOLTS" terminal-group. The resistors in this terminal-group are the usual multipliers for increasing the meter range, similar to those employed for increasing d-c voltage ranges.

Meters of this type are equipped with multi-scale dial faces so as to be direct-reading when measuring either d-c voltages, a-c voltages or d-c milliamperes. However, when the higher ranges of any one scale are being employed, it is often necessary to multiply the observed reading by a certain number called a "multiplying factor" in order to arrive at the true value. In the case of commercial instruments of this kind, the multiplying factor for any one particular range of measurement is specified by the manufacturer of the tester.

MEASURING RESISTANCE

There are several ways in which the resistance values of radio resistors may be determined by measurement. First, we will explain how this is done with the aid of a voltmeter and ammeter or milliammeter in the event that no direct-reading resistance measuring instrument is available.

VOLTMETER-AMMETER METHOD

One way to measure resistance values by this method is illustrated in Fig. 13. Here, you will observe that the resistance to be measured is connected in series with a switch, battery and an ammeter or milliammeter.

Upon closing the switch, battery current will flow through the circuit --- its value being indicated by the ammeter. Then, if a d-c voltmeter is connected across the ends of the resistance, it will show the voltage-drop across it. We can therefore apply Ohm's Law in the form $R = \frac{E}{I}$, where "R" is the resistance value to be determined; "I" is the current flowing through the resistance and "E" is the voltage-drop across it. For example, if the ammeter reads 0.5 ampere and the voltmeter 100 volts, the value of the resistance being measured is 200 ohms, thus:

$$R = \frac{E}{I} = \frac{100}{0.5} = 200 \text{ ohms.}$$

The value of the applied emf (battery voltage or any other constant d-c voltage source) should be chosen so that the resistor does not become hot as the current flows through it. Also, care should be taken not to place a shorted resistor or one of very low value in the circuit, as the resulting large current might damage the ammeter.

Since the voltmeter will draw a certain amount of current with which to energize its movement, this will introduce an error into the computation of the resistance value. However, this method is fairly satisfactory for measuring comparatively low resistance values; as under

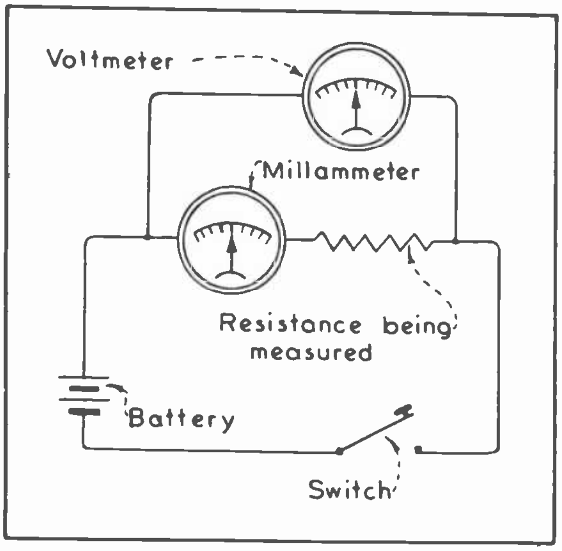


FIG. 14
MEASURING HIGH-RESISTANCE VALUES

these conditions the current flow through the resistance will be relatively large, so that even if a few milliamperes of voltmeter current are added to the ammeter reading no appreciable error will occur.

The above method is not suitable for measuring high resistance values. In this case, the current passing through the resistance is very small; hence, the current flowing through the voltmeter may be just as great as that through resistance. Then, since the milliammeter reads the combined current through the resistance and voltmeter an appreciable error enters into the measurement. In other words, the smaller the proportion of the total current flowing through the voltmeter to that flowing through the resistance, the more accurate will be the resistance measurement.

For measuring high resistance values, where the current value is very small, it is preferable to measure the voltage-drop across both the ammeter or milliammeter and the resistance being measured, as illustrated in Fig. 14. Although it is true that the voltmeter now measures the voltage-drop across both the ammeter and the resistance, the resistance of the ammeter winding is so small in comparison to the resistance being measured that the percentage of error will be appreciably small.

VOLTMETER METHOD

Fig. 15 shows how it is possible to measure resistance with a voltmeter alone. To do this, connect the resistance to be measured in series with the voltmeter and the d-c voltage source, and connect a short-circuiting switch across the ends of the resistance.

The first step is to close the short-circuiting switch. This will connect the voltmeter directly across the battery or other d-c voltage-source so that the source of emf can be measured accurately by the voltmeter. This is generally called the "line reading".

After this reading has been carefully noted, open the short circuiting switch. This will connect the resistance in series with the voltmeter and the voltage-source. Therefore, the voltmeter reading will now be less than formerly --- we call this, the "drop-reading". To determine the value of the resistance in question, use the following formula:

$$\text{Unknown Resistance} = \frac{\text{Line reading} - \text{Drop reading}}{\text{Drop reading}} \times \text{resistance of voltmeter}$$

To illustrate the use of this formula, let us work out the problem appearing below:

Assume that upon closing the short-circuiting switch, the voltmeter reads 180 volts. This is the "line reading".

Now suppose that the voltmeter reads 40 volts when the switch is opened. This is the "drop reading".

The voltmeter being used has a full-scale range of 250 volts and an internal resistance of 1000 ohms per volt. Therefore, its total resistance will be 250 x 1000 or 250,000 ohms. So, substituting into the formula the data thus far acquired, we have:

$$\text{Unknown Resistance} = \frac{180 - 40}{40} \times 250{,}000 = \frac{140}{40} \times 250{,}000 = 3.5 \times 250{,}000 = 875{,}000 \text{ ohms.}$$

This method is only applicable for measuring resistance of high value. If the resistance is of low value, there will be very little difference in the reading when the voltmeter is connected directly across the source of emf or in series with the unknown resistance.

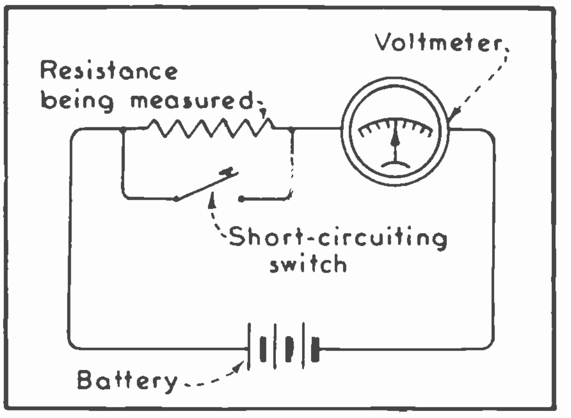


FIG. 15
VOLTMETER METHOD OF MEASURING RESISTANCE

OHMMETERS

Instruments are now available which enable one to read resistance values on a meter scale which is calibrated directly in ohms. Such instruments are called OHMMETERS.

The principle of the ohmmeter is illustrated in Fig. 16. This instrument consists of a milliammeter whose scale is calibrated in ohms. The meter is connected in series with a small 4 1/2 volt dry battery (usually, three series-connected flashlight cells), a calibrating resistance and two terminals.

To measure a resistor of unknown value, the resistor is connected across the terminals pointed out in Fig. 16. The meter will then indicate the resistance value directly in ohms. A typical ohmmeter scale, with a range of 0 to 1 megohm, is shown in Fig. 19.

What really takes place is that when an unknown resistor is connected across the terminals, the meter deflection will be proportional to the current flow; and, since the scale is calibrated in ohms, the resistance value is determined quickly and easily.

To compensate for the reduction in battery voltage, as the battery becomes aged, the value of the calibrating resistance that is effective in the circuit will have to be changed. This is done by temporarily short circuiting the ohmmeter terminals with the test leads, a piece of wire, screwdriver or some other convenient means that provides very nearly zero resistance; and resetting the adjusting screw of the calibrating resistance so that the meter needle comes to rest at the zero mark.

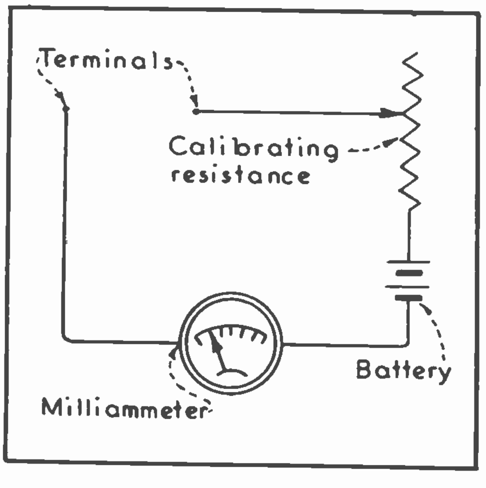


FIG. 16
PRINCIPLE OF THE OHMMETER

This setting for zero should always be checked before measuring resistance.

When the battery is no longer usable, it can be removed from the instrument case, and a new one installed. The instrument should then be re-calibrated for zero setting as previously explained.

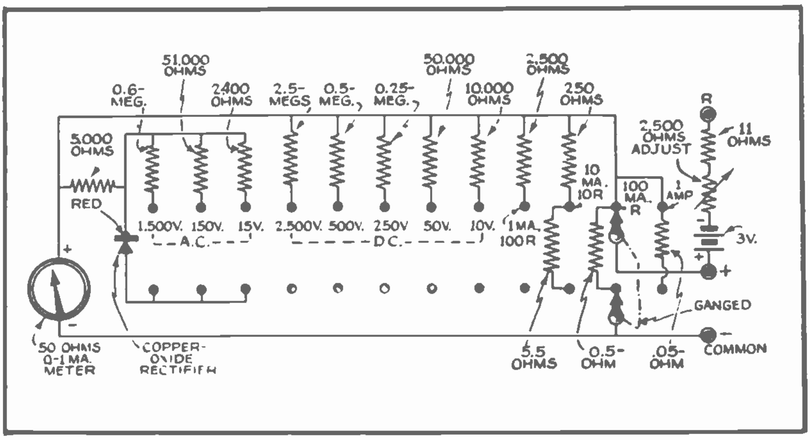


Fig. 17
Circuit Diagram of Multitester

MULTITESTERS

In radio service work, as well as for radio testing in general, it is common practice to use combination meters that will measure a-c and d-c voltage, d-c current and resistance. Such instruments are known as "multitesters", "universal testers", and by other names that are indicative of the various kinds of tests that can be made with them. Instruments of this type, embracing many different features of design, have been placed on the market by numerous manufacturers. In this lesson we show several examples that illustrate the basic principles employed in the majority of them, and which will serve to acquaint you with their circuit arrangements in general.

EXAMPLE NO. 1

The circuit diagram of a multitester of simple design appears in Fig. 17. The ranges of this versatile instrument are: d-c volts of 0 to 10, 50, 250, 500, 2,500; a-c volts of 0 to 15, 150, 1,500; d-c current of 0 to 1, 10, 100, 1,000 ma. or 1 amp; resistance of 0 to 5,000, 50,000, 500,000 ohms; output meter ranges of 0 to 15, 150, 1,500; and db ranges of 18, 38 and 58. The different ranges are selected by means of a 12-position dual selector switch that is similar in appearance to a band-selector switch as used on all-wave receivers. Naturally, the panel arrangements on instruments of this type differ in detail just as do the circuits, but that employed on the tester shown in Fig. 18 is typical for multitesters equipped with a range-selector switch.

In the case of the tester diagramed in Fig. 17, d-c voltage, a-c voltage and the d-c current ranges are utilized by inserting the test leads in the tip jacks marked "+" and "-"; and setting the range-selector switch in the proper position for the range desired.

CURRENT MEASUREMENT:

To measure current values up to 1 ampere on the tester illustrated in Fig. 17, we would place the dual switch in the extreme right-hand position which would connect the test leads directly across the 0.05 ohm resistor. This

Fig. 18
Panel Design of Typical Multitester

same resistor will now be connected in parallel with the meter; and since it has a very low resistance value, the greater portion of the current being measured will flow through it instead of through the meter. As the selector switch is moved to the left, one position at a time, the shunting resistor value becomes greater and the range of current measurement becomes less. Finally in the 1 ma. position, no shunting resistor at all is employed; but a 2500 ohm resistor is now connected in series with the meter and test leads. Obviously, the scale on the meter is calibrated so that the instrument will read correctly with this resistor included in the circuit.

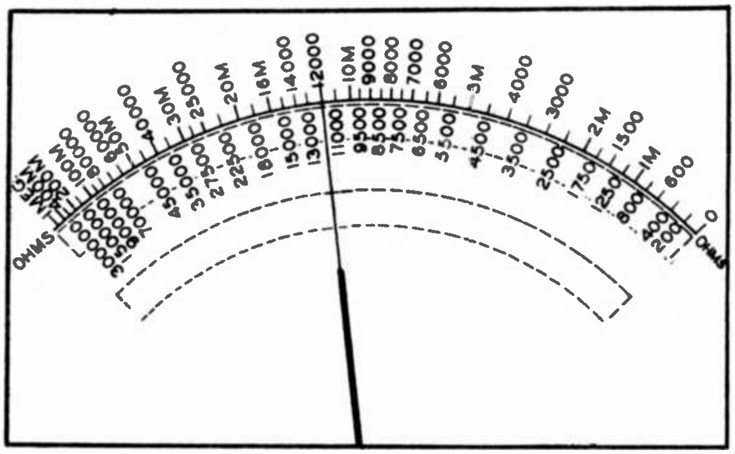


FIG. 19
TYPICAL OHMMETER SCALE

D-C VOLTAGE MEASUREMENT:

As the selector switch is moved further toward the left, it will connect the test leads in series with the meter and a multiplier resistor of proper value so as to make possible measurements of the d-c voltage values indicated at these different positions.

A-C VOLTAGE MEASUREMENT:

The last three positions of the selector switch, at the extreme left, connect a half-wave copper oxide rectifier across the meter terminals through a 5,000 ohm resistor. The latter is a current-limiting resistor, the purpose of which is to prevent needle-shimmy that would otherwise occur due to the pulses of the rectified current supplied by the half-wave rectifier. It also serves as a calibrating resistor, balancing the rectifier to the meter. You will also observe in Fig. 17 that placing the range-selector switch in the three available positions for making a-c voltage measurements will automatically connect a multiplier resistor of the correct value in series with the test leads and the rectifier for the range of voltages covered by that switch position.

HIGH-RESISTANCE MEASUREMENTS:

To measure resistor values, insert the test leads into the tip jacks marked "COMMON" and "R". If the value of resistor to be measured exceeds 50,000 ohms, but is less than 500,000 ohms, place the selector switch in the fourth position from the right marked "1 MA. 100 R". Then short circuit the test leads and set the 2,500 ohm "adjust" potentiometer so that the meter needle swings across the scale to the position of maximum reading. Since the ohmmeter scale of this meter is calibrated from zero to maximum in a right-to-left direction (See Fig. 19), the operation just described constitutes the correction for "zero setting" previously mentioned. (Note: This reversal of the ohmmeter scale with respect to the current scale on the same instrument comes about from the fact that with a given voltage applied across a resistor being measured, the flow of current through it increases as the resistance decreases. Therefore, the needle-position of maximum current corresponds to minimum resistance).

Note that a 2,500 ohm fixed resistor is at this time connected in series with the meter and the resistance-measuring circuit, and that no shunting resistor within the tester is connected between the "+" and "common" tip jacks.

The notation "100R" on this selector switch terminal tells us that the reading indicated on the meter must be multiplied by 100 in order to arrive at the true value of the resistance being measured.

MEDIUM-RESISTANCE MEASUREMENTS:

To measure resistances having values up to 50,000 ohms and greater than 5,000 ohms, place the selector switch in the third position from the right in Fig. 17, marked "10MA.10R". So doing will include the 250 ohm resistor in series with the meter and the resistance-measuring circuit, thereby reducing by a definite amount the voltage drop in the ohmmeter circuit, which together with the shunting effect of the 5.5 ohm resistor will reduce the current through the 50,000 ohm resistor being measured to a value which causes the needle to point to a resistance indication of 5,000 ohms at the extreme left of the ohmmeter scale. This, we multiply by 10 to obtain the true value of 50,000 ohms as directed by the notation "10 R" on this selector-switch position.

LOW-RESISTANCE MEASUREMENTS:

To measure resistances between 0 and 5,000 ohms set the selector switch at the second position from the right, marked "100 MA. R", and read the ohmmeter scale direct. No additional resistance is now connected in series with the meter and the resistance-measuring circuit, and the value of shunting resistance has been reduced to 0.5 ohm; therefore, the circuit arrangement is now such that when a 5,000 ohm resistor is connected across the "COMMON" and "R" terminals, current flow will be such as to indicate 5,000 ohms on the scale.

It is to be remembered that the instrument must be adjusted to a "zero-setting" by means of the potentiometer before attempting to measure resistance values on any one of the three ohmmeter ranges. It is interesting to note that in the tester just described, the same shunt resistors that are used for the three resistance ranges are also employed when current alone is measured.

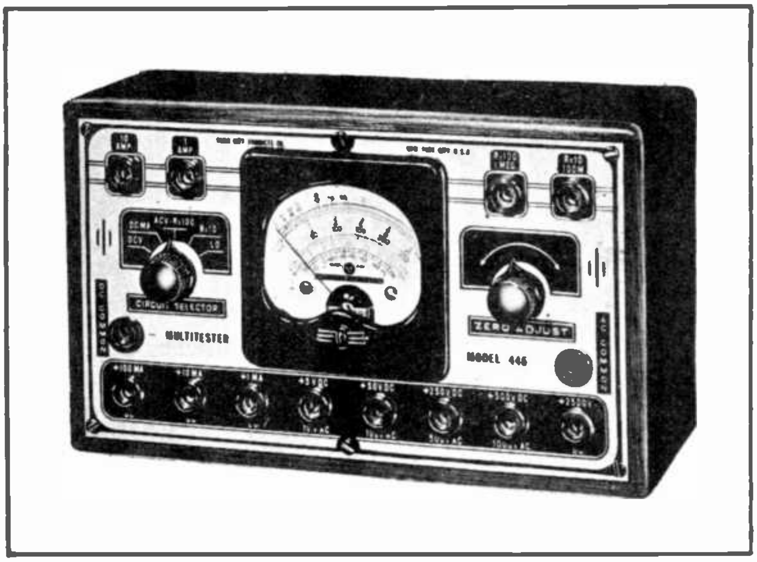


FIG. 20
ANOTHER POPULAR MULTITESTER DESIGN

The method of selecting ranges on the tester shown in Fig. 18 differs from that employed in the tester diagramed in Fig. 17, in that one tip jack is provided for the common lead connection when measuring a-c voltages, and another for the d-c ranges. The knob below the meter must be turned to the right when it is desired to make d-c measurements, and to the left for making a-c measurements. The selector switch can then be set to the same voltage positions, when either a-c or d-c voltages are to be measured.

This instrument is employed as an output meter by using the a-c voltage scale in any of its ranges, and inserting a 0.5 mfd 400-volt condenser in series with one of the test leads and the circuit across which the measurement is to be made. The chief purpose in using the instrument in this manner is to obtain an indication of the audio voltage (signal) available at the output of a receiver as a means for comparison in checking how adjustments such as alignment, etc., affect the strength of the signal reaching the loud speaker. The db scale is provided so that a-f voltages in audio amplifier circuits can be interpreted in terms of decibels; abbreviated to "db". (Note: the decibel is a unit of measurement of variations in sound intensity, and is explained in detail later in the course.)

EXAMPLE NO. 2

D-C VOLTAGE MEASUREMENT:

Another popular multitester is shown in Fig. 20. To measure d-c voltage in this case, insert one test lead into the "D-C COMMON" pin jack at the left; and the other test lead into the pin jack along the lower edge, next to which the voltage range desired is marked. The circuit selector switch at the left-center is then placed in the "DCV" position, and the reading noted on the voltage scale of the meter. In the higher ranges, the indicated voltage must be multiplied by the constant (multiplying factor) specified by the manufacturer of the instrument in the operating instructions furnished with the tester.

D-C CURRENT MEASUREMENT:

To measure current, insert one test lead into the "D-C COMMON" pin jack and the other test lead into another pin jack alongside of which the desired current range is marked. The circuit selector switch is then placed in the "DCMA" position.

A-C VOLTAGE MEASUREMENT:

To measure a-c voltages, one test lead is inserted into the "AC COMMON" pin jack at the right, and the other lead into one of the other pin jacks along the bottom of the panel, next to which the voltage range desired appears. The circuit selector is then placed in the "ACV-Rx100" position. The meter readings are multiplied by the prescribed constant when using the high-voltage ranges.

RESISTANCE MEASUREMENT:

To measure resistances of less than 500 ohms, one test lead is inserted into the "DC COMMON" pin jack and the other into the third pin jack from the left which is marked "+1MA LO". The latter marking means that this jack is to be used for both the 1 ma and the low-resistance range. The circuit selector is then set at the "LO" position, and the resistance across which the test points are connected is read directly on the dial scale. However, before making low-resistance measurements, the meter must first be adjusted to read full-scale by

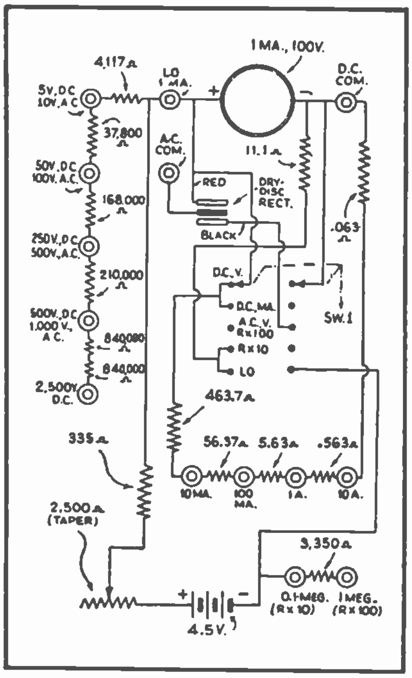


FIG. 21
CIRCUIT DIAGRAM
OF MULTITESTER

means of the control knob at the right-center of the panel labeled "ZERO ADJUST". But in this case, the design of the circuit is such that the test leads are not to be shorted together when making this adjustment. This differs from the meter balancing adjustment previously described, and is more fully explained later in the lesson.

Higher values of resistance are measured by leaving one test lead in the "DC COMMON" jack and inserting the other lead into that one of the pin packs at the upper right on the panel alongside of which the desired resistance range appears. If the 100M (100,000 ohm) range is being used, place the circuit selector in the "R x 10" position and multiply the scale reading by 10. If the 1 meg. range is being used, place the circuit selector in the "ACV-R x 100" position and multiply the scale reading by 100. For the higher resistance ranges, this meter must be adjusted for zero setting with the test leads shorted before making the measurement.

USE AS AN OUTPUT METER:

To use the instrument as an output meter, insert one test lead into the "AC COMMON" jack and the other lead into whichever one of the a-c volt jacks that corresponds to the range desired. Connect an 01 to .1 mfd condenser in series with one of the test leads, and set the circuit selector switch in the "ACV-R x 100" position. The condenser may be omitted if measurements are being taken from the secondary of an output transformer, but should always be employed when taking measurements from any circuit where a d-c component is present in order to prevent this d-c from affecting the meter reading.

USE AS A "DB" METER:

To use the instrument as a db meter, the same lead connections and circuit selector settings are used as when employing it as an a-c voltmeter, only that the decibel scale is read.

CIRCUIT BREAKDOWN

The circuit diagram of this multitester is presented in Fig. 21. The milliammeter is a 0 - 1 ma type with an internal resistance of

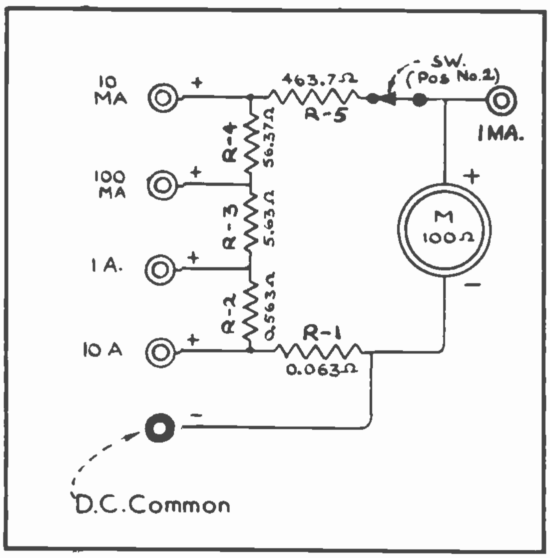


FIG. 22
D-C CURRENT SECTION

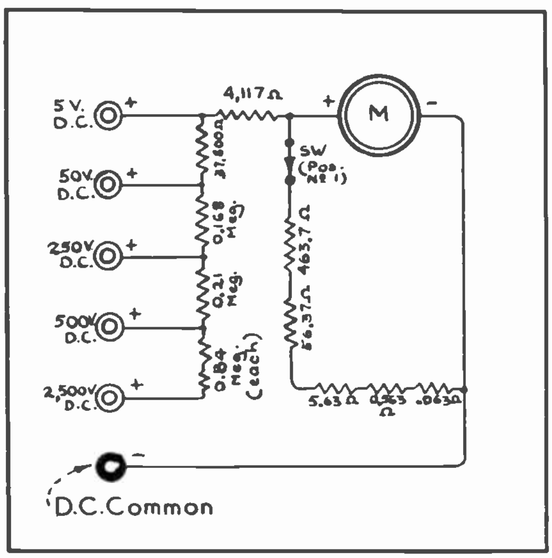


FIG. 23
D-C VOLTAGE SECTION

100 ohms, and the circuit selector is a dual switch similar to that employed in the multitester previously described in connection with Figures 17 and 18.

CURRENT-MEASURING SECTION:

This circuit can be analyzed more easily by breaking it down into sections. The current-measuring section is connected into the system when the selector switch is placed in position #2; and is illustrated in Fig. 22, with all other parts eliminated that do not pertain to this type of measurement. Here, you will observe that all of the current shunts are jointed together to form, with the 100-ohm meter, a closed circuit having a resistance of 626.3+ Ohms. Thus, when the test leads are inserted into the "DC COMMON" and "10A" jacks, the current under measurement will divide between two paths ---- one comprising only resistor R-1; the other including all of the other resistors and the meter. Then, since the path through R-1 has by far the lesser resistance, the greater portion of the current being measured flows through R-1, and not more than 1 ma through the meter.

When one of the test leads is inserted in a jack corresponding to a lower range, the shunt path increases in resistance while the path through the meter decreases; thus decreasing the current range of the multitester.

D-C VOLTAGE MEASURING SECTION:

Fig. 23 shows the arrangement employed for measuring d-c voltages. Notice that the shunt path for current measurement is left connected across the meter. This is done so that the meter sensitivity (840 ohms per volt) will be maintained on the different ranges. This feature also simplifies the construction and switching arrangement of the instrument. As will be noted from both Figs. 21 and 23, the circuit selector switch is now in position #1.

Multiplier resistors of the proper value are connected between the various voltage-range jacks and the meter circuit, in the usual manner. For example, with one of the test leads inserted in the "DC COMMON" jack, and the other in the "5V D-C" jack, the 4,117-ohm resistor will be connected in series with this jack and an effective resistance of 83 ohms comprising the 100 ohm meter and the 526.326-ohm shunt path

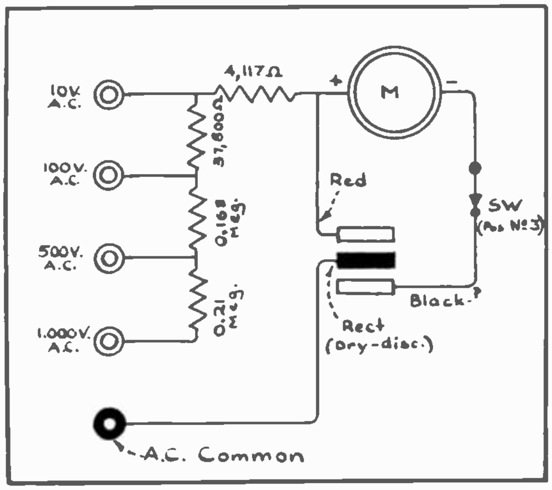


FIG. 24
A-C VOLTAGE SECTION

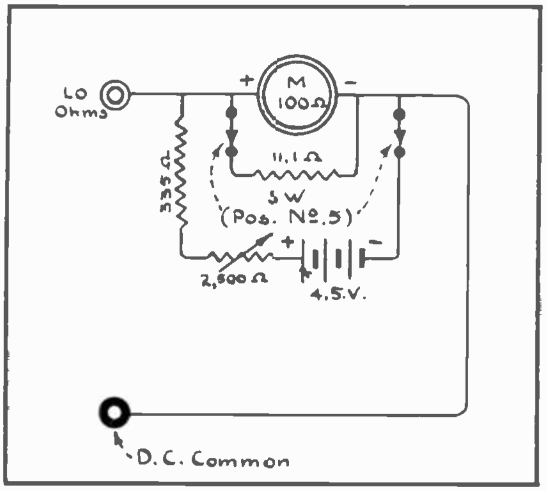


FIG. 25
LOW-OHMS SECTION

that is connected across it. This would amount to a total resistance of 4,200 ohms being included in the circuit at this time. When the 50-volt tip jack is being used, the total resistance of the instrument circuit is 42,000 ohms, etc.

A-C VOLTAGE MEASURING SECTION:

Details of the instrument circuit for making a-c voltage measurements appear in Fig. 24. This circuit is similar to that of Fig. 23, with the exception that the shunt network is automatically switched-out and the rectifier cut-in when the selector switch is set in position #3. The copper-oxide rectifier is of the half-wave type, but connected in the circuit so as to prevent inverse peak voltages of damaging magnitude being developed across the rectifier during use of the higher voltage ranges.

LOW-RESISTANCE MEASURING SECTION:

In Fig. 25 is shown the circuit arrangement when the selector switch is set in position #5 for the measurement of low resistance values. The meter is at this time shunted with the 11.1-ohm resistor to provide a 10 ma range. With the test leads inserted in the "LO OHMS" and "D-C COMMON" jacks, but not short circuited, the variable 2500 ohm resistance is adjusted until the meter reads maximum resistance on the "low-ohms" scale. Then, when the resistance being measured is connected between the "D-C COMMON" and the "LO OHMS" terminals, it will act as an additional meter shunt and thereby decrease the meter reading accordingly.

Since the resistance values on this ohmmeter scale increase in the same direction as the current values on the milliampere scale (from left-to-right), higher values of resistances being measured will cause the meter needle to come to rest farther toward the right of the scale, because less current is flowing through the resistance and more current through the movement of the meter.

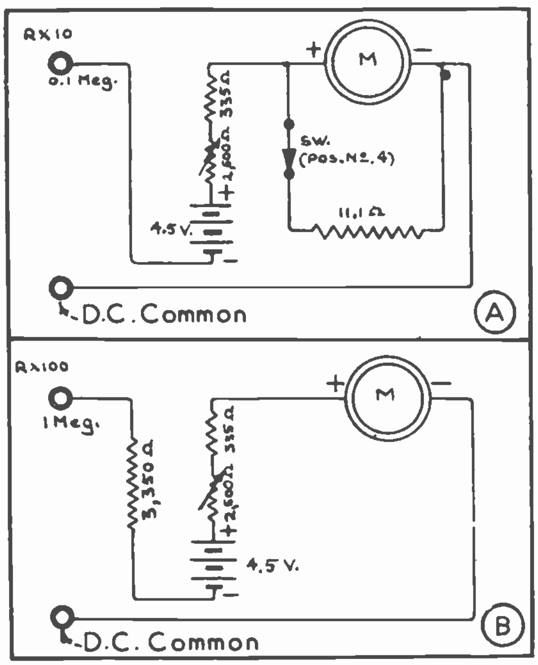


FIG. 26
MEDIUM AND HIGH-
RESISTANCE MEASURING SECTIONS

When the "LOW OHMS" scale is no longer being used, the circuit selector switch should be turned away from the "LO" position. This is necessary to prevent the dry cells from discharging needlessly through the meter and its shunts. On the particular instrument being described, a separate "LO OHMS" scale is provided so that such low resistance values can be measured accurately; readings down to 0.2 ohm being obtainable with this arrangement.

MEDIUM AND HIGH-RESISTANCE MEASURING SECTIONS:

The circuits employed for the 0.1 megohm and 1-megohm ranges are shown in illustrations (A) and (B), respectively, of Fig. 26. These two circuits are similar --- with the exception that in the case of

(A), placing the selector switch in position #4 keeps the 11.1-ohm shunt resistor connected across the meter, but the "Rx10-0.1 MEG" jack is connected in the circuit in such manner so that when one of the test leads is inserted therein, the variable resistor and the 335-ohm resistor will be connected in series with the meter and the resistance being measured, instead of in parallel with the meter.

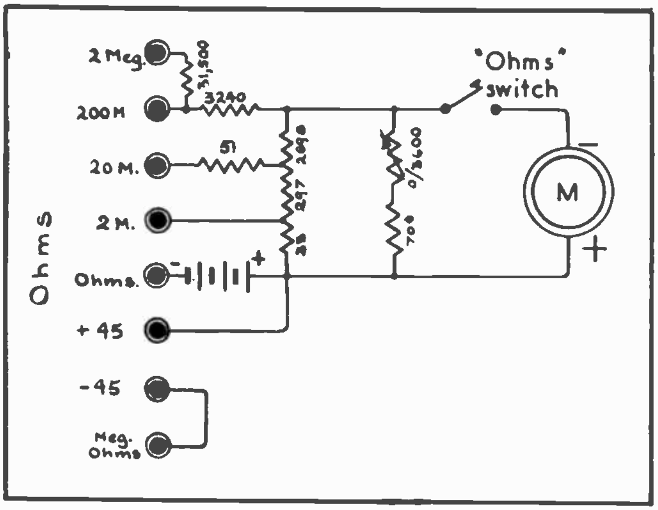


FIG. 27
INCREASING OHMMETER RANGE BY APPLYING MORE VOLTAGE

Use of the "Rx100-1MEG" jack for measuring resistance values up to 1 megohm, and placing the selector switch in position #3, disconnects the 11.1 ohm shunt from the meter; and at the same time includes an additional resistance of 3,350 ohms in series with the meter circuit and the resistance being measured.

The same as in all other ohmmeters described in this lesson, the meter must be adjusted for zero setting before using any of the resistance-measuring ranges.

This instrument is used as an output meter and db meter in the same manner as explained for the multitester described under "EXAMPLE NO. 1" in this lesson.

INCREASING OHMMETER RANGE BY APPLICATION OF MORE VOLTAGE

In Fig. 27, is shown a method that is often employed for increasing the range of an ohmmeter to the extent where a resistance of several megohms can be measured. You will find this circuit to be such that one 4 1/2 volt battery is connected in series with the common "OHMS" tip-jack for measuring resistances up to 200,000 ohms. Then, if it is desired to measure resistances as great as 2 megohms, an external 45-volt battery is connected into the circuit through the two jacks marked "+45" and "-45". Thus, by inserting one of the test leads in the jack marked "MEGOHMS" and the other into the jack marked "2MEG", a higher voltage will be available to force sufficient current through the greater resistance value so that the indication on the meter's dial scale can be read accurately.

It is extremely important that the radio technician be thoroughly acquainted with the structural features and operating principles of all types of radio testing and measuring equipment. In this way only will he be able to use such instruments effectively. With this thought in mind, make sure that you have mastered this lesson in its entirety before laying it aside.

EXAMINATION QUESTIONS

LESSON NO. 50

1. - Describe the thermocouple type meter.

2. - Mention two disadvantages of ordinary type a-c voltmeters.

3. - Explain briefly how a full-wave copper oxide rectifier may be used in conjunction with a d-c meter in order to measure a-c voltages.

4. - Describe briefly the voltmeter-ammeter method of measuring resistance.

5. - Draw a circuit diagram of a meter that can be used to measure both a-c and d-c voltages, as well as d-c current. Indicate the type of instrument used, the multipliers, shunts, etc.

6. - Describe a simple ohmmeter and explain how it is used.

7. - Why is it that resistance values increase in a right-to-left direction across most ohmmeter scales?

8. - Let us assume that you are measuring a resistor by the voltmeter method. The meter being used for the purpose has a range of 500 volts and an internal resistance of 1000 ohms per volt. While making the measurement, the "line reading" is 200 volts; and the "drop reading", 50 volts. What is the resistance value of the resistor being measured?

9. - Besides a copper-oxide rectifier, what other means may be employed so that a-c voltages can be measured with a meter that has a d-c movement?

10. - Why is it important that an ohmmeter be adjusted for "zero-setting" before measuring resistance values?

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LESSON NO. 51

WAVEMETERS AND SIGNAL GENERATORS

We start this lesson with an explanation of the WAVEMETER, which, though very simple in construction is, nevertheless, a valuable testing device for measuring the wave length of r-f energy.

WAVEMETERS

Wavemeters are most used to determine the wave length of the r-f energy being radiated by an oscillator or transmitter. In Fig. 2, is shown the fundamental circuit for this apparatus.

You will observe in Fig. 2 that the wavemeter is nothing more than an ordinary tuning circuit, consisting of an inductance or coil connected in series with a variable condenser.

By selecting the proper inductance and condenser values, this circuit can be tuned over a definite range of wave lengths. The variable condenser used for this purpose should preferably be of the straight-line wave length type, so that the wave length to which the circuit is tuned will vary in direct pro-

FIG. 1
TECHNICIAN CALIBRATING SIGNAL GENERATOR

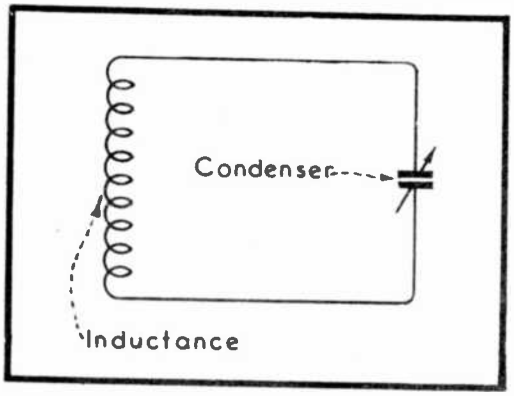

FIG. 2
FUNDAMENTAL WAVEMETER CIRCUIT

portion to the movement of the condenser plates and tuning dial indicator.

FREQUENCY METERS

Wavemeters and frequency meters are constructed alike, with the exception that the wavemeters are calibrated in wave lengths expressed in meters, whereas frequency meters are calibrated in frequencies expressed in kilocycles. It is preferable to use a straight-line frequency condenser for frequency meters so that the frequency to which the circuit is tuned will vary approximately in direct proportion to the movement of the condenser plates and tuning dial indicator. The dial used on both these instruments is generally of the vernier type in order to insure accuracy.

As you will recall from your studies of resonance circuits, the current flow through a series resonance circuit is maximum at the resonant frequency and decreases rapidly towards either side of resonance. This is the basic principle governing the operation of wavemeters and frequency meters.

RESONANCE INDICATORS

In applying a wavemeter or frequency meter, some means must be provided whereby one can determine when it is tuned to resonance with the wave in question. This can be accomplished in several different ways, the most simple of which is illustrated in Fig. 3.

You will observe in Fig. 3 that a small flashlight bulb is connected in series with the tuning circuit of the wavemeter. This method is suitable only for making a test when the r-f energy being picked up is quite strong so that a considerable voltage is induced into the coil of the wavemeter. Such is the case when conducting a test on transmitters, signal generators, etc.

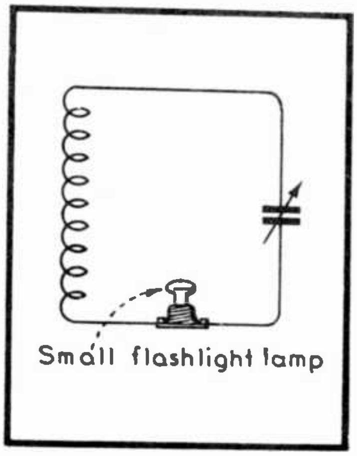

FIG. 3
LAMP RESONANCE INDICATOR

When using this set-up, the lamp will burn with increased brilliance as the wavemeter is tuned nearer to resonance with the wave under test, for the reason that current flow through the wave meter circuit increases as the resonant frequency is approached. Thus, the condition of resonance is indicated when the lamp burns at maximum brilliance.

When making such a measurement, the wavemeter should be coupled to the circuit under test as loosely as possible. That is, the wavemeter coil should be kept as far away from the circuit under test as consistent with an indication from the lamp. The looser the coupling between the wavemeter and the circuit under test, the sharper will be the tuning characteristic of the wavemeter and the greater the degree of accuracy.

COMMERCIAL WAVEMETERS

Fig. 4 will familiarize you with the physical appearance of a simple form of wavemeter. Notice that plug-in coils are used in order to cover a greater range of wave lengths and frequencies.

The more expensive wavemeters generally employ a hot-wire milliammeter as a resonance indicator, the meter being connected in series with the tuning circuit as shown in Fig. 5. The meter usually used for this purpose has a range of about 0 to 3 ma.; and a .01 mfd condenser is connected across it in order to reduce the high-frequency resistance of the circuit. Ordinarily, the resistance of the circuit to high frequencies would be increased appreciably by including the meter in the circuit.

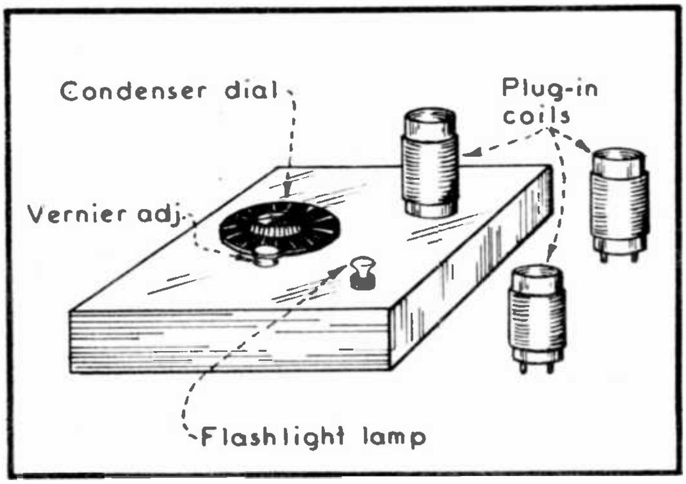

FIG. 4
COMPLETE WAVEMETER

Also observe in Fig. 5 that the wavemeter illustrated here does not require any plug-in coils. A selector switch provides three wave ranges. For instance, with the switch closed to position #1, only coil #1 will be included in the circuit. When the switch is in position #2, coils #1 and #2 are connected in series, thereby increasing the inductance; when in position #3, all three coils are connected in series, thereby increasing the inductance still more.

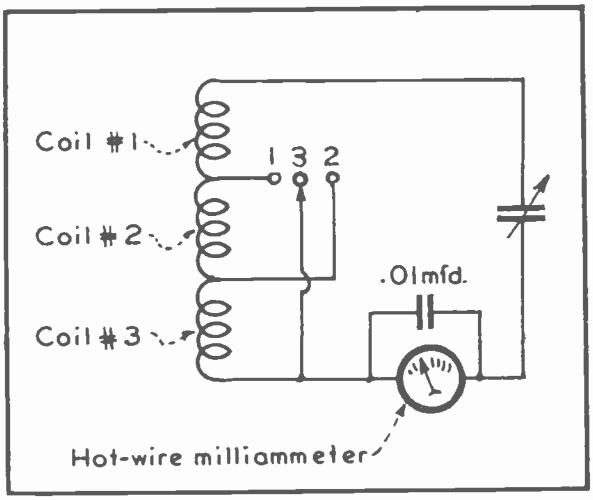

FIG. 5
WAVEMETER WITH MILLIAMMETER
RESONANCE INDICATOR

COUPLED RESONANCE INDICATORS

The chief objection to connecting any type of resonance indicator in series with the tuning circuit of a wavemeter is that such a device adds to the resistance of the circuit, causing it to tune broadly. To maintain accuracy, a wavemeter should be rather sharp tuning, and therefore the resistance of its circuit must be kept down to a minimum value. It is for this reason that the indicating device of some wavemeters is coupled to the tuning circuit inductively.

An example of this appears in Fig. 6, where the resonance indicator consists of a set of headphones used in conjunction with a carborundum crystal. This indicator circuit is coupled to the wavemeter coil inductively by means of the indicator coupling coil. The r-f energy picked up by the tuned winding from the circuit will therefore induce corresponding voltages in the indicator coupling coil. The transfer of energy will be greatest at resonance, and is indicated by maximum sound in the headphones.

The r-f wave under test must, of course, be modulated by an audio frequency in order for the signal to be heard in the headphones. The crystal acts as a detector, so making the signal audible.

Very little current is required to produce an audible sound in the headphones; and the sound increases rapidly as the wavemeter is tuned closer to resonance with the circuit being tested. Consequently, this method is very sensitive, and capable of testing comparatively weak r-f energy.

The indicator coupling coil in Fig. 6 may consist of from 1 to 20 turns of #18 B & S magnet wire, wound on a tubular bakelite form of about 2" diameter. It is placed several inches from the wavemeter's winding, but is enclosed in the same box or container.

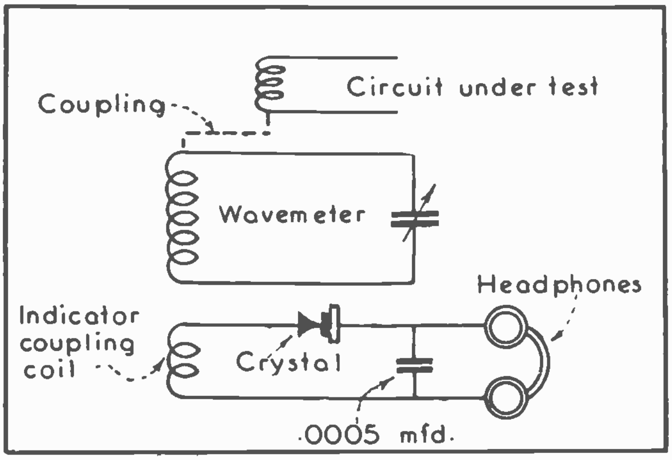

Fig. 6
Coupled Indicator Circuit

If too many turns are used on the coupling coil, and it is coupled too close to the tuned winding, it will absorb too much energy from the tuned circuit and also cause poor tuning. Too few turns on the coupling coil, and too loose coupling between it and the tuned winding, may result in such a small transfer of energy that the indicating device will not respond in a definite manner. It is therefore necessary to use as few turns as possible on the coupling coil, and only sufficient coupling between the two circuits as will result in a definite response of the indicating device.

In the event that conditions are such as to make inductive coupling between the circuit under test and the wavemeter impractical, so that hardly any energy is accepted by the wavemeter, then the desired coupling can generally be accomplished by connecting a length of wire between one end of the wavemeter's tuned winding and some convenient point on the circuit under test, as indicated by the dotted line in Fig. 6.

APPLYING THE ABSORPTION PRINCIPLE

We can also look upon the wavemeter or frequency meter as being an absorption circuit, in that it has the ability to absorb r-f energy when acted upon by such a field. This "absorbing effect" is most pronounced at the resonant frequency, and can be applied in the following manner:

If, for example, a d-c milliammeter is connected in series with the plate circuit of an oscillator, and the oscillator is tuned to a frequency of, let us say, 700 kc., a definite reading will be noted on the meter. Now, if a frequency meter is loosely coupled to the oscillator, we will find that the reading of the milliammeter in the oscillator circuit will increase as the frequency meter is gradually tuned to 700 kc. --- and that it will be maximum when the frequency meter is tuned exactly to 700 kc.

Thus, by already having the dial of the frequency meter accurately calibrated in kilocycles, it is obvious that if an oscillator is radiating energy of unknown frequency, the frequency meter could be loosely coupled to it and its dial slowly turned. Then, when the d-c milliammeter in the oscillator's plate circuit registers maximum current, we know that the oscillator and frequency meter are in resonance. And, the frequency indicated by the dial position of the frequency meter tells us the frequency of the energy radiated by the oscillator.

To determine the frequency of a signal being picked up by a radio receiver, the calibrated frequency meter can be loosely coupled to the receiver input. When the frequency meter is tuned to resonance with this same signal, a decrease in signal strength will be indicated by the receiver's loud speaker. The setting of the frequency meter's dial then tells us the frequency of the signal being received.

Although simple in construction, this type of frequency meter is quite dependable. Resistance is kept at a minimum by noting the change in the oscillator or receiver circuit instead of connecting a resonance indicator in the frequency meter circuit. Thus, greater accuracy is possible.

SIGNAL GENERATORS

Many different makes of good factory-built signal generators (test oscillators) are available on the market, yet a number of our students wish to construct their own. It is for the latter reason that this information on signal generators is presented from a construction standpoint. Even though you may not be particularly interested in constructing such a unit, yet the manner in which the subject is treated in this lesson will give you a good basic knowledge of the structural features and principles of signal generators. We shall start with the simpler designs first, and then advance through the more complex commercial units such as illustrated in Fig. 7.

FIG. 7
COMMERCIAL SIGNAL GENERATOR

BATTERY-OPERATED SIGNAL GENERATOR

The circuit of a simple battery-operated signal generator is shown in Fig. 8. You will observe that it employs a single tube. This tube may be a type 30, 1G4-G, 1H4-G or any other triode that is suitable for use as a detector or amplifier. The A battery voltage depends upon the type of tube used. In some cases, adequate resistance will have to be inserted in the filament circuit to reduce the A battery voltage to the value required by the tube filament. However, if a tube with a

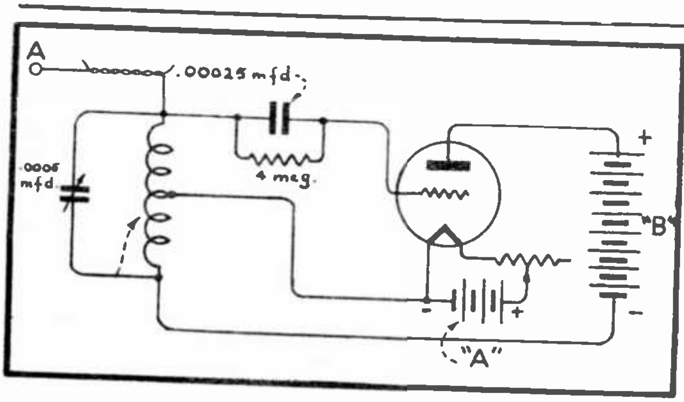

FIG. 8
BATTERY-OPERATED OSCILLATOR

1.4 volt filament rating is used, a single flashlight cell can be employed as the A supply; and no additional resistance will then have to be included in the filament circuit. A 22-1/2 volt battery is suitable as a B voltage source.

The tuned winding of this signal generator consists of 50 turns of #20 B & S double cotton-covered magnet wire, wound on a piece of insulative tubing 2-1/2" in diameter. This will permit the .0005 mfd condenser to tune the circuit through the standard broadcast band. The tap is made at the 25th turn of the winding.

By studying this diagram more closely, you will notice that half of the winding is included in the grid circuit and half in the plate circuit of the tube, so that there is very close coupling between them. This condition produces regeneration to such an extent that the circuit commences to oscillate and generate radio frequency energy just like the oscillator in a superheterodyne receiver. The frequency of these oscillations will, of course, be determined by the tuning constants of the circuit, as fixed by the coil and condenser combination.

In order for the generator's r-f signal to be audible at the receiver undergoing test, it must be modulated at an audio frequency. This is accomplished by installing a fixed condenser and leak resistor in the grid circuit of the signal generator's tube. The effect of this grid condenser and leak is to block and free the tube at an audible frequency rate, thereby modulating the r-f wave form. This modulated signal is then picked up by a receiver and reproduced by the speaker as a buzzing sound. Changing the values of the grid condenser and leak will change the pitch of the sound.

The signal generator is coupled to the receiver under test by connecting terminal "A" of the generator (see Fig. 8) to the antenna terminal of the receiver. Inside of the signal generator, one end of a short piece of insulated wire is connected to terminal "A". The end of another short piece of insulated wire is connected to one end of the generator's tuned winding. The free ends of these two pieces of wire are then twisted together for a length of from 1 to 2 inches. This twisting of the wires will introduce capacitive coupling of a comparatively low order between terminal "A" and the coil. The signal generator is therefore coupled to the receiver under test capacitively.

If preferred, a 10 mmfd. condenser could be used instead of the twisted wires to produce capacitive coupling.

110 VOLT AC-DC SIGNAL GENERATOR

In Fig. 9, we have the circuit diagram of a signal generator that can be operated from either a 110 volt a-c or d-c line. The tube used in this circuit is a double-section type, the diode section serving as a half-wave rectifier, while the tetrode section is triode-connected in a conventional oscillator circuit. If it should be so desired, the single 117L7 tube could be replaced by two separate tubes -- one a cathode-type rectifier such as the 25Z5 or 35Z5, and the other, a 6 or 12-volt triode.

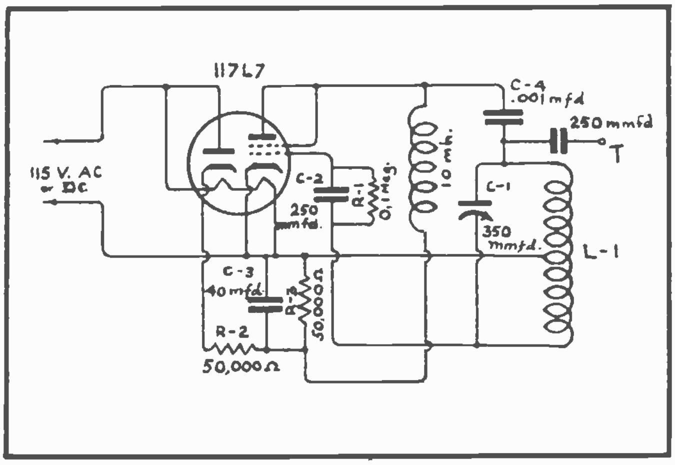

Fig. 9
Signal Generator For Operation From 110 Volt A-C or D-C Line

A suitable ballast resistor would then have to be placed in series with the filament circuit. All of the other parts values could remain as indicated on the diagram in Fig. 9.

Coil L-1 consists of 42 turns of No. 20 double silk covered magnet wire, wound on a 1-1/2 inch diameter form, and tapped at the tenth turn from the upper end.

R-2 and R-3 serve as the filter and bleeder resistors for the rectifier or d-c voltage supply circuit. C-3 is the filter condenser for this same section of the circuit. C-2 and R-1 are the usual grid condenser and leak combination. C-1 is the variable condenser, used for tuning the signal generator over the standard broadcast band.

The 10 mh r-f choke, in conjunction with condenser C-4, forces the r-f energy that is present in the plate circuit into the upper portion of coil L-1, thereby transferring it back to the grid circuit and so promoting oscillation. The signal produced by this generator is fed to the circuit under test through condenser C-5 and terminal T.

CALIBRATING SIGNAL GENERATORS

Now that you are familiar with basic signal generator circuits, the next step will be to learn how such testing equipment is calibrated. For the present, we shall consider the calibration of signal generators which are designed to cover the standard broadcast band only.

Before attempting to calibrate a signal generator, be sure that all parts and wiring are intact, that the tube voltages are correct and that all shielding is in place. Should the unit be calibrated without all shielding in place, its tuning would be affected by the proximity of the shielding later on, and the calibration would therefore be in error.

If no calibrated wavemeter or frequency meter is available, the newly constructed signal generator can be calibrated with the aid of a good broadcast receiver. To use a receiver for this purpose, it is necessary to first calibrate the receiver dial in the following manner:

Starting at the low frequency end of the dial, tune in as many of the good broadcast stations as you can until the indicator of the dial has traveled across the entire scale. As each station is tuned in by the receiver, take note of the dial setting. Write this dial number on a piece of paper, and next to it indicate the frequency at which the particular station operates. Do this for all stations heard.

Upon completion of the procedure, you will have ten or so different dial numbers at which stations are received, and the corresponding frequency in kilocycles. Let us suppose, for example, that the dial of the receiver being used is numbered from 0 to 100, and that upon tuning in the different stations, you obtain the data given in TABLE I.

TABLE I

DIAL READING	FREQUENCY OF STATION BEING RECEIVED
95	600 KC.
85	625 KC.
75	700 KC.
58	875 KC.
50	975 KC.
38	1125 KC.
30	1250 KC.
20	1400 KC.
13	1500 KC.

Using this data, you can plot a calibration curve similar to that shown in Fig. 10. To do this, use cross-ruled paper or "graph paper" --- laying off the dial numbers along the bottom, from the left toward the right; and frequencies along the left edge, from the bottom toward the top.

Then mark a point on the graph where the 95 dial number line crosses the 600 kc. line, to conform with the first reading of Table I. In the same manner, mark similar points on this graph paper to correspond with the rest of the data in Table I. Then connect all of these points together with a continuous line, to produce the "calibration curve."

By referring to such a graph, we can tell at a glance to which frequency the receiver is tuned at any one dial setting. If the receiver is equipped with a dial already calibrated in kilocycles, its settings should be carefully checked against the different station frequencies, because the dial readings are not always accurate. In fact, for this purpose, a numbered receiver dial scale is preferable to one calibrated in kilocycles --- particularly if the kilocycle dial calibrations are inaccurate.

Having calibrated the receiver dial, disconnect the receiver from its antenna and grounding system, and connect the signal generator to it. Tune the receiver to any known frequency, and adjust the signal generator's tuning dial until the generator's signal is picked up by the receiver. The signal generator will then be tuned to resonance with the receiver; its dial setting should therefore be noted.

By repeating this procedure at several different frequencies, you will have available a number of signal generator dial settings, with corresponding frequencies. From this data, a dial calibration curve can be plotted for the generator similar to that already prepared for the receiver in Fig. 10. From this calibration curve, one can quickly convert any dial setting of the signal generator to its equivalent frequency expressed in kilocycles. We then say that the signal generator has been "calibrated."

While we are on the subject of calibration, it will be well to mention a few things regarding the calibration of wavemeters and frequency meters. These units can be calibrated in a similar manner as just described for signal generators, and a suitable calibration curve plotted. In this case, it is only necessary to tune a calibrated signal generator to various known

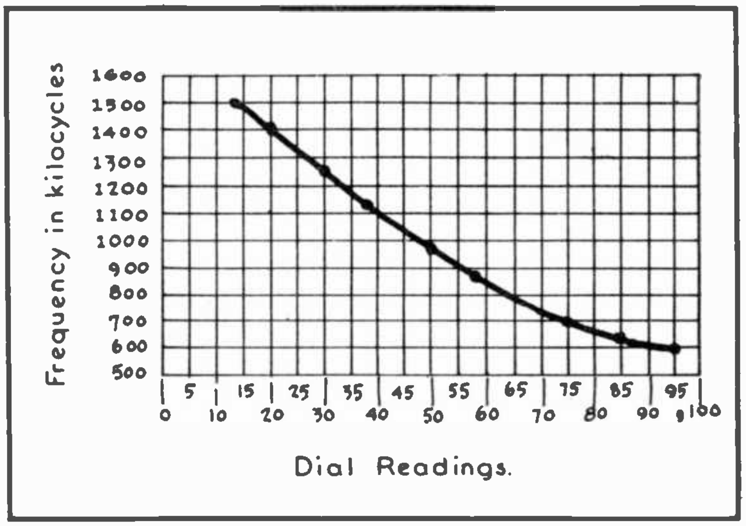

FIG. 10
DIAL CALIBRATING CURVE

frequencies. As the frequency meter is tuned to resonance with these different signals, its dial readings are noted. From the data thus obtained, the dial readings of the frequency meter can be plotted against the corresponding frequencies, and a calibration curve drawn. In the case of a wavemeter, the frequencies can be converted to corresponding wave lengths, and the calibration curve plotted on the basis of dial readings against wave length in meters.

These signal generators, which were just described, can also be tuned through the frequency range used in the i-f amplifiers of superheterodyne receivers by simply using a coil and condenser combination which will tune the circuit to the desired i-f frequency. The signal generator can then be used as an aid to align the i-f stages in superheterodyne receivers.

SELF-MODULATED, TWO-BAND SIGNAL GENERATOR

The signal generator,whose circuit is diagramed in Fig. 11, can be used for the alignment of the i-f, oscillator and r-f stages in superheterodyne receivers. The information already given on batteries and types of tubes suitable for the circuit illustrated in Fig. 8, applies also to our circuit of Fig. 11.

Coil L_1 consists of 80 turns of #26 B & S double silk-covered wire, wound on a tubular form 3" in diameter. This coil should be center-tapped at the 40th turn. Coupling coil L_3 should consist of the same wire, wound at a distance of about 1/2" from coil L_1.

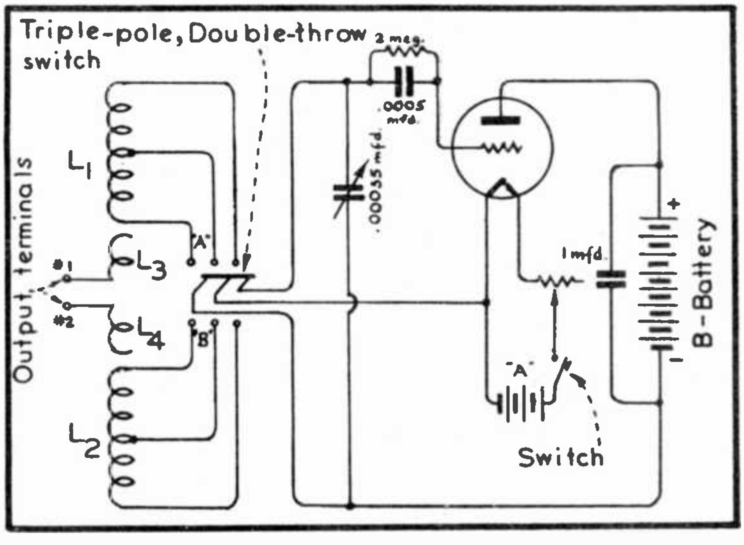

FIG. 11
CIRCUIT OF RF-IF OSCILLATOR

Coil L_2 consists of 140 turns of #30 B & S double silk-covered wire on another tubular form, having a diameter of 1-1/4". This coil is tapped at the 35th turn from the B-minus end. Coupling coil L_4 consists of 3 turns of the same wire, wound at a distance of about 1/2" from coil L_2. The winding form containing coils L_1 and L_3 should be mounted at right angles to the form containing coils L_2 and L_4 when these units are assembled in the case.

To cover the standard broadcast band (545 - 1500 kc.) with this signal generator, close the triple-pole switch to position "A", and close the filament circuit switch. Use output terminal #1 to couple the unit to the receiver under test, and tune the signal generator to the desired broadcast frequency by means of the .00035 mfd tuning condenser. The signal generator will of course require "calibration" over this frequency band, as already explained in this lesson.

To tune over the 440 - 510 kc. band for adjusting i-f transformers of superheterodyne receivers, close the triple-pole switch to position "B", and also close the filament circuit switch. Use output terminal #2 to couple the test unit to the receiver, and adjust it to the desired intermediate frequency by means of the .00035 mfd tuning condenser.

The dial setting required for this condenser, in order to tune to the various commonly used intermediate frequencies, can be determined by calibrating the tester with any good commercial signal generator of standard make. For example, with the i-f transformers of a superheterodyne receiver adjusted to exactly 456 kc., with the aid of a reliable commercial signal generator, couple your newly constructed signal generator to the i-f stages of the same receiver, and adjust its tuning condenser until the signal is reproduced by the receiver's speaker at maximum intensity. Your signal generator is then tuned to 456 kc., so note and mark its dial setting for future reference. The signal generator can be calibrated for any other intermediate frequency within its range, in the same manner.

COMMERCIAL SIGNAL GENERATOR

The circuit diagram of a commercial type signal generator is presented in Fig. 12. This signal generator is designed to cover a frequency band of 125 to 1500 kc., inclusive. Coil "A" can be tuned from 125 to 450 kc., and ooil "B" from 450 to 1500 kc.; a band selector switch being used to include the proper coil into the circuit for the frequency desired. The design of the coils used is such that they are tuned by a two-gang variable condenser having a capacity of .00035 mfd per section, and with the two sections connected in parallel.

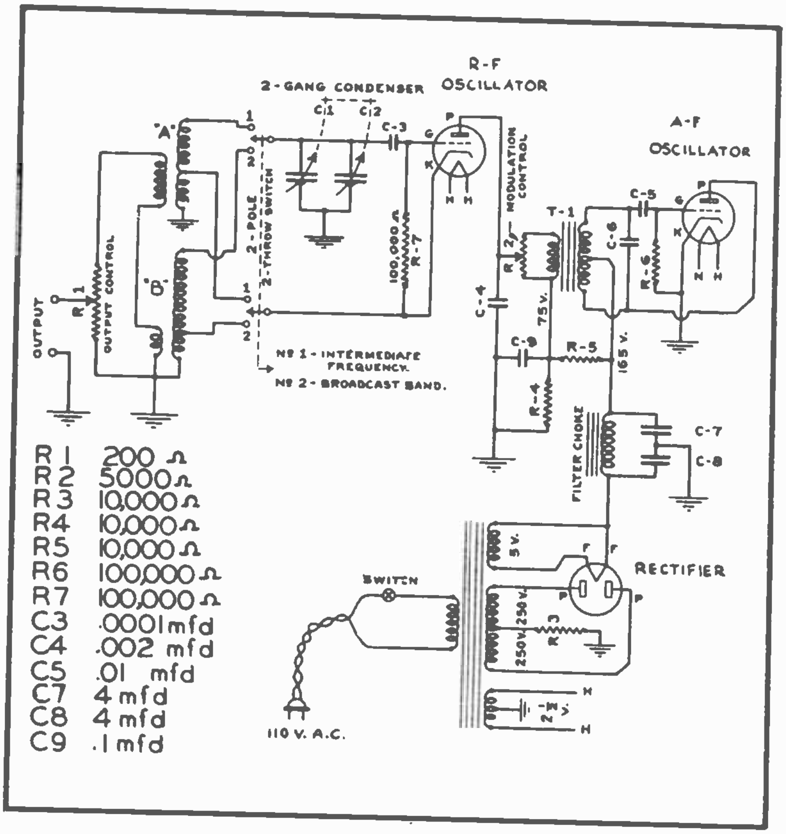

FIG. 12
CIRCUIT OF COMMERCIAL SIGNAL GENERATOR

The method of modulation is quite different from that employed in the other signal generators thus far shown you in this lesson. That is, instead of the r-f signal being modulated by a grid condenser and leak resistor, an audio oscillator is used for the purpose. The audio oscillator produces a 500 cycle note, which frequency is present in the secondary winding of transformer T-1. The primary winding of this same transformer is connected in series with the plate circuit of the r-f oscillator tube; thereby varying the plate voltage of the r-f oscillator tube at a 500 cycle rate. By this means, the r-f signal is modulated at 500 cycles per second, and the modulated signal appears across the output terminals.

Potentiometer R-1 permits control of the intensity of the output signal. Potentiometer R-2 makes it possible to control the strength of the audio signal prior to applying it to the r-f oscillator circuit, in this way governing the degree or percentage of modulation. When aligning a receiver, these two potentiometers are adjusted so that a clear and distinct signal is produced by the loud speaker of the receiver.

Upon inspecting the audio oscillator section more closely, you will observe that its circuit is quite similar to that of a conventional r-f oscillator, in that a portion of the signal energy present in the plate circuit is returned to the grid circuit through the tapped transformer winding that couples these two circuits together. However, since the inductance of this winding is rather high, the circuit oscillates at an audio frequency instead of at a radio frequency. The capacity value of condenser C-6 that is connected across the secondary winding of the audio transformer, together with the inductance value of this transformer winding, determines the frequency at which this circuit oscillates. This frequency may be altered somewhat by changing the value of condenser C-6.

The feed-back winding in the r-f oscillator section of the signal generator is connected in series with the tube's cathode. The same value of plate current flows through this winding as if it were connected in the plate circuit, and thus serves to promote oscillation.

Any heater-type triode, suitable for operation as either a detector or amplifier, may be used in both the r-f and a-f oscillator sections. The 56, 76 and 6C5 are typical examples. The power supply is conventional, the power transformer being equipped with secondary windings suitable for the tubes being used.

It is to be noted that resistors are included in the circuit for reducing the output of the power supply to approximately 75 volts for application to the r-f oscillator tube. This is done to prevent excessive heating of the tube elements and frequency drift resulting therefrom.

Obviously, the range of frequencies covered by this signal generator can be increased by incorporating an additional coil in the r-f circuit, and using a three-section band selector switch instead of the two-section switch now being employed.

The circuit arrangement illustrated in Fig. 12 is used in many commercial signal generators, whether operated from the lighting circuit or batteries.

Having studied this lesson, you should now have a good understanding of the structural features of wavemeters, frequency meters and signal generators. In another portion of the course you are given specific information on the use of this test equipment in radio practice. For the present, we are concerned only with the circuits and operating principles of these testers.

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EXAMINATION QUESTIONS

LESSON NO. 51

1. - Describe the basic principles of the wavemeter.

2. - What is the difference between a wavemeter and a frequency meter?

3. - Explain the action of the wavemeter when a lamp is used as a resonance indicator.

4. - What is the chief advantage of using electromagnetic coupling between the wavemeter and resonance indicator circuit instead of connecting the resonance indicator directly in the tuning circuit of the wavemeter?

5. - Draw a circuit diagram of a battery-operated signal generator.

6. - Explain how the signal generator you diagramed in answer to question #5 operates.

7. - Mention two methods by which the r-f energy produced by a signal generator may be modulated.

8. - Explain how you would calibrate a receiver dial which is marked in numbers from 0 to 100, so that its readings can be easily converted to equivalent frequencies expressed in kilocycles.

9. - How can you calibrate a newly constructed signal generator to cover the standard broadcast band, using a radio receiver for the purpose?

10. - Draw a circuit diagram of a simple signal generator which can be operated from either a 110 volt a-c or d-c lighting circuit.

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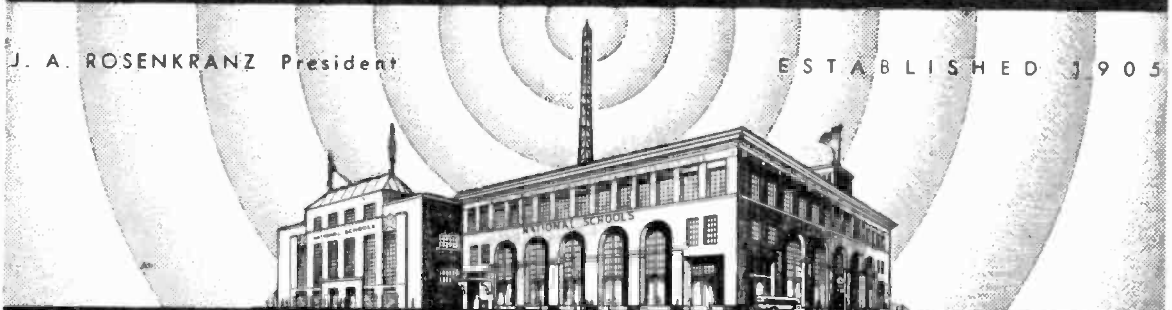

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LESSON NO. 52

TUBE CHECKERS

Of all the parts contained in radio receivers, amplifiers and other electronic equipment, TUBES are the most fragile. They are subject to mechanical breakdown if abused through careless handling, and become less efficient with continued use.

Whenever a receiver does not operate properly, the average radio-owner glances at the tubes first of all. And if he finds thatthe

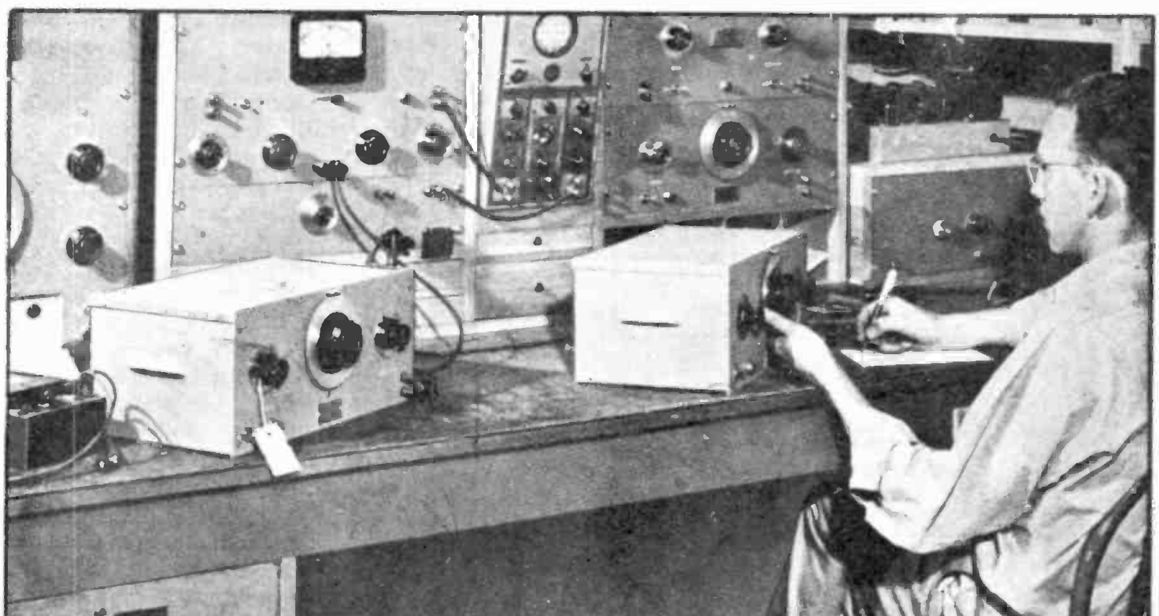

FIG. 1
YOUR KNOWLEDGE OF TESTING EQUIPMENT IS
APPLICABLE TO RADIO SERVICE, RESEARCH AND PRODUCTION WORK

filaments light up o.k., he assumes that they are in good condition and immediately suspects some other part of the circuit as being at fault.

But you, as a technician, must understand that just because the filament heats to incandescence, this does not necessarily mean that the tube is good. Even though the filament be intact, the tube may fail to perform properly because of a short between its electrodes, poor electron emission, or other causes that will be brought to your attention later in this lesson. Furthermore, it must be remembered that the filament is not visible in some types of tubes (notably metal tubes); whereas in other cases, the current normally drawn by the filament is so small that the glow of the filament is hardly perceptible.

It is therefore apparent that a more reliable method for determining a tube's condition must be employed---so we use a tube checker for the purpose.

Commercial tube checkers of so many different designs have been manufactured in years past that it would be impossible to describe all of them in this lesson. We will therefore confine our discussion solely to the types of tests performed on standard tube checkers of the most popular makes. In this way, you will become acquainted with the fundamental principles employed in all of them, and thereby be enabled to figure out for yourself any minor variations in some specific instrument that you may encounter later on.

TEST FOR SHORTED ELECTRODES AND FILAMENT CONTINUITY

To avoid damage to the checker, it is advisable to first test tubes for short circuits that might exist between their electrodes. Most tube checkers have the necessary provisions incorporated in them with which to do this; but before considering such tube checkers in their entirety, we will first explain the principles employed in making tests of this kind.

OHMMETER METHOD

In Fig. 2, you are shown how an ohmmeter may be used for testing between the grid and cathode of a tube, for a possible short. If the grid and cathode should be shorted together, the ohmmeter will read zero or very nearly zero ohms---depending upon how complete the shorting effect is. By this same means we can test between the plate and grid, between the cathode and heater, or between any other pair of electrodes.

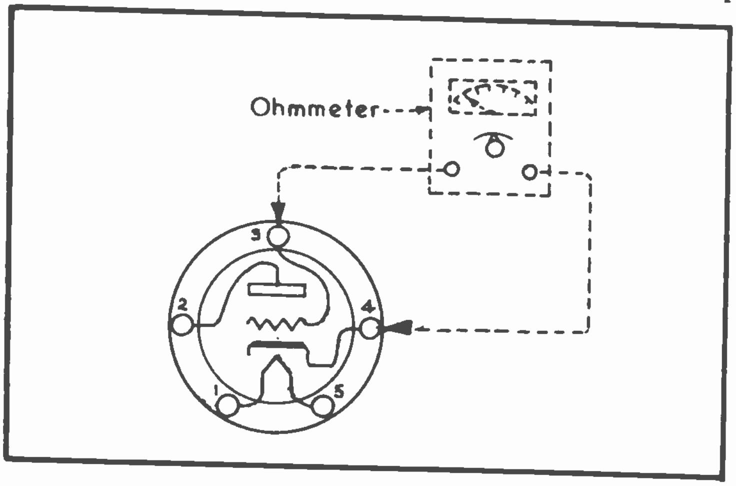

FIG. 2
OHMMETER TEST FOR SHORTED TUBE ELECTRODES

The ohmmeter can also be used to determine whether or not the filament of the tube is open (burned out), by connecting the test leads across the filament (heater) terminals. However, care must be taken when doing this so that the voltage applied across the filament will not exceed that for which it is rated. This is particularly true of tubes which are designed for a filament emf of 1.4 volts.

LAMP METHOD

Fig. 3 illustrates how a lamp may be applied as an indicating device for the same purpose. Here, a flashlight or dial lamp is used in conjunction with a battery whose voltage corresponds to that for which the lamp is rated. Thus, when the test points are shorted together, the lamp will burn at full brilliance.

The lamp connections illustrated in Fig. 3 will test for a short circuit between the plate and filament of the tube---the lamp lighting only if a short exists. But, as the ohmmeter, this test can be applied between any pair of electrodes by merely connecting the test leads across the proper terminals. And, as in the case of the ohmmeter test, care must be taken not to apply a voltage across the filament that exceeds its rating.

It is further to be understood that when conducting either the ohmmeter or lamp test, the socket must be free of all other circuit connections that might affect the indications of the test. Instead of installing the tube in a socket, these same tests can be made by touching the test points of the indicating device directly to the base prongs of the tube.

VOLTMETER METHOD

The same procedure, as just explained, can also be employed by substituting a d-c voltmeter of the proper range for the lamp in Fig. 3; and then using the voltmeter as a conventional continuity tester.

NEON TUBE METHOD

Fig. 4 shows how a neon tube may be used to test between tube electrodes for a short circuit. If the grid and cathode of the tube should be shorted when the connections illustrated in Fig. 4 are made, the neon lamp will glow. If these electrodes are not shorted together, the neon tube will not be affected. In this case, too, the test can be made between any pair of electrodes.

SHORT CIRCUIT TEST APPLIED TO TUBE CHECKER

Obviously, in order to apply the short circuit test to tubes conveniently, it is advisable to provide this feature in the tube checker. There are several ways in which this is done, a simple one being illustrated in Fig. 5.

By studying Fig. 5 closely, you will observe that we have here a socket, the terminals of which are connected to the 115-volt secondary winding of a transformer and neon lamp through two sets of single pole-double throw switches. Each switch also has a dead-center or neutral position.

With this checker, it is possible to test tubes for an inter-electrode short when either in a hot or cold

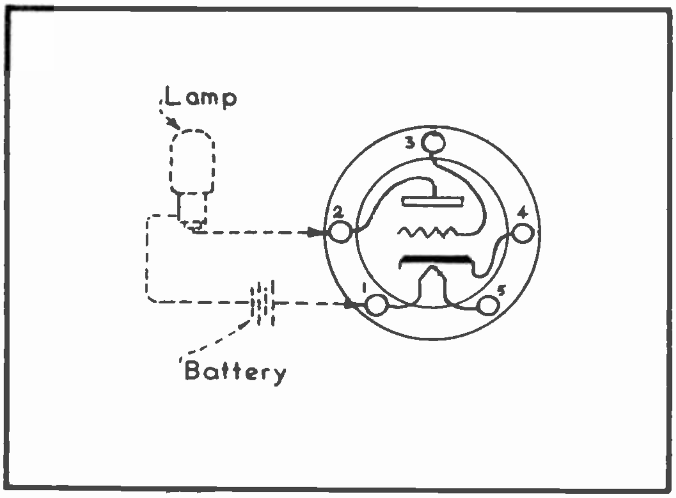

FIG. 3
LAMP TEST FOR SHORTED TUBE ELECTRODES

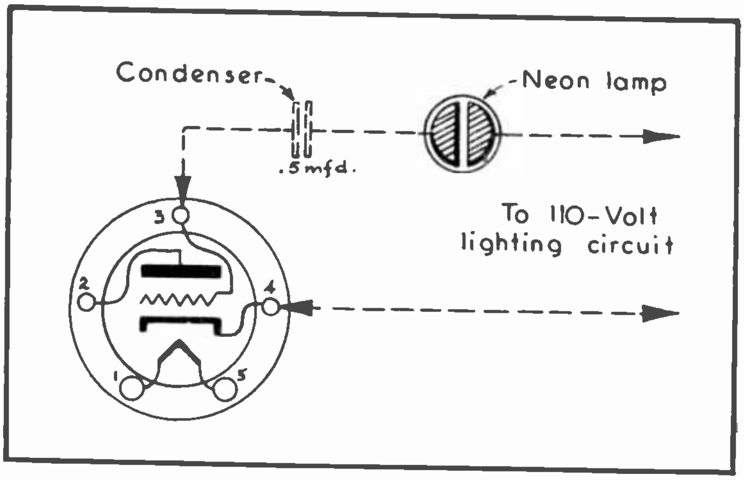

FIG. 4
TESTING FOR SHORTED ELEMENTS WITH NEON TUBE

condition (filament lighted or extinguished). A so-called "cold" short test is made by closing switch Sw-1 and placing the selector switch Sw-2 in its lowermost position, at which time it will be connected to the bottom or zero-volt end of the secondary winding. Then if it is desired to test for a short between the grid and cathode, all of the other switches are left in their center or neutral position, with the following exceptions:

Switch 3A is closed upward, while switches 4A and 4B are both closed downward-- as illustrated by the dotted connections in Fig. 5. This will place the secondary winding of the transformer, neon lamp, condenser, and grid-cathode capacitance of the tube in series with each other. Hence, if the grid and cathode should be shorted together, the neon lamp will glow; if not shorted, the neon lamp will not glow.

A "hot" test for a possible short between the grid and cathode is made by placing switch Sw-2 in that position which will furnish the proper filament voltage to the tube being checked--6.3 volts in the example illustrated in Fig. 5. All other switches are left in the positions described above; in addition, switches 1A and 5B are closed upward, and 5A downward.

There is an advantage in testing for inter-electrode shorts when the tube is heated to normal operating temperature, since expansion of metal parts due to heat may cause shorts to appear which do not show up when the tube is tested cold.

Only slight revisions are necessary to conduct these same tests on six, seven and eight-prong tubes; the only requirements being that corresponding sockets be supplied, together with the additional switches and wiring so that the test can be performed between a greater number of electrodes. However, regardless of the type of socket employed, the principles described relative to Fig. 5 still apply. This will become more evident later in this lesson.

EMISSION TEST

After a tube has been checked for inter-electrode shorts, it should next be subjected to a test that will show the quality of the tube with respect to its ability to perform satisfactorily in a radio circuit. The "emission test" is the simplest method for doing this, and is most used in commercial tube checkers. This test is based on the fact that the ability of a heated cathode (or filament) to emit electrons decreases as the tube nears the end of its useful life.

The fundamental circuit for making an emission test appears in Fig. 6, where it will be noted that all of the electrodes, except the cathode, are connected to the plate. The heater is then operated at normal voltage, and a positive emf of approximately 30 volts is applied to the plate. After the filament has come up to operating temperature, the plate current is read on the milliammeter. A reading which is appreciably below that obtained when checking a perfect tube of the same type, under identical conditions, indicates that the tube undergoing test is no longer capable of emitting a sufficient number of electrons to operate efficiently. If the tube should be shorted when this test is made, the plate current may be so great as to burn out the meter. This is why it is advisable to make the short circuit test first.

Although battery symbols appear in Fig. 6, as well as in several of the fundamental circuits that follow, it is to be noted that batteries are not actually employed in commercial tube checkers. The symbols are used here solely to designate the presence of the various potentials necessary for conducting the test---irrespective of how they may be supplied.

The emission test is not altogether reliable, in that coated filaments or cathodes often develop active spots from which the emission is so great that the relatively small grid area adjacent to these spots cannot control the electron stream. Under such conditions, the total emission may indicate the tube to be normal, while in reality it is unsatisfactory for further service. On the other hand, coated filaments are capable of so much emission that the tube will often operate properly after emission has dropped far below the original value.

To simplify matters, many tube checkers of this type have their meter scale divided into colored sections marked "Poor Tube" and "Good Tube", instead of in numbers, as in Fig. 7--or in some similar manner. Thus, when the needle comes to rest in one of these colored areas, it gives a satisfactory indication of the condition of the tube.

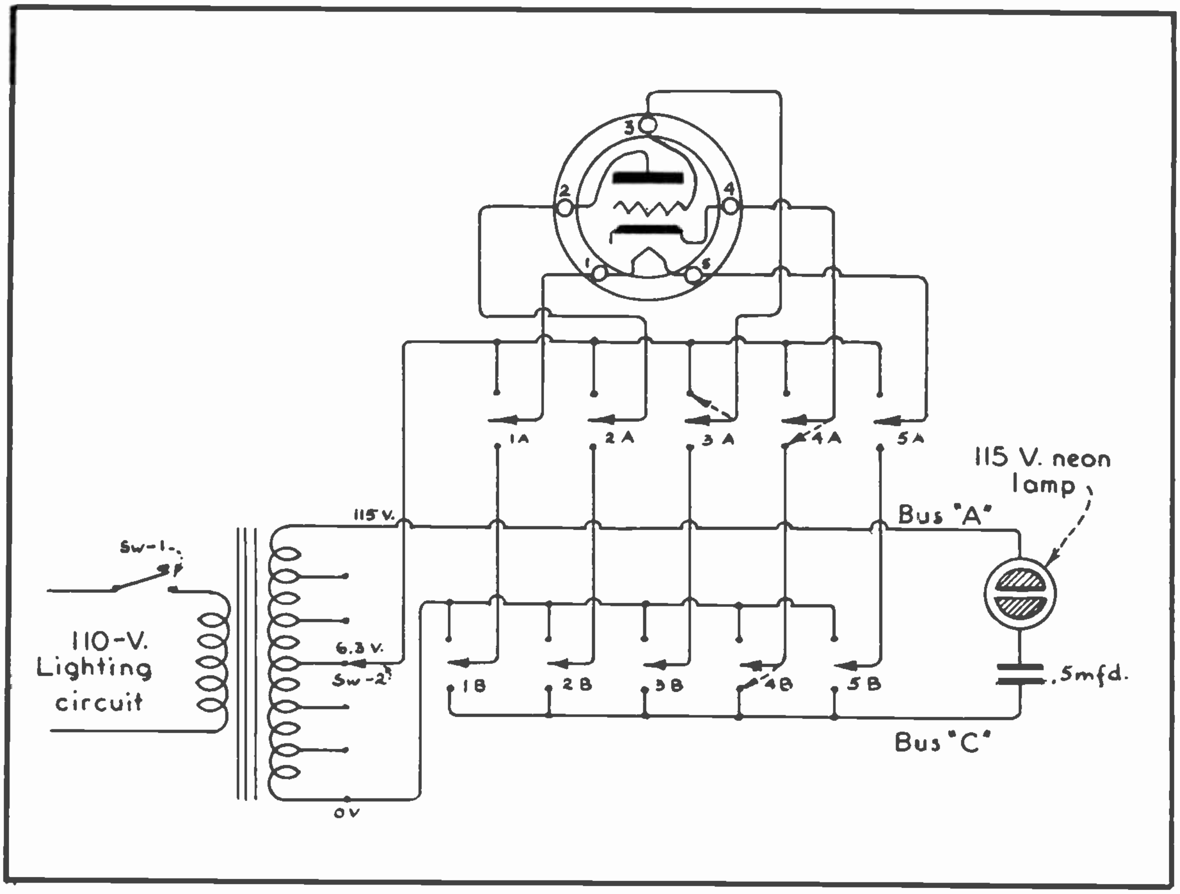

FIG. 5
SHORT CIRCUIT TEST APPLIED TO TUBE CHECKER

STATIC TRANSCONDUCTANCE TEST

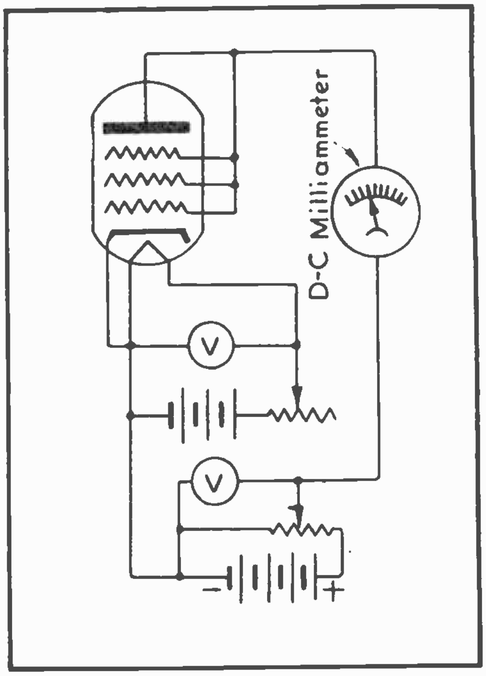

FIG. 6
EMISSION TEST

Fig. 8 shows a circuit set-up with which a static transconductance test can be made. To make this test, rheostat R-1 and potentiometers R-2, R-3 and R-4 should be adjusted so that the filament, plate, screen and bias voltages will all correspond to the values normally used when the tube is being operated in a radio circuit. The switch in Fig. 8 is closed in the "down" position, to begin with.

A definite plate current will flow when these voltages are applied to the tube. This plate current value can very easily be compared to that specified by the tube manufacturer for the same type of tube when operated under identical conditions. To some extent, this in itself is an indication of how well the tube will function in a radio circuit.

The next step is to change the grid bias and observe the resulting change in plate current as indicated by the milliammeter. To do this in the circuit appearing in Fig. 8, simply close the switch in the "up" position. The volt-drop developed across potentiometer R-5 will now be added to the bias formerly impressed on the tube's grid; thereby increasing the bias accordingly.

To illustrate this, let us assume that R-5 has been adjusted to produce a drop of 1 volt. This increased bias will reduce the plate current, the new value being indicated on the milliammeter. The transconductance is then determined by means of the conventional formula:

$$\text{Transconductance} = \frac{\text{Change in plate current produced}}{\text{Change in grid potential producing it}}$$

For example, let us suppose that when testing a tube in Fig. 8 we find that with the switch closed downward, a bias of -3 volts is impressed on the grid; and that the plate current is 6 ma. Then, let us assume that upon closing the switch upward, the grid bias becomes -4 volts and that the plate current drops to 5 ma.

From this, it is apparent that a change of 4 minus 3 or 1 volt in bias voltage produced a change of 6 minus 5 or 1 ma. (.001 amp.) in plate current. Substituting these values in our formula, we have:

$$\text{Transconductance} = \frac{.001}{1} = .001 \text{ mho or } 1000 \text{ micromhos.}$$

(Note: It is common practice to express the transconductance of tubes in terms of micromhos, one micromho being equal to .000001 mho.)

The transconductance obtained in this way can then be compared to that specified by the manufacturer for a new tube of the same type, and the worth of the tube thus judged. This is sometimes called the "mutual conductance" or "grid-shift" method of testing tubes; and is employed in some commercial tube checkers.

So that the technician need not stop to work out the transconductance formula for the tube being tested, some manufacturers of tube checkers supply a chart which specifies the desirable plate-current change for the different types of tubes when tested in their checker. Therefore, one need only note the two milliammeter readings obtained during the test, subtract one from the other and compare this difference (change) with that appearing on the chart.

This test provides a sufficiently accurate check in the majority of cases, but it isn't absolutely "fool proof" in judging a tube's ability to work correctly under operating conditions. Sometimes, such a check will show a tube as being "perfect", yet it may fail to function satisfactorily when subjected to the signal voltages as they exist in the circuit in which it is to be used.

DYNAMIC TRANSCONDUCTANCE TEST

The fundamental circuit in Fig. 9 illustrates how a dynamic transconductance test can be made. This is superior to the static transconductance test, in that an a-c voltage is applied to the control grid so that the tube is tested under conditions approximating those encountered in operation. These are often called "dynamic tube testers"

The alternating component of the plate current is read by means of a special a-c milliammeter; and transconductance of the tube is then equal to the a-c plate current divided by the input signal voltage. In other words, if a one-volt RMS signal is applied to the grid, the plate current reading in milliamperes multiplied by one thousand will be the transconductance in micromhos.

Now that we have investigated the basic principles used in conventional tube checkers, let us next study the circuits of complete tube

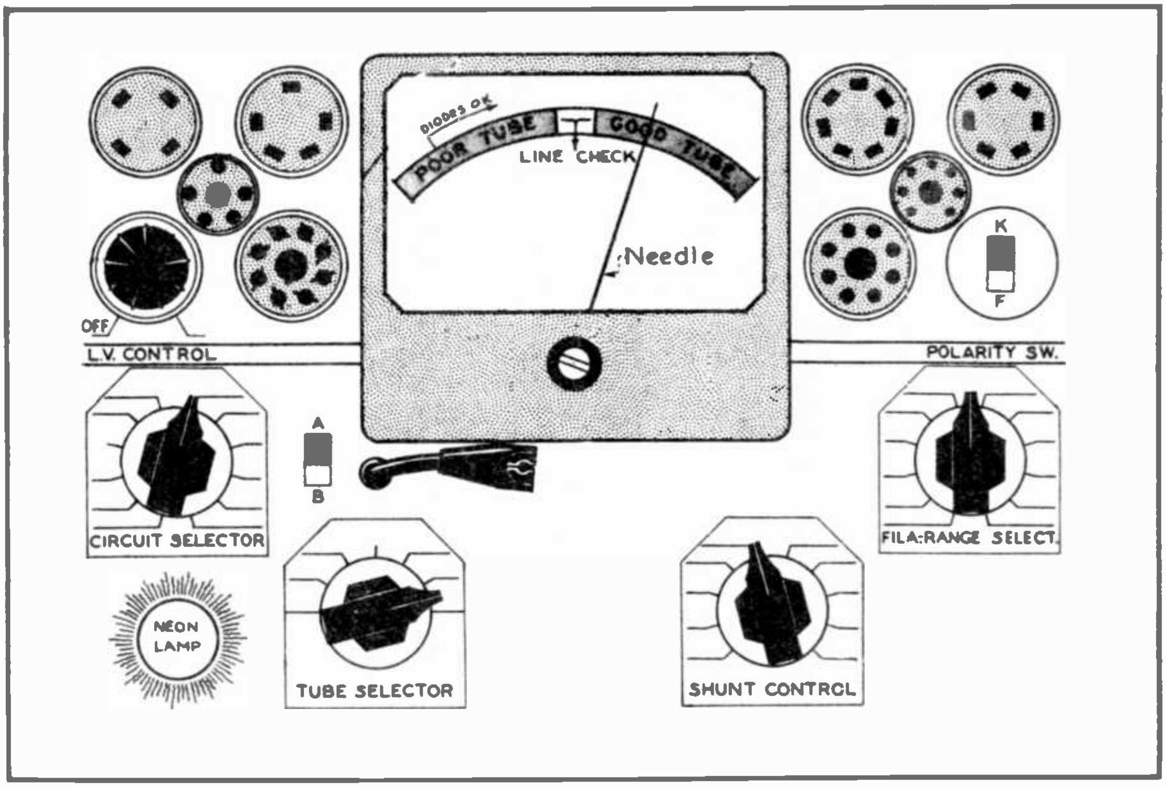

FIG. 7
SIMPLIFIED TUBE CHECKER SCALE

checkers and learn how many different types of tubes can be tested thereon.

TUBE CHECKER FOR EMISSION TEST

In Fig. 10, we have the circuit diagram of a tube checker of simple design that checks tubes by means of the emission test previously described. You will no doubt recognize this circuit as being fundamentally the same as that shown in Fig. 5 of this lesson, but with the necessary additions incorporated therein to make possible the emission test as well as tests for inter-electrode shorts. Provisions are also included for testing tubes with many different base arrangements.

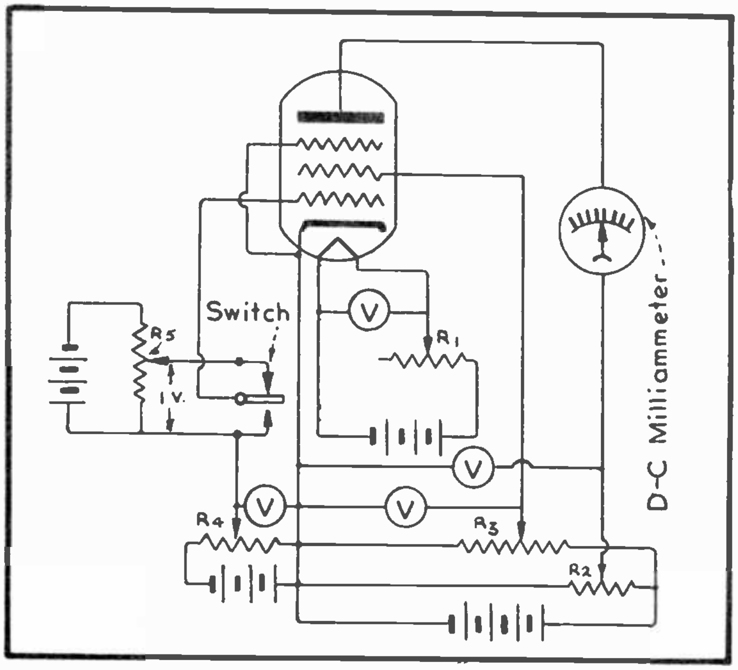

FIG. 8
STATIC TRANSCONDUCTANCE TEST

For the purpose of clarity, we show only standard six and eight-prong sockets connected to this tube-checking circuit. However, the other sockets necessary in order to test all of the different types of tubes now on the market would be wired into the circuit in the same manner as those illustrated. That is to say, the various terminals of the other sockets would then simply be connected to the numbered terminal of the tester in accordance with the standard numbering system of tube base prongs; as, for instance, base prong #1 to checker terminal #1, base prong #2 to checker terminal #2, etc.

This tester is versatile in design for the reason that the independent switches permit connection into either the meter or neon tube circuit any of the tube electrodes, regardless of the tube's base arrangement. The arm terminal of switch 9A is connected to a flexible lead, to the end of which is attached a control grid cap clip for tubes that require its use.

The filament voltage suitable for the tube being tested is secured from the secondary winding of the transformer by setting the selector switch Sw-11 at the proper position. The 5000-ohm variable resistance at the lower end of the transformer's secondary winding provides a means for securing filament voltages of less than 1.5 volts whenever this is necessary. Switch Sw-12 must be open when the 5,000-ohm rheostat is in use, and closed so as to short out the rheostat when selector switch Sw-11 is set for voltages of 1.5 or more.

Switch Sw-13 is the conventional off-on switch. The 115-volt pilot lamp serves to light up a red bull's eye when the checker is turned on. When switch Sw-14 is closed upward, it connects the neon lamp into the circuit and disconnects the meter. When switch Sw-14 is closed downward, it connects the meter into the circuit and disconnects the neon lamp.

The meter, which has a range of 0-50 milliamperes, is shunted by a 25-ohm rheostat; and also has a 60-ohm resistor connected in series with it when switch Sw-15 is closed upward. When switch Sw-15 is closed downward, the shunt is disconnected from the meter and the 60-ohm series resistor is shorted out. The purpose of the shunt and series resistor is to protect the meter when mercury-vapor tubes are tested, as such tubes pass appreciable current.

To illustrate how this checker is used, let us go through the procedure employed when testing a type 6A8 tube.

First, we insert the tube in the octal socket as illustrated in Fig. 10, apply the grid cap clip and place switches #1 to 9 inclusive (both rows) in their center or neutral position. Next, set selector switch Sw-11 to the 6.3-volt position; and since the filament of this tube is connected to prongs #2 and #7, close switches No. 2A and 7B upward and switch No. 7A downward. This will apply 6.3 volts across this tube's filament after the checker has been turned on, and so bring the tube up to normal operating temperature.

SHORT CIRCUIT TEST

Close switch Sw-14 upward to place the neon lamp in the circuit, and close switch Sw-13 so as to set the checker in operation. To test for a short circuit between the cathode (pin #8) and grid No. 1 (pin #5) close switch No. 5A upward, and switches No. 8A and 8B downward.

This places the grid-cathode capacitance in series with the neon lamp and the high voltage circuit so that if a short circuit should exist between these two electrodes, the neon lamp will glow. To test for a short between grid No.1 (pin #5) and grid No. 2 (pin #6), leave switch No. 5A closed upward, return switches No. 8A and 8B to neutral (center), and close switches No. 6A and 6B downward. This will place the high-voltage neon lamp circuit in series with these two grids, so that if there should be a short between them, the lamp will glow. By following this same procedure, one can test for a short circuit between any pair of electrodes desired. It will be noted that the numbering of the individual circuit-selector switches corresponds with the standard base-prong numbering system for tubes.

Since the filament of the tube was in operation during the test just described, this constitutes what we commonly call a "hot" short test. The same test could be made with the filament cold, if we suspected an intermittent short, by merely placing the filament circuit switches in their neutral position and continuing with the inter-electrode short circuit tests, in the manner already explained.

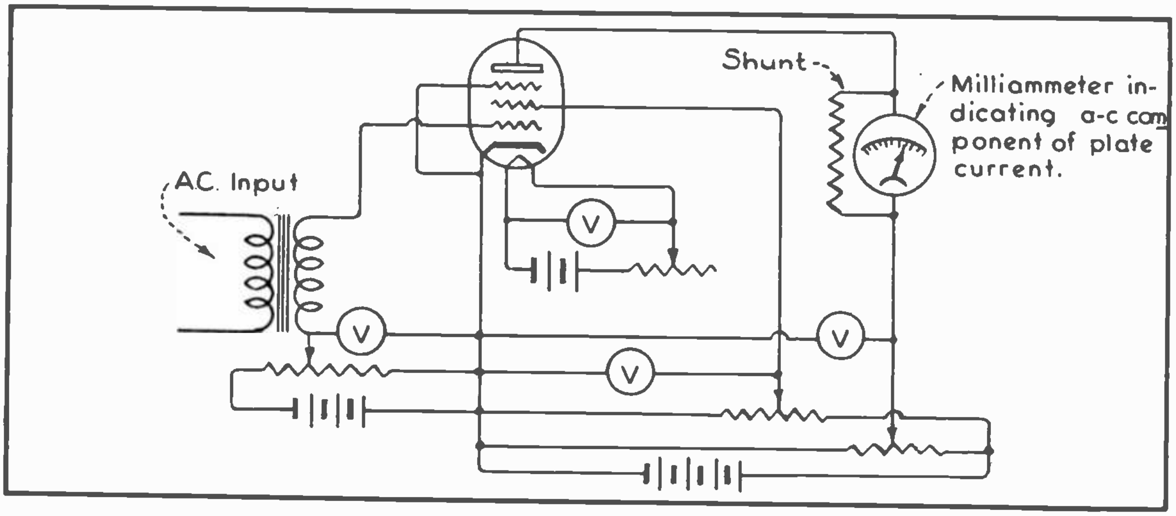

FIG. 9
DYNAMIC TRANSCONDUCTANCE TEST

EMISSION TEST

To perform the emission test, start with switches No. 1 to 9 inclusive (both rows) in the down position. Then, close switches No. 2A, 7B and 8B upward, and close switches Sw-14 and Sw-15 downward. All grids will now be shorted to the plate through bus C, and the meter will be connected in series with the plate circuit and 30 volts supplied by the transformer. The meter reading is then noted and compared with what it should be for this same type of tube when in first-class condition. (Note: the tube being tested acts as a rectifier so that a direct current will flow through the meter even though an a-c voltage is supplied to its plate).

Variations within 15% to 20% of the reading for a perfect tube are considered as indicating that the tube under test is normal. Tubes giving a reading of 40% less than the criterion are classed as doubtful, while those resulting in a reading of less than 50% of the criterion should be rejected and replaced with a new one.

Instead of being calibrated in milliamperes, the scale of the meter used in this type of instrument may be divided into colored bands as previously explained. The length of each band then allows for the permissible variations mentioned above.

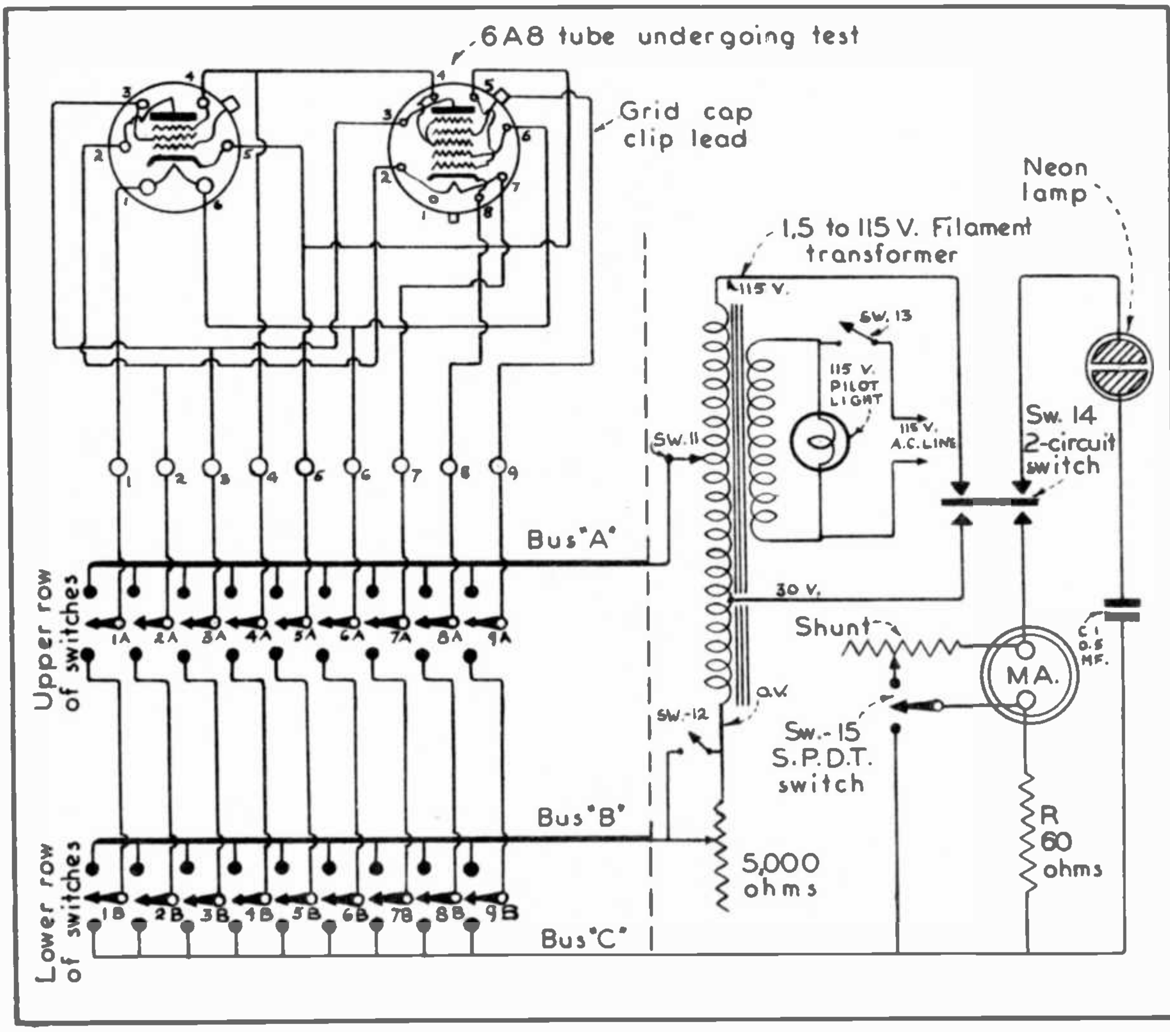

FIG. 10

TUBE CHECKER WITH PROVISIONS FOR CONDUCTING SHORT CIRCUIT AND EMISSION TESTS

CATHODE LEAKAGE

If we wish to know if there is any cathode leakage, all we have to do is to place switch No. 8B in mid-position and observe the meter. If there is current leakage between the cathode and heater, this leakage will be indicated by the meter as current flow. If no indication is noted on the meter, there is no leakage between the cathode and heater. This test is based on the fact that placing switch 8B in mid-position opens the cathode circuit; therefore, the only way in which a flow of plate current could possibly be indicated by the meter is for such current to be flowing by leakage between the cathode and heater, in order to complete its circuit.

Although we have selected a type 6A8 tube to demonstrate the operation of this tester, the same general procedure would be followed in the case of any other tube. The only modifications necessary would be those as dictated by the base prong arrangement.

TRANSCONDUCTANCE TEST APPLIED TO TUBE CHECKER

In Fig. 11 is shown the circuit diagram of a tube checker wherein the transconductance principle of testing is employed. To operate a tester of this kind, proceed as follows:

Place the line-voltage switch Sw-2 in the position corresponding to the voltage of the lighting circuit being used, and set switch Sw-3 to provide the correct filament voltage for the type of tube being tested. Pull switch Sw-1 to the "out" position. Insert the tube in the proper socket, and connect the control grid cap clip if the tube is of the type requiring this to be done.

SHORT CIRCUIT TEST

The pilot-size incandescent lamp will now be connected between one end of the transformer's primary winding and the common plate circuit lead through switch Sw-1. Then, if there should happen to be a short between the plate (or any of the electrodes that are connected to it by the checker), and the interconnected heater and cathode, such a short would complete the lamp circuit through the filament wiring and so cause the lamp to light. On the other hand, if there is no such short through the tube, the lamp will not light.

No doubt, you have noticed that this test for tube shorting does not tell us exactly between which electrodes the short exists, but this is of

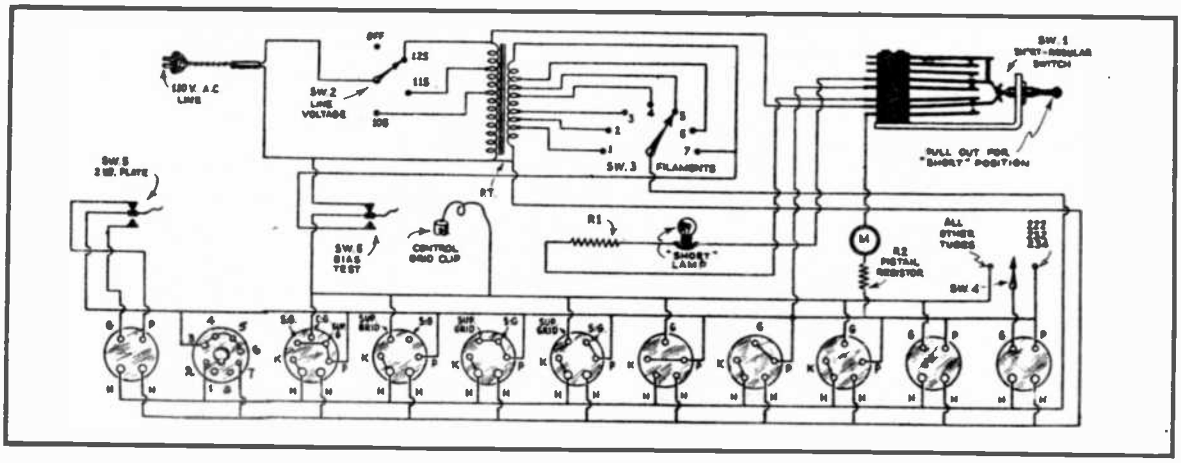

FIG. 11
TRANSCONDUCTANCE-TEST TUBE CHECKER

little importance because the mere fact that the tube is shorted makes it worthless so that it will have to be replaced anyhow. Quite a number of commercial tube checkers test for inter-electrode shorting in this way. A resistor is connected in series with the short-testing lamp to reduce the voltage to the value required by the lamp.

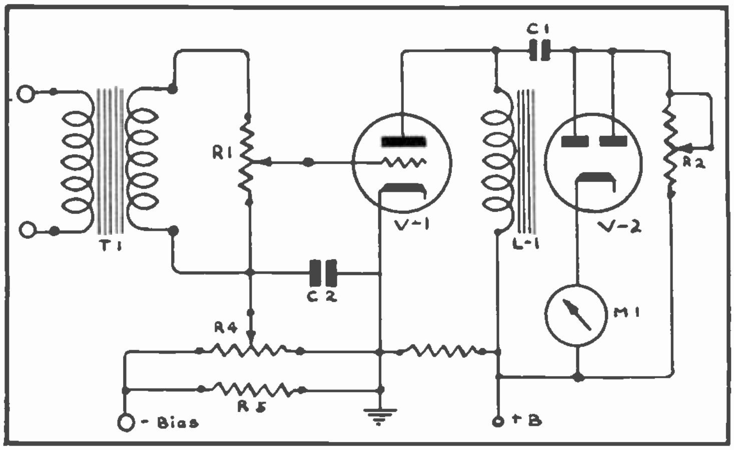

FIG. 12
FUNDAMENTAL CIRCUIT OF DYNAMIC TUBE CHECKER

TRANSCONDUCTANCE TEST

To check the transconductance of this tube, push switch Sw-1 inward. This will disconnect the lamp from the circuit, and at the same time connect the milliammeter in series with the common plate circuit wiring of the checker.

With switch Sw-6 in the "up" position, the control grid of the tube will be connected to one side of the tube's filament, under which condition a certain amount of plate current will flow and be indicated by the milliammeter. The same as in the checker previously described, the tube itself acts as a rectifier so that the a-c supplied to its plate by the transformer will be rectified, permitting a direct current to flow through the plate circuit for measurement by the d-c milliammeter.

Having noted this plate current reading, we next press down on switch Sw-6, thus connecting the tube's control grid to the other side of the filament. The voltage drop across the filament is the difference in the bias applied to the tube during these two stages of the test. The meter reading with switch Sw-6 depressed is therefore also noted; and the arithmetical difference between it and the reading obtained before depressing Sw-6 is checked against the normal change in plate current that should be produced, and which is given for each type of tube on a special chart furnished by the manufacturer of the instrument. Tubes are considered to be in poor condition if the difference between the two readings or "change" is less than 25% of the normal change listed for the same type of tube on the chart.

Provisions are made on this checker for testing the electron stream through each half of full-wave rectifiers, separately. When switch Sw-5 is in the "up" position, voltage is applied to one of the rectifier's plates for checking that section. Placing switch Sw-5 in the "down" position applies voltage to the other plate and thus tests this section independently.

The same principle would be employed if additional sockets should be added to this checker for testing other types of tubes.

DYNAMIC TUBE TESTER

The majority of commercial tube checkers are either of the emission or simple transconductance-type, such as just described, because they are less costly to manufacture than are dynamic tube testers. Besides, they meet all requirements satisfactorily enough for most practical purposes. However, it is well to describe briefly at this time how precision dynamic testing may be applied to a checker of commercial design.

The basic principle is illustrated in Fig. 12, where V-1 is the tube being tested. Its grid is excited by a-c voltage of the lighting circuit frequency through transformer T-1; the magnitude of this voltage being controlled by the setting of potentiometer R-1. The bias voltage recommended for the tube in question by the manufacturer is obtained by adjustment of potentiometer R-4.

Since the operation of this checker is based on impressing an a-c voltage on the tube's grid, and resulting variations in plate current, it is not feasible to connect a d-c milliammeter in series with the plate circuit. Instead, an a-f choke is inserted in the plate circuit, and an a-c voltage is developed across the ends of its winding by the flow of the varying plate current through it. This a-c voltage is applied across the half-wave rectifier tube V-2, through condenser C-1. Since the d-c milliammeter is connected in series with the cathode of the rectifier, direct current obtained from the rectification of the a-c voltage applied to tube V-2 is measured by it.

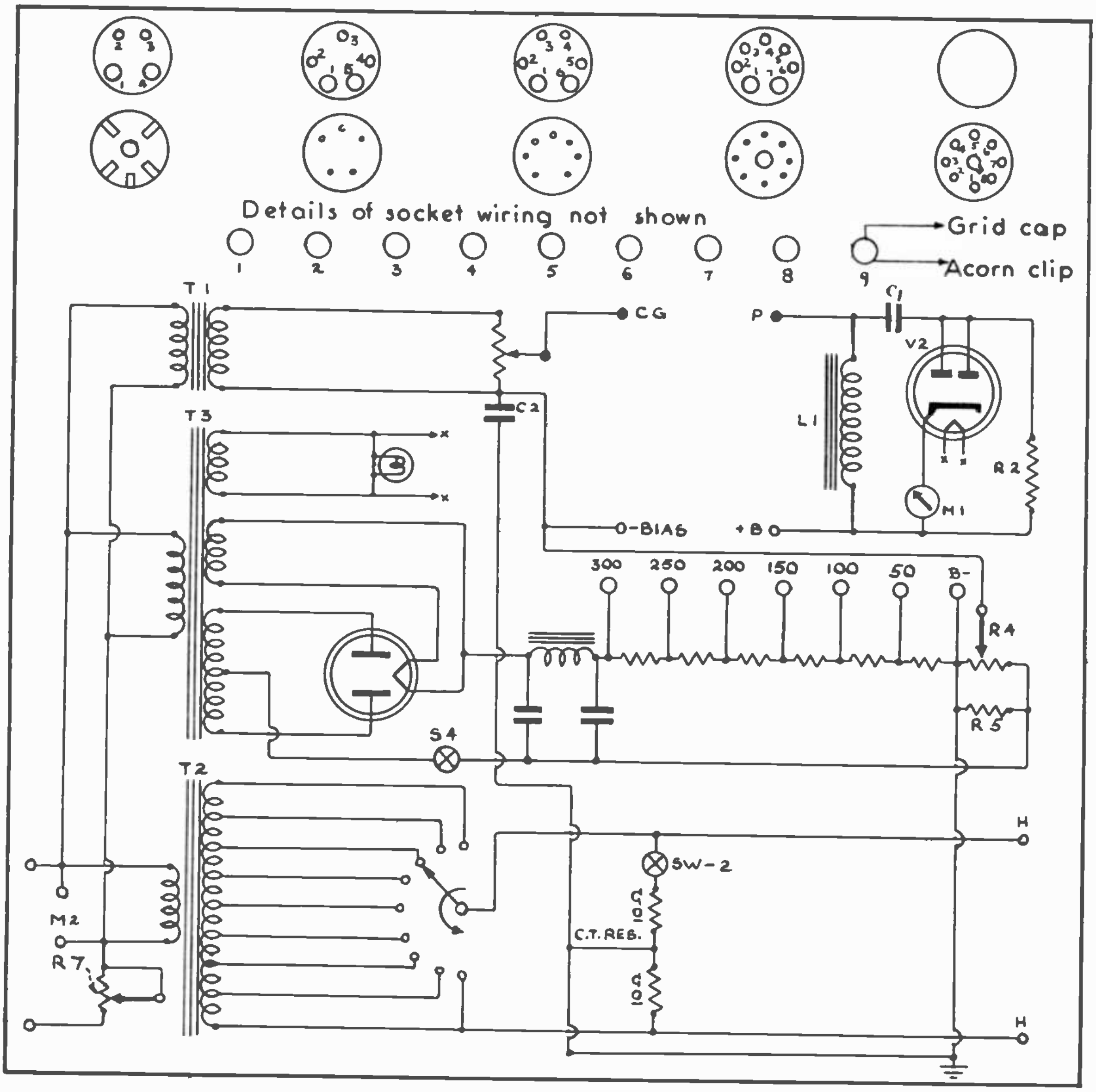

FIG. 13
CIRCUIT OF DYNAMIC TUBE CHECKER

Thus it is apparent that with a given voltage on the plates of V-1 and V-2, and a certain bias on V-1, the a-c voltage acting on the grid of the tube being tested will produce a definite indication on the meter. However, the scale of the meter used for this purpose is calibrated in micromhos instead of d-c milliamperes. This can be done for the following reason:

If an a-c signal of 1 volt is impressed between the grid and cathode of a tube while normal plate and bias voltages are applied to it, and its a-c plate current component measured in microamperes, the result is a direct reading in micromhos. For example, if the a-c output is 1 ma (1000 microamperes), the tube's transconductance will be equal to the a-c component of plate current (1000 Microamperes in this case), divided by the a-c grid voltage (1 volt in this case); which calculation results in an answer of 1,000 micromhos transconductance.

In like manner, a meter reading of 2 ma would represent a transconductance of 2,000 microhos; 3 ma -- 3,000 micromhos; 4 ma -- 4,000 micromhos, etc. The meter scale can therefore be calibrated accordingly. These transconductance values are then compared with those specified by the tube manufacturer for similar type tubes.

The method of obtaining the filament, bias, a-c signal and B voltages for the tube under test is illustrated diagrammatically in Fig. 13. The socket wiring has been eliminated for the sake of clarity; but in reality, the terminals of the various sockets are connected to the horizontal row of pin jacks that are numbered from 1 to 8, inclusive. The numbers on these pin jacks correspond to the standard numbering of socket terminals.

The output jacks of the heater (filament) voltage supply ("H" and "H") are connected to the terminals of the proper socket pin jacks so as to conform with the placement of the tube's filament prongs. The various B+ voltage jacks are connected to the tube jacks so as to provide the proper B-voltage to the tube electrode requiring it. The "CG" "-BIAS" "P" and "+B" jacks likewise are connected to the tube jack terminals to correspond with the connections shown in Fig. 12; and in accordance with the way in which the cathode, grid and plate are connected to the base prongs and cap of the tube undergoing test. All of these connections may be made by means of patch cords (jumper wires) fitted with pins at each end for insertion in the jacks, or else by using selector switches in place of the jacks and patch cords.

Thus, by inserting the tube into the proper socket and completing the various circuit connections, the same test may be applied as already explained with regard to Fig. 12.

A center-tapped resistor is used when testing filament type tubes, so as to prevent a 60-cycle voltage being impressed on the grid (independent of T-1), due to unbalance in the filament circuit. This resistor path will have to be opened by switch Sw-2 when checking tubes with high filament voltage ratings, or else it will burn out.

Terminals M-2 are furnished so that an a-c voltmeter can be connected across the primary winding of the transformers conveniently while checking the line voltage. Potentiometer R-7 is adjusted to compensate for any variations in line voltage, by restoring it to the value at which the tube checker was calibrated.

* * * * *

We have not concerned ourselves in this lesson with the specific controls and their arrangement on commercial tube checkers --- as in Fig. 7, for example --- because they vary on different instruments, and are therefore fully explained in the instructions furnished with the particular make and model of tube checker by the manufacturer. For instance, the method of switching meter and neon lamp circuits, selecting filament voltage and meter shunts, adjusting line voltage, reversing meter connections with respect to polarity, completing cr changing tube circuits during tests, etc., may be accomplished in different ways. However, regardless of the method used, the basic principles as given in this lesson still apply.

Therefore, the knowledge that you have acquired from the study of this lesson will give a fuller meaning to factory instruction sheets that you may encounter later on and, at the same time, will enable you to use commercial tube checkers of all types to the greatest advantage possible.

WHATEVER you undertake, be ENTHUSIASTIC about it. Enthusiasm is the key to happiness. It will drive you to do better work, and will bring you the harvest of work well-done.

The enthusiast never becomes despondent and "tired of it all," for he is too busy "making good" -- and capitilizing on past mistakes, and using them as stepping-stones on the pathway to success.

He who lacks enthusiasm deprives himself of the joy of living -- to him the task of earning a living is a monotonous routine, rather than a series of interesting accomplishments, the successful completion of which he can be proud.

J. A. ROSENKRANZ

EXAMINATION QUESTIONS

LESSON NO. 52

1. - If the filament or heater of a radio tube is heated to incandescence, does this necessarily mean that the tube is in satisfactory working order?

2. - Describe briefly how a static transconductance tube test is made.

3. - Explain briefly how an emission tube test is made.

4. - What is the general procedure for determining whether or not there is a short between two electrodes of a tube?

5. - Even though a tube checks perfect when subjected to a short, emission and static transconductance test is it still probable that it may not operate properly when installed in a receiver?

6. - What provisions are generally made on commercial static transconductance-type tube checkers so that the service technician need not actually calculate the transconductance value when checking the tube?

7. - How are the various filament voltages necessary for checking the different types of tubes obtained in commercial tube checkers?

8. - Why is a simple emission tube test not altogetner reliable?

9. - What advantage does a dynamic transconductance tube test have over a static transconductance test?

10. - Why is it advisable to test for shorts between the electrodes of a tube before making an emission test?

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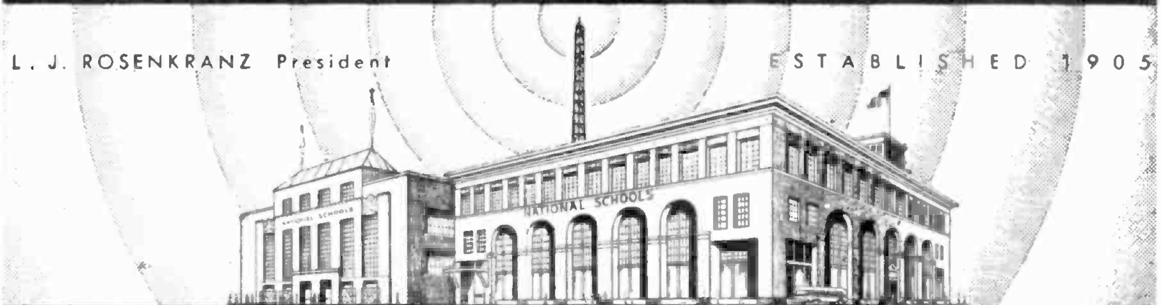

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LESSON NO. 53

ELECTRONIC VOLTMETER-OHMMETER

In the past, the most popular type of voltmeter consisted of a D'Arsonval movement (Figs. 2 and 3), in conjunction with numerous multiplier resistors which permitted the range of the voltmeter to be extended from 1 to 1,000 (or more) volts.

Basically, the D'Arsonval type of movement is an AMMETER. Although it may be used as a "Voltmeter" (or Ohmmeter, or Capacity-meter, etc.), its function is entirely dependent upon the amount of current (amperage) flowing thru the moving-coil and also upon the strength of the magnet within the movement. Consequently, when employed as a Voltmeter, the voltage-source being measured MUST BE ABLE TO SUPPLY A SUFFICIENT AMOUNT OF AMPERAGE TO PROPERLY ACTUATE THE MOVEMENT; otherwise, little or no voltage reading will be obtained.

Of extreme popularity is the sensitive and rugged "0-1 ma." or "1000 ohms-per-volt" type of meter. These terms imply that 1 milliampere (.001 ampere) of current must flow thru the moving-coil before the meter-pointer will deflect full-scale; and, when this meter is used for the purpose of

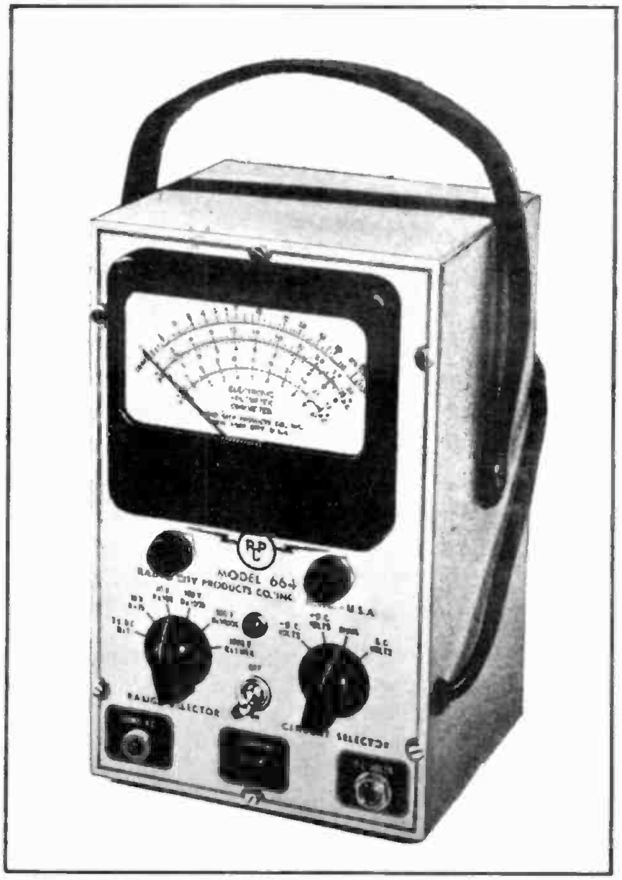

FIG. 1
ELECTRONIC D.C. VOLTMETER-OHMMETER

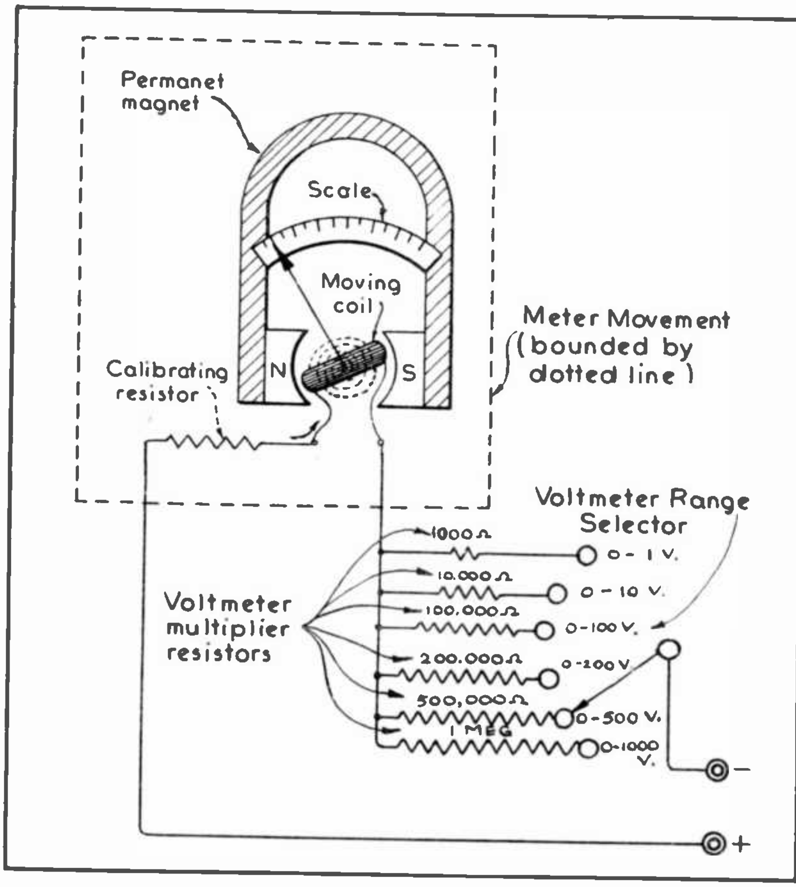

FIG. 2
DIAGRAMMATIC ILLUSTRATION OF MULTI-RANGE D-C VOLTMETER EMPLOYING CONVENTIONAL D'ARSONVAL-TYPE METER MOVEMENT

measuring volts, 1,000 ohms of resistance must be placed in series with the moving coil for each volt to be measured. Hence, to measure up to 5 volts, a multiplier resistor of 5,000 ohms would be used; to measure up to 10 volts, a resistor of 10,000 ohms would be employed, etc., etc.

SENSITIVE VOLTMETER REQUIRED

With the complex and intricate radio and electronic circuits of today, it is frequently necessary to measure input, output, AVC, control-grid, and other voltages in circuits wherein the power is rated in MICRO-WATTS! Such voltage-sources, therefore, cannot furnish a sufficient amount of amperage to properly actuate the D'Arsonval movement. And so, when attempting to measure low-wattage voltages, little or no movement of the meter-pointer occurs; hence, an incorrect (or no) voltage-reading is obtained.

Since this type of meter draws OPERATING CURRENT, it imposes a LOAD upon the voltage-source and thus lowers the voltage-output of the source--much in the same manner that the voltage-output of a generator is reduced when a load is connected to it.

The internal resistance of such a meter (resistance of the moving-coil plus the series-connected multiplier resistor) is small, in relation to the high impedances employed in modern circuits.

Many of these impedances are utilized for the purpose of developing a voltage-drop across them. The voltage-drop developed across an impedance, as you will recall, is dependent upon the amount of current (in amperes) flowing thru the impedance multiplied by the value of the impedance expressed in ohms ($E_{vd} = I \times Z$). Since E_{vd} is the product of I x Z, we may increase the E_{vd} across an impedance by increasing either one of these factors (I or Z). Hence, if the value of I is extremely low---as it is in many portions of the circuit---such as the diode section of an AVC circuit (Fig. 4), it is necessary to resort to the use of a high value of impedance to obtain the required voltage-drop for proper AVC action.

HOW A D'ARSONVAL TYPE VOLTMETER AFFECTS CIRCUIT ACROSS WHICH IT IS CONNECTED

To measure the voltage-drop developed across an impedance, we connect a voltmeter across the impedance. In doing so, the low internal resistance of the voltmeter acts as a shunting (parallel) resistor.

Some of the current that is flowing thru the impedance is thus diverted to flow thru the voltmeter; and, since a lesser amount of amperage now flows thru the impedance, the product of I x Z is thereby lowered. Consequently, a reduced amount of voltage-drop exists across the impedance. An accurate measurement of the voltage-drop existing across the impedance, under normal operating conditions, is therefore impossible*. To demonstrate the shunting effect of the 0-1 ma. type meter, let us consider the following example:

Assume that we desire to check the plate voltage of a detector tube whose plate-load resistor (R_L) is 200,000 ohms (Fig. 5). The plate-current flow, under static (no-signal) conditions, is 1 ma. (.001 ampere), as indicated by the milliammeter in series with the plate circuit of this tube. The plate-supply (E_b) is 250 volts, as represented by the battery symbol in this diagram.

With a plate-current flow of .001 ampere thru R_L, a voltage-drop of 200 volts is developed across this resistor (E_{vd} = I x R; hence, .001 ampere x 200,000 ohms = 200 volt-drop). This leaves a balance of 50 volts existing between the cathode and plate electrodes of the tube.

Therefore, to check the plate voltage of this tube, we select the 0-50 volt range of our voltmeter (by means of the RANGE selector switch) and place the red (positive) voltmeter-prod upon the plate terminal of the tube socket, and the black (negative) prod upon the B- point of the circuit (or chassis, if this is at B- potential). Theoretically, our voltmeter pointer should now swing to full-scale of the meter and thus read 50 volts. Surprisingly, however, the pointer merely swings to approximately half-scale and only reads 28 volts.

The reason for this inaccurate reading is probably obvious by now. However, we will analyze the reason for this inaccuracy in detail so that the key principles involved are thoroughly understood.

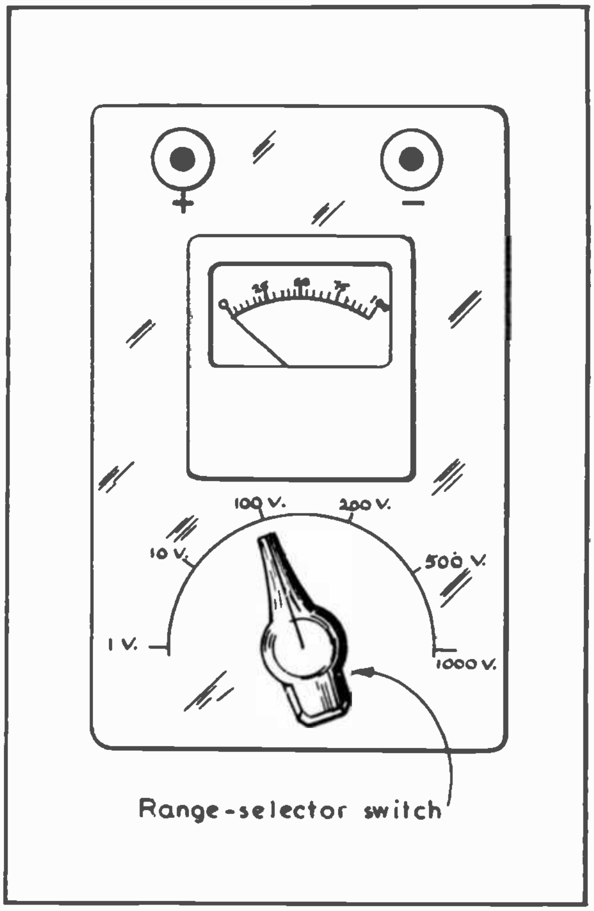

FIG. 3
MULTI-RANGE D.C. VOLTMETER

*Unless, of course, the D'Arsonval movement can be made so sensitive that full-scale deflection of the pointer occurs with an extremely small amount of current flowing thru its moving-coil. The series multiplier resistor could then be of an extremely high value; in which case, the shunting effect of the meter (upon the voltage-source being measured) would then be practically negligible.

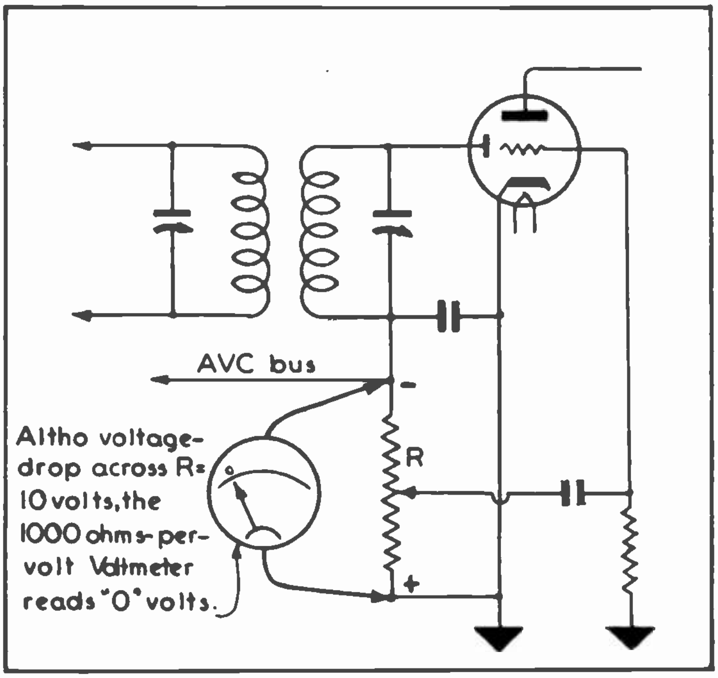

FIG. 4
ILLUSTRATING THE UNDESIRABLE SHUNTING EFFECT OF THE METER'S INTERNAL RESISTANCE UPON THE HIGH IMPEDANCE IN AN AVC CIRCUIT

In selecting the 0-50 volt range of the voltmeter, we automatically place a 50,000 ohm "multiplier" resistor in series with the meter-movement. Disregarding the negligible ohmic resistance of the moving coil, our circuit, in reality, now appears as shown in Fig. 6. (Note that the plate resistance of the tube is represented by an imaginary resistor of 50,000 ohms, since this is the r_p value of the tube, in this instance).

When the voltmeter is connected between B- and the plate of the tube, we are shunting the meter-resistance (50,000 ohms) across the r_p resistance of the tube, as shown in Fig. 6. With two resistance values of 50,000 ohms in parallel with one another, their combined effective resistance is 25,000 ohms. (Note: $\frac{1}{R} = \frac{1}{50,000} + \frac{1}{50,000} = \frac{2}{50,000}$ Hence, $R = \frac{50,000}{2} =$ 25,000 ohms).

In series with this effective 25,000 ohms resistance is the plate load resistor (R_L). Since the latter is in series with the parallel circuit previously mentioned, we have a total of 225,000 ohms in series with the 250 volt power-supply voltage (Note: 25,000 + 200,000 = 225,000 ohms). The current flow thru this entire circuit is therefore no longer .001 ampere---as it was before the voltmeter was applied---but is now .00111 ampere. ($I = \frac{E_b}{R\ total} = \frac{250}{225,000} = .00111$ amp)

In flowing thru the circuit, this .00111 ampere of current divides when it encounters the parallel-connected resistors. Since the resistance of both the meter and r_p are of an identical value (50,000 ohms), the .00111 ampere of current will divide equally; hence, .00056 ampere (.00111 ÷ 2 = .00056 ampere) flows thru the meter, and an identical amount flows thru the tube. The voltage-drop across the voltmeter will therefore be 28 volts (E_{vd} = .00056 ampere x 50,000 ohms = 28 volts) which means that our voltmeter

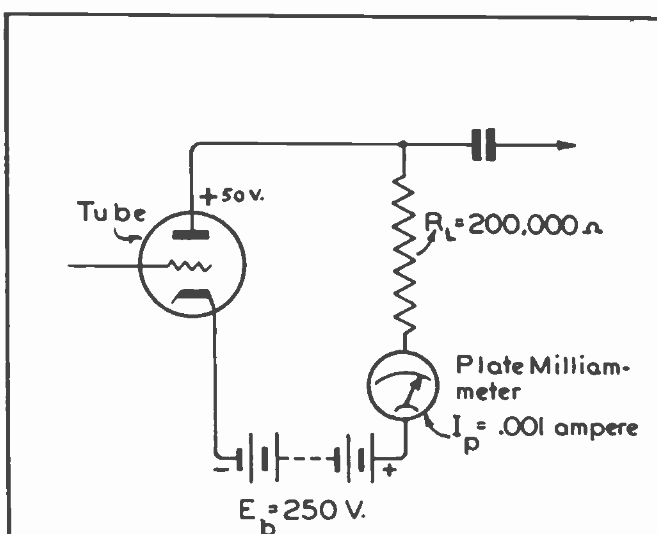

FIG. 5
HOW PLATE-LOAD RESISTANCE AFFECTS PLATE VOLTAGE

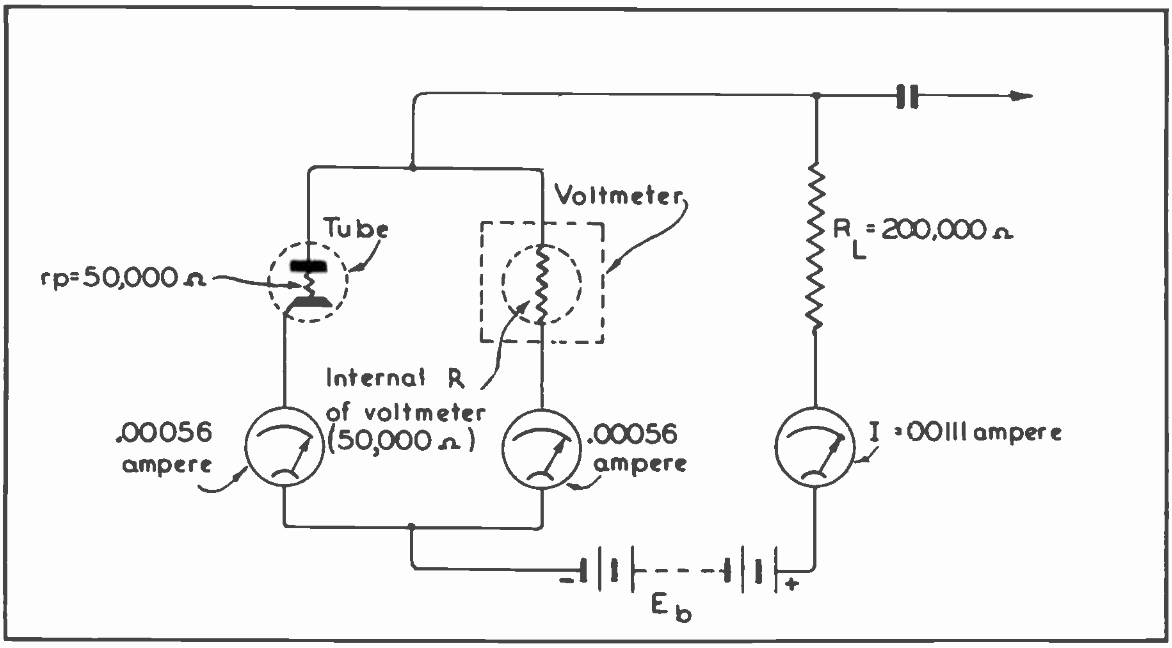

FIG. 6
METER-RESISTANCE SHUNTS TUBE'S PLATE RESISTANCE

will read 28 volts. This is almost 50% of what the voltage upon the plate of the tube actually is.

It is obvious, therefore, that the D'Arsonval type of voltmeter, when employed in the conventional manner, is not especially suitable for measuring voltages in those portions of the circuit operating at extremely low wattages because of its undesirable LOADING effect; or, where high impedances are involved because of its undesirable SHUNTING effect.

The IDEAL voltmeter would be one whose voltage measurement indication depended solely upon the VOLTAGE being measured. Such an instrument would then be a VOLTMETER in its true sense; since the amperage being supplied by the voltage-source (under measurement) would have no bearing upon the accuracy of the meter-reading. The internal resistance and impedance of this meter would be infinite, so that when the voltmeter prods were placed across the highest value of impedance employed in the circuit, negligible shunting---and thus negligible disturbance to the circuit function---would occur.

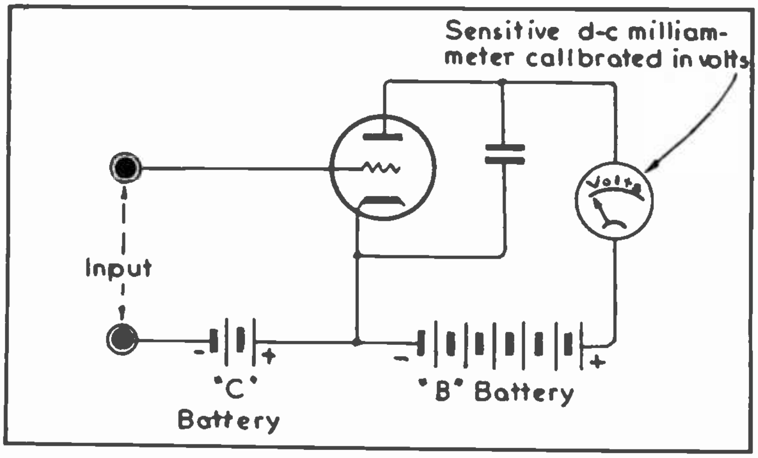

FIG. 7
BASIC VTVM CIRCUIT

The Vacuum Tube Voltmeter ("V.T. Voltmeter" or "VTVM" --as it is often referred to) closely approaches this ideal.

VACUUM TUBE VOLTMETER

We are well acquainted, by now, with the amplifying properties of a vacuum tube. We know that by impressing small voltages upon the control-grid of an amplifying tube, relatively large changes in plate current occur. Hence, by inserting a sensitive milliammeter in

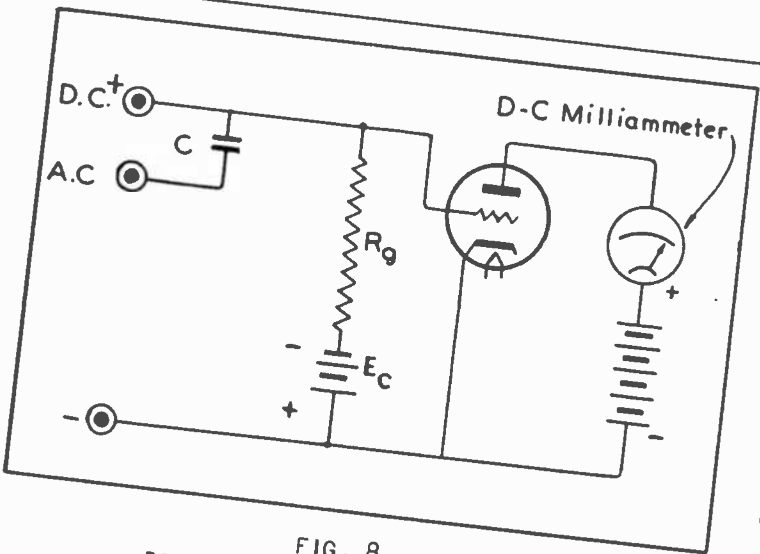

FIG. 8
POPULAR TYPE OF VTVM CIRCUIT

the plate circuit of a vacuum tube to indicate this plate-current change; and, by calibrating the scale of this meter in terms of the INPUT VOLTAGE (voltage being impressed upon the control-grid of the tube)--rather than output plate-current flow (in MILLIAMPERES)---we now have the basic form of Vacuum Tube Voltmeter, illustrated in Fig. 7. By employing such a system, we have a voltmeter that offers the following features:

1. Increased sensitivity due to the amplification properties of the tube.

2. This type of voltmeter does not require operating CURRENT, since its function depends entirely upon the value of VOLTAGE impressed upon the control-grid of the vacuum tube.

3. Such type of voltmeter does not draw any current from the voltage source (or circuit) being measured, since the impedance of the input (control-grid) circuit of the VTVM tube is extremely high.

4. Requiring no OPERATING CURRENT, it does not "load" the voltage-source under test. Since no load is imposed upon the voltage-source, its voltage output is not affected or altered while a measurement is being made; hence, a true reading of the voltage may be obtained.

5. Because of the extremely high impedance of the VTVM input circuit (from 10 to 200 megohms) its "shunting-effect" upon the circuit constants (resistance, impedance, capacity, etc.), is negligible. In that case, minimum disturbance to circuit function occurs during the time voltage measurements are made.

"VTVM" CIRCUITS

As stated previously, the VTVM is merely a vacuum tube circuit, in which the plate current flow is calibrated in terms of the input (grid) voltage. A popular type of VTVM circuit is shown in Fig. 8.

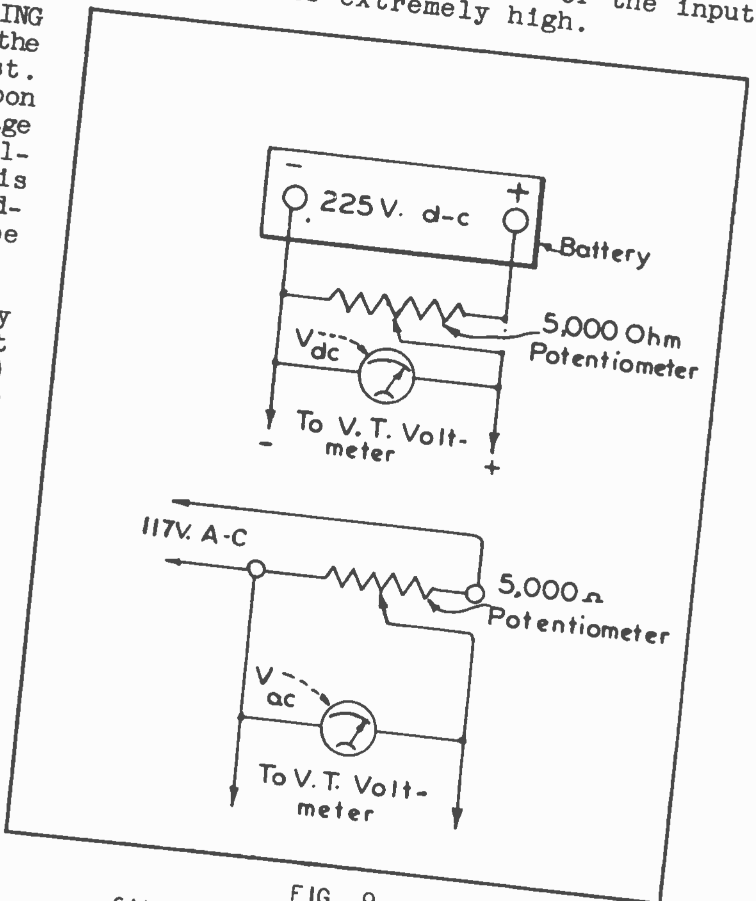

FIG. 9
CALIBRATING CIRCUITS FOR THE VTVM

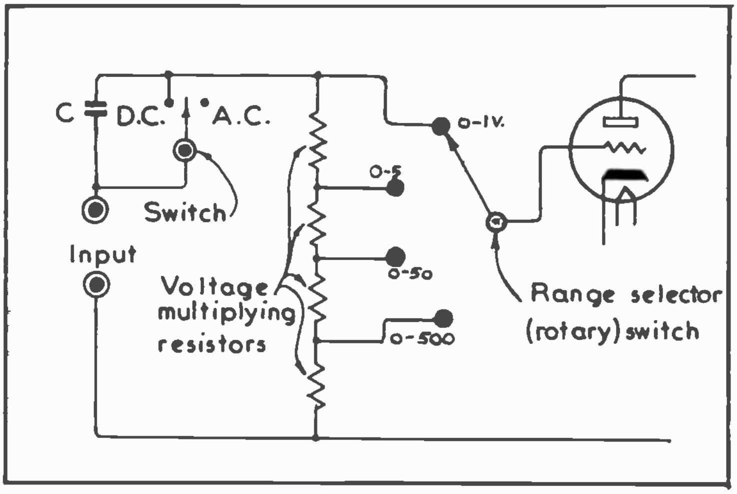

FIG. 10
VOLTAGE DIVIDER USED TO INCREASE RANGE OF VTVM

Essentially, this is nothing more than a "power" or bias type of detector circuit --- with a milliammeter inserted in the plate circuit. (The meter may also be inserted in the "plate return" or cathode circuit).

In the circuit shown, a "C" battery provides a sufficiently high biasing voltage to the grid (thru the grid resistor R_g) so as to reduce the plate-current flow to "zero"-- such as is done in class B operation. Thus, when no voltages are being measured, the meter in the plate circuit reads zero. If a positive potential is now applied to the control-grid, this element will permit passage to the electrons trying to reach the plate and, as a result, plate current flows.

The amount of plate current flow is dependent upon:

(1) The value of positive potential placed upon the grid.

(2) The characteristic curve of the particular type of tube being employed.

EFFECTIVE OR PEAK VOLTAGE MEASUREMENTS

In general, the amount of plate current flow at the lower grid voltages is proportional to the square of the (effective) value of the applied voltage (E^2); due to the fact that the tube is functioning at the "bend" or "knee" of its characteristic curve. When higher voltages are applied to the grid, however, the tube functions closer to the linear portion of its curve so that a more uniform relationship exists between the grid (input) voltage and resultant plate-current flow. If the grid bias voltage is increased appreciably beyond the plate-current "cut-off" point (such as is done in Class "C" operation), the amount of plate-current flow is largely determined by the positive peaks of the a-c input voltage so that the instrument may then be used as a PEAK-reading voltmeter. (Providing, of course, that the scale of the meter is calibrated in terms of "peak volts").

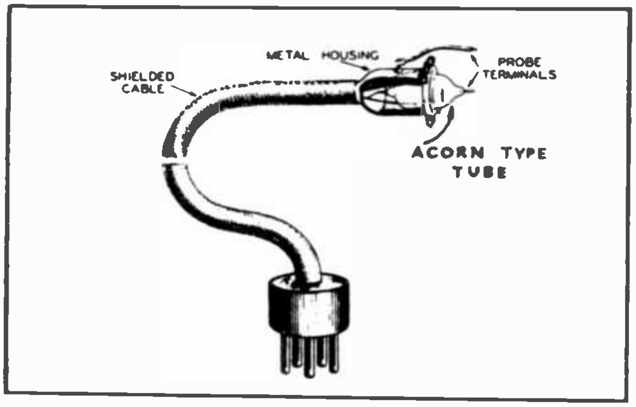

FIG. 11
USING CONTROL GRID CONNECTION OF ACORN TUBE AS A PROBE

Calibration of this type VTVM may be accomplished by the use of the calibrating equipment shown in Fig. 9.

Essentially, a known d-c or a-c voltage is applied to the input circuit, and the resultant plate-current reading on the milliammeter scale of the VTVM is calibrated in terms of the amount of input voltage applied to the grid.

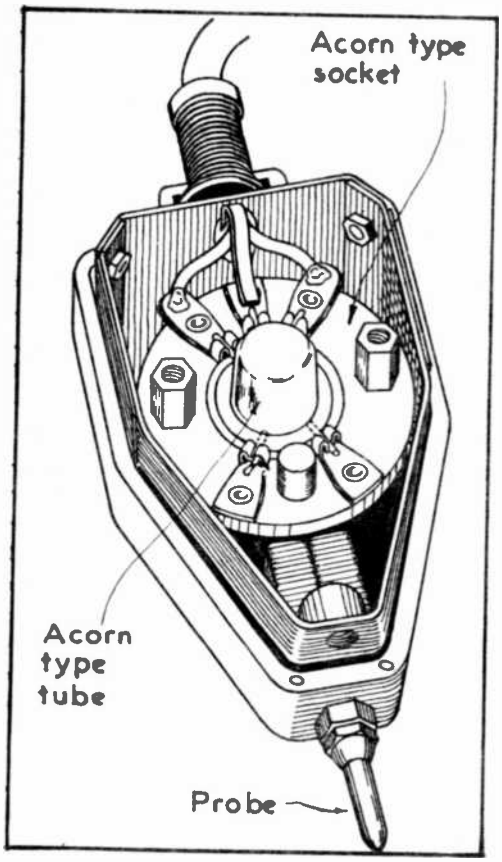

FIG. 12
PROBE WITH ACORN
TUBE INCORPORATED THEREIN

The values of input voltages are indicated by precision-type voltmeters V_{ac} and V_{dc}.

The range of the VTVM may be extended by the use of an INPUT VOLTAGE (MULTIPLYING) DIVIDER, in conjunction with a RANGE selector switch, as shown in Fig. 10. The resistors used for this purpose are referred to as "voltmeter multiplying resistors",and are designed so as to maintain an exceedingly high degree of accuracy under all climatic conditions. They are also constructed in such a manner so as to introduce minimum inductive and capacitive reactance in the circuit, since impedance of this type would greatly impair the accuracy of the VTVM when used for high-frequency measurements.

In Figs. 8 and 10, you will note that a condenser (C) is placed in series with the VTVM input circuit when measuring a-c voltages. This condenser serves to block out any d-c voltages that may be present in the a-c line under test. Such provision is especially useful when measuring the signal output of an amplifier circuit at the plate socket terminal of the amplifying tube, since we not only have an amplified signal component at this point but also the d-c plate-supply voltage. The capacity value of this condenser is generally between .01 and .05 microfarad so that it offers negligible impedance to the audio and radio-frequency currents. (This small amount of impedance is taken into consideration at the time the VTVM is calibrated).

HIGH-FREQUENCY MEASUREMENTS

When the VTVM is designed for high-frequency voltage measurements, the vacuum tube is enclosed within a small shielded container; the control-grid of the tube being exposed so that this electrode may come into direct contact with the point at which the voltage measurement is made (Fig. 11).

"Acorn" type tubes, especially designed for use on extremely high frequencies, lend themselves very efficiently for this use and so are often employed for this purpose (Fig. 12).

"Zeroing" THE VTVM METER

As you probably realize, it is necessary for the meter to read zero during the time when no voltages are being measured. In the foregoing VTVM circuit, this was accomplished by biasing the vacuum tube to the plate-current "cut-off" point; which means that no plate current flows until a positive voltage is applied to the grid.

Another method is to allow the tube to draw a sufficient amount of plate current so that the tube functions on a more linear portion of its characterstic curve (just above the bend or "knee" of the curve). This "idling" plate current is then shunted past the meter by a resistor (R), as shown in Fig. 13.

The disadvantage of such a method is that some of the indicating current is also by-passed by this resistor during voltmeter tests, so that the sensitivity of the VTVM is thereby decreased.

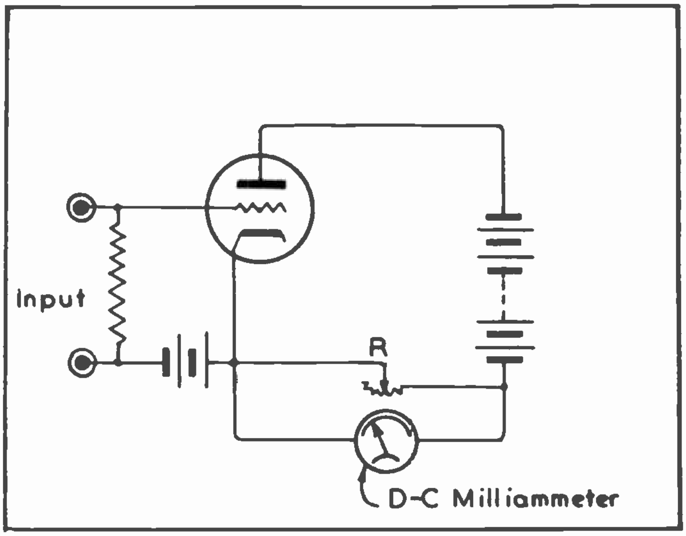

FIG. 13
METHOD OF BALANCING-OUT "IDLING" CURRENT

A more efficient method is by use of the "Bridge" principle. Such a bridge circuit is illustrated in Fig. 14, in which the plate resistance r_p of the vacuum tube functions as the fourth arm of the Wheatstone Bridge circuit. When no (positive) voltages are applied to the control-grid of the tube, the bridge is perfectly balanced; consequently, no current flows thru the meter (M) at this time. However, by appling a positive potential upon the control-grid of the tube, the r_p of the tube is altered so that the bridge now becomes unbalanced; hence, current flows thru meter (M). A circuit of this type is especially adaptable to vacuum tube voltmeters operated from an a-c power supply, since variations, in the amount of current flowing thru the meter, occurs only when the balance of the bridge circuit is disturbed. Therefore, line voltage fluctuations have a minimum effect upon the accuracy of the voltage measurements.

The stability of an a-c operated type of VTVM may be further improved by the use of a second vacuum tube to replace one of the bridge resistors (Fig. 15). Although the sensitivity of the instrument is reduced, the measurements made with this type of VTVM are almost totally independent---and thus totally unaltered (unaffected)--by any variations in the plate or filament-heater supply voltages. This circuit is often referred to as a "Wynn-Williams" bridge circuit.

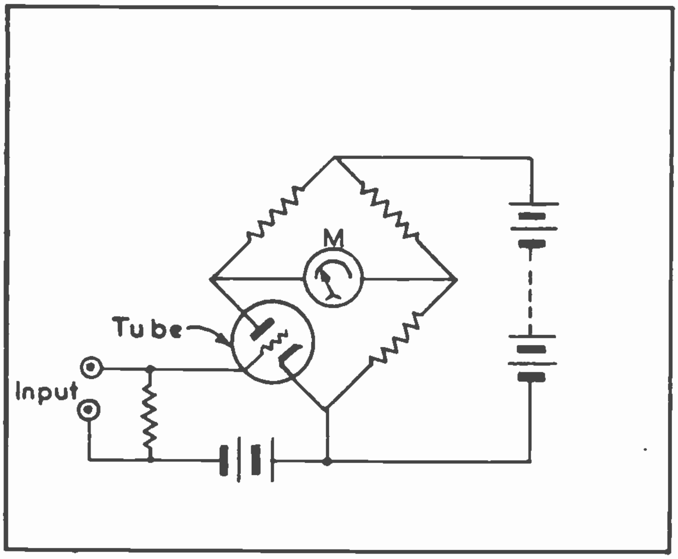

FIG. 14
BRIDGE METHOD OF BALANCING-OUT "IDLING" CURRENT

REFLEX TYPE OF VTVM

The meter-scale range of a VTVM may be greatly increased by incorporating a feature known as "reflexing" into the VTVM circuit. A circuit of this type is shown in Fig. 16.

In this type of circuit, a common impedance in the form of a resistor (R) is inserted into the cathode circuit. As the plate current flows thru this resistor, it creates a voltage-drop here; the negative end of which is used to increase the grid-biasing voltage. Hence, as the plate current flow is increased, the grid-biasing voltage is also automatically increased. As a result, the plate-current changes---per input (grid) voltage changes--are

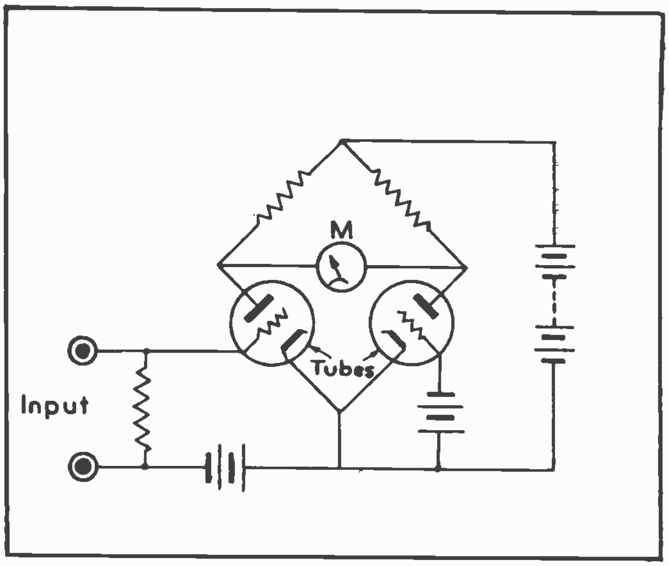

FIG. 15
WYNN-WILLIAMS TYPE OF VTVM BRIDGE CIRCUIT EMPLOYING TWO VACUUM-TUBES

smaller; and, consequently, the graduations on the meter-scale are closer together and more compact---thus permitting a greater coverage of voltage range on a single meter-scale.

"VTVM" VOLT-OHMMETER

An instrument that is very popular with the radio service and laboratory technician, is the Electronic or VTVM Volt-Ohmmeter (frequently referred to as the "Volt-Ohmyst"; a name given to this type of instrument by one of the leading manufacturers of such equipment). As the name implies, this instrument is merely a combination of a VTVM and an electronic type of ohmmeter. The circuit diagram of a typical electronic volt-ohmmeter is shown in Fig. 17.

PRINCIPLE OF OPERATION

The basis of the VTVM is the Wynn-Williams bridge circuit illustrated in Fig. 15, wherein the r_p of two vacuum tubes replace the usual resistor-arms of the Wheatstone Bridge circuit. The plate resistors R_{L1} and R_{L2} in Fig. 17 have the same value, and the tubes are biased equally so that the r_p of both tubes are identical. As a result, the meter reads zero. Any discrepency between the r_p values of the tubes are compensated for by the ZERO ADJUSTMENT Control installed on the front of the instrument panel. The instrument is also generally provided with a Calibration Adjustment (refer to Fig. 17), which is used only when it is necessary to compensate for small variations in meter sensitivity or tube characteristics. Ordinarily, this adjustment requires no attention except when tubes are replaced.

When the tubes are closely matched, and with proper adjustment of the Calibration Control, the ZERO ADJUSTMENT Control will bring the pointer to zero in approximately the center of its range. ONCE THIS ADJUSTMENT IS MADE ON ANY ONE OF THE VOLTMETER RANGES, NO FURTHER ZERO ADJUSTMENT IS REQUIRED ON ANY OF THE OTHER RANGES.

Upon analyzing the circuit diagram, you will note that a common cathode biasing resistor (Rc) is used for both tubes. This resistor is of a comparatively high ohmic resistance value (approximately 100 times larger than is employed in the conventional tube circuits). Two additional resistors are employed (Rc1 and Rc2) in the cathode circuit of each tube, but their resistance value is small in comparison to that of Rc (approximately 6% of the resistance value of Rc). These two resistors pro-

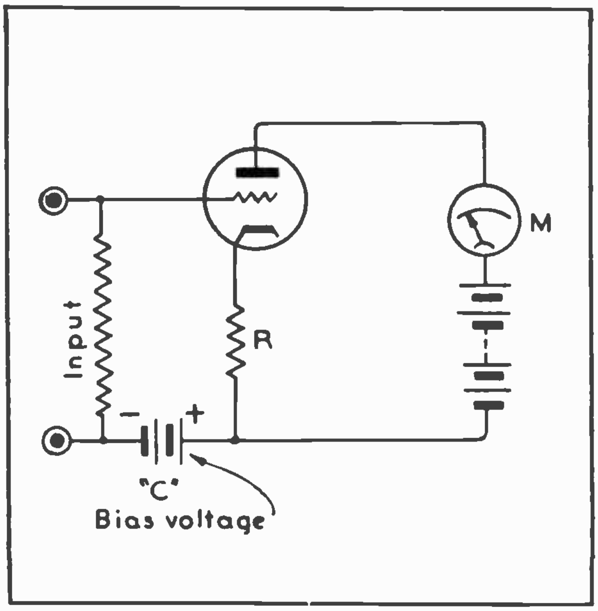

FIG. 16
REFLEX TYPE OF VTVM

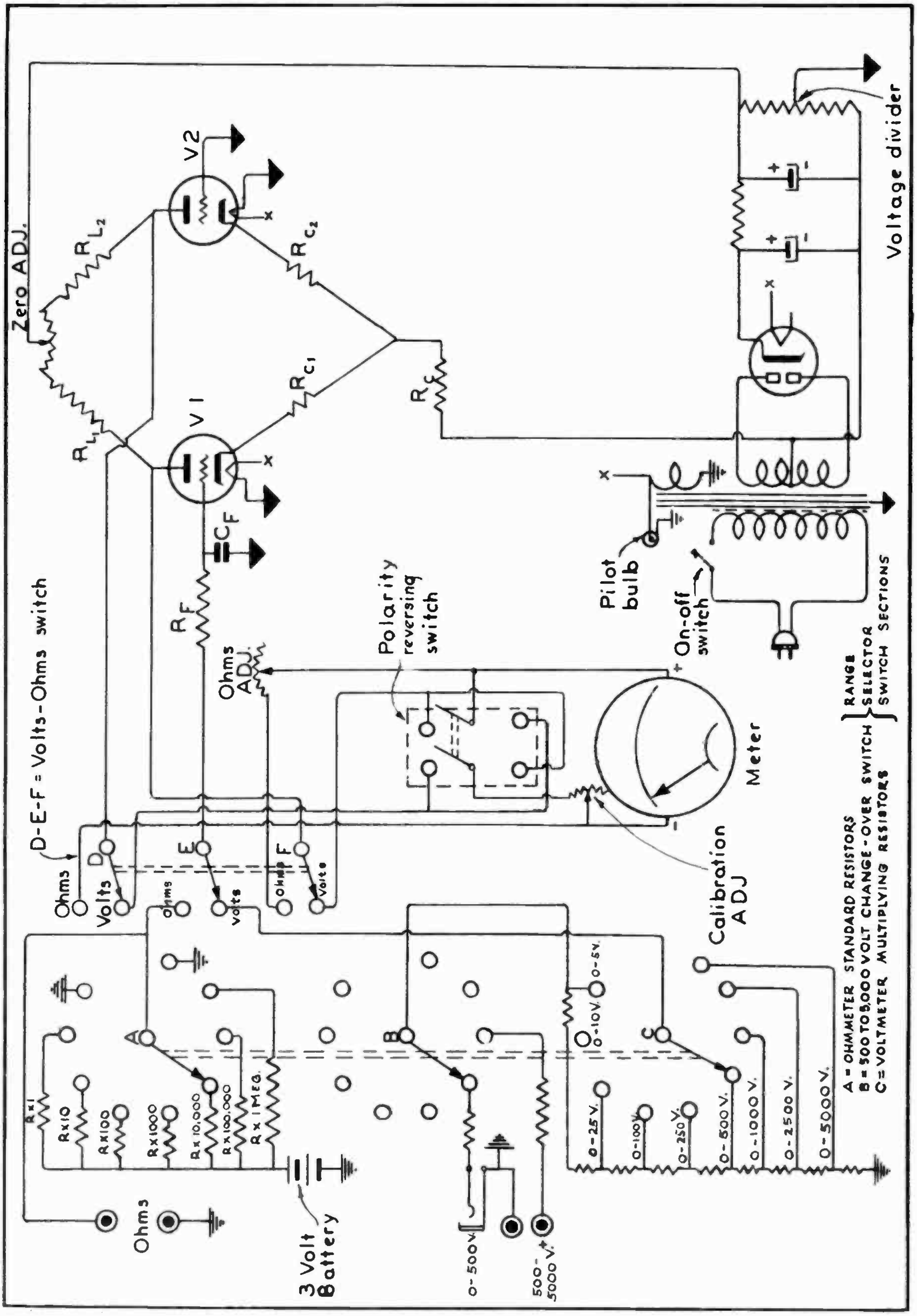

FIG. 17
TYPICAL ELECTRONIC VOLT-OHMMETER CIRCUIT

vide more stable operation of the tubes, and also tend to minimize any undesirable effects between two tubes because of any slight difference existing in their characteristics. The reason for using an extremely high biasing resistor (Rc) is as follows:

When employing a cathode resistor to obtain our biasing voltage, we refer to such method as the AUTOMATIC BIAS method. The reason for this term is because of the self-regulatory or automatic biasing feature that this method provides when the plate voltage (and, hence the plate current) is apt to vary because of variations in the a-c power supply line. Such a method is therefore highly desirable where maximum stability of operation is required, regardless of a-c line variations. Especially, is it desirable in the VTVM circuit, since the purpose of this instrument is to provide accurate measurements even though the a-c line, from which it operates, may be constantly fluctuating or varying.

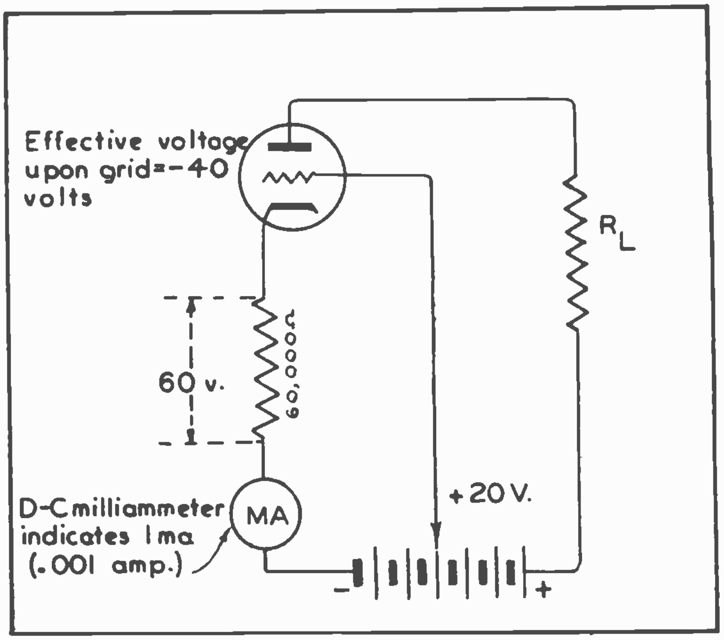

FIG. 18
SPECIAL GRID CONNECTION USED TO REDUCE BIASING VOLTAGE

Hence, by the use of a cathode resistor, our biasing voltage is automatically increased each time the plate-current flow thru the tube increases. Plate-current increases, as you probably realize, are due to an increase in plate voltage; which, in turn, occurs each time the line-voltage rises to a higher value. On the other hand, should the line-voltage drop, the plate voltage on the tube will also be reduced; which, in turn, will reduce the plate current flow thru the tubes and thus the amount of current flowing thru the cathode resistor. As a result, the biasing voltage will thereby be reduced automatically; thus allowing more plate current to flow thru the tubes. The net effect of such a biasing method is to stabilize the plate-current flow thru the tubes, regardless of plate-voltage fluctuations.

Since maximum stability is of such extreme importance in this type of instrument, it would be to our greatest advantage to make use of this self-regulatory property to the maximum extent. So that the slightest a-c line voltage fluctuation will cause a useful compensative bias voltage change, it is necessary to employ quite a high value of bias resistor. With a high value of resistance, any small variation in the plate-current flow thru that resistor, would increase or decrease the voltage-drop (and thus the grid-biasing voltage) sufficiently to maintain a constant plate-current flow thru the tubes.

Because the cathode resistor is of such a high value, the grid-biasing voltage developed across it is exceedingly high. This means that the control-grids of the tubes would be biased far beyond the plate-current "cut-off" point. To reduce this excessively high negative biasing voltage to a normal value, the control-grids are therefore connected to a POSITIVE source of voltage (a tap on the power-supply voltage-divider); thus partially neutralizing this excessively high negative voltage.

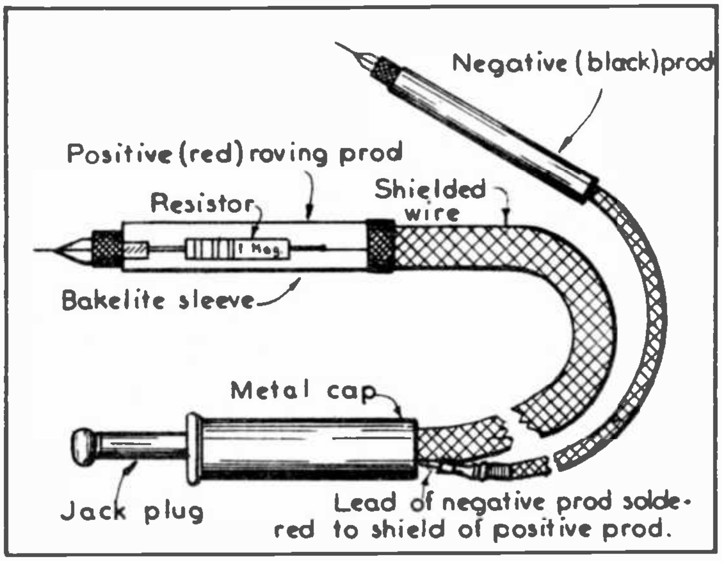

FIG. 19
0-500 VOLT PROBE AND PLUG

An example of this is presented in the diagram of Fig. 18. Here, we show a plate-current of .001 ampere (1 ma.) flowing thru the cathode resistor whose value is 60,000 ohms. The voltage-drop thru this resistor is, therefore, 60 volts. Ordinarily, this would mean that the control-grid is biased to the extent of -60 volts---if it were tied to the extreme negative end of the "B" supply voltage---as it conventionally is. However, since it is tied to the + 20 volt tap on the battery, the control-grid is merely - 40 volts with respect to the cathode (Note: -60 + 20= -40 volts).

Returning to our circuit in Fig. 17, we find that in the balanced condition (controlled by the ZERO ADJUSTMENT control), the meter M reads zero. When the instrument is used to check voltages, a positive potential is applied to the control-grid of V-1. Although voltages up to 5,000 volts may be measured with this instrument, the voltage that is actually impressed upon the control grid of V-1 does not exceed 10 volts because of the resistance network of the input voltage dividing system (RANGE selector switch, denoted by the letter "C" in the lower left-hand corner of Fig. 17).

When this positive voltage is applied to the control-grid of V-1, the plate-current flow thru this tube will increase. Because of the increase in current through the cathode resistor, a greater biasing-voltage is supplied to tube V-2 causing the plate current flow thru that tube to decrease. Hence, as the plate-current flow thru one tube increases, the plate-current flow thru the opposite tube decreases. Because of this action, the circuit is commonly referred to as a "push-pull" type of circuit.

Negative voltages may be applied to the control-grid of V-1. When this polarity is applied to the grid of V-1, the meter-pointer deflects in the reversed direction. However, by changing the POLARITY reversing switch from "+" to "-", the current flow thru the meter is thereby reversed so that the meter-pointer reads in the proper direction (upscale), indicating the value of the negative voltage.

For the 0-500 volt range, the probe may be plugged into a jack labelled "0-500 VOLTS". A probe suitable for this instrument, is illustrated in Fig. 19. Note that a 1-megohm resistor is built into the bakelite sleeve of the probe. This resistor functions as an isolation resistor, preventing the capacitance of the shielded cable and input circuit from reacting upon the circuit under test. Because of this construction, dynamic voltage measurements may be made in circuits where a-f, i-f or r-f signals are present.

When checking d-c voltages in circuits where an a-c component is present, the latter is suppressed by the a-c filter network comprised of R_f (Fig. 17); the value of which is approximately 2.5 megohms and C_f, the value of which is approximately 5000 mmf. An additional pair of terminals are generally provided for the higher voltage range (500-5000 volts). These are to be plugged into the two pin-terminals marked "500-5000 volts".

OPERATION OF THE ELECTRONIC VOLTMETER

Preliminary adjustments: (Steps a to d, inclusive)

a. Rotate the VOLTS-OHMS knob to the VOLTS position, and the POLARITY knob to "+".

b. Plug the instrument into the line voltage socket and turn the A-C switch to the "ON" position.

c. Allow the instrument to warm up for a few minutes; during which time the pointer may swing off-scale towards the left and then swing to the right---perhaps beyond the zero graduation.

d. By means of the ZERO ADJUSTMENT knob, return pointer to the "0" mark.

To measure voltages:

1. If the voltages to be measured are in the 0-500 volt range, use the voltage test-prods illustrated in Fig. 19. These are connected to a plug which is inserted into the 0-500 ohm jack on the panel. To measure voltages within the 500-5000 volt range, use heavily insulated test-prods which are inserted into the terminals marked 500-5000 volts on the panel.

2. Rotate RANGE control to the desired voltage range.

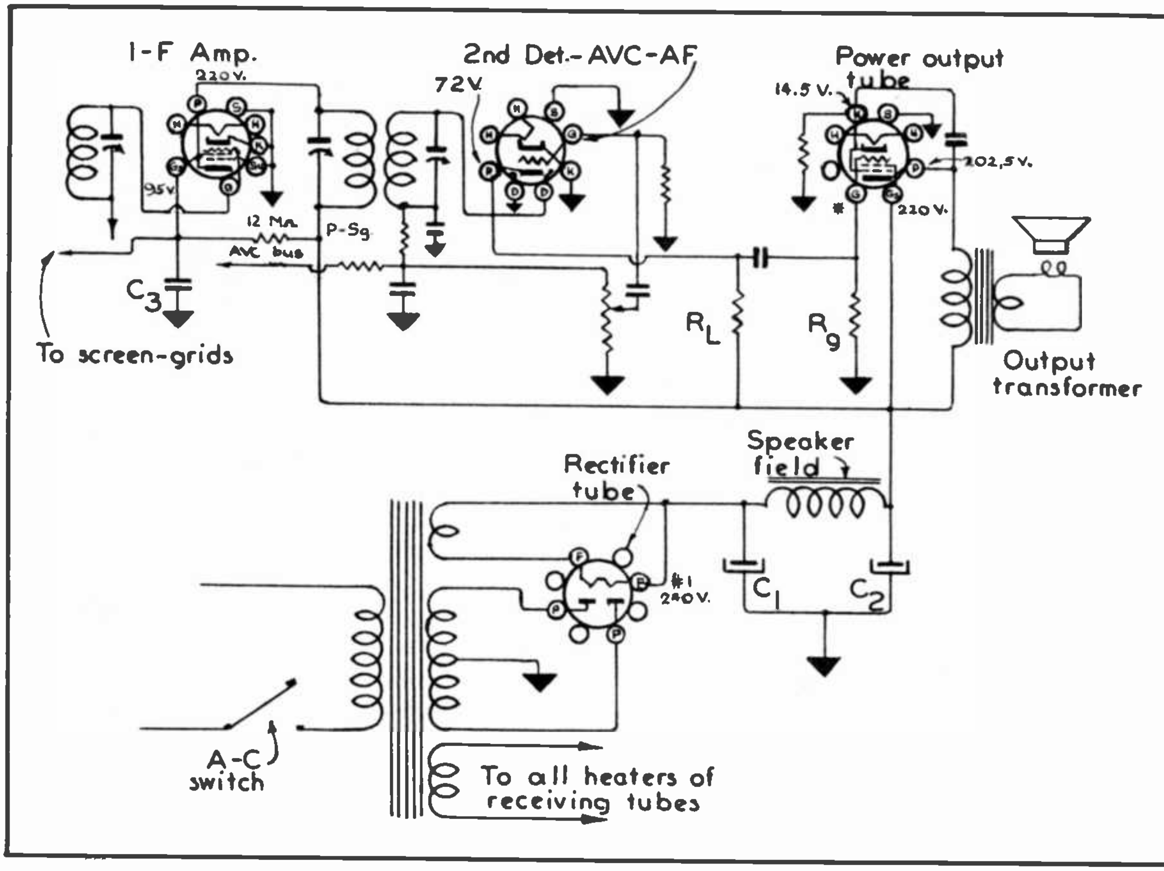

FIG. 20
PARTIAL CIRCUIT DIAGRAM OF A TYPICAL RECEIVER

3. Apply test prods to the terminals across which the voltage is to be measured. If the meter-pointer should swing in the wrong direction, rotate the polarity switch to the "-" position, or reverse the test-prods.

SERVICING RECEIVERS WITH THE VTVM

To demonstrate the manner in which the VTVM may be employed by the technician to measure voltages in a receiver, let us refer to the partial circuit diagram illustrated in Fig. 20. The first step in this procedure is to set up the VTVM for voltmeter operation, as outlined in the preceding chapter. While waiting for the VTVM to warm up to its stable, operating temperature, let us once again refer to the circuit diagram in Fig. 20 to get an idea of how we will go about measuring the various d-c voltages of the receiver.

Upon glancing at the circuit diagram, we note that the center-tap of the high-voltage winding of the power transformer connects to the chassis. Since this center-tap constitutes the B- side of the power supply, and since it connects directly to the chassis, we may therefore use the chassis for the B- side of the power supply. In that case, we clip our black or negative voltmeter test-lead to the chassis. The red or positive prod then becomes the "roving" test-probe.

Assuming that our VTVM has heated up to its optimum operating temperature, we rotate the RANGE selector switch to the 0-500 volts position and proceed to check the power-supply B+ voltages. Although these voltages (also the plate and screen-grid voltages of all tubes) may be measured with sufficient accuracy for most practical purposes, by means of a 1000 ohm-per-volt voltmeter, the VTVM provides a more accurate reading; hence, is to be preferred.

Plugging the receiver line cord plug into the line-voltage socket, we turn the receiver A-C switch to the "ON" position and allow a period of approximately one minute for the receiver tubes to warm up. We now place our positive voltmeter probe so that it contacts the filament socket terminal of the rectifier tube. The VTVM meter indicates a voltage reading of 240 volts at this point---which is close enough, since a 20% tolerance is allowable in most cases. By placing our probe upon the "G_S" (Screen-grid) socket terminal of the Power Output tube, we obtain a voltage of 220 v., which informs us that the B+ circuit is in good condition up to this point.

According to the circuit diagram, the voltage at the cathode (K) of this tube should be 14.5 volts. We therefore change the position of our RANGE selector switch to the 0-25 volt position and check the voltage at the K terminal of the tube. Our meter reads 14.5 volts; and since this voltage constitutes the control-grid biasing voltage, we may now use the VTVM to assure ourselves that this voltage is actually being applied to the control-grid electrode of the tube. Rotating the polarity reversing switch to the "-" position, we place the probe on the "G" terminal of the tube socket (marked* in the diagram) and the negative lead of the meter on the K terminal of the same socket. The meter indicates a reading of approximately 14.5 volts,which informs us of the integrity of the grid-resistor Rg.

We have thus checked all voltages on the Power Output tube and find that they are satisfactory. We now proceed to check the plate voltage of the 2nd detector-AVC-AF tube.

According to the diagram, the voltage at socket terminal "P" should be approximately 72 volts. We therefore return the Polarity Reversing-Switch to the "+" position and rotate the RANGE selector switch to the 0-100 volt range.

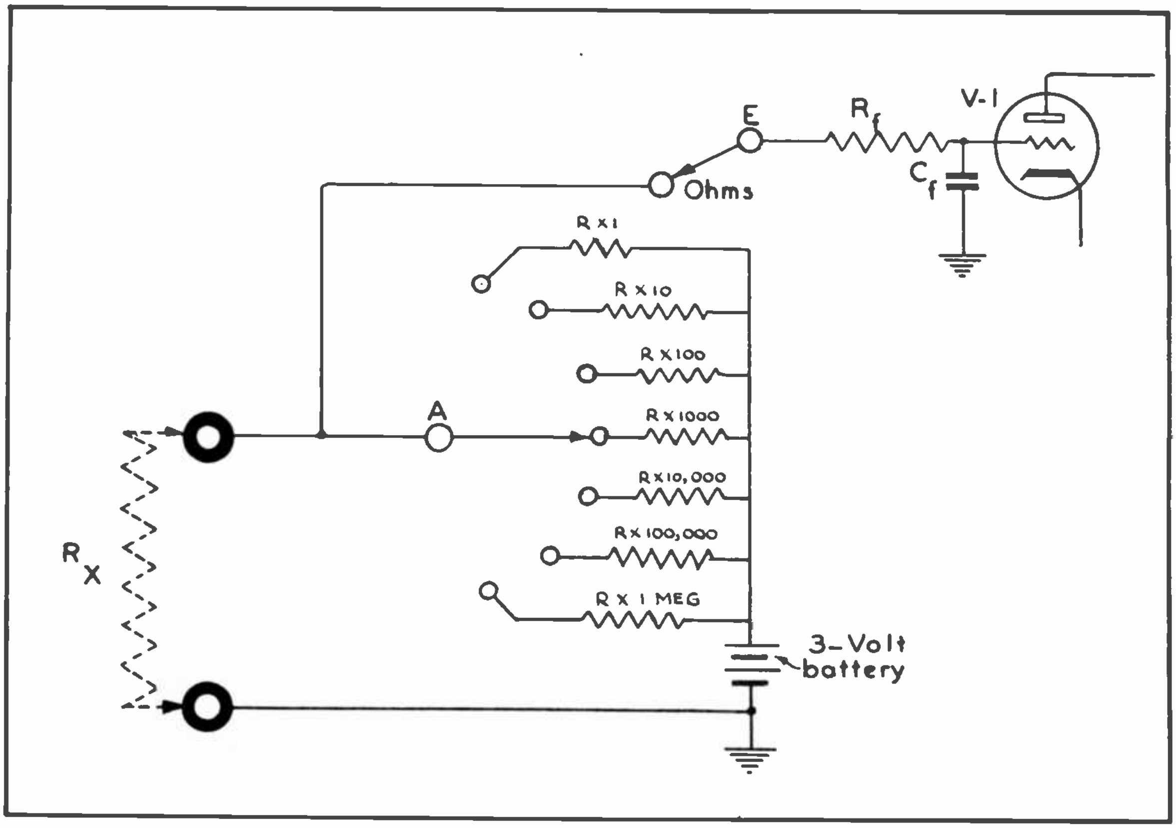

FIG. 21

OHMMETER PORTION OF THE ELECTRONIC VOLT-OHMMETER

Contacting the "P" terminal with our probe point, we obtain a reading of approximately 72 volts.

From here, we transfer our attention to the I-F amplifier stage. The plate voltage for this tube is listed as 220 volts. By rotating our RANGE selector switch to the 0-250 volt range position, we may now apply our probe to the "P" socket terminal to check this voltage. The reading obtained on the VTVM meter approximates this value within 20%, and so we consider this satisfactory.

Our circuit diagram now informs us that we should obtain a screen-grid voltage of approximately 95 volts on this tube. We therefore place our probe upon the "G_s" terminal of the tube socket. However, at this point we do not obtain a meter reading or indication. Evidently, something is wrong here.

Tracing the screen-grid wiring of the circuit,we find that the screen grid voltage is obtained by dropping the 220 volt B + voltage down to 95 volts thru a 12,000 ohm resistor (Point P-S_g in diagram). Turning the receiver off, we trace our screen-grid leads within the receiver in an attempt to find a brown-red-orange resistor since such a color combination represents a resistance value of 12,000 ohms. Eventually, we find that the screen-grid leads do connect to a resistor, but this resistor is so badly burnt and charred that it is impossible to determine its color-code. Since there must always be a reason for a resistor burning out, we once more glance at the circuit diagram and find a by-pass condenser connecting between the screen-grid side of this resistor and the chassis (B-). Disconnecting this condenser from the circuit, we apply the test prods of an ohmmeter (high-resistance range) across the condenser and find that this condenser is short-circuited. Here, then, are two defective units responsible for the inoperative condition of the receiver.

Replacing these defective units with a good-quality 12,000 ohm resistor (of the proper wattage) and a good-quality by-pass condenser of the proper value, we again check for screen-grid voltage at the S_g terminal of the tube socket and are successful in obtaining the proper voltage indication. To further confirm our tests, the receiver functions normally once again.

THE OHMMETER SECTION

The ohmmeter portion of this circuit is quite unique. The VTVM portion continues to function in its role as a voltmeter; this time, however, indicating the voltage-drop that occurs across the resistance value being measured. This voltage-drop is read directly in terms of "Ohms" since the meter-scale is provided with a scale thus calibrated.

The graduations upon the "Ohms" scale are marked off in values of 0-1,000 ohms. Resistances within this range are measured by rotating the RANGE selector switch to "R x 1". Higher resistance values up to 10,000 ohms may be read by rotating the RANGE switch to "R x 10". Multiplying factors of R x 100; R x 1000; R x 10,000; R x 100,000 and R x 1,000,000 are also provided so that resistances up to 1,000 megohms may be measured with this instrument.

In the upper, left-hand corner of Fig. 17, may be seen the ohmmeter portion of the circuit. Seven precision-type resistors are shown, each connecting to its respective RANGE switch tap. These, in conjunction with the 3-volt battery, determine the ohmmeter ranges in steps of 0-1000 ohms; 0-10,000 ohms; 0-100,000 ohms; 0-1megohm; 0-10 megohms; 0-100 megohms and 0-1000 megohms. For reference purposes, we shall refer to these as the "standard" resistors since the function of this type ohmmeter is dependent upon measuring the ratio between the voltage-drop across the unknown resistance and one of the seven standard resistors.

OPERATION OF THE OHMMETER

To operate the ohmmeter portion of the Electronic Volt-Ohmmeter:

1. Make all preliminary adjustments as described under "Operation of the Electronic Voltmeter".

2. Turn the VOLT-OHM switch to the "OHMS" position. Meter pointer will deflect to the full-scale position at this time.

3. Rotate the OHMS ADJUSTMENT knob until the pointer is accurately aligned with the very last graduation on the Ohms scale ("1000 ohms"). Once this adjustment is made on any one of the ohmmeter ranges, no further adjustment is required for the other ranges.

4. Rotate RANGE selector to the desired ohmmeter range.

5. Apply ohmmeter test-prods to unknown resistor or resistance to be measured. Meter-pointer will FALL BACK (towards left), indicating a resistance value which, when multiplied by the multiplying factor designated by the RANGE selector switch, will provide the value of the unknown resistor.

ANALYZING THE OHMMETER CIRCUIT

Actually, the functioning part of the ohmmeter circuit appears as shown in Fig. 21. Here, we have the ohmmeter RANGE selector switch (A); (E)=the section of the VOLT-OHM selector switch used to transfer the control-grid of V-1 from the voltmeter RANGE selector switch to the ohmmeter RANGE selector switch; the 3 volt battery; the unknown resistance being measured (R_X), and the tube V-1. Rf and Cf are also shown in this diagram; but since they do not play any part in the functioning of the ohmmeter circuit, these two units may be disregarded and will be omitted from all further discussions pertaining to the ohmmeter's operation.

For analysis purposes, let us imagine that we desire to measure the resistance value of the resistor whose value we believe to be in the neighborhood of 500,000 ohms. We therefore rotate our RANGE selector switch to "R x 1000". The functioning part of the ohmmeter circuit now appears as shown in Fig. 22.

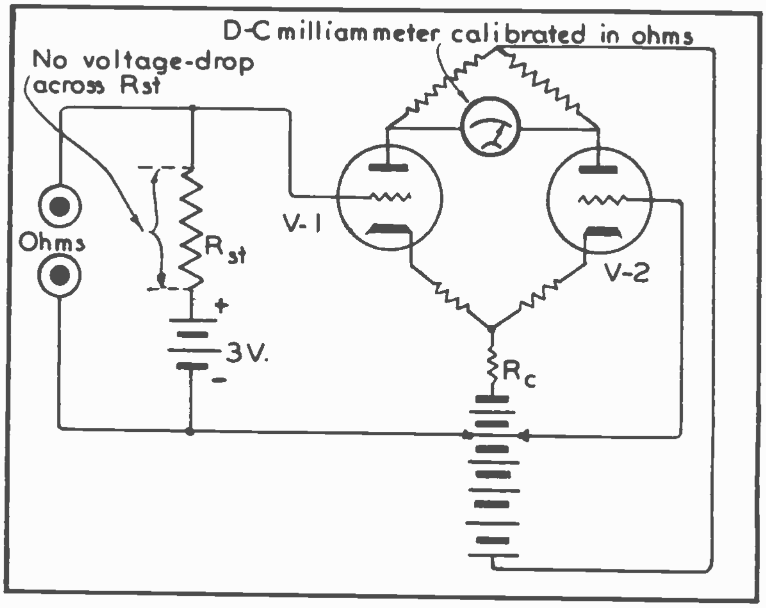

FIG. 22
OHMMETER CIRCUIT OF THE ELECTRONIC VOLT-OHMMETER
(NO VOLT-DROP ACROSS RST WHEN NO RESISTANCE IS BEING MEASURED)

In analyzing this circuit, we note that because of the manner in which the 3-volt battery is connected to the circuit, a positive voltage is being applied to the control-grid of V-1. This positive voltage partially neutralizes the negative biasing voltage existing upon the control-grid of V-1 so that this tube draws an increased amount of plate current. However, since the control-grid of V-1 remains negative (in relation to the cathode), in spite of this increased positive voltage, the grid circuit of V-1 remains incomplete in the sense that no electrons flow from the cathode to the control grid within the tube; nor through the grid circuit. Because of this, the battery circuit is open; consequently, no battery current flows thru the standard resistor (Rst.).

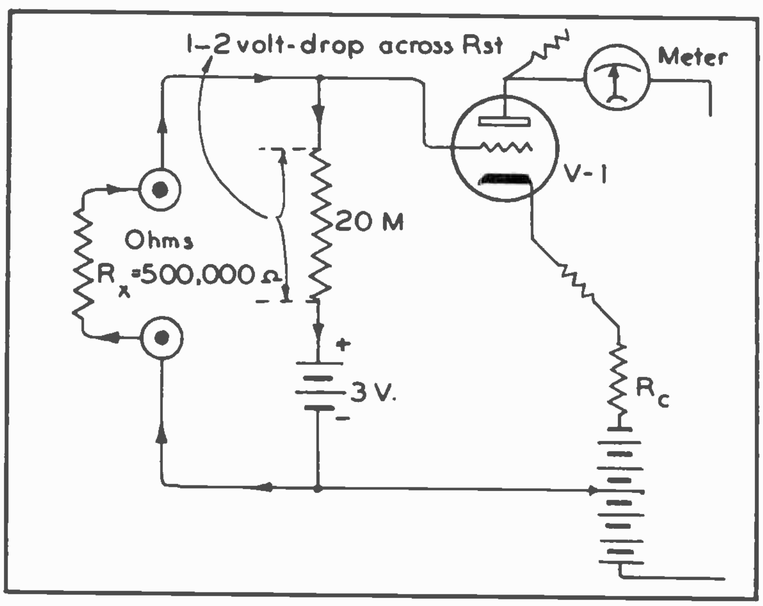

FIG. 23
VOLTAGE-DROP DEVELOPED ACROSS THE STANDARD RESISTOR RST WHEN THE UNKNOWN RESISTOR RX IS CONNECTED TO THE "OHMS" TERMINALS

Because the biasing voltage on the control-grid of tube V-1 has been reduced to the extent of 3 volts by the 3-volt battery, the plate current thru this tube increases. As a result, the bridge circuit is now unbalanced and current flows thru the meter so that the meter-pointer swings over to the full-scale position. By proper manipulation of the OHMS ADJUSTMENT control, the meter-pointer is made to line up precisely with the "1000" graduation on the Ohms scale. Now, let us see what happens when we place an unknown resistor (Rx) across the OHMS terminals of the ohmmeter, as shown in Fig. 23. Note that the 3-volt battery circuit HAS NOW BEEN COMPLETED through Rx (although the grid circuit is still open). Tracing this battery circuit, we find that the battery current flow is from the negative terminal of the battery, thru Rx, thru Rst, and back to the positive terminal of the battery. For analysis purposes, we will compute the actual value of current-flow thru this circuit. Using the formula I = E ÷ R, in which E = 3 volts and R = the sum or total resistance value of Rx + Rst (since both of these resistors are in series with the 3-volt battery), and assuming that the value of Rx is 500,000 ohms, our formula will appear thus:

$$I = \frac{3}{500,000 + 20,000} = \frac{3}{520,000} = .00000577 \text{ ampere}$$

Flowing thru Rst, a voltage-drop of .115 volts occurs here (Evd = .00000577 ampere x 20,000 ohms = .115 volts). Because of this voltage drop, we now have.only 2.885 volts of positive potential directed towards the control grid of V-1, instead of the former 3 volts. (3- .115 = 2.885). The plate-current flow of V-1 is thereby reduced. This causes the meter-pointer to fall back so that it reads 500 on the "Ohms" scale. Multiplying this reading by 1000 (the multiplying factor), we are thus informed that the resistance value of our unknown resistor is 500,000 ohms.

In this lesson, we endeavored to present the advantages and functioning principles of the VTVM instrument; also how the VTVM would be used on a typical radio service job. As pointed out in the lesson, the VTVM is particularly suited for conducting voltage measurements where extreme sensitivity is required and where the process of making these measurements will have a negligible affect upon the normal operation of the circuit; hence, upon the value of voltage normally developed by the circuit.

It is quite within reason to predict that the VTVM type of voltmeter promises to become the voltmeter of the future; possibly incorporating rugged, button-size tubes drawing an infinitesimal amount of operating current from tiny batteries; thereby adding portability to the many other features of this fine instrument.

EXAMINATION QUESTIONS

LESSON NO. 53

1. What are two (2) disadvantages in respect to the use of the 1000 ohms-per-volt voltmeter for checking voltages in modern receivers?

2. Draw a circuit diagram of a basic VTVM circuit.

3. List at least (4) advantages of the VTVM over the 1000 ohms-per-volt type voltmeter.

4. What special advantage does the "bridge" type VTVM circuit offer when the VTVM is operated from the electric socket---rather than from batteries?

5. Draw a basic type of VTVM circuit in which the r_p of the vacuum tube functions as the fourth arm of a Wheatstone Bridge circuit.

6. What type of tubes are used quite extensively in VTVMs designed for high-frequency voltage measurements?

7. Basically, what type of circuit is used for the VTVM Volt-Ohmmeter described in this lesson.

8. Draw a circuit diagram of the basic circuit referred to in Question No. 7 and state the chief difference between this circuit and the circuit referred to in Question No. 4 (above).

9. (a) Does a voltage-drop occur across resistor R_{st} (shown in Fig. 23) when NO unknown resistor (R_x) is being tested?

   (b) Why?

10. Briefly, what is the chief purpose of using a comparatively high value of resistance for the common cathode resistor in the VTVM Volt-Ohmmeter circuit?

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LESSON NO. 54

RADIO-PHONOGRAPH EQUIPMENT

A combination radio-phonograph is shown in Fig 1. In this particular case, the phonograph turntable and pickup arm are located in the left compartment of the cabinet, and the receiver in the right compartment.

FIG. 1
COMBINATION RADIO-PHONOGRAPH

Factory - built radio-phonograph combinations are more expensive than conventional radio receivers,due to the additional equipment required for the reproduction of phonograph records, and also because of the cabinet of such sets generally being of a more expensive design. Nevertheless, a large percentage of the total number of radio receivers manufactured each year is of the combination type,and they are becoming increasingly popular. It is, therefore, important that you become thoroughly familiar with these sets.

Insofar as the receiver circuits of radio-phonograph combinations are concerned, they are practically the same as those of conventional receivers about which you have already studied. That is, they comprise the conventional r-f amplifying stages, a detector, an audio amplifier, a loudspeaker and a power supply system. The additional equipment required is an electric pickup, a turntable, a motor, an "on-off" power switch for the electric motor, a "radio-phono" switch to make changing from radio to phonograph operation convenient, and, in some cases, an additional volume control which is provided so that the volume of recordings may be controlled independently of the receiver. Thus, it is apparent that only the accessory equipment involved need be studied at this time.

THE PHONOGRAPH RECORD

As you undoubtedly already know, phonograph records are made by recording sound vibrations on a flat circular disc made of a resinous material. These recorded sound vibrations take the form of variations in a continuous spiral groove cut into the surface of the record. This groove starts at the outer edge of the record and gradually approaches the center of the disc. It is illustrated in a rather exaggerated manner at (A) of Fig. 2 so as to make this point clear.

Actually, this spiral groove is not uniform in width, but has small waves or "wiggles" incorporated in its sides. These waves correspond to the audio frequencies of the sounds which were originally produced in the studio at the time of recording. Such being the case, we might say that these waves "modulate" the groove or that the groove is "modulated" by them.

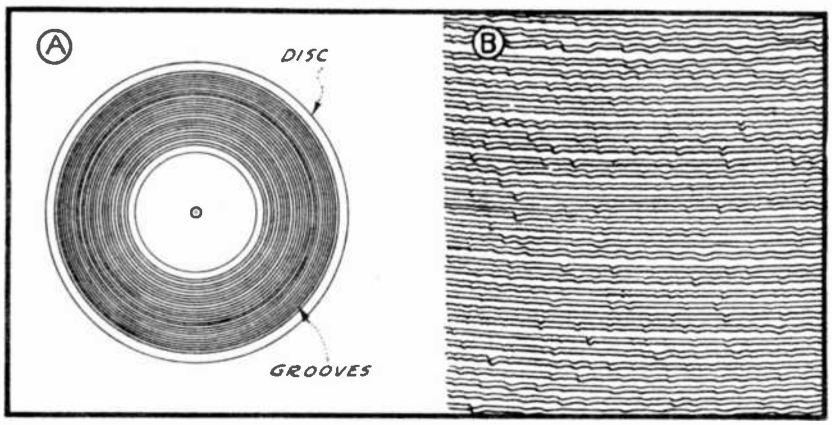

FIG. 2
THE MODULATED RECORD GROOVE

If we were to look at the groove under a powerful magnifying glass, it would appear somewhat as shown at (B) of Fig. 2, where is shown a section of the record so that adjacent grooves of the spiral can be seen more clearly. When unmodulated, the grooves are all of constant width -- adjacent grooves of the spiral being spaced about 1/100 of an inch apart. Upon modulating the groove with a high-frequency sound, many waves of short length will follow each other in rapid succession; modulating at a low-frequency forms waves of greater length which do not follow each other in such rapid succession.

Now, it is evident that any device (such as a pickup needle), upon being placed in the groove and made to follow it while the record is being rotated at the proper speed, will be forced to vibrate back and forth sideways as it follows the waves in the grooves. The amplitude of this vibration will correspond to the amplitude of the waves, and its frequency will correspond to the number of waves which pass the needle point each second. This means, of course, that if the sounds are to be reproduced correctly as to frequency, the record must be rotated at the same speed at which it was rotated during the original recording process. The conventional phonograph record is designed to be rotated at a speed of 78 revolutions per minute. This accounts for the fact that 12-inch records play for as long as four minutes, whereas 10-inch records play but 2½ minutes. Some turntables, for special purposes, operate at a speed of 33⅓ revolutions per minute.

A-C motors are rated in accordance with the frequency of the circuit from which they are to be operated -- as, for example, 50 cycle, 60 cycle,etc. Connecting a 50-cycle motor to a 60-cycle circuit will cause it to operate above its normal speed,while connecting a 60-cycle motor to a 50-cycle circuit will cause it to operate below its normal speed. Then, since the speed of the motor and turntable affects the frequency of the recorded sounds, care must be used never to connect a 60-cycle motor to a 50-cycle circuit or vice versa.

For the present, this is all that you need to know regarding the record itself. The process of recording is treated in detail later in the course. At this time, we are interested solely in the phonograph equipment used with the receiver.

TURNTABLES AND ELECTRIC MOTORS

Phonograph turntables may be rotated either by the old-fashioned mechanical spring-type motor, or by the more modern electric motor-drive which does not need to be re-wound after playing each record. A typical electric motor and turntable is shown in Fig. 3. Units of this type usually consist of an induction type electric motor and an 8, 10, or 12-inch turntable that is often equipped with an automatic trip-stop and a brake and switch arranged for either manual or automatic operation. The motor shown in Fig. 3 is also supplied with a simple speed regulation adjustment.

Induction-type motors are employed almost exclusively for this purpose, as they require no brushes or commutator and therefore cause no electrical disturbances which might affect the receiver. However, another type of motor that is also used considerably, due to its low cost, is known as the "synchronous type." The latter is not self-starting as is the induction type, and therefore requires hand-starting, which is accomplished by spinning the turntable by hand in a clockwise direction as the motor switch is closed.

The speed of most turntables is regulated by a screw or lever which controls the action of the governor that operates in conjunction

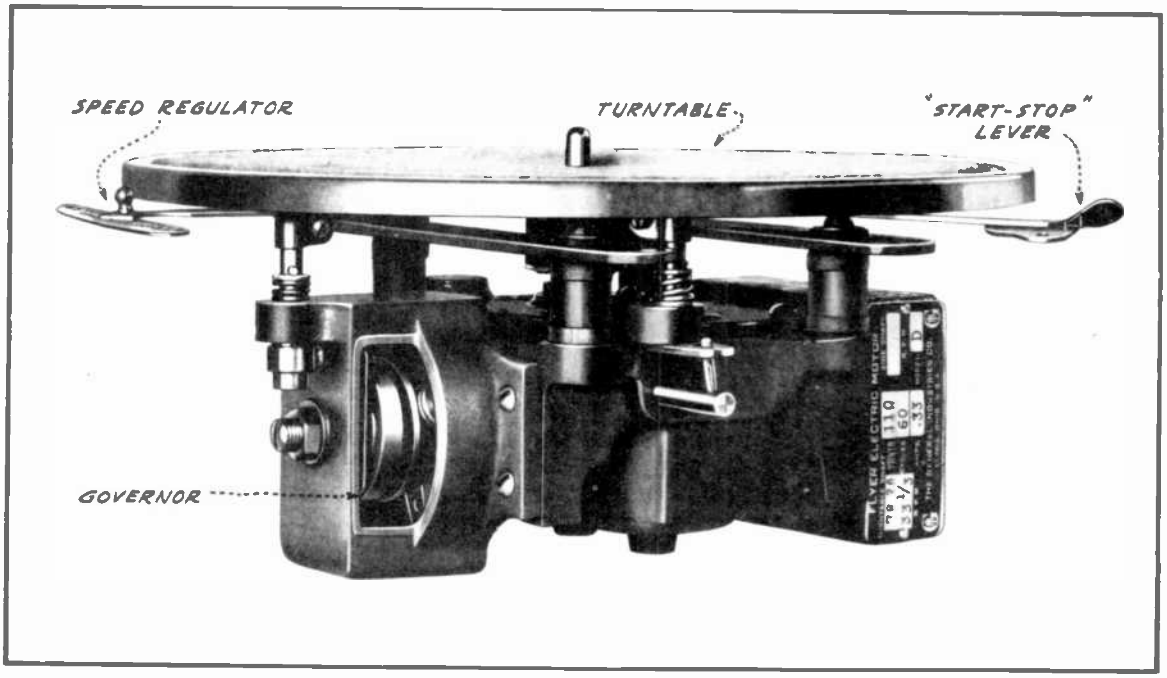

FIG. 3
MOTOR, TURNTABLE AND CONTROLS

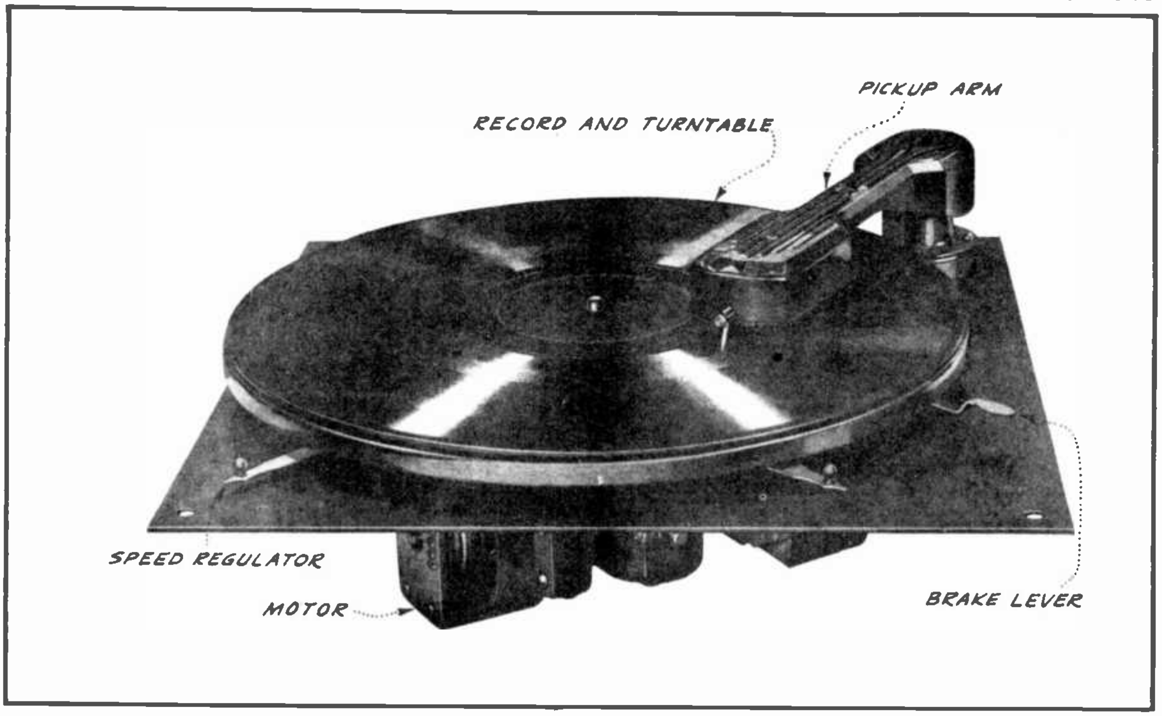

FIG. 4
TURNTABLE WITH RECORD AND PICKUP IN PLACE

with the electric motor. The illustration appearing in Fig. 3 shows this arrangement.

In Fig. 4 is shown a complete electric phonograph assembly, consisting of a turntable, record and electric motor that is equipped with a speed regulator and a "stop-go" brake lever arm, and a pickup arm.

PHONOGRAPH PICKUPS

The REPRODUCER or phonograph pickup is the most important piece of equipment comprising the phonograph record player. It is also the most delicate and often the most costly. This unit may well be defined as "an electro-mechanical device actuated by the phonograph record in such manner as to apply a voltage to an audio amplifier -- the wave form of this voltage corresponding to the wave-form in the groove of the phonograph record."

While several types of pickups have been developed, the MAGNETIC and CRYSTAL types are the most popular. In Fig. 5 are shown typical views of each of these units, along with its symbol.

THE ELECTROMAGNETIC PICKUP

The magnetic type phonograph pickup is used extensively on account of its high-voltage output, comparative freedom from extraneous noises and simple mechanical construction. Another advantage is that its frequency-response may be modified easily to compensate for any peculiar characteristics of the record or amplifier systems, and thus produce a satisfactory overall response.

CONSTRUCTIONAL DETAILS: The constructional details of an electromagnetic phonograph pickup are shown in Fig. 6. In appearance, it is quite similar to a balanced armature type speaker unit. However, the operating principles of this pickup device are different from any of those given you thus far.

Referring to Fig. 6, you will note that we have a permanent magnet which is bent into the shape of a horseshoe. A U-shaped pole piece is fastened to each of its extremities. In this illustration you are looking at the pickup unit from the front so that you can see how the armature is pivoted near its lower end, between the pole pieces; the armature is thus free to vibrate from right to left on its pivot. A coil is placed around, but separate from, the armature, and its ends are connected across the input of the a-f amplifier as will be explained in greater detail later.

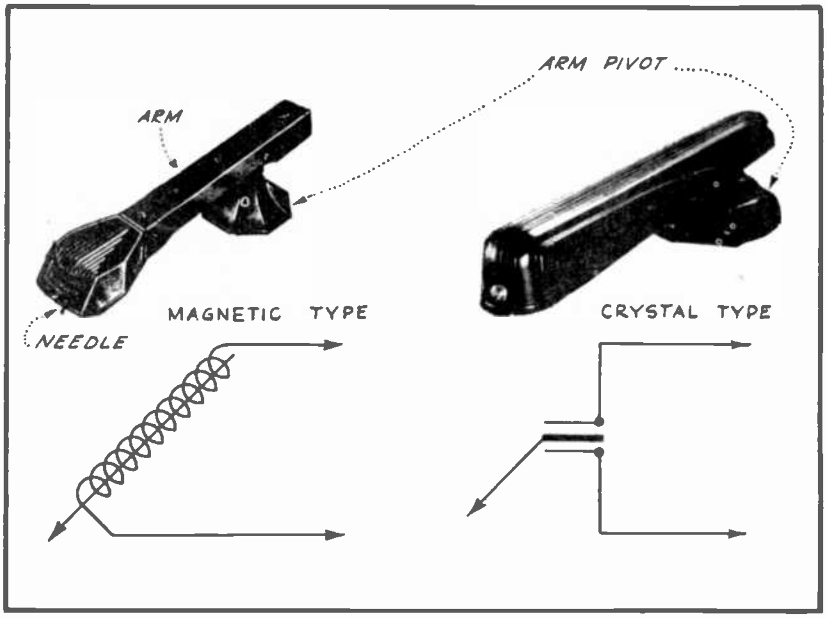

FIG. 5
MAGNETIC AND CRYSTAL PICKUPS

REPRODUCING RECORDED SOUNDS

The pickup is mounted on the end of a pivoted arm so as to permit its needle to ride in the groove of the record as the record rotates about its center on a turntable. Some pickup assemblies are equipped with an adjustable counterweight by means of which the needle pressure upon the record can be adjusted.

As the turntable rotates the record, the point of the pickup's needle follows the modulated spiral groove in the surface of the record. In so doing, the irregularities of the modulated groove cause the pickup needle to vibrate from side to side.

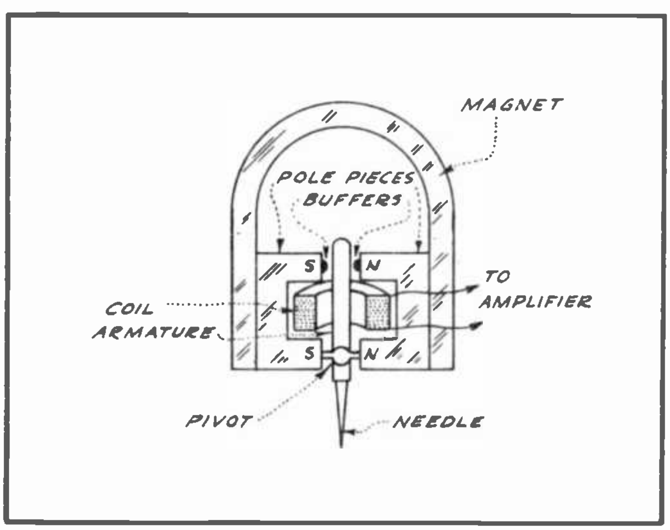

FIG. 6
SECTIONAL DRAWING OF MAGNETIC PICKUP

The armature of the pickup vibrates from side to side with its needle, and in so doing, varies correspondingly the flux (lines of magnetism) in the air gap between the pole pieces of the permanent magnet. This variation in the magnetic field reacts upon the pickup coil in such manner as to induce voltage impulses in it. These voltage impulses are the exact electric representation of the modulation impressions in the groove of the record which move past the pickup needle and actuate the armature.

Since these voltage impulses across the pickup coil are the exact electrical reproduction of the modulation impressions in the groove of the record, they will correspond to the audio frequencies which were originally recorded. By applying these voltage impulses across the input of a vacuum tube amplifier, they can be amplified sufficiently to operate a loudspeaker and thus reproduce the sounds originally recorded.

DAMPING PICKUPS

The armature has a natural vibrating period of its own. In the best modern pickups, such a resonance point usually lies between frequencies of 3000 and 4000 cycles per second.

To prevent an excessive response at the resonance frequency, it is necessary to damp the system. This is generally accomplished by applying rubber buffers for the free end of the armature. (These are generally mounted on the upper portion of the pole pieces as shown in Fig. 6.) Such buffers also serve to center the armature in the air gap where the flux is concentrated.

Besides affecting the resonant frequency, this buffer system also damps the higher frequencies more than the lower ones, thus accentuating the lower tones which otherwise might not be heard. The effective frequency-range of the best modern electromagnetic pickups is from about 100 to 5000 cycles per second, which also corresponds to the usual range of phonograph recordings.

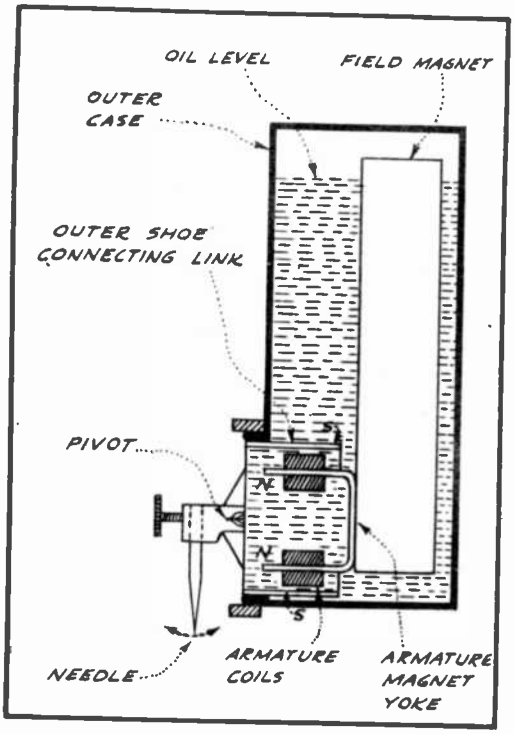

FIG. 7
DETAILS OF OIL-DAMPED MAGNETIC PICKUP

In some of the expensive electromagnetic pickups, damping is accomplished through use of a heavy oil contained in a chamber, and against whose resistance the armature vibrates. A cross-sectional view of a typical oil-damped pickup, showing the relative arrangement of the parts, appears in Fig. 7.

CRYSTAL PICKUPS

Crystal pickups do not provide as high a voltage output as do the magnetic types, but they do furnish a much more uniform frequency response.

From its outward appearance, this reproducer is quite similar to the magnetic type, as will be observed upon inspecting both types in Fig. 5, and the crystal pickup, in particular, in Fig. 8.

As its name implies, this type of pickup uses a piezo-electric crystal as the voltage-producing unit. The physical nature of this type of crystal is such that subjecting it to variations in either pressure or vibration will cause it to generate a voltage, the amplitude and wave-form of which will correspond to the <u>mechanical</u> action being applied to its surface. This point will become more understandable as you learn more about its constructional features and operating principle.

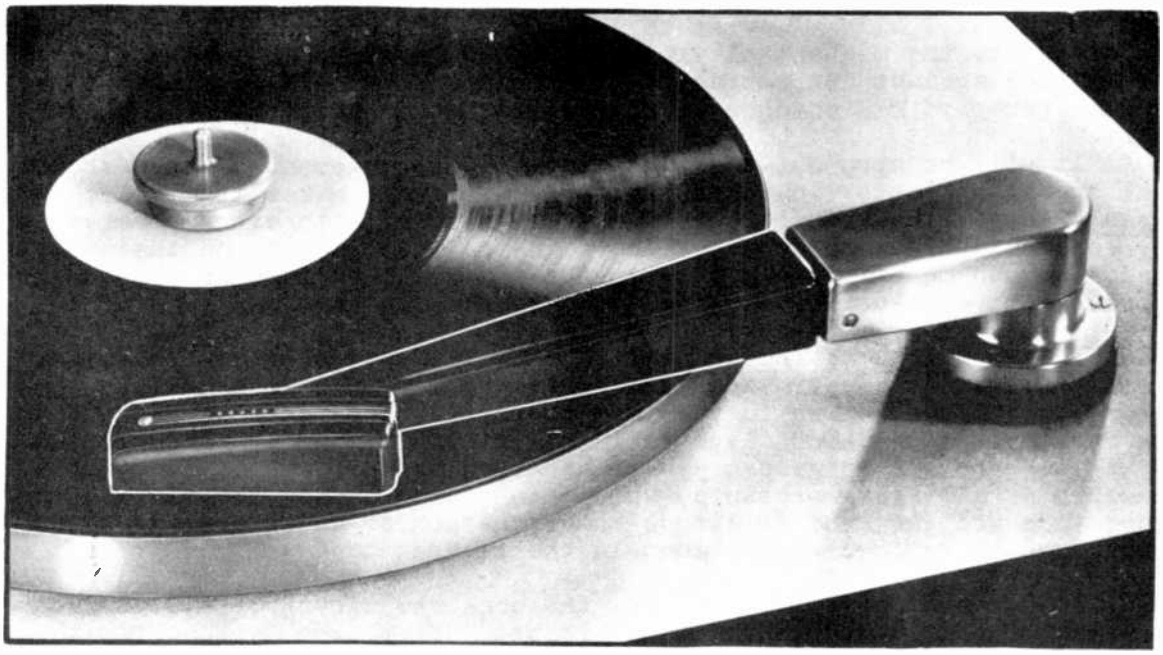

FIG. 8
CRYSTAL PICKUP MOUNTING

THE CONSTRUCTIONAL DETAILS: The cross-sectional drawing of the crystal pickup appearing in Fig. 9 shows that it consists primarily of only three parts: a needle chuck (needle holder), a tuning fork axis, and the crystal. The complete operating mechanism is fitted snugly into a compact holder; this complete assembly is called a "reproducer head" or "cartridge".

Observe further that the needle and its chuck are held in a "floating" position by rubber supports, thus leaving these parts free to vibrate in accordance with the vibration of the needle as it follows the record groove. The crystal assembly, as shown in the side view in Fig. 9 is also suspended in a floating mounting, being held in place by a substance known as

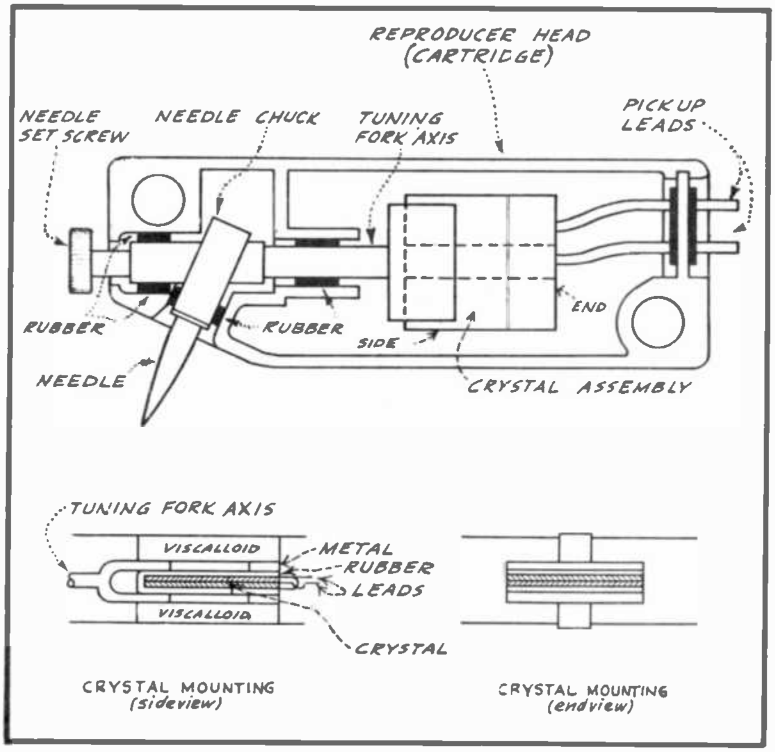

FIG. 9
STRUCTURAL DETAILS OF CRYSTAL PICKUP

"viscalloid." This substance will protect the crystal against violent jarring and will also allow it to "expand" and "contract" while being subjected to the mechanical vibrations or variations in pressure that are exerted against its surface by the tuning fork. It will also compensate for physical changes of the crystal due to temperature and age.

It will be apparent that the floating arrangement of the essential operating parts in this type of reproducer makes it a delicate piece of apparatus. Therefore, it must be handled with extreme care -- any severe jars may damage it. The magnetic type pickup, on the other hand, is much more ruggedly constructed and can therefore be subjected to comparatively severe handling without damaging it.

OPERATING PRINCIPLE OF THE CRYSTAL PICKUP: The crystal pickup operates in the following manner: Modulated grooves of the record cause the needle to vibrate, which in turn applies a twisting force to the tuning fork axis (see upper illustration of Fig. 9). Thus, the modulation waves in the record groove are transferred to the crystal element in the form of a varying pressure, which in turn causes the crystal to generate a voltage, the amplitude and wave-form of which are the counterpart of the groove modulations in the record.

The moment of inertia of the complete vibratory system is a fraction of that found in the magnetic type of pickup. (That is, the vibratory system of the crystal pickup is not as sluggish as that of the magnetic pickup.) The tuning fork oscillates only on its longitudinal axis, and the pressure-operated crystal generator is affected by the slightest movement.

The average crystal pickup delivers approximately one volt at its terminals on open circuit, and its response curve is very smooth with no sudden peaks or hollows. This output voltage is only about half that obtained from a magnetic pickup under similar operating conditions.

REPRODUCER NEEDLE PRESSURE

Of extreme importance in all types of phonograph pickup units, is the amount of needle pressure applied to the surface of the record. Correct needle pressure is desirable in order to reduce wear of the record as well as to maintain background noise at a low level. In actual practice, it has been found that the reproducer head should be so balanced that approximately 2 to 3 ounces of needle pressure will be applied to the record. In other words, for minimum record wear the needle pressure should be low. Let us now see how one manufacturer accomplishes this.

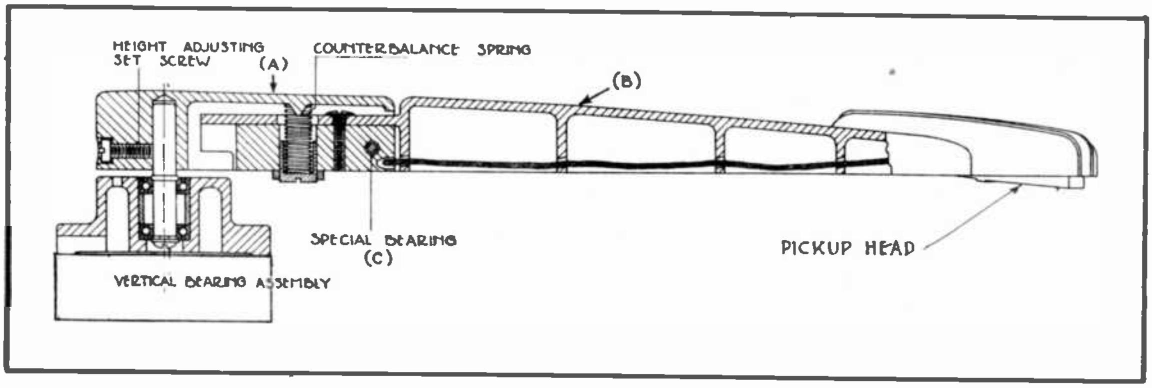

FIG. 10
SECTIONAL-VIEW OF PICKUP ASSEMBLY, SHOWING BALANCING ARRANGEMENT

In Fig. 10 is shown a cross-sectional view of the crystal pickup appearing in Fig. 8. While it is desirable that a pickup should have a large moment of inertia in the horizontal plane so that it does not chatter while following the modulated groove, it is equally desirable that the arm be extremely light in the vertical plane. To secure these objectives, the arm proper (B) is held by bearings (C) in the heavy section (A). Part (B), being made of molded bakelite, is extremely light and has so little mass that the pickup needle will follow the record groove without trouble. The needle-end of the arm is counter-balanced by a spring, adjustment of which alters its effect as a counterbalance.

All of these adjustments are originally made at the factory and as a rule should not have to be altered.

REDUCING TRACKING ERRORS

Another very important factor which is considered in the design of phonograph pickup heads, or cartridges, is the position of the needle in the groove as it traverses the record. In order to insure the best possible frequency response, the needle must "track" perfectly as it follows the groove. This is also necessary to reduce record wear.

The perfect condition exists when the axis of the needle and an unmodulated part of the record groove bear the relationship shown at (A) in Fig. 11. When this condition does not exist, as shown at (B), several undesirable effects will result. These are:

(1) With a large tracking error, such as shown at (B) of Fig. 11, the needle pressure is exerted mainly on one side-wall of the groove instead of being equally divided between the groove walls. This results in rapid wear of the record; also, the groove cannot then exert a proper grip on the needle so as to cause the latter to follow the modulation of the groove exactly.

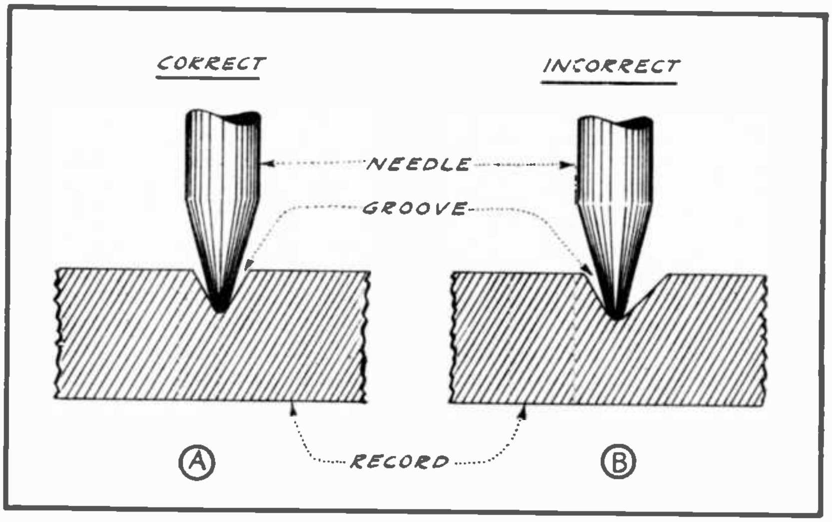

FIG. 11
CORRECT AND INCORRECT NEEDLE TRACKING

(2) A large tracking error at one point is naturally accompanied by a large variation in tracking error from point to point on the record surface. That is, a needle point which has become worn in the first few turns of the spiral groove to a shape which fits the groove at that point, will become a fairly effective cutting tool after it has reached a point on the record where the tracking angle has changed considerably. It will cause considerable wear of the record in this region.

(3) Since the needle point must vibrate about an axis not aligned with the center of the groove, uniform modulation of the groove will not produce uniform vibration of the needle point even when close contact

is maintained. Therefore, a certain amount of wave-form distortion occurs when a large tracking error exists.

These factors all indicate why it is important that the needle follow the center of the groove at all times as shown at (A) in Fig.11.

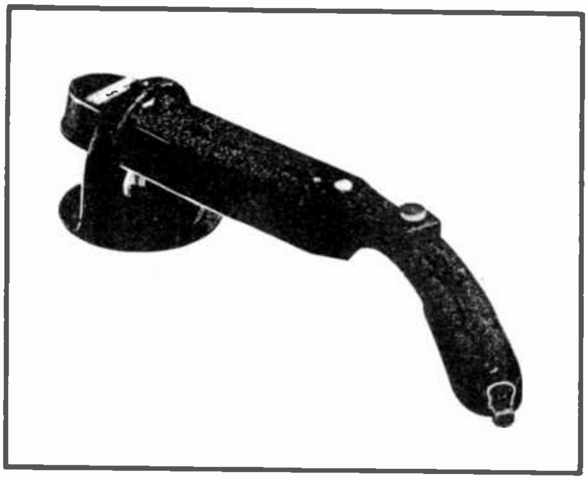

FIG. 12
PICKUP ARM CURVED FOR CORRECT NEEDLE TRACKING

REDUCING CHANGES IN NEEDLE TRACKING

As was mentioned previously, it is desirable for the needle to follow a path equi-distant between the side-walls of the groove and without any appreciable change in its angle of tracking as it follows the groove radially across the face of the record. However, due to several natural tendencies toward tracking angle changes, this is not the case in actual practice.

Several methods have been developed by manufacturers to provide a partially constant tracking angle. One method is to construct the arm with a slight curve incorporated in it as in Fig. 12, rather than being perfectly straight. A second method is to mount the reproducing head to the arm at an angle as is the case in Fig. 8. Still another method is to incline the needle as in Fig. 13 where (A) shows the needle as viewed from the side, and (B) the same needle as viewed from the front.

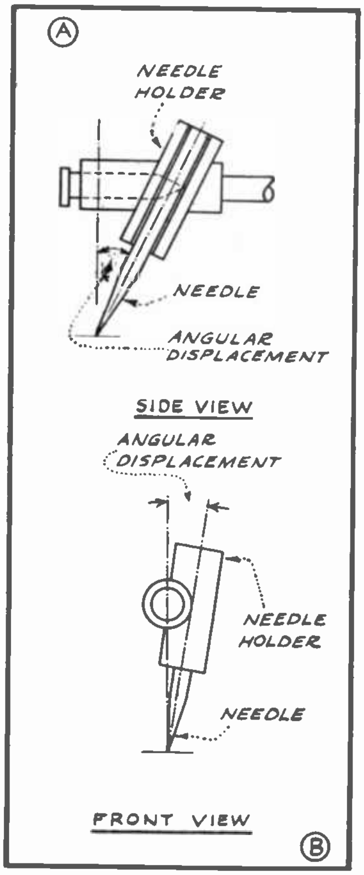

FIG. 13
NEEDLE-INCLINATION TO CORRECT TRACKING ERROR

Reproducer arms are generally so mounted that the needle will travel on the circumference of a circle as the pivoted arm is swung across the record, which path lies about one-half inch from the center of the record, toward the far side of the arm's point of pivot, as illustrated in Fig. 14. Such positioning of the arm also aids in causing the needle to track correctly in the groove of the average record.

Since Fig. 14 illustrates the pickup arm as viewed from above, it also shows clearly how the reproducer head is mounted at an angle to the arm, for reasons already explained.

PHONOGRAPH PICKUP IMPEDANCE RATINGS

All types of phonograph pickup units contain a certain amount of impedance, which must necessarily be correctly matched for the input device or circuit to which it is to be connected. They are usually classified as being either of the low or high impedance type. The impedance value of low-impedance types generally ranges from 50 to 500 ohms, while that of the high-impedance types varies from 25,000 ohms to 2 megohms.

MAGNETIC TYPES: The coils of low-impedance magnetic pickups contain less turns of wire than do those used in high-impedance magnetic pickups. Therefore, the voltage generated by the low-impedance type is less than that produced by the high-impedance types.

To provide faithful reproduction of the recorded sound, it is necessary that the impedance rating of the pickup be approximately equal to the impedance value of the circuit into which it feeds. That is, if the impedance rating of the particular pickup happens to be 500 ohms, then its load circuit must also have an impedance value of 500 ohms, as shown at (A) of Fig. 15.

Should it be necessary to connect the pickup to a line or load that contains a different impedance value, then a suitable impedance coupling transformer must be employed which will correctly match the two loads. The turns-ratio of such a transformer is equal to the square root of the impedance ratio required (the impedance ratio is equal to the impedance of the secondary winding divided by the impedance of the primary winding). For instance, to connect a 100-ohm pickup to a 500-ohm line through an impedance-matching transformer, as at (B) of Fig. 15, the turns-ratio would be $\sqrt{500 \div 100} = \sqrt{5}$, or approximately 2.24 to 1. Since a voltage step-up is obtained through the transformer in this instance, the disadvantage of the low output voltage furnished by the low-impedance pickup is partly overcome.

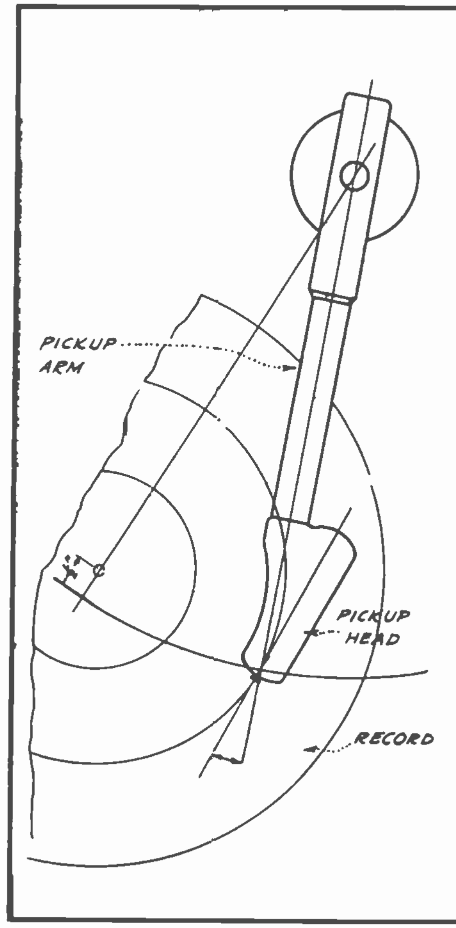

FIG. 14
RELATIVE POSITIONING OF PICKUP ARM AND HEAD

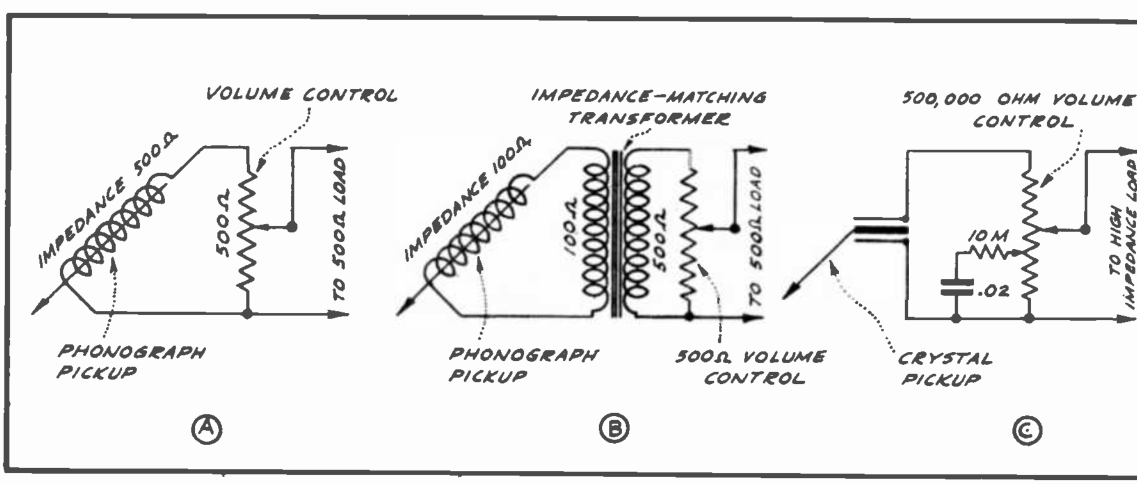

FIG. 15
VOLUME CONTROL AND IMPEDANCE-MATCHING CIRCUITS

CRYSTAL TYPES: Crystal pickups are of the high-impedance types -- their impedance value approximating that of a fixed capacity. For this reason, crystal pickups offer a high reactance to low audio frequencies, which decreases steadily with an increase in frequency. Constant voltage for constant amplitude of vibration is also maintained under open circuit conditions by this type of pickup, and a load resistance of sufficiently high value must be maintained so that the very low frequencies will not be attenuated. The capacitive value of the conventional crystal pickup is in the order of .002 mf, and a matching load impedance or resistance of not less than one-half to two megohms is required to avoid excessive attenuation of the lower frequencies.

VOLUME CONTROL FOR PHONOGRAPH PICKUPS

The output voltage at the terminals of a phonograph pickup can be controlled effectively by means of a potentiometer connected across it as shown at (A) and (C) in Fig. 15.

A great many pickups are constructed with the volume control potentiometer built into the base of the unit. When such is not the case, the volume control is connected externally; or, if it is to be operated in conjunction with the amplifier of a radio receiver, the receiver's volume control may serve as the volume control for either phonograph reproduction or radio reception. In the latter case, the receiver's volume control must necessarily be connected in the audio section of the set. In many instances, compensating volume controls, as shown at (C) of Fig. 15, are employed. In this case, some of the high frequencies are bypassed through the 10,000-ohm resistor and .02 mf condenser, thus emphasizing the low notes at low volume.

In cases where it is necessary to employ an impedance-matching coupling transformer, it is customary to include the transformer in the circuit as shown at (B) in Fig. 15. However, the volume control may be connected either across the primary or secondary winding of the transformer.

NEEDLE-SCRATCH FILTERS

Quite often, a disagreeable scratching sound is noticed while playing a record -- this is commonly referred to as "needle-scratch." This condition is caused by the fact that the sides of the wavy grooves in the record are not cut absolutely clean and smooth, resulting in the presence of microscopic rough edges. These rough edges affect the motion of the needle and are responsible for the generation of voltages at audio frequencies (around 2000 to 3000 cycles per second) that cause a scratching sound.

These "scratch voltages" can be effectively bypassed and attenuated by means of a filter constructed in the form of a series wave-trap that is tuned to the most bothersome "noise frequency," thereby preventing this undesirable frequency from being amplified.

In Fig. 16 are shown two typical phonograph pickups having such scratch filters connected across their output circuits. At (A) is shown a filter connected across the output terminals of a magnetic type pickup, while such an arrangement of a crystal pickup is illustrated at (B). Whether the volume control is connected before or after the filter makes little difference -- the important thing is to connect the filter across the pickup's output line.

In some cases, as at (A) of Fig. 16, the filter is adjusted to the most annoying scratch frequency by means of a variable trimmer condenser. When this resonance circuit is tuned to the unwanted frequency, the filter circuit will offer a low-impedance for that frequency so that it prefers this path to that offered by the normal load circuit. This results in their being effectively bypassed and attenuated so that they will be inaudible.

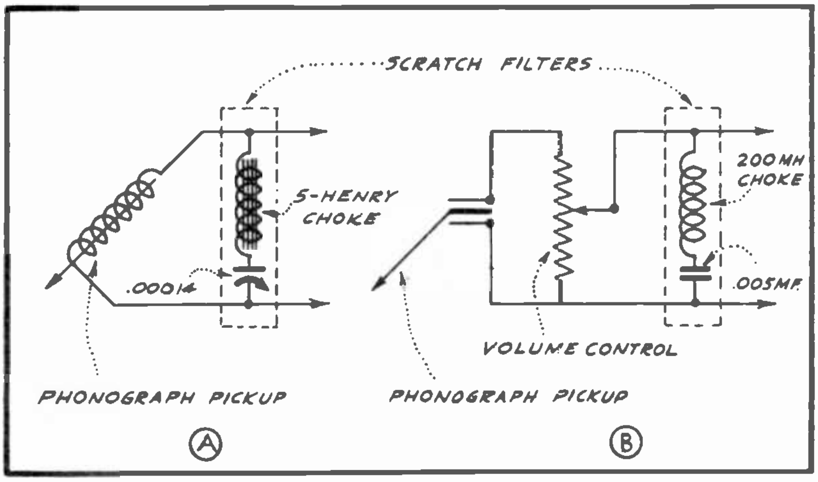

FIG. 16
APPLICATION OF NEEDLE-SCRATCH FILTER

Most pickups of better design are constructed to eliminate the greater part of the scratch-noise, while others have a suitable scratch-filter incorporated in them. In any case, the filter unit must be shielded and so placed as to avoid coupling between it and parts of the receiver that may result in hum pickup.

PHOTOELECTRIC CELL PICKUP

In an attempt to increase record life, to eliminate the necessity of changing the needle frequently, and to improve reproduction, a photoelectric phonograph pickup has been developed.

This pickup consists essentially of a floating jewel (polished sapphire) stylus (needle) connected to a small mirror, a light source, and a photoelectric cell -- all related to each other as illustrated at (A) of Fig. 17.

The unit operates as follows: The small mirror, shown enlarged at (B), is mounted in elastic bushings in such manner that it will

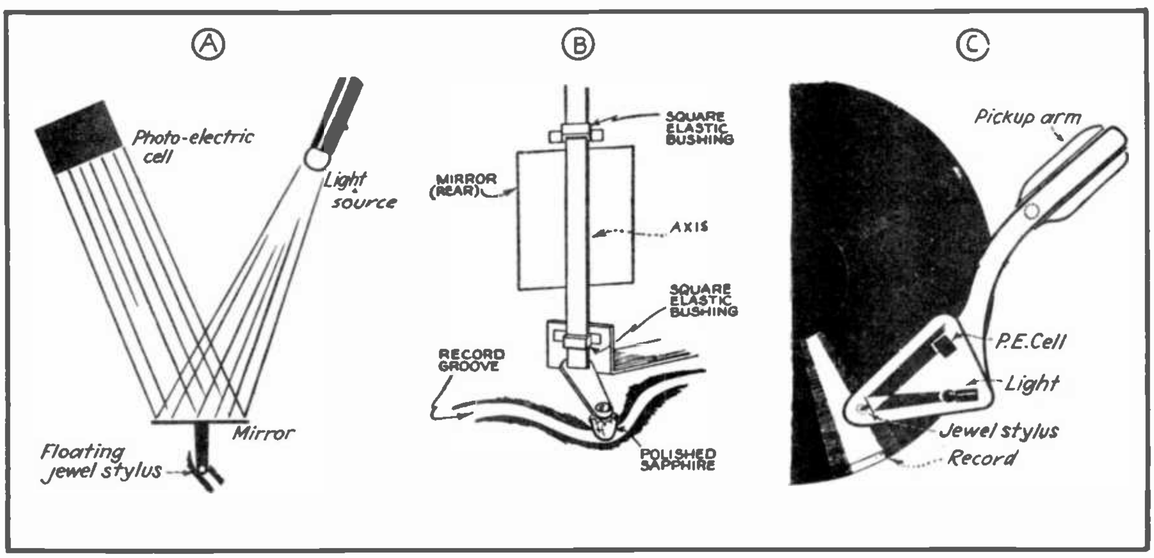

FIG. 17
STRUCTURAL FEATURES OF THE PHOTOCELL PICKUP

oscillate on its axis as the jewel stylus follows the curved record groove (see illustration (B) of Fig. 17). A beam of light, shown at (A) of Fig. 17, is directed toward this mirror at an angle, and is reflected onto a photoelectric cell.

(NOTE: A photoelectric cell (P.E. cell) or "electric eye," as it is sometimes called, converts changes in the intensity of light into corresponding current and voltage variations. A description of how this is accomplished is beyond the scope of this lesson, but a detailed discussion of the theory involved is presented in a later section of the course wherein the photoelectric cell is made use of extensively. For the time being, it is sufficient for you to know that the voltage generated by a photoelectric cell is controlled by the amount of light that is directed upon it.)

As the floating stylus follows the curve of the record groove, the pivoted mirror swings from side to side (oscillates) on its axis, flashing the beam of light on and off the photoelectric cell. The photoelectric cell thus translates light into electrical energy, the flow of current generated varying in proportion to the amount of light flashed upon the cell as the mirror is swung by the stylus.

The placement of the mirror assembly, light source, and photoelectric cell, with relation to the pickup arm and record is shown at (C) of Fig. 17.

The light source in the pickup arm is unique in that it consists of a special bulb that is caused to light up by utilizing energy provided by the r-f oscillator in the receiver. This oscillator is of the power pentode type and is operated at a higher voltage when the phonograph equipment is in use. The r-f energy required to light the filament of the bulb is obtained by coupling the filament to the plate winding of the oscillator inductively, as shown in Fig. 18.

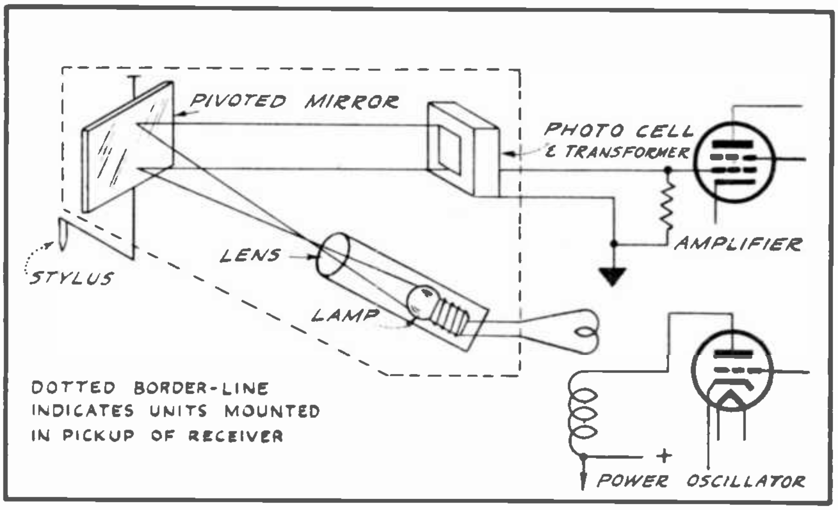

FIG. 18
CIRCUIT AND PRINCIPLE OF THE PHOTOCELL PICKUP

The current reversals through the lamp filament will thus be of such a very high frequency value that the lamp will emit light of practically constant intensity. This is important, as it prevents the generation of hum in the audio output.

Should the lamp be excited by a 60-cycle a-c supply, as in the average home, the current reversals through the filament would be so slow that a 60-cycle hum would be reproduced by the loudspeaker. In fact, even well filtered d-c, when used for this purpose, would cause noise due to voltage changes. A special shielded transformer is used to transfer the voltages generated by the photoelectric cell to the amplifier's input circuit.

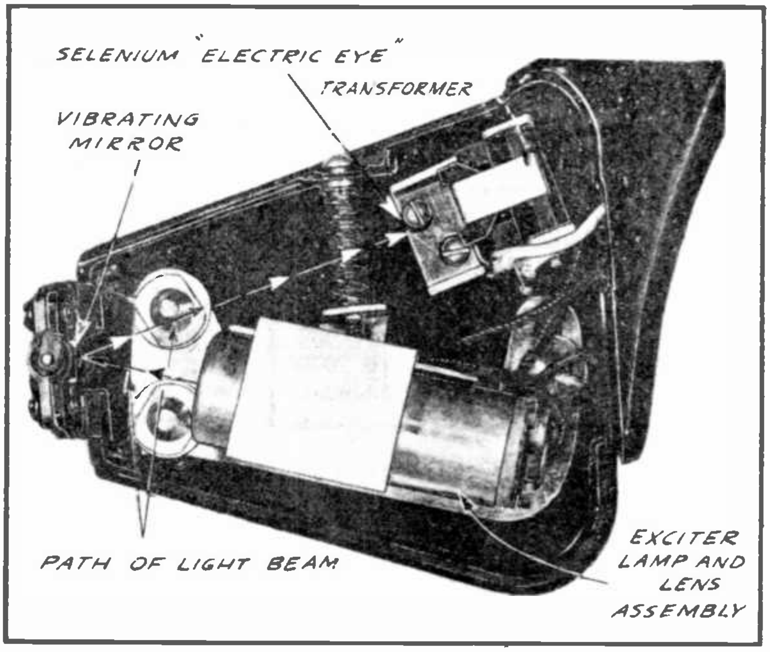

FIG. 19
ARRANGEMENT OF PARTS IN PHOTOCELL PICKUP

The floating jewel needle of this unit has a rounded tip instead of the usual dagger-like point as used on old-fashioned needles. For this reason, it moves thru the record groove without digging into the record to an injurious extent. Thus, wear and tear of the record is reduced to a minimum, and frying effects at the output due to needle-scratch are virtually eliminated.

The sapphire stylus has a life of from 8 to 10 years, and its use increases the life of records to such an extent that they may be played as much as 1000 times. It is claimed that this pickup unit is forty to sixty per cent more sensitive than other types, and that it will respond to frequencies as high as 25,000 cycles per second.

In Fig. 19 you are shown a photograph of a photoelectric cell pickup head as viewed from below. This illustration shows you how the various parts of this pickup, already described, are related to each other on the actual unit.

REPRODUCING NEEDLES

Much work has been done during the past twenty-five years toward perfecting the phonograph needle, the principle objective being to obtain the best tonal qualities possible and to increase the life of both the needle and the record. The advantages and disadvantages of the more commonly used types of needles may be summed up as follows:

NON-METALLIC NEEDLES: Needles made of bamboo, fiber, thorn and cactus were sometimes used on mechanical phonographs but are of no value on the modern electric phonograph as they do not provide full-range musical reproduction because of their inability to transmit the full range of frequencies from the groove to the pickup. Furthermore, because of these materials being soft, they become charged with grit, dust, etc., and actually grind out the record grooves. They are also likely to fill the record groove with bits of fiber which imbed themselves into the record material and thereby shorten the life of the record.

METALLIC NEEDLES: The steel needle is by far the most widely used of all types because it is the least expensive. Although satisfactory, the steel needle is subject to wear, and can, as a rule, be played only a few times. However, some steel needles are manufactured from special alloys which make them quite durable -- these needles are made entirely of chrome-steel alloys or in the form of chrome-plated steel cores.

JEWELED NEEDLES: Much experimentation has been done with jewel tips, particularly with DIAMOND and SAPPHIRE points that are now used extensively. The diamond possesses extreme hardness, and, for this reason, is not an ideal material for the tip of a reproducing needle. Furthermore, its cost is prohibitive to the average user.

TABLE I	
NEEDLE	PLAYINGS
FIBER, THORN, ETC. - - -	1
STEEL - - - - - - - - -	1 TO 3
ALLOY - - - - - - - -	500 TO 1000
SAPPHIRE - - - - - - -	1000 TO 2000
DIAMOND - - - - - - -	5000 OR MORE

The sapphire is the second hardest material, and its useful life for needle purposes is only slightly shorter than that of the diamond. Thus, the sapphire possesses practically all of the desirable characteristics of the diamond for this purposes and has the additional advantage of being less expensive. Sapphire-pointed needles are therefore used extensively.

Table I will furnish you with a general idea of the comparative life of the various types of pickup needles.

In the next lesson, we will continue our discussion of radio-phonograph combinations with an analysis of the circuits used in such systems.

******

EXAMINATION QUESTIONS

LESSON NO. 54

1. - Describe briefly the operating principle of the magnetic type phonograph pickup.

2. - Why are the reproducing heads of phonograph pickups sometimes mounted at an angle to the arm?

3. - What causes needle-scratch?

4. - Why is the mirror used in the photoelectric cell pickup?

5. - Describe briefly the operating principle of the crystal type phonograph pickup.

6. - (a) Why are magnetic type pickups damped?
   (b) How may this damping be accomplished?

7. - What method is sometimes employed to prevent excessive needle pressure?

8. - How may needle-scratch be reduced?

9. - What quality of recorded sounds is most noticeably affected by the speed of the turntable?

10. - What is the difference between a record groove that is modulated and one that is not?

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LESSON NO. 55

RADIO-PHONOGRAPH CIRCUITS

Radio-phonograph circuits, automatic record-changers, "wireless" record players and combination radio and home recorders are covered in this lesson.

Phonograph Input Circuits

Connecting the output terminals of a phonograph pickup to a conventional receiver, in order to make use of its audio amplifier and speaker system, may be accomplished in a number of ways, depending upon the receiver's circuit and type of pickup being used.

It makes little difference in regard to "quality" of reproduction whether the phonograph pickup is connected to the detector, or to the first audio tube -- provided that the detector tube is operated as a linear amplifier when the pickup is used; however, there is a difference in the volume of sound made available by these two methods. When considerable volume is required, or, when the receiver contains only one audio stage, it is usually the practice to connect the phonograph pickup to the detector circuit so that the additional amplification of the detector tube may be used advantageously. When the receiver has two

Fig. 1
Recording, Radio-phonograph Combination

efficient audio stages, it is usually the practice to connect the phonograph pickup directly to the input of the audio amplifier circuit and not to the detector stage.

Receivers employing a diode-triode operating as an a-v-c, detector, and audio coupling tube are ideally suited for a phonograph pickup connection. The circuit arrangement in these receivers is usually such that the regular volume control of the receiver may also be used for controlling the volume of phonograph reproductions.

In presenting these two basic phonograph input circuits, we will describe first the arrangements most generally used when the detector circuit is utilized.

PHONOGRAPH CONNECTION TO SIMPLE DETECTOR STAGE

The first of these arrangements is shown at (A) of Fig. 2, where you will observe that the phonograph pickup terminals are connected directly across the grid circuit of the detector tube -- also, notice that a change-over switch is employed to make possible a quick and easy change from radio to phonograph operation.

To cause the detector tube to operate as a linear amplifier during the reproduction of phonograph recordings, the regular bias resistor is disconnected from the tube's cathode circuit and another resistor of much lower value is connected in its place. The change-over switch used for this purpose is usually ganged with the radio-phono change-over switch so that both these operations will be simultaneous. (Note: A linear amplifier tube is a tube operating under such conditions that its plate current variations are exact but magnified reproductions of the voltage changes exciting its grid.)

Notice also in this circuit diagram that closing the change-over switch to the phonograph position (P) interrupts the grid circuit insofar as radio reception is concerned, but completes it through the phonograph pickup. Thus, no radio signals will "come through" during the reproduction of phonograph recordings. The audio signal voltages generated across the terminals of the phonograph pickup are now applied across the tube's grid circuit, operating this stage as an audio amplifier.

No volume control is shown in this circuit, but it may be connected directly across the terminals of the pickup unit as described in the previous lesson. On the other hand, if the volume control for the receiver happens to be located in the audio section of the set, it may serve for both radio and phonograph operation.

The phonograph pickup shown at (A) in Fig. 2 is of the high-impedance type, and may therefore be connected directly to the grid circuit of the tube. The same would apply to a crystal pickup, provided that a grid leak resistor of about 500,000 ohms is connected in parallel with it. Should a low-impedance unit be used at this point, it would then be necessary to employ an impedance-matching transformer in order to "match" it properly to the tube's high-impedance grid circuit.

In the circuit diagrammed at (B) of Fig. 2, the electromagnetic pickup is connected in the cathode circuit of the detector tube, the d-c resistance of its winding taking the place of the cathode resistor and so furnishing the bias voltage for the tube during phonograph operation. Closing the switch to the "R" position disconnects the pickup and places the regular bias resistor in the cathode circuit for normal power detection.

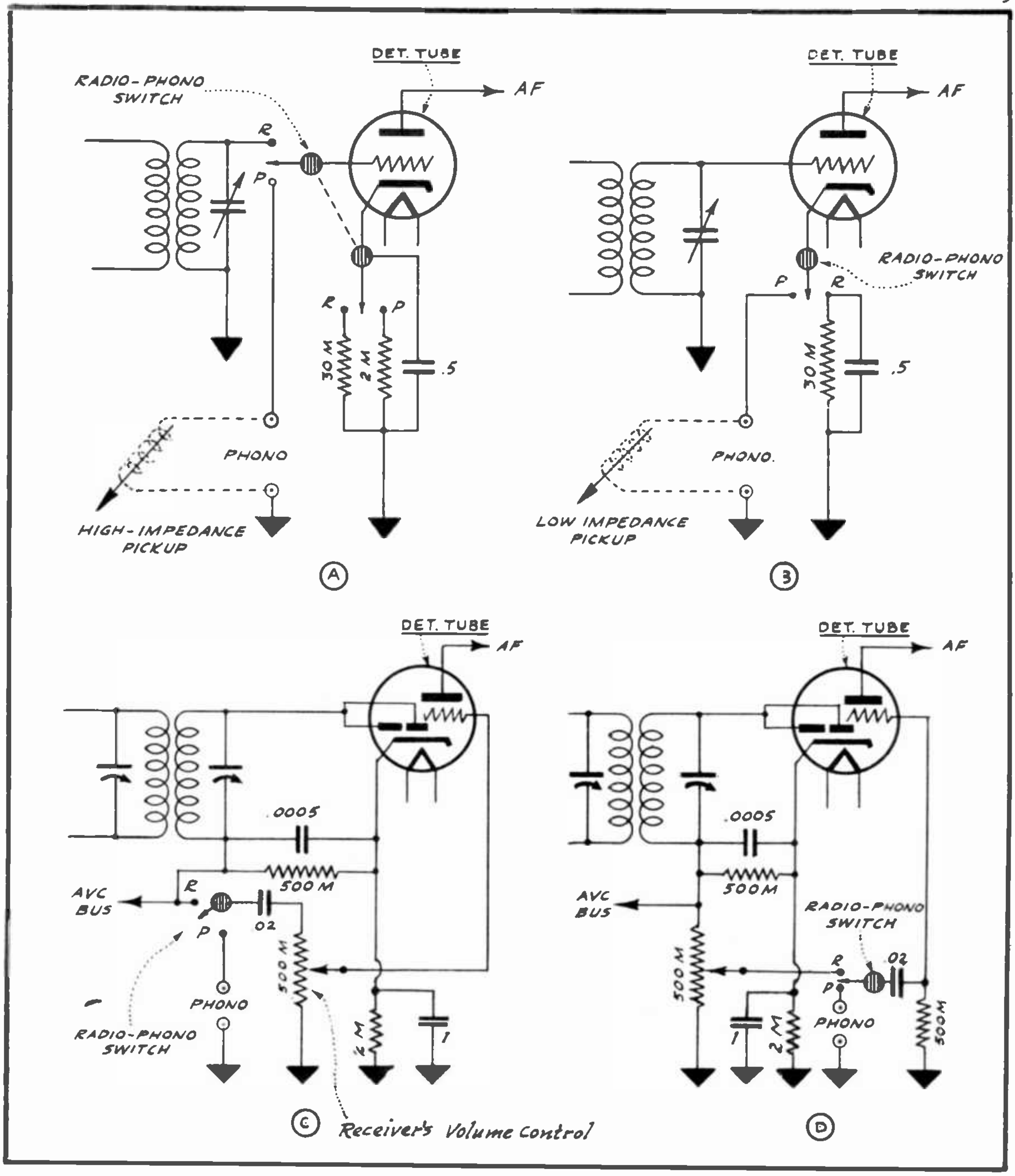

FIG. 2
PHONOGRAPH INPUT CONNECTIONS IN DETECTOR STAGE

A pickup having an impedance rating of around 500 to 3000 ohms is required in this case to permit the tube to be operated as a linear amplifier. If a high-impedance pickup were to be used in such a circuit, an impedance-matching transformer would be included. A crystal type pickup will not function in this circuit unless coupled through an impedance-matching transformer, the reason being that the impedance value of a crystal pickup is so high as to practically constitute an open circuit; this would leave the cathode circuit virtually open.

The arrangement operates as follows: The audio-frequency voltages generated by the pickup are applied between the tube's cathode and ground. Then, since the tube's grid is also connected to ground through the r-f or i-f transformer's secondary winding, these a-f voltages will also be effective between the grid and cathode of the tube -- thus, operating the tube in the normal manner.

The problems of controlling the volume in this circuit are similar to those discussed relative to (A) of the same illustration. However, unless some means is provided in circuit (B) so as to make the radio-frequency section of the receiver inoperative during phonograph operation, the receiver's dial would have to be set at some point where no radio reception is obtained.

The two detector input circuits, just discussed, employed triodes -- and are similar to those used in a great many of the earlier receivers. Let us now turn our attention to a typical detector circuit as used in more modern receivers, wherein a single tube functions as a diode detector, an a-v-c control tube and as an audio amplifier.

PHONOGRAPH CONNECTION TO MULTI-PURPOSE DETECTOR STAGE

Two circuits of this type are shown at (C) and (D) of Fig. 2. Both of these circuits are conventional and similar to those that you have studied in earlier lessons.

From a close inspection of circuit (C), it will be observed that the radio-phono switch serves to disconnect the radio-frequency section of the receiver from the audio section when in the "phonograph or (P) position," and also connects the phonograph pickup to the volume control circuit.

The audio-frequency voltages generated by the pickup are applied through the .02 mf coupling condenser, producing a voltage drop across the extremities of the 500,000-ohm volume control potentiometer. The setting of the volume control arm determines the percentage of the total signal voltage delivered to the grid of the tube for amplification.

This type of input circuit is suitable for either a high-impedance magnetic, crystal, or other pickup of similar characteristics. Low-impedance pickups can also be adapted to it by using an impedance-matching transformer.

In circuit (D), closing the switch in position "P" connects the pickup across the leak resistor of the tube's grid through the .02 mf coupling condenser, and at the same time "breaks" the connection at switch terminal "R" so that no audio signal, as received from broadcast stations, may be applied to the audio section of the receiver during phonograph operation. Here again, the circuit is ideally suited for a high-impedance pickup, unless an impedance-matching transformer is used. Also, since the receiver's volume control is not connected in the phonograph circuit, it is necessary in this case to use a pickup having a volume control incorporated in it.

AUDIO INPUT CIRCUITS

Now that you are acquainted with the more general arrangements employed for connecting a phonograph pickup to the detector circuit of a receiver, let us turn our attention to the methods used for connecting it directly to the audio system.

The first of these circuits is shown at (A) in Fig. 3, where you will observe that the pickup, together with its volume control, is connected in the grid circuit of the first audio tube. When using a pickup in this manner, as is true of all grid circuits -- a high-impedance

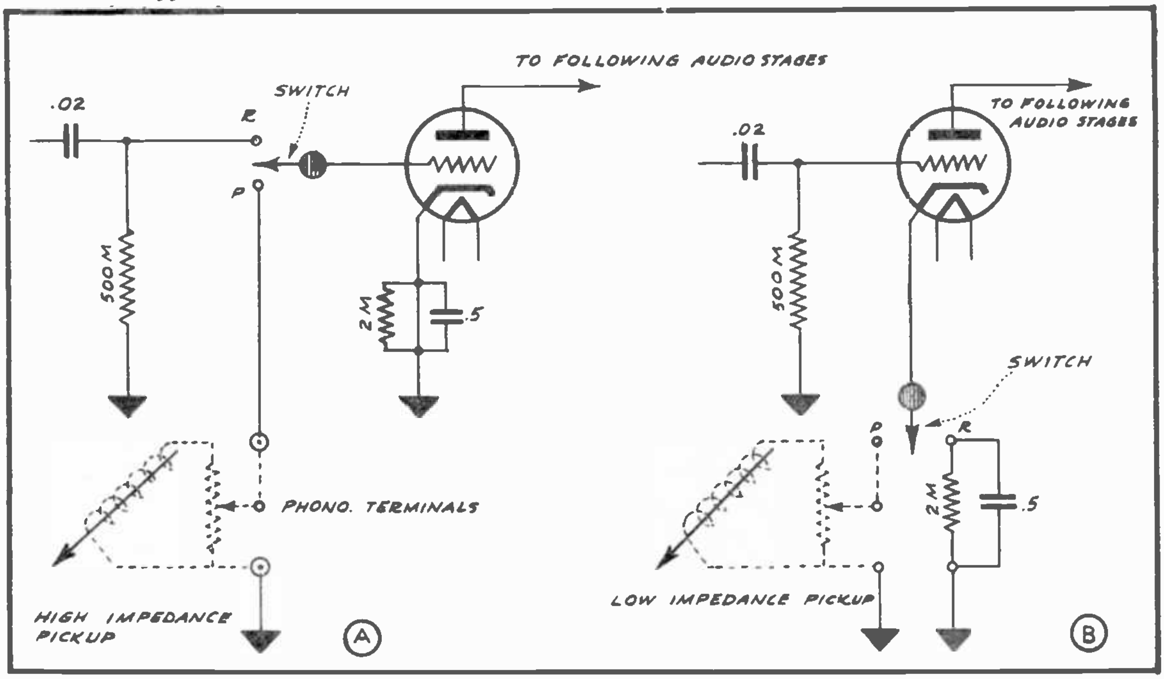

FIG. 3
PHONOGRAPH INPUT CONNECTIONS IN AUDIO STAGE

unit must be employed. However, a low-impedance unit could be used if an impedance-matching transformer were employed to couple it to the grid circuit. Notice further, how a change-over switch is employed to change from one form of operation to the other. Since no volume control is included in this part of the receiver, it will have to be incorporated in the pickup as shown.

At (B) is shown another application, where the pickup is inserted in the cathode circuit of the tube, as is also the change-over switch. In this case, a low-impedance pickup would be used so that its d-c resistance will provide the proper bias for the tube; otherwise, an impedance-matching transformer would be required.

Since no provisions are made in circuit (B) of Fig. 3 for interrupting the radio signal during phonograph operation, it will be necessary to detune the receiver from all stations during this time. Of the circuits shown in Fig. 3, the grid input method appearing at (A) is by far the more popular arrangement.

The circuit diagrammed in Fig. 4 is well suited for connecting a crystal or other high-impedance pickup to the audio amplifier when it is desired to have the volume control incorporated in the receiver proper.

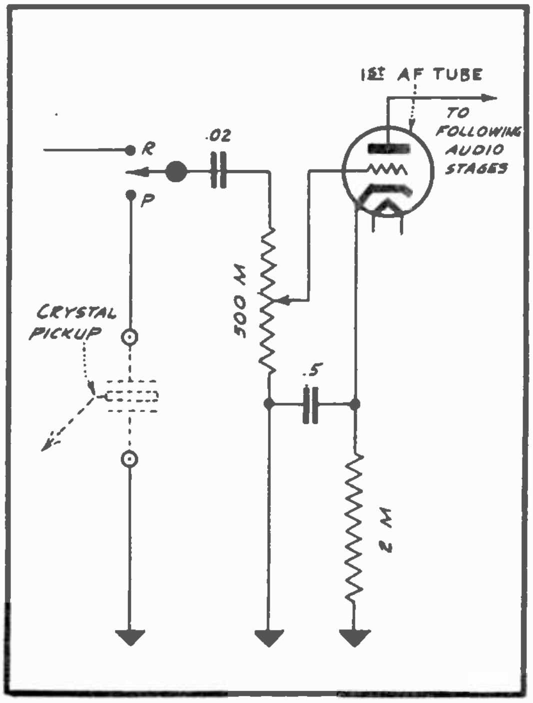

FIG. 4
CRYSTAL PICKUP CONNECTED TO AUDIO STAGE

Radio-Phonograph Assemblies

Now that you are acquainted with the purpose and operation of the various units used in radio-phonograph combinations, let us see how these different parts are assembled into a complete, commercial product.

FIG. 5
CONSOLE RADIO-PHONOGRAPH COMBINATION

In Fig. 5 you are shown a typical console-type combination, where the receiver proper is placed in the cabinet to the right and the phonograph assembly to the left. The door of the phonograph compartment is opened when this section of the combination is to be used.

The great popularity of radio-phonograph combinations has increased to such an extent that nearly every receiver manufacturer includes at least one model of this type in his line. The table-model type is by far the largest seller of all combinations. In Fig. 6 is shown a combination set that is typical of such models. Here the receiver proper is housed in the cabinet -- the dial assembly and controls being at the right and the speaker at the left. The turntable, pickup and motor switch are placed on the deck of the cabinet, and are accessible upon raising the lid.

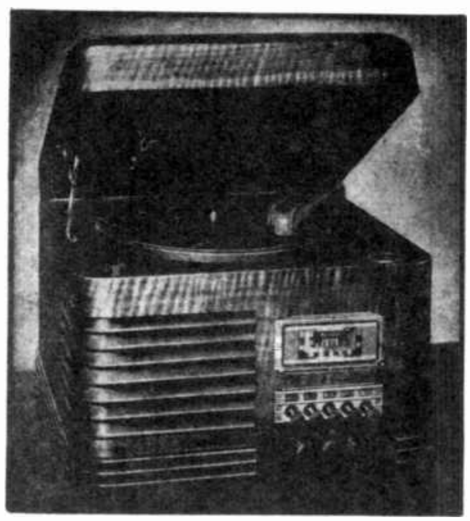

FIG. 6
TABLE-MODEL RADIO-PHONOGRAPH COMBINATIONS

The popularity of combinations has extended their use to the portable field -- models operated from the lighting circuit or from self-contained batteries having appeared on the market. Such a portable combination model is shown in Fig. 7. However, the turntable is in this case operated by a spring-type motor that is wound by means of the crank handle protruding from the side of the carrying case.

"Wireless" Record players

In all the arrangements considered up to this point, the phonograph pickup was connected directly to the circuits of the radio receiver. From what has already been discussed in this lesson, it must be apparent that it is not always a simple task to connect phonograph pickups to the circuits of receivers not originally designed for this purpose. Furthermore, if satisfactory performance is to be expected, there are several factors to be considered, as for instance, the type of pickup, the number of audio stages employed in the receiver, the type of audio tubes and circuit, the type of detector tube and circuit, etc.

The desire to overcome these difficulties, and also to do away with the necessity for connecting any wires between the phonograph pickup and the receiver, has lead to the development of what are known as "wireless" record players. These units are actually miniature broadcast transmitters.

FIG. 7
PORTABLE RADIO-PHONOGRAPH COMBINATION

A typical application of the wireless record player is shown in Fig. 8, where the record player is shown at the right on top of a record cabinet, while the receiver from which the sounds are emitted is located in the far corner of the room. There are no wired connections between the record player and the receiver.

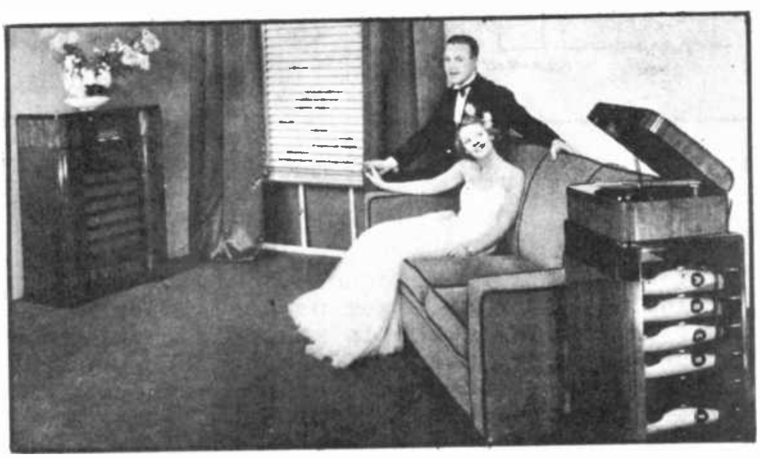

FIG. 8
WIRELESS RECORD-PLAYER OPERATING IN CONJUNCTION WITH RADIO RECEIVER

A close-up view of a "wireless" record player is shown in Fig. 9. Notice that only the turntable and phonograph pickup are visible -- all other parts and circuits are enclosed in the cabinet.

FIG. 9
WIRELESS RECORD-PLAYER

CIRCUIT DETAILS

In Fig. 10 is shown the circuit diagram of a typical two-tube "wireless" record-player, employing a pentagrid converter tube and a rectifier tube. Its circuit is adapted to either 110-volt a-c or 110-volt d-c operation. The unit is also equipped with a crystal pickup, a turntable, and a motor.

The rectified voltage is filtered by a resistor-condenser filter arrangement installed at the output of the rectifier tube. The ballast resistor for the filament circuit may either be of the line cord, tube, or individual resistor type -- all of which were described in an earlier lesson. A pilot light is generally included for the purpose of indicating whether or not the record-player is in operation. The motor winding is connected across the line circuit with a switch in series.

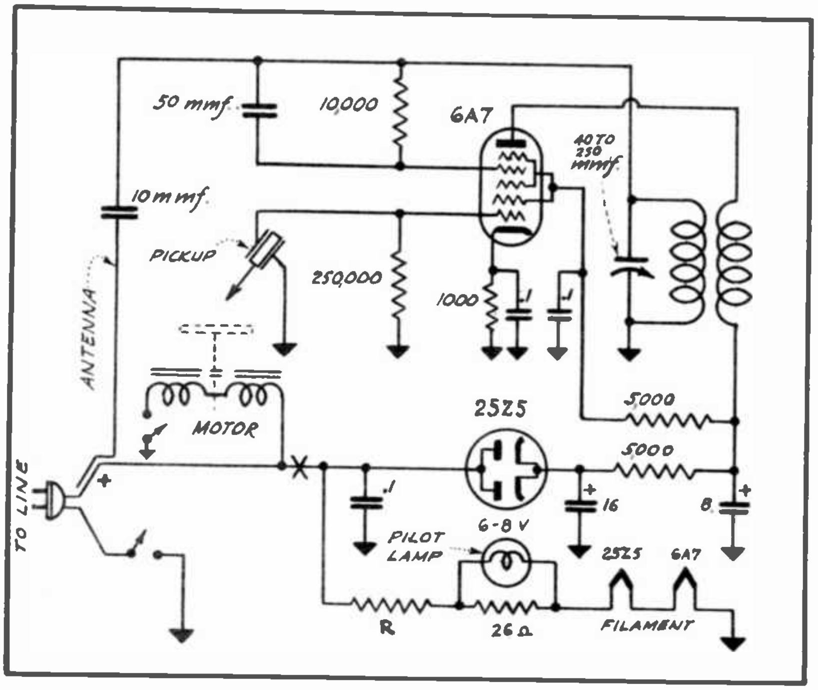

FIG. 10
CIRCUIT OF WIRELESS RECORD-PLAYER

The antenna is sometimes constructed in the form of a metal plate, mounted inside of the record-player's cabinet; a short length of wire extending from the cabinet; or, as in the case of Fig. 10, a third wire may be incorporated in the line cord but not connected to the plug -- thus serving as an antenna. Usually, such record-players are effective up to about twenty feet from the receiver.

CIRCUIT OPERATION

The converter tube is used in much the same manner as the combination mixer-oscillator in a superheterodyne receiver. That is, the plate is connected to B+ through the primary winding of an ordinary r-f transformer or oscillator coil. The tuned secondary winding of this transformer is closely coupled to the primary and connected to the control grid of the converter tube. The anode grid and screen grids of the tube are together connected to B+, but to a point of a slightly lower voltage value than that used for the plate connection. The close coupling between the plate and grid circuits, aided by the voltage values applied to the tube elements, causes the circuit to regenerate to the point of oscillation -- the frequency of oscillation being controlled by tuning the secondary circuit of the oscillator coil.

The tuned circuit of the oscillator coil is connected to the antenna of the record-player and so radiates a continuous type radio wave, the same as does a broadcast transmitter or signal generator (test oscillator). The radiated energy, although sufficient to be picked up by a good receiver located 20 feet or so from the record-player, is not strong enough to interfere with the neighbors' programs. So much for the radiated wave -- now to make the signal audible.

As will be observed in Fig. 10, the crystal phonograph pickup is connected across the regular oscillator grid and cathode of the tube.

The audio voltage variations generated by the pickup, upon being applied to the grid of the tube, vary the electron stream through the tube accordingly and thus modulate the r-f carrier signal. Therefore, the wave radiated by the record-player is modulated in accordance with the a-f signal voltages supplied by the phonograph pickup.

When the receiver is tuned exactly to the carrier frequency of the record-player's output, it will amplify and demodulate this signal just as though the modulated signal were being received from a broadcasting station. Thus, the phonograph recording is reproduced by the loudspeaker of the receiver.

To place the system in operation, the receiver is tuned to approximately 540 kc, where no station is likely to interfere. With the record-player in operation, the trimmer condenser across its r-f transformer's secondary winding is adjusted until the recording is heard through the receiver. This adjustment is made carefully, so that the record-player's oscillator is exactly in tune with the receiver. Once adjusted in this way, it will not be necessary to readjust the frequency of the record-player at any future time -- only the dial of the receiver need be set at the corresponding frequency position during phonograph operation. The receiver's volume control can be employed for controlling the volume of phonograph reproductions as well as for radio reception.

In the particular circuit diagrammed in Fig. 10, the ballast resistor (R) should have a value of 275 ohms, 75 watts if the record-player is to be connected to a line carrying 110 to 125 volts. For a 150-volt line, this value should be changed to 400 ohms, 75 watts.

If it is desired to connect this apparatus to a 220-volt line, resistor (R) should be rated at 275 ohms, 75 watts. An additional 350 ohm, 75-watt resistor should then also be installed at the point marked "X" in Fig. 10.

In all cases, it is important that the motor for the turntable be rated for the line voltage used, and also that it be adapted to the kind of current being supplied. Spring-type motors are sometimes used for this purpose.

Automatic Record Changers

Numerous mechanical devices are now available for permitting continuous playing of as many as ten 10 or 12-inch records without the need for changing each record by hand. Such devices are known as AUTOMATIC RECORD CHANGERS -- a typical example of which is shown in Fig. 11.

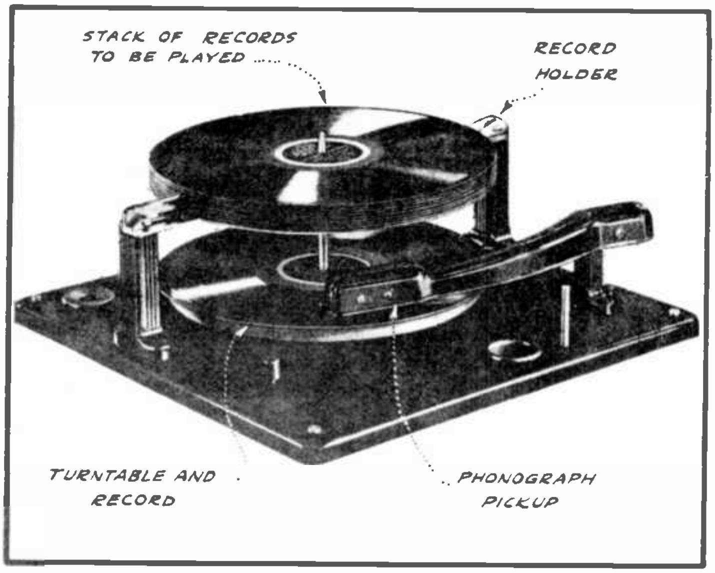

FIG. 11
AUTOMATIC RECORD-CHANGER

The operating principle of a popular type of automatic record-changer for home use is illustrated in Fig. 12. At (A) is shown the assembly with a record on the

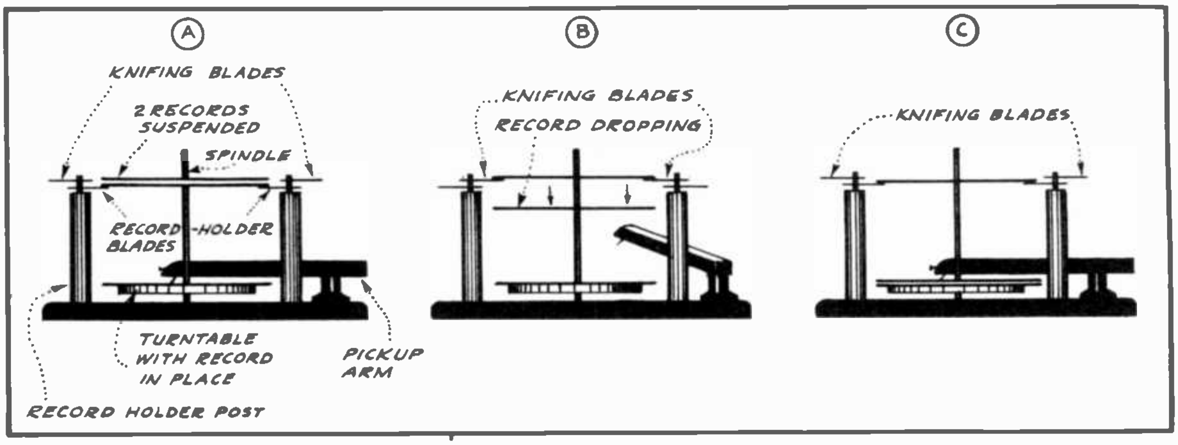

FIG. 12
OPERATING PRINCIPLE OF AUTOMATIC RECORD-CHANGER

turntable and two records suspended by the record-holder, waiting to be played. For the purpose of simplicity, only two suspended records are shown, although as many as ten records can be accommodated. The records are held up by the record-holder blades which are fastened to the two record-holder posts. When the pickup arm reaches the end of the record being played, it trips a lever which causes a gearing arrangement (coupled to the motor and not shown) to lift the pickup arm up and away from the record, as at (B). At the same time, the mechanism rotates the knifing blades around to the other side, separating the lower record from the stack and supporting the remaining records during the cycle change. The record-holder blades will by this time have rotated so as to clear the records, thus permitting the lower record of the stack to drop on the turntable as shown at (B).

FIG. 13
RECORD-PLAYER WITH AUTOMATIC RECORD-CHANGER

In the meantime, the lower record having been dropped into place, the pickup arm is automatically returned to the starting groove of the record, as shown at (C). Also, the blades are rotated so that the record-holding blades support the remaining records -- leaving the knifing blades free to "slice off" another record during the next cycle.

In Fig. 13 is shown a wireless record-player equipped with an automatic record-changer.

Recording, Radio-Phonograph Combinations

Recently, elaborate recording,radio-phonograph combinations have become popular with the radio public. Thus, combining in one unit the features of a radio receiver; a phonograph reproducer; a public address system and home recording equipment. The latter permits the operator to make his own recordings of the voices of his family and friends (see Fig. 14), to record his favorite radio programs, etc. -- later playing them back through the amplifying system of the combination unit.

FIG. 14
RECORDING A PROGRAM WITH COMBINATION INSTRUMENT

Combination units are available in either table, portable, or console-type cabinets --- typical examples of which are shown in Fig. 15.

Some of these combinations make use of the same pickup device for recording as for the reproduction of recordings. However, the majority use a separate cutter for recording and a conventional pickup for reproduction. In the latter case, the cutting head, microphone and pickup are all properly adjusted with respect to each other so as to provide optimum frequency response for both recording and playback. However, this matching of individual response of the cutter, microphone and pickup prevents good quality reproduction of recordings cut on one type of machine from being played-back on another type or make of machine.

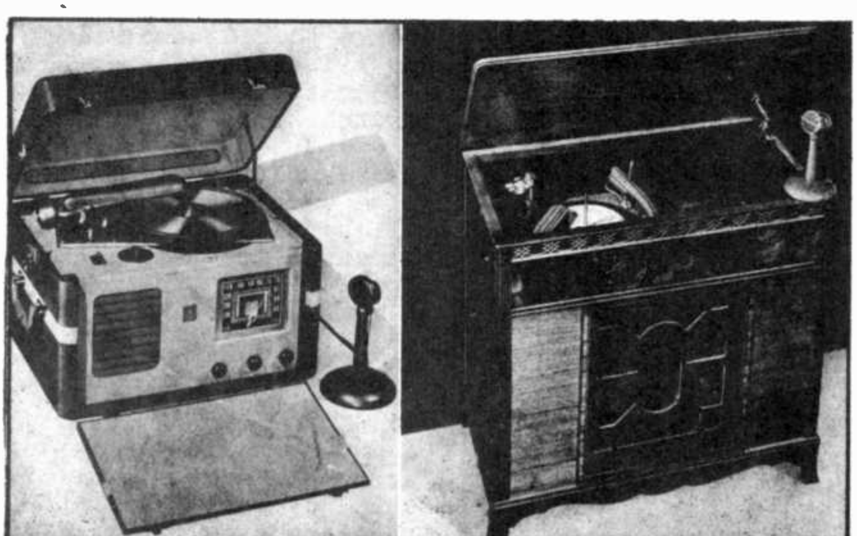

FIG. 15
TABLE AND CONSOLE MODELS OF RECORDING, RADIO-PHONOGRAPH COMBINATIONS

Later in the course, you will receive detailed instruction on the technique of recording. For the present, it is sufficient for you to know that a recording cutter is essentially a phonograph pickup being operated in reverse order. That is, applying audio-frequency voltage variations across its terminals will cause its needle (stylus) to vibrate accordingly and so cut a modulated groove in a blank record or modulate a pre-cut groove in a record which is being rotated on a turntable.

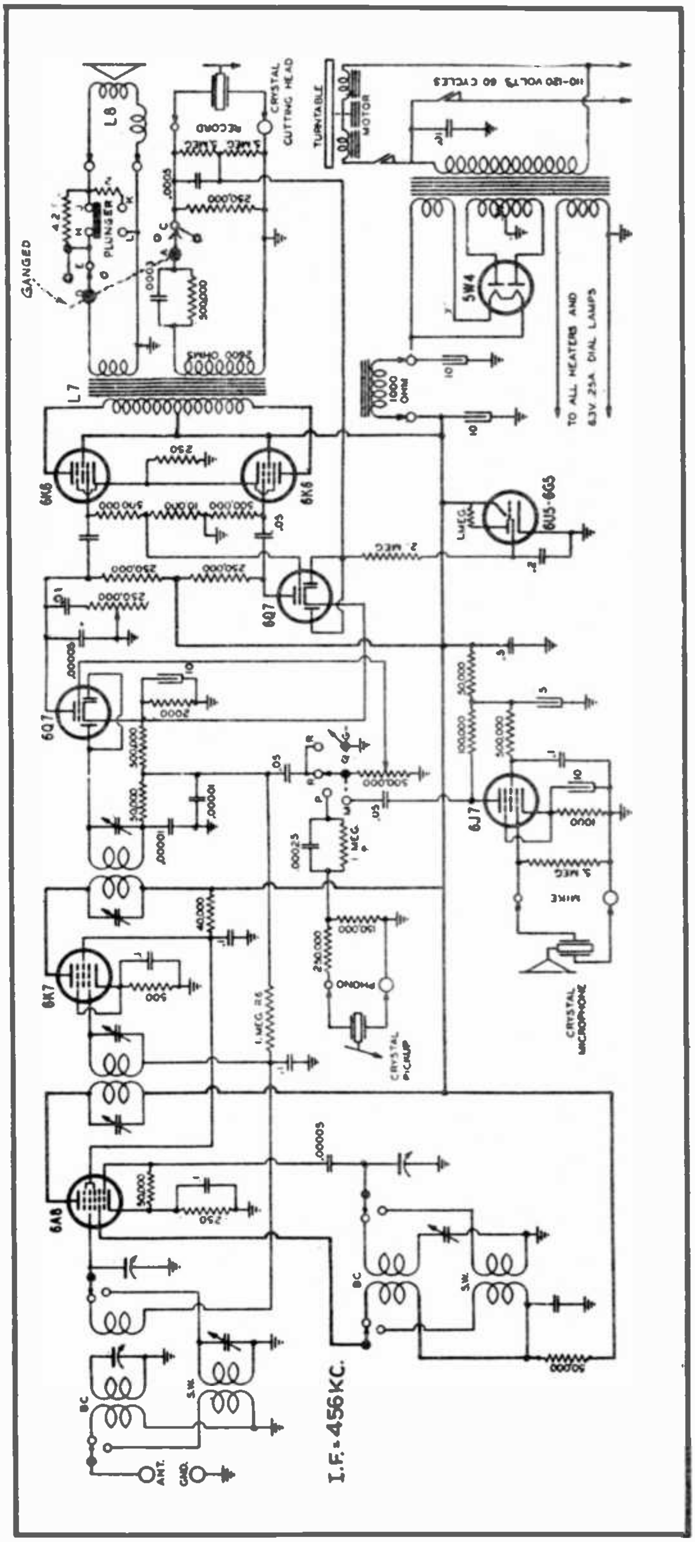

Fig. 16
Circuit Diagram of a Recording, Radio-phonograph Combination

CIRCUIT OPERATION

A schematic wiring diagram of one of these combinations is shown in Fig. 16. Two 2-gang selector switches are provided to operate the system either as a radio receiver, public address amplifier, for recording sounds picked up by the microphone, for recording broadcast programs, or for the reproduction of phonograph records. A study of the switching sequences given in the schematic diagram will indicate that the loud speaker is operated as a monitor at reduced output while recording broadcast programs, but is silenced when recording sounds picked up by the microphone. The cutter head is not energized when the switches are in the radio, public address, or record reproducing positions. These switch operations are as follows:

<u>TO USE AS A RADIO RECEIVER</u>: Master switch Q is placed in the R position, and switch D is closed to E, while the adjacent plunger is raised to connect H and J. At the same time, switch A is open. Thus, the crystal pickup, microphone and crystal cutting head are disconnected from all portions of the audio circuit, and the receiver operates in the conventional manner.

<u>TO USE AS A PHONOGRAPH</u>: Master switch Q is placed in the P position, which connects the crystal pickup to the audio input circuit of the 6Q7 tube. At the same time, the r-f tuning sections of the set are disconnected from the volume control potentiometer and grounded direct by

the simultaneous closing of switch G to R. Thus, no radio signals are passed through the receiver at this time.

The ganged switches D and A remain in the same position as for radio reception; that is, with D closed to E, and A open.

TO USE AS A PUBLIC ADDRESS SYSTEM WITH MICROPHONE: Master switch Q is placed in the M position and G remains closed to R. This leaves the radio tuning sections and the phonograph pickup disconnected. The ganged output switch D remains closed to E, and A open, thus leaving the loudspeaker in circuit and the cutting head disconnected.

TO RECORD FROM THE MICROPHONE: Master switch Q remains in the microphone or M position and G in the R position. Switch A is closed to C so as to connect the crystal cutting head into circuit. Switch D is opened so as to disconnect the loudspeaker.

TO RECORD RADIO PROGRAMS: Master switch Q is placed in the R position, which disconnects both the crystal pickup and the microphone. Switch D is closed and A is closed, thus placing both the speaker and cutting head in circuit. However, the plunger in the speaker circuit is now dropped so as to connect points L and K, in order to allow the speaker to be operated at reduced volume for monitoring the radio program being recorded.

Sometimes, the master switch Q is ganged with switches G, D, and A to give simultaneous operation of the input and output circuits according to the type of operation desired.

A separate secondary winding is provided on the output transformer (L-7) to furnish a higher impedance and higher voltage to properly drive the crystal cutting head. The cutting head has an impedance rating of about 1000 ohms as compared to 9 ohms of the speaker's voice coil.

A resistance network and tube rectifier (6Q7) are included in the cutting head circuit, and so connected to the "tuning eye" of the receiver (the 6U5 or 6G5 tube) that the latter will furnish a visual indication of the approximate output power available for driving the cutting head. The driving power for either the cutting head or the loudspeaker is regulated by the main volume control potentiometer of the receiver.

Since the subject of recording is thoroughly covered in later lessons of the course, we will not discuss these principles further at this time.

Volume Expansion

In the music of a symphony orchestra, the sound intensity of the loud passages is very much higher than that of the soft passages. We then say that such music has a "very large volume range." When such music is recorded, it is not feasible to make the ratio of the maximum amplitude to minimum amplitude as large on the record as it is in the original music. Therefore, the recording process is monitored so that the volume range of the original music is compressed on the record; in other words, the amplitude of the loud passages is suppressed more than that of the soft passages so there is now not as great a difference between the intensity of the soft and loud passages as actually produced by the orchestra. To compensate for this compression, while playing the record, a VOLUME EXPANDER amplifier system is used.

The volume expander has a variable gain which is greater for a high-amplitude signal than for a low-amplitude signal. Therefore, it amplifies the loud passages more than the soft passages and thus restores to the music being reproduced from the record the identical volume range of the original.

In Fig. 17 is shown a typical volume expander amplifier circuit, employing a 6L7 pentagrid tube as an audio amplifier, a 6C5 triode amplifier, and a 6H6 diode half-wave rectifier.

The action of this circuit depends on the fact that the gain of the 6L7 tube as an audio amplifier can be varied by variation of the bias on its #3 grid. When the bias on this #3 grid is made less negative, the gain of the 6L7 tube increases. In the circuit shown, the signal to be amplified is applied to the #1 control grid of the 6L7 and is then accordingly amplified by the tube.

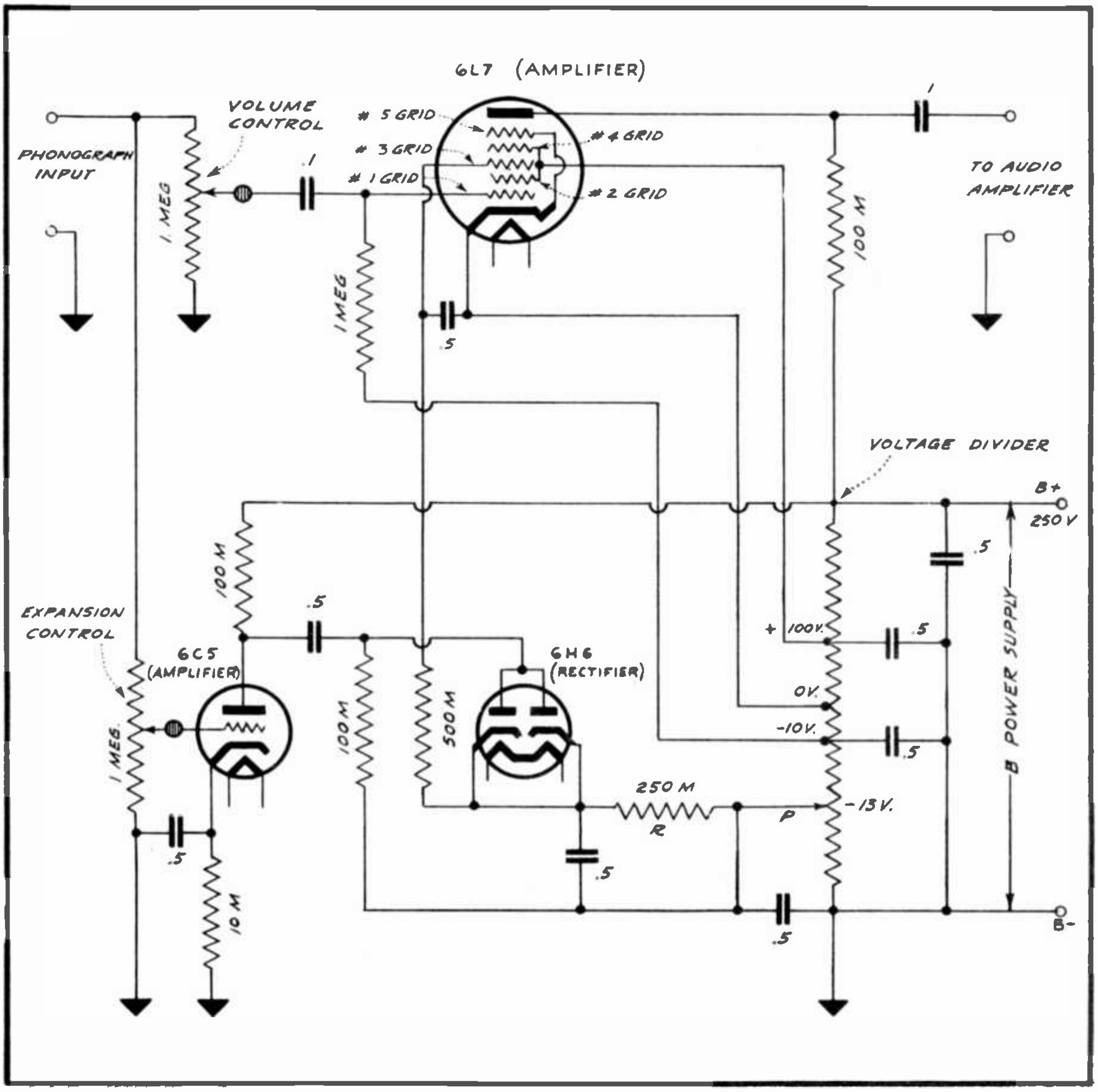

FIG. 17
VOLUME EXPANDER CIRCUIT

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This signal is also applied to the grid of the 6C5 tube, is amplified by it and is then applied across the diode load circuit of the 6H6 tube. Because of the latter tube functioning as a half-wave rectifier, the rectified current will flow through resistor R which is connected in series with this tube's cathode and diode plates. It is then rectified by the 6H6 diode. The rectified voltage developed across R is then applied as a positive bias to the #3 grid of the 6L7 tube. Then, when the amplitude of the signal input increases, the voltage across resistor R also increases, and the bias on the #3 grid of the 6L7 is made less negative. Because this increases the gain of the 6L7, the gain of the amplifier increases with an increase in the signal amplitude and thus produces VOLUME EXPANSION of the signal.

The #1 control grid of the 6L7 is a variable-mu grid and therefore will produce distortion if the input signal is too large. For that reason, the signal input to the 6L7 must not exceed a peak value of 1 volt. (This value is of the same order as the voltage obtained from the usual magnetic phonograph pickup.) The no-signal bias voltage on the #3 grid is controlled by the adjustment of contact P on the voltage divider. This contact is adjusted initially to give a no-signal plate current of around 0.15 milliampere, in the case of the 6L7 tube.

The volume expansion circuit is always placed between the phonograph input and the audio amplifier, as designated in Fig. 17. Any conventional phonograph pickup circuit may be connected to the input of the volume expander, and any conventional high-quality audio amplifier circuit may be connected to its output. It is to be understood that volume expansion is used only when reproducing phonograph recordings -- and not during the reception of radio programs.

Volume expansion is not used in the majority of radio-phonograph combinations due to the added expense of incorporating this feature -- but if used -- it will be found only in the more expensive models. Circuits of such receivers are arranged so that the volume expansion circuit is switched into the system during phonograph operation and disconnected therefrom during the reception of radio programs.

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EXAMINATION QUESTIONS

LESSON NO. 55

1. - Explain briefly the operating principles of a "wireless" record-player.

2. - Draw a circuit diagram of a multi-purpose detector stage, showing how it may be adapted to either radio reception or for the reproduction of phonograph recordings.

3. - Why is it necessary to change bias resistors in the circuit diagrammed at (A) of Fig. 2 of this lesson when switching from radio to phonograph operation?

4. - Why is it not practical to connect a crystal pickup directly across the "PHONO" terminals in the circuit diagrammed at (B) of Fig. 2?

5. - When using the automatic record-changer described in this lesson, what prevents two records from dropping on the turntable simultaneously?

6. - What equipment is used on recording radio-phonograph combinations that is not found on the conventional radio receiver which is designed for the reception of radio programs only?

7. - Why is volume expansion employed in some audio amplifiers?

8. - What must be done to prevent radio signals from interfering with the reproduction of recordings if no means is provided on a combination radio-phonograph for making the radio-frequency amplifier inoperative during phonograph operation?

9. - What prevents the records from dropping on the pickup during the operation of the record-changer described in this lesson?

10. - What is the purpose of the rectifier as used in a volume expansion circuit?

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LESSON NO. 56

FILTER SYSTEMS

From what you have learned thus far concerning radio receivers and associated equipment, you will realize how extensively filter systems are used in electronic equipment of all kinds. You have seen how we employed filter circuits in conjunction with power packs to remove the ripple from B current after it has been rectified; how various types of r-f and a-f filter systems are used in receivers and amplifiers to separate certain frequencies from others; how the band-pass principle is applied to selector circuits, etc.

Now that you know how these different types of filters are applied in radio, we shall proceed with the various design problems related to circuits of this type.

We can classify filter systems into the following four distinct groups: (1) LOW-PASS FILTERS; (2) HIGH-PASS FILTERS; (3) BAND-PASS FILTERS; (4) BAND-SUPPRESSION filters. These will now be discussed in detail.

LOW-PASS FILTERS

Low-pass filters are designed to pass all frequencies below a definite frequency which is known as the CUT-OFF FREQUENCY, and to substantially reduce or "attenuate" the amplitude of currents of all frequencies above the predetermined cut-off frequency. This type of filter will permit direct current to flow through it without appreciable opposition.

FIG. 1
TYPICAL COMMERCIAL FILTER UNITS

In Fig. 2 you are shown a typical low-pass filter. You will no doubt immediately recognize it as being the type of filter which is used extensively in the power pack of a-c receivers to filter the "B" current after is has been rectified.

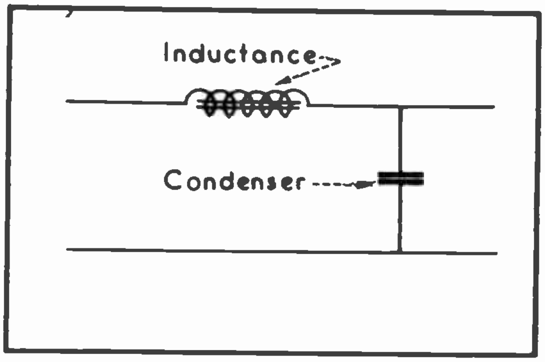

FIG. 2
LOW-PASS FILTER

LOW-PASS FILTER ACTION

For the sake of simplicity, we shall assume, first, that a d-c emf is applied to the filter. In Fig. 3, we have a diagram which illustrates clearly the conditions existing in the system in which the filter is being used. The source of emf is in this case considered as being a d-c generator, connected to what is known as the source end of the filter. A resistor is connected across the load end of the filter.

You can readily see that the applied emf tends to force current through the load, and that the inductance is connected in series with the source of emf and the load. The condenser is connected in parallel with the load; or "shunted across it," as we generally say. Thus, it is apparent that if a d-c emf is applied to the system, the inductance offers no opposition towards the flow of direct current, other than its ohmic resistance --- which is quite low. The condenser, on the other hand, does not permit direct current to flow through it. Therefore, all current which is caused to flow by the emf must pass through the load.

Now, let us see what happens when an alternating emf is applied to this circuit. An inductance, you will recall, opposes the flow of either an alternating or a pulsating direct current; and the higher the frequency of such current, the greater will be the opposition. A condenser, however, permits the flow of alternating or pulsating current; and the higher the frequency of the current, the less will be the opposition.

So, with an a-c voltage source applied to the filter, conditions become as illustrated in Figs. 4 and 5. Assuming the polarity of the generator voltage at one particular instant being as indicated in Fig. 4, and that the frequency of the generated emf is such as to be opposed by the filter, we find that as the generator voltage rises in a positive direction, there will be a flow of electrons in the direction indicated by the arrows. (Note: Electrons flow from negative towards positive). These electrons leave the upper condenser plate, pass through the inductance, generator, and gather on the lower condenser plate. Comparatively few of these electrons pass through the load; since in actual practice, the load resistance is much higher than the capacitive reactance of the condenser. The inductance opposes this increasing

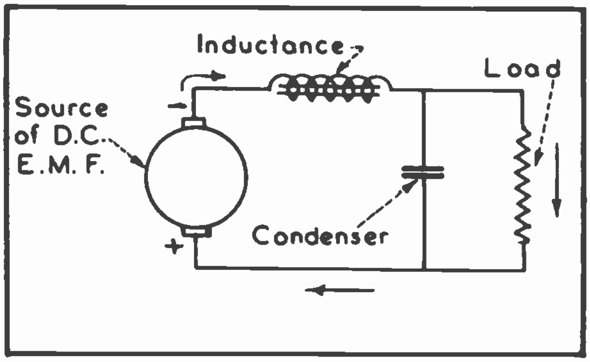

FIG. 3
PASSAGE OF D-C THROUGH THE FILTER

current; and the condenser, operating as just explained, assists the inductance in reducing the flow of current through the load at this frequency.

As the generator emf reaches its peak value and commences to decrease, the collapsing magnetic field around the inductance generates a self-induced emf in the inductance. The polarity of this self-induced voltage is such as to keep the electrons flowing into the lower condenser plate.

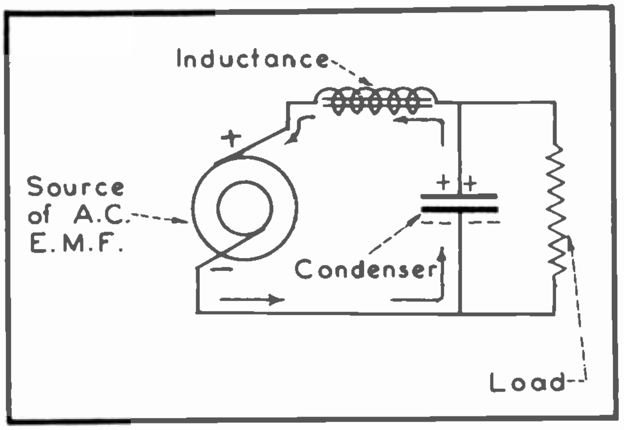

FIG. 4
ACTION OF FILTER TOWARDS A-C

Finally, when the applied emf reaches a value of zero, and the magnetic field around the inductance dies down, the condenser discharges electrons from its lower plate toward its upper plate. And, as the generator emf reverses its polarity, it tends to drive a still greater number of electrons towards the upper condenser plate as indicated by the arrows in Fig. 5. Thus, the upper condenser plate becomes negatively charged.

After reaching its peak value in this direction, the voltage again approaches zero, as also does the magnetic field around the inductance. But, the self-induced voltage generated by this collapsing field keeps the electrons moving in the same direction. Finally, the generator voltage commences to build up in the opposite direction; and the electron flow illustrated in Fig. 4 again occurs. This cycle of events continues in this order repeatedly as the a-c emf is applied.

The important fact to remember about this system,when subjected to a-c or pulsating d-c voltages, is that although the inductance alone opposes variations in current and so reduces the flow of electrons through the circuit, some of this current would pass through the load, were it not for the condenser. However, by using the condenser in combination with the inductance, the condenser serves to "store" an appreciable number of electrons each time that the applied emf reverses or varies in value, and in this way by-passes them around the load. Therefore, the current through the load is reduced materially at this frequency. This effect will be still more pronounced when the reactance of the condenser is much less than the resistance or impedance of the load; and which is the case in actual practice where filters of this type are used.

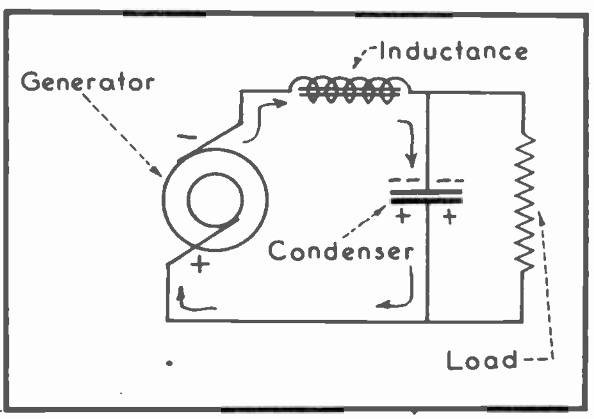

FIG. 5
REVERSE ELECTRON FLOW

At frequencies below cut-off, the opposition and by-passing effect becomes less; and therefore, more current passes through the load. At frequencies above cut-off, the opposition and by-passing effect becomes greater, and less current passes through the load.

"T"-TYPE LOW-PASS FILTERS

Although the single-section filter has a definite effect upon reducing the flow of current through the load at frequencies above cut-off, yet it doesn't cause a very sharp reduction in current at the cut-off frequency. To make the cut-off more abrupt (or sharper) at the desired cut-off frequency, another inductance can be connected in series with the load-end of the filter as illustrated in Fig. 6.

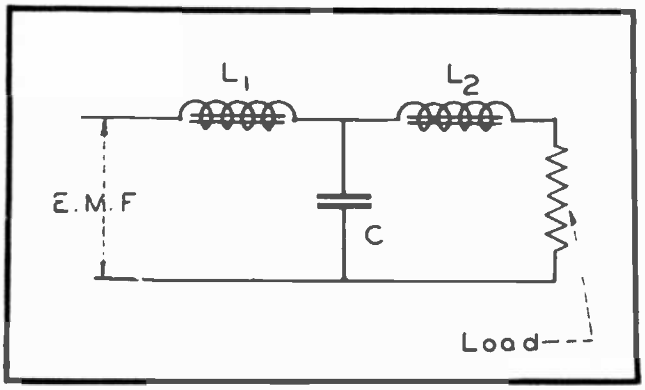

Fig. 6
T-Type Filter

This is known as a "T"-type filter, for the reason that the two inductances, L_1 and L_2, together with condenser C, take the shape of the letter "T".

In order to provide a still sharper frequency cut-off, two of these T-sections can be connected together as illustrated in Fig. 7. Here, we have inductances L_1 and L_2 together with condenser C_1, forming one T-section; while inductances L_3 and L_4 with condenser C_2 form the second T-section.

If the inductance value of L_1-L_2-L_3 and L_4 are all equal, then the combined inductance of L_2 and L_3 will be twice that of the individual inductances L_1 and L_4. Or, the outer individual inductances L_1 and L_4 each have one-half the inductance of L_2 and L_3 combined.

This is an important rule to remember. Quite often, in practice, the two chokes L_2 and L_3 are replaced by a single choke as illustrated in Fig. 8. In this case, the inductance of each of the end chokes is equal to one-half that of the center choke.

For the sake of simplicity, we designate the center inductance as L, and the two end inductances as 1/2 L.

In some instances, three-section T-filters, such as the one shown in Fig. 9, are used. In this type of filter, the two end chokes L_1 and L_4 each have one-half the inductance value of L_2 and L_3.

The greater the number of filter sections used, the sharper will be the frequency cut-off. Frequently, a single section is sufficient, but sometimes two or three sections are required. This depends chiefly upon how sharp the frequency cut-off must be, and the allowable cost for this part of the equipment.

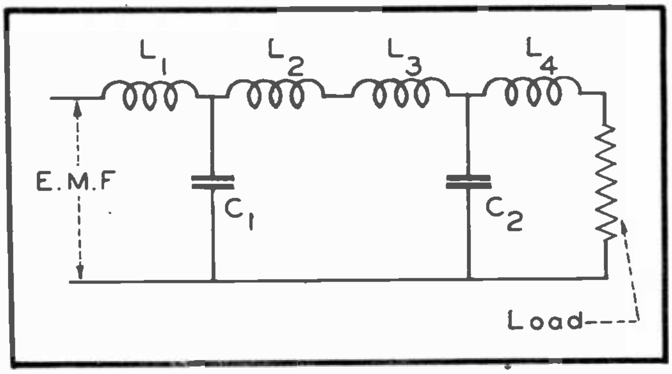

Fig. 7
Two-Section T-Filter

"PI" TYPE LOW-PASS FILTER

In Fig. 10, you are shown another form of filter where a condenser is connected across the line at each end of an inductance. This is known as a "PI" filter, since its circuit diagram somewhat resembles the Greek letter, π. This filter operates on the same principles as already explained for the T-type filter, only that there are now two condensers per section connected across the line.

The "T" and the "PI" filter each have their distinct advantages. The T-filter is more desirable for constant voltage circuits, while the "PI" filter is most desirable when a more nearly constant current is required.

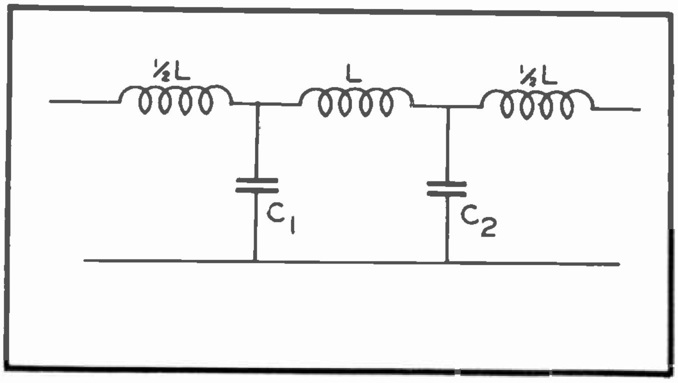

FIG. 8
TWO-SECTION T-FILTER WITH
SINGLE CENTER INDUCTANCE

In this case, also, the frequency cut-off can be made sharper by increasing the number of filter sections in the system. In Fig. 11, for instance, we have two "PI" sections connected end-to-end. Under these conditions, condensers C_2 and C_3 are connected in parallel, which means that if all of the individual condensers have the same capacity, the capacitance at the junction will be equal to the capacity of C_2 plus C_3. Thus, capacitance at the point of junction is equal to twice the capacitance at either end of the filter.

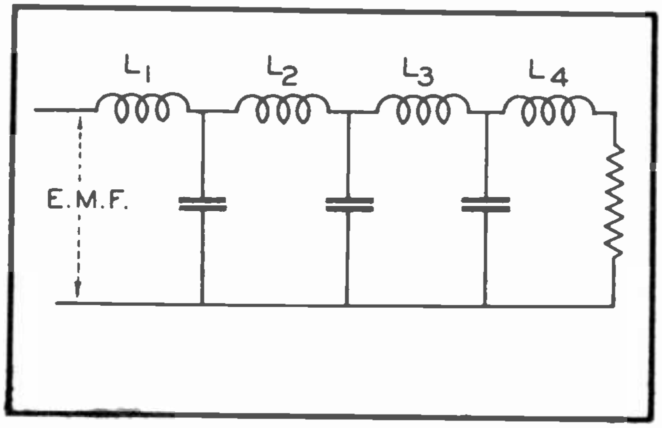

FIG. 9
THREE-SECTION T-FILTER

This same effect may be obtained by using a single condenser of twice the capacity at the junction point of the series-connected inductances, as shown in Fig. 12. The center condenser C will in this case have twice the capacity of the two end condensers which for the sake of simplicity are designated as 1/2 C. Inductances L_1 and L_2 are equal in value.

Fig. 13 shows how a three-section "PI" filter is arranged. Here, the three inductances each have the same value. The two end condensers each have one-half the capacity of the condensers which are used in the center or "repeating section" of the filter. This is designated in Fig. 13 by the fact that the two center condensers are both marked "C" while the two end condensers are each marked 1/2 C.

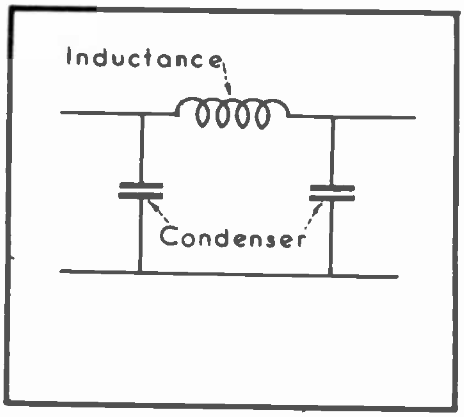

FIG. 10
SINGLE-SECTION "PI"
FILTER

Having considered the operation and structural features of the various forms of low-pass filters, we are now ready to discuss the design problems pertaining thereto.

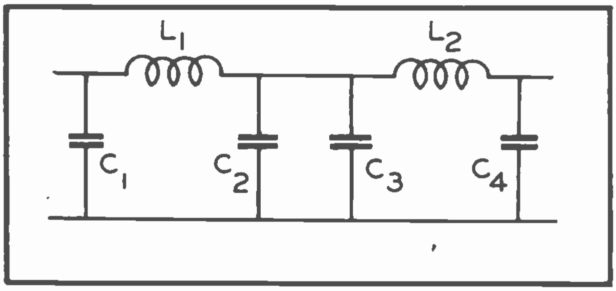

FIG. 11
TWO-SECTION "PI" FILTER

LOW-PASS FILTER DESIGN

The first point to bear in mind is that in order for a filter to be efficient, its source and load impedance should be approximately equal to what is known as the "characteristic impedance" of the filter.

If the nature of the problem happens to be such that the load and source impedance are known, and are already equal, then this same impedance value is chosen as the characteristic impedance of the filter which is to be designed. Should either the load or source impedance, but not both already be established --- and of known value --- then this known terminal impedance can be selected as the desired characteristic impedance of the filter. The other terminal impedance is then adjusted to this value.

To determine the inductance and condenser values for a low-pass filter of a given cut-off frequency, use the following formulas:

$$L = \frac{0.3183 \times Z_c}{f}$$

Wherein L = the inductance, expressed in henries; Zc = the characteristic impedance, expressed in ohms; f = cut-off frequency in cycles per second.

$$C = \frac{0.3183}{f \times Zc}$$

Wherein C = the capacity, expressed in farads; f = cut-off frequency in cycles per second; Zc = the characteristic impedance, expressed in ohms.

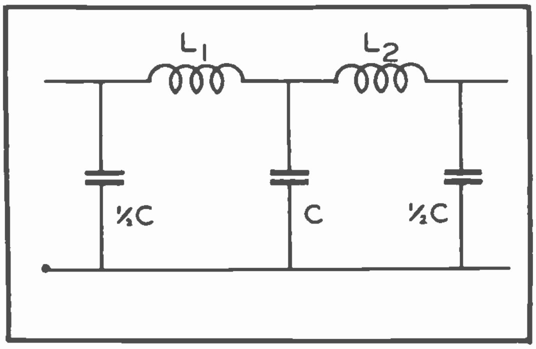

FIG. 12
ANOTHER TWO-SECTION "PI" FILTER

Example: In Fig. 14, is illustrated a problem where a low-pass filter is installed in the plate circuit of a vacuum tube which is handling both radio frequency and audio frequency energy. The purpose of this filter is to prevent r-f energy from getting into the following a-f stage, while at the same time permitting the a-f signal to pass through to the audio frequency amplifier.

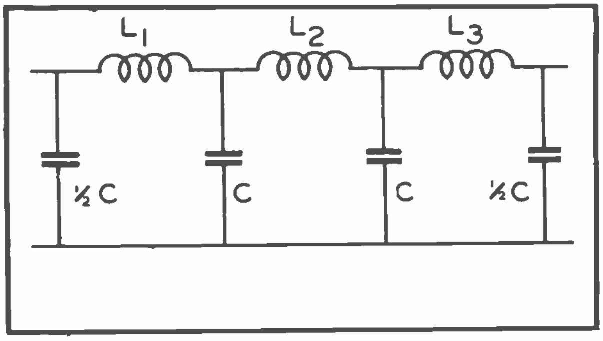

FIG. 13
THREE-SECTION "PI" FILTER

The load resistor of this circuit has a resistance value of 50,000 ohms, and the plate resistance of the tube is known to be 250,000 ohms. Since the highest audio frequency to be passed by the filter is 20,000 cycles, we choose this as our cut-off frequency.

In order for the filter to operate at maximum efficiency, the source impedance should be equal to the load impedance. This can be accomplished by connecting a resistor R_2 in parallel with the tube's plate resistance.

The total resistance of two parallel connected resistances is determined by the formula $R = \frac{R_1 \times R_2}{R_1 + R_2}$. Hence, since "R" in this case is equal to the plate load resistor, (50,000 ohms), and as the tube's plate resistance (R_1) is already set at 250,000 ohms, the value of R_2 can be found by using the parallel resistance formula in the form $R_2 = \frac{R \times R_1}{R_1 - R} = \frac{50,000 \times 250,000}{250,000 - 50,000} = \frac{12,500,000,000}{200,000} = 62,500$ ohms. From this, we see that by connecting the 62,500 ohm resistor (R_2) in parallel with the tube's plate resistance, the source impedance of the filter will be equal to the load impedance, or 50,000 ohms. The characteristic impedance of the filter should therefore also be 50,000 ohms.

With this value determined, the required inductance for the filter can be found by using the formula: $L = \frac{0.3183 \times Zc}{f} = \frac{0.3183 \times 50,000}{20,000} = \frac{15,915}{20,000} = .79$ henries. This is the value for L in our filter diagrams.

To find the value of each filter condenser, use the formula: $C = \frac{0.3183}{f \times Zc} = \frac{0.3183}{20,000 \times 50,000} = \frac{0.3183}{1,000,000,000} = .0000000003183$ farads = .0003183 mfds. or approximately .00032 mfds. This is the value for "C" in our filter diagrams.

When constructing the filter, its resistance should be kept down to as low a value as possible because resistance tends to oppose even currents of those frequencies which it is desired to pass, and prevents a sharp cut-off. Also, it is to be remembered that the current intentionally suppressed by the filter is never reduced to absolute zero at any frequency; however, zero current can be more nearly approached by employing a series of properly designed filter sections. The design constants are worked out in the same manner whether the filter be of the "T" of "PI" type. The choice of the type depends upon the advantages most desired, and which were mentioned for each form earlier in this lesson.

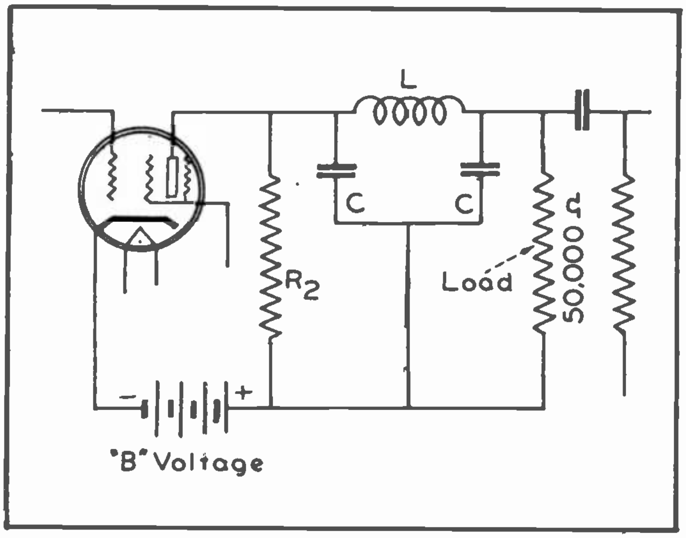

FIG. 14
CALCULATING THE FILTER

In the average r-f filter, such as used in the plate circuit of the detector tube in a radio receiver, a frequency of 10,000 cycles per second is generally chosen for the highest frequency to be passed freely while frequencies above 20,000 cycles are to be suppressed materially. Thus, radio frequencies will be suppressed or rejected by the filter, and audio frequencies will pass through it to the a-f amplifier.

In the case of power supply filters, direct current and all other currents having a frequency up to about 20 cycles per second are generally offered free passage. Frequencies above 20 cycles should be blocked. This will reject the undesirable 60 and 120 cycle "hum frequencies."

HIGH-PASS FILTERS

Although the high-pass filter also employs a condenser in conjunction with an inductance, yet these two components are arranged in a different manner than in low-pass filters. This is illustrated in Fig. 15, where you will notice that the condenser is now connected in series with the line, and the inductance is shunted across the load. This is just the opposite to the arrangement of these same parts in a low-pass filter.

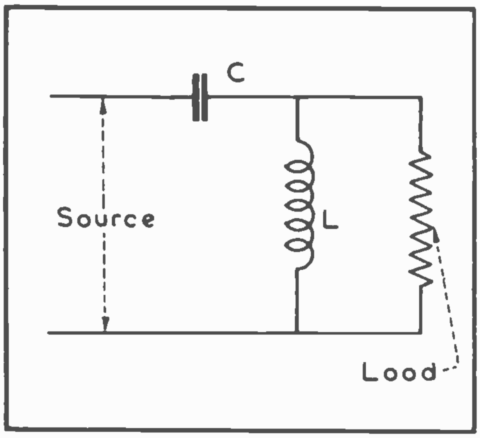

FIG. 15
HIGH-PASS FILTER

In this circuit, the condenser opposes the passage of d-c and low-frequency current, but its ability to oppose the flow of current decreases rapidly as the frequency of the current increases. This means that the higher the frequency, the easier it will be for the current to flow from the source toward the load end of the filter, and vice versa.

These high-frequency currents, which are effective at the load end of the condenser, find it difficult to pass through the inductance. Therefore, they flow through the load, the resistance of which is much less than is the reactance of the inductance towards these same frequencies.

If some of the lower frequencies should react through the condenser, the reactance of the inductance would be quite low in comparison to the load resistance so that it will practically short circuit such currents around the load; thereby materially reducing the flow of current through the load. In order for this filter to work most effectively, the reactance of the choke should be low in value as compared to the load resistance, at the lower frequencies.

High-pass filters can also be arranged in a T-pattern, an example of which is shown in Fig. 16. By thus shunting the inductance across the load from the point of junction between the two condensers, the low-frequency currents find it still more difficult to reach the load on account of the additional opposition offered by the second condenser (C_2); whereas the higher frequencies can continue on through to the load. This will result in a still sharper frequency cut-off than when condenser C_2 is omitted.

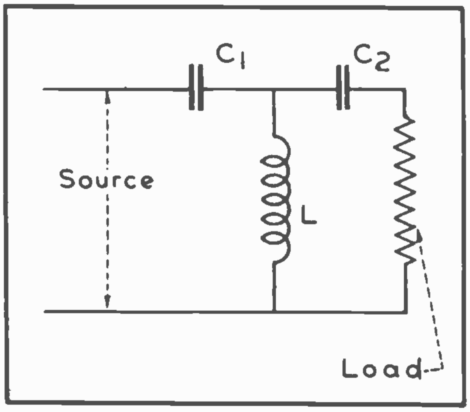

FIG. 16
T-TYPE HIGH-PASS FILTER

Fig. 17 illustrates a "double-T", high-pass filter in which the two condensers C_2 and C_3 are included between the two inductances. If the capacity values of all these condensers are alike, then the combined capacity of C_2 and C_3 will be just one-half that of the individual capacities C_1 and C_4. Therefore, if it is desired to replace condensers C_2 and C_3 by a single condenser as in Fig. 18, then this single condenser should have just half the capacity of the two end condensers. This relation is indicated in Fig. 18 by the fact that the center condenser is marked C and the two end condensers, 2 C. The two inductances are equal.

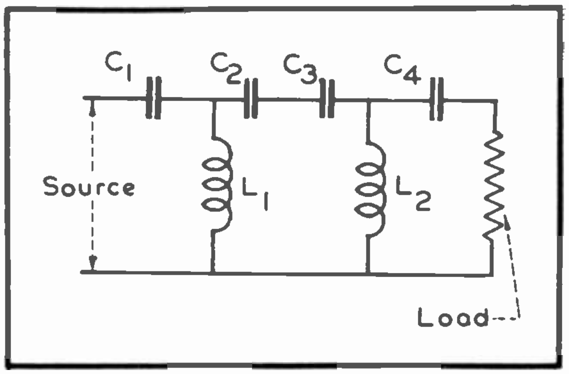

FIG. 17
DOUBLE-T HIGH-PASS FILTER

It is also possible to have a high-pass "PI" filter as shown in Fig. 19. Here, the filter is terminated at each end by an inductance, with a condenser installed between them in one side of the line. In this case, the first choke (L_1) serves as a shunt around the load for low frequency and direct currents, at the input or source end of the filter. Condenser C rejects such currents.

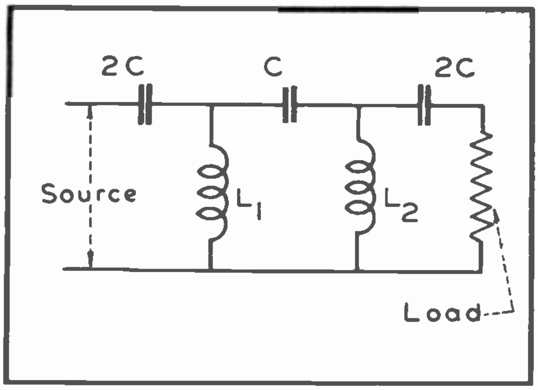

FIG. 18
DOUBLE-T WITH COMMON CAPACITY

Whatever undesired currents should be effective at the load end of C will again have the opportunity of being shunted around the load by the second inductance (L_2). High-frequency currents, however, must pass through the load because of the opposition offered to them by L_2.

Here again, the cut-off can be made sharper by adding another section. So, in Fig. 20, we have the two-section "PI" type high-pass filter. In this circuit, the two inductances L_2 and L_3 are connected in parallel, which means that their combined inductance becomes only one-half that of inductances L and L_4, individually; provided, of course, that all four of these inductances have the same value.

Conditions being such, it is clear that if the two inductances L_2 and L_3 are to be replaced with a single inductance, as in the filter shown in Fig. 21, then this common inductance L in Fig. 21 should have just one-half the inductance value of the two inductances at the ends of the filter. For convenience, we say that the common inductance has a value of "L", while the two end inductances each have a value of 2 L.

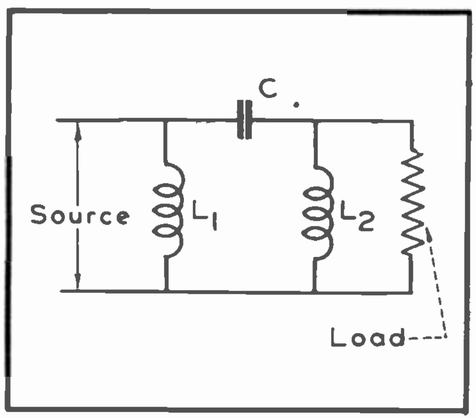

FIG. 19
"PI" TYPE HIGH-PASS FILTER

POWER PACK FILTER CHOKES

Before concluding this lesson, and while we are still considering the

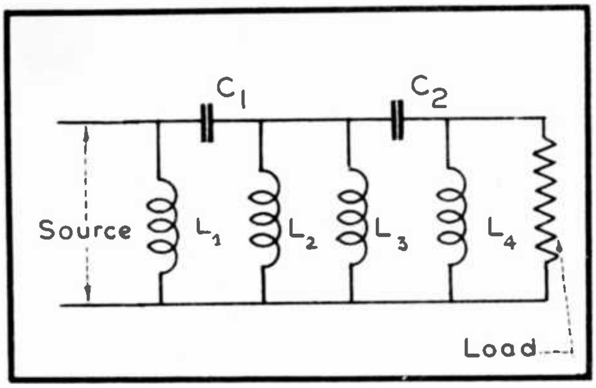

FIG. 20
TWO-SECTION "PI" HIGH-PASS FILTER

subject of filters, it is advisable to present several additional facts concerning power pack filter chokes.

As you already know, chokes for this purpose consist of many turns of fine wire, wound on a laminated steel core so that the choke will have a rather high inductance value ---- usually from 15 to 30 henries. When selecting such a choke, it is important to take into account the total d-c current which the choke will be required to pass at full load. A current overload is undesirable from the standpoint of exceeding the safe current-carrying capacity for the size of wire used on the winding.

It is also to be noted that the inductance value of the choke decreases materially as the current flow through it increases beyond a certain point. In other words, if a choke is rated as having an inductance of 30 henries, this value applies only when a definite direct current is passing through its winding.

Should the current be increased above this rated value sufficiently, then the inductance of the choke may drop down to 15 henries, or so. Any appreciable reduction in the inductance of a filter choke will impair the filtering action considerably and may result in more hum at the output. This is worth remembering, because it will impress upon your mind the importance of selecting filter chokes from the standpoint of inductance rating at a specific current load.

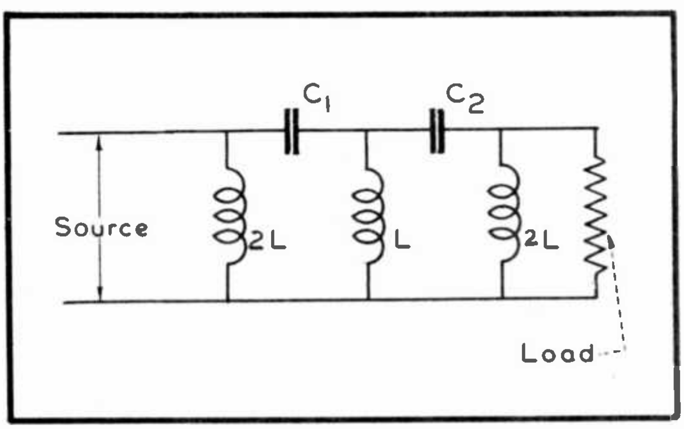

FIG. 21
TWO-SECTION "PI" HIGH-PASS
FILTER WITH COMMON INDUCTANCE

In the next lesson you are going to learn still more about the various types of filter systems employed in Radio. Here, you will find the basic formulas for designing high-pass filters, band-pass filters, etc. You will also become better acquainted with such electrical characteristics as mutual inductance, coefficient of coupling, and other features that are of interest and importance.

EXAMINATION QUESTIONS

LESSON NO. 56

1. - What four types of filter systems are frequently employed in Radio?

2. - What is a low-pass filter expected to do?

3. - Draw a diagram of a T-type, low-pass filter.

4. - Draw a diagram of a PI-type, low-pass filter.

5. - What is meant by the "characteristic impedance" of a filter?

6. - What is a high-pass filter expected to do?

7. - Draw a diagram of a simple high-pass filter, and explain how it operates.

8. - Would you classify a power supply filter as being a low-pass filter or a high-pass filter? Give the reason for your answer.

9. - When designing a filter, is it advisable that the source, load, and characteristic impedance of the filter all be equal?

10. - What is the formula for calculating the inductance of the choke to be used in a low-pass filter?

A great factory with machinery all working and revolving with absolute and rhythmic regularity, and with the men all driven by one impulse and moving in unison as though a constituent part of the mighty machine, is one of the most inspiring examples of directed force that the world knows. One rarely sees the face of a mechanic in the act of creation which is not fine, never one which is not earnest and impressive.

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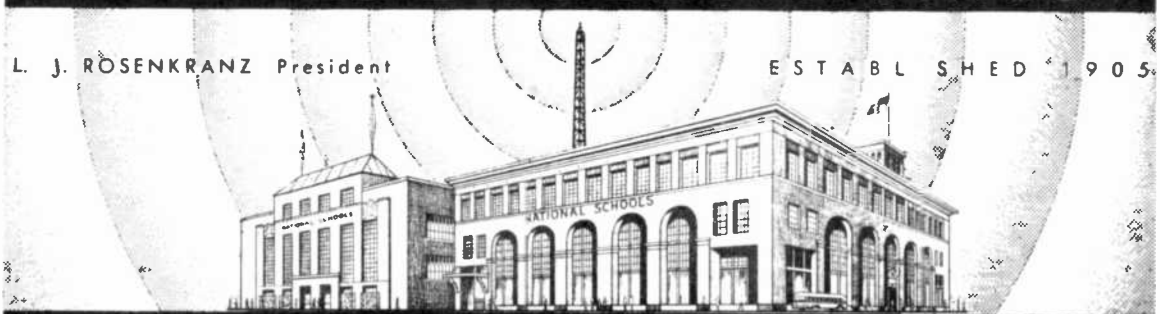

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LESSON NO. 57

HIGH-PASS AND BAND-PASS FILTER DESIGN

In this lesson, you are going to continue the study of filter systems. We shall begin with a description of the procedure for designing the high-pass filters presented to you in the previous lesson.

To calculate the inductance and capacity values for a high-pass filter of either the "T" or "PI" types, two handy formulas are available. They are:

$L = \frac{0.07958 \times Z_c}{f}$, wherein L is the inductance, expressed in henries; Z_c is the characteristic impedance, expressed in ohms; and f is the cut-off frequency, expressed in cycles per second.

$C = \frac{0.07958}{f \times Z_c}$, wherein C is the capacity, expressed in farads; f is the cut-off frequency, expressed in cycles per second; and Z_c is the characteristic impedance, expressed in ohms.

The characteristic impedance for high-pass filters is determined in the same manner as already described for low-pass filters in the previous lesson. For most effective results, the source impedance, load impedance and the characteristic impedance of the filter should all be approximately equal.

In Fig. 1, is shown the application of a high-pass filter to a radio circuit; for which we shall now work out the design.

This high-pass filter is connected between the plate and grid circuits of

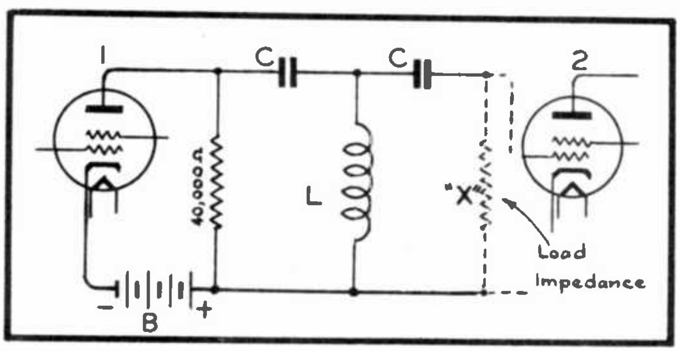

FIG. 1
APPLICATION OF A HIGH-PASS FILTER

two tubes in an r-f amplifier. Radio and audio frequencies are both being fed into the amplifier; and it is desired to separate them and only amplify the radio frequencies. In other words, the audio frequencies are to be rejected or suppressed by this filter, while the radio frequencies are to be transferred from the plate circuit of tube #1 to the grid circuit of tube #2.

We shall assume that the plate resistance of tube #1 is 250,000 ohms, that the plate coupling resistor has a resistance of 40,000 ohms and that the cut-off frequency is to be set at the upper limit of audibility or 20,000 cycles.

Now then, our first step is to determine the effective source impedance. Since the plate coupling resistor is connected in parallel with the tube's plate resistance, the effective impedance at this point is found by applying our formula for finding the total resistance of two parallel-connected resistors, or $R = \frac{R_1 \times R_2}{R_1 + R_2}$. In our problem, R_1 = 250,000 ohms, and R_2 = 40,000 ohms.

$$\text{Therefore, } R = \frac{250{,}000 \times 40{,}000}{250{,}000 + 40{,}000} = \frac{10{,}000{,}000{,}000}{290{,}000} = 34{,}483 \text{ ohms.}$$

The characteristic impedance of the filter should also be chosen as 34,483 ohms. And, substituting this value in our formula for calculating the filter inductance, we have:

$$L = \frac{0.07958 \times Z_c}{f} = \frac{0.07958 \times 34{,}483}{20{,}000} = \frac{2744.16}{20{,}000} = .14 \text{ henries (ap-}$$
proximately), or 140 millihenries.

$$C = \frac{0.07958}{f \times Z_c} = \frac{0.07958}{20{,}000 \times 34{,}483} = \frac{0.07957}{689{,}660{,}000} = .0000000001 \text{ farads}$$
or 0.0001 mfds. (approximately).

Bear in mind that the inductance and capacity values as determined by these two formulas correspond to "L" and "C" in the high-pass filters illustrated in the previous lesson. When double-section filters are used, the values 2L and 2C apply, in accordance with the particular type of filter, as pointed out in the previous lesson.

Since in the circuit of Fig. 1, the source and characteristic impedance are both 34,483 ohms, the load impedance (represented by "X") should also be approximately 34,483 ohms. Note that the component "X" in Fig. 1 is the electrical equivalent of a load circuit, whatever that may be; and not a resistor connected physically at the points indicated. The grid-cathode resistance within tube #2 is of a very high order, so we may neglect its parallel effect upon load "X".

BAND-PASS CIRCUITS

Having studied both the low and high-pass filter systems individually, you can no doubt see the possibilities for combining these two distinct filters in such manner that each will offer its own cut-off frequency. This will result in the passage of a frequency band extending between these two cut-off points, and suppression of all other frequencies.

In Fig. 2, for instance, we have such a combination where the source feeds into a low-pass filter which is followed by a high-pass filter before the load is finally reached. Assuming that the high-pass filter is designed for a 600 kc cut off, and the low-pass filter for an

800 kc cut-off, all frequencies below 600 kc and all frequencies above 800 kc will be suppressed; and only a band of 800 minus 600 or 200 kc will pass through the filter. Hence, this is called a band-pass filter.

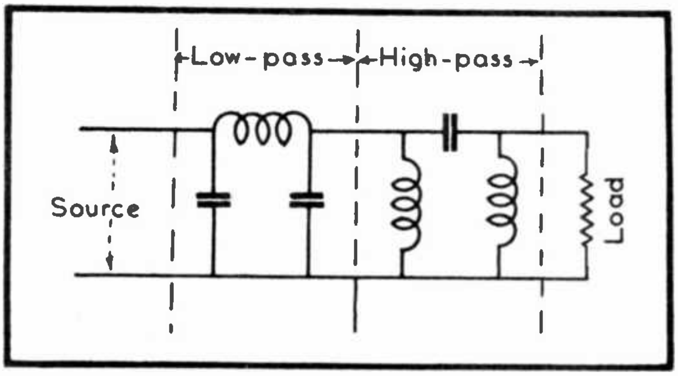

FIG. 2
PRODUCING BAND-PASS EFFECT

In Fig. 3, we have a typical band-pass filter. Here, the series condensers are designated as "C" and the parallel condensers as "C_1".

In working out the design of such a band-pass filter, we first take into account the source and load impedance --- equalizing them; and set the characteristic impedance of the filter to this same value. The next point to consider is the lower and upper cut-off frequencies. The value for C in the filter of Fig. 3 can then be determined by using the formula: $C = \frac{F_1 + F_2}{4\pi F_1 F_2 Z_c}$, where C is the capacity in farads; F_1 is the lower frequency cut-off in cycles per second; F_2 is the higher frequency cut-off in cycles per second; and Z_c is the characteristic impedance of the filter expressed in ohms. In other words, to find the value of "C" add F_1 to F_2 and divide this sum by the product you obtain from the following operation: 4 times 3.14 times F_1 times F_2 times Z_c.

To find the value of C_1 in Fig. 3, use the formula: $C_1 = \frac{F_1}{\pi F_2 (F_2 - F_1) Z_c}$. To solve this problem, subtract F_1 from F_2 and multiply this difference by Z_c times πF_2. Then divide F_1 by this final product.

The value for the inductance "L" in Fig. 3 is found by using the formula: $L = \frac{(F_2 - F_1) Z_c}{4\pi F_1 F_2}$. That is, subtract F_1 from F_2 and multiply this difference by Z_c. Divide the number thus obtained by the product derived from multiplying 4 times 3.14 times F_1 times F_2. The inductance will be expressed in henries.

FUNDAMENTAL RELATIONS IN BAND-PASS CIRCUITS

You are now ready to study some other important relations that exist between the circuit constants of band-pass systems such as used in band selector circuits of the type illustrated in Fig. 4. Here, the common inductance L is used as the coupling coil, or coupling inductance.

First, let us consider the coefficient of coupling of this circuit. The coefficient of coupling is a number which expresses to what extent the magnetic lines of force originating around one winding also encircle a second winding that is inductively coupled

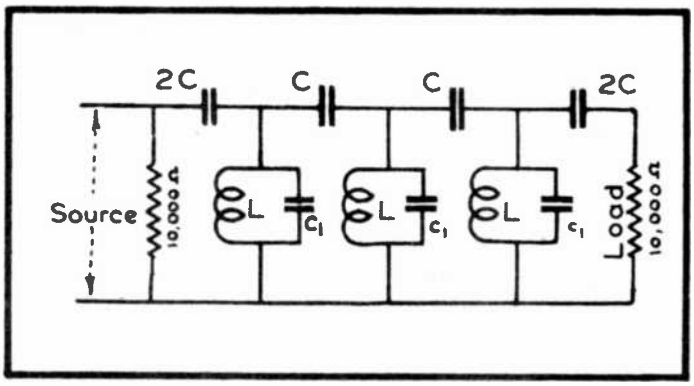

FIG. 3
TYPICAL BAND-PASS FILTER

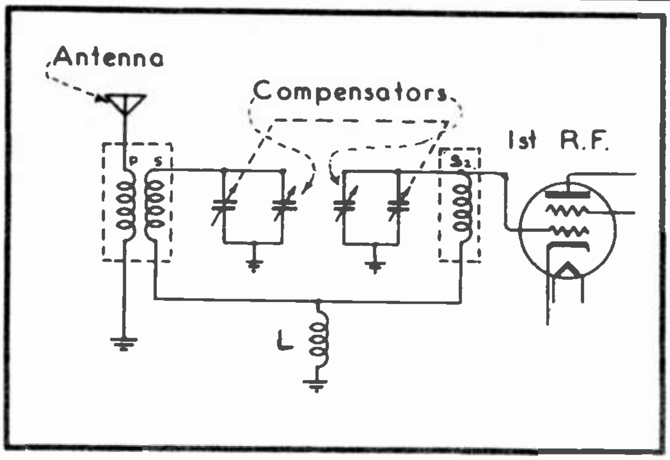

FIG. 4
BAND-PASS CIRCUIT WITH COUPLING COIL

to the first. Fig. 5 illustrates this. Here, the magnetic field originating around coil #1 also links coil #2. If conditions were such that all of the lines of force were utilized by coil #2, we would say that there was unity coupling between them, or that the coefficient of coupling was 1. The letter "K" is generally used to designate the coefficient of coupling.

In actual practice, however, there is always a certain amount of magnetic leakage so that not all of the magnetic field produced by coil #1 is utilized by coil #2. Therefore, the coefficient of coupling becomes less than 1, generally being expressed as a decimal fraction such as .2 or .5, etc. --- or as a percentage as, 3%, 8%, etc. The coefficient of coupling in good iron-core transformers is quite high --- frequently attaining a value of .98 or 98%. However, in air-core transformers, where the magnetic leakage is greater, the coefficient of coupling may be as low a value as .1 or less.

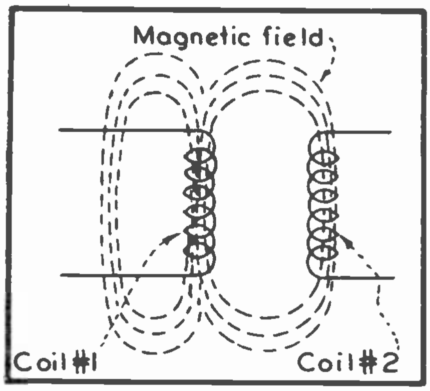

FIG. 5
TWO INDUCTIVELY COUPLED WINDINGS

In a circuit as illustrated in Fig. 6, where the inductance "L_m" is connected across it as here shown, the coefficient of coupling between the two windings "L_1" and "L_2" can be determined approximately by means of the following formula:

$$K = \frac{L_m}{\sqrt{(L_1 + L_m)\,(L_2 + L_m)}}$$

, wherein K is the coefficinet of coupling, expressed as a decimal fraction; L_m is the inductance of the coupling coil, expressed in micrchenries; L_1 is the inductance of winding L_1, expressed in microhenries; and L_2 is the inductance of winding L_2, expressed in microhenries.

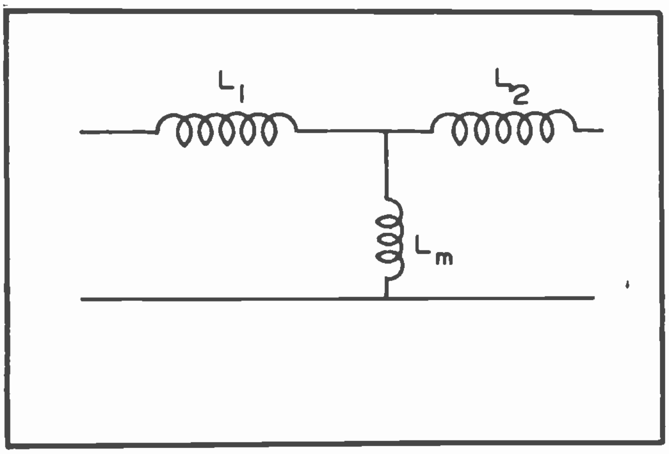

FIG. 6
CIRCUIT WITH COMMON COUPLING INDUCTANCE

If the circuits are capacitively coupled, as in Fig. 7, then the coefficient of coupling can be determined by the formula:

$$K = \frac{\sqrt{C_1\ C_2}}{\sqrt{(C_m + C_1)\,(C_m + C_2)}},$$

wherein K is the coefficient of coupling expressed as a decimal fraction; C_1 is the capacity of condenser C_1, expressed in microfarads; C_2 is the capacity of condenser C_2 expressed in microfarads; and C_m is the capacity of the coupling condenser, expressed in microfarads.

Now then, assuming that each of the two tuned circuits are resonated individually at the same frequency (which is the case in band-selector circuits), the difference between the lower and upper frequencies passed, or the width of band passed --- expressed in kilocycles --- can be found with the aid of the following formula: Width of band passed is equal to the resonant frequency of the tuned circuits multiplied by the coefficient of coupling.

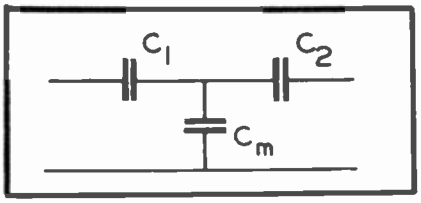

FIG. 7
BAND-PASS CIRCUIT WITH CAPACITIVE COUPLING

As you will recall from previous studies on band-pass or band-selector circuits, the selectivity curve obtained with this type of circuit has a resonance peak toward either side of the fundamental resonant frequency as shown in Fig. 8. The relation which these two peak frequencies bear to the fundamental resonant frequency is expressed by the following two formulas:

Higher frequency peak (in kc.) = $\frac{K_{c\ res.}}{\sqrt{1 - K}}$

Low frequency peak (in kc.) = $\frac{K_{c\ res.}}{\sqrt{1 + K}}$, where— in $K_{c\ res.}$ is the resonant frequency, expressed in kilocycles, and K is the coefficient of coupling.

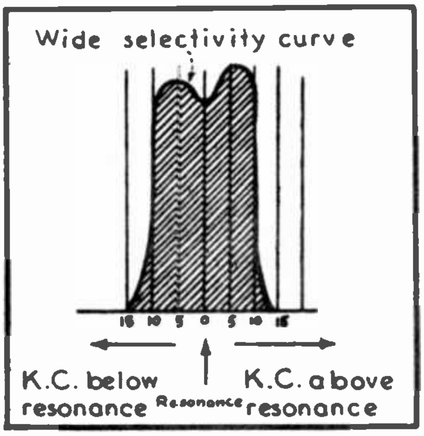

FIG. 8
SELECTIVITY CURVE

BAND-PASS RECEIVERS

When a band-pass circuit is employed in the first r-f stage of a receiver in which rather sharply tuned circuits follow as in Fig. 9, then the band-pass circuit at the input of the receiver is generally referred to as being a band-selector circuit.

In this case, the regular band-pass features are obtained in the band selector circuit itself, and the following circuits may decrease materially the width of the band passed by the band selector circuit. Although the narrowing effect upon the band will not be quite so apparent as when the input circuits are also sharp tuning, yet it does exist.

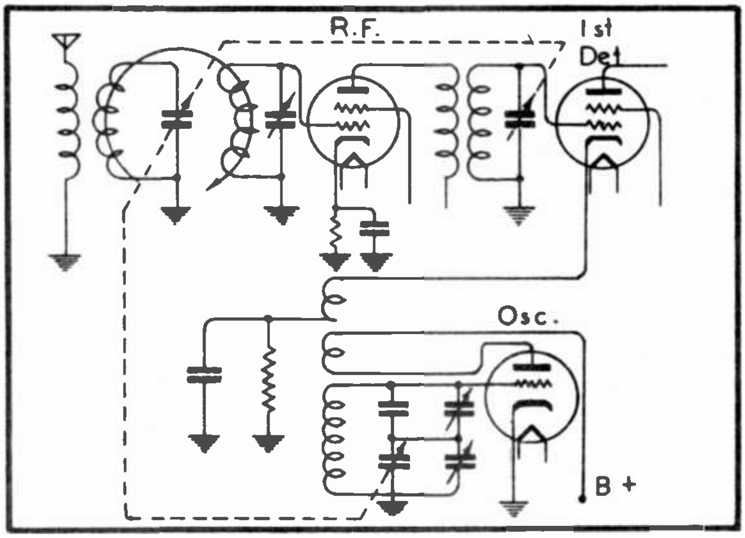

FIG. 9
APPLICATION OF THE BAND-PASS CIRCUIT

If the band-pass feature is to be retained throughout the entire r-f section of the receiver, then one method of accomplishing this is illustrated in Fig. 10. In this system, all of the tuning circuits in the r-f section are of the band-pass type, each being

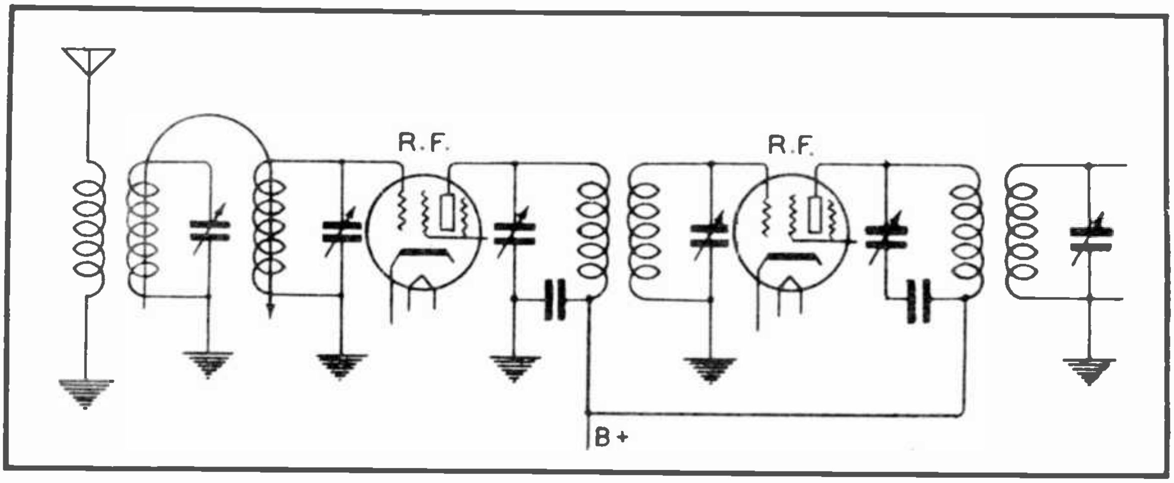

FIG. 10
CIRCUIT WITH COMPLETE BAND-PASS

designed to pass the same band of frequencies. The entire r-f amplifier of the receiver then becomes a true band-pass system.

Bear in mind that all of the variable condensers here shown are regular tuning condensers which tune both the plate and grid circuit windings. Although the symbols are similar to those of i-f transformers, as used in superheterodyne receivers, the parts differ greatly in construction and appearance.

Another method for securing band-pass characteristics in an r-f amplifier is illustrated in Fig. 11. To begin with, a regular band-selector circuit is used between the antenna input and the first r-f tube. This is followed by successive r-f stages which are coupled together by means of untuned r-f transformers. Thus, all frequency selection is taken care of in the band selector circuit preceding the first r-f tube; and the following stages serve only to amplify the signal already selected.

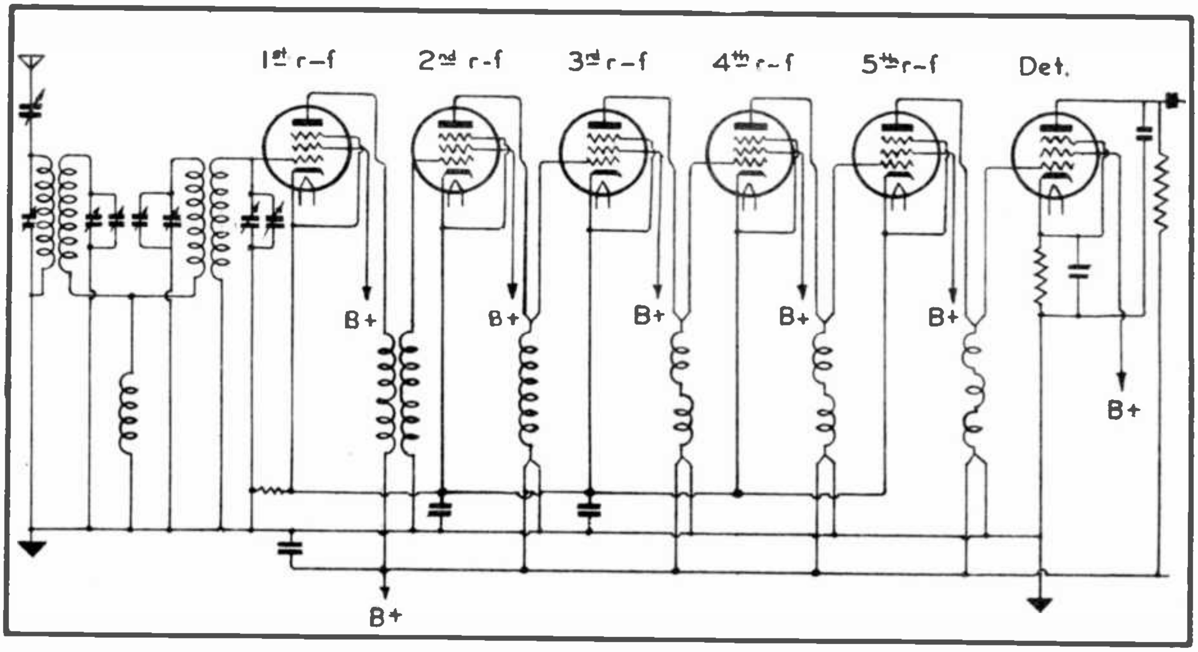

FIG. 11
BAND-PASS PRE-SELECTOR CIRCUIT

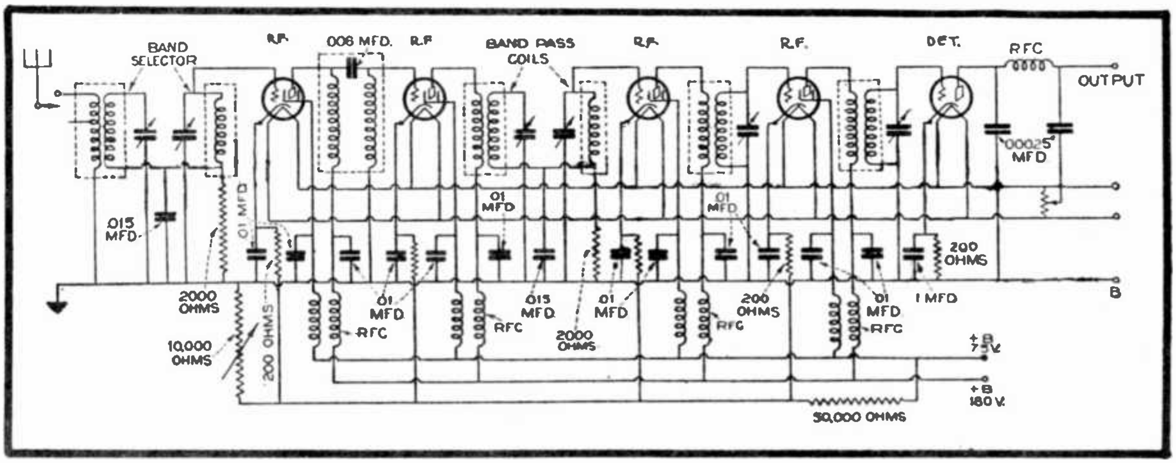

FIG. 12
SPECIAL R-F TUNER

In Fig. 12, still another arrangement is shown. This circuit was designed to secure the advantages offered by band-pass circuits. In this instance, a capacitively-coupled band-pass circuit is being used ahead of the first r-f tube. This is followed by an untuned r-f stage, after which another band-pass coupling is included between the second and third r-f tubes. The following r-f tube, and the detector tube, are preceded by r-f transformers of the conventional type having tuned secondary windings. The output of this tuner can be connected to any suitable a-f amplifier.

MAGNITUDE OF MUTUAL INDUCTANCE

In the early part of the course dealing with basic electrical principles, you learned what is meant by the expression "mutual inductance." At this time, however, you are going to be told more about it.

In Fig. 13, we have two similar coils which are inductively coupled in such manner that their magnetic fields do not oppose one another. We then say that these coils are connected series aiding. The following relation then applies:

$L_a = L_1 + L_2 + 2M$, or $M = \frac{L_a - L_1 - L_2}{2}$. In these formulas, L_1 is the inductance of coil #1; L_2 is the inductance of coil #2; L_a is the total inductance supplied by the series aiding connection; and M is mutual inductance, expressed in the same units as are L_1 and L_2.

Another important fact to remember about coils connected in the series aiding arrangement is that if unity coupling exists, the total inductance of the two coils will be four times the inductance of either one alone. In other words, the two individual inductances would in this case be equivalent to a single inductance of double the number of turns; and since the inductance of a coil varies according to the square of the number of turns, doubling the number of turns increases the inductance four times.

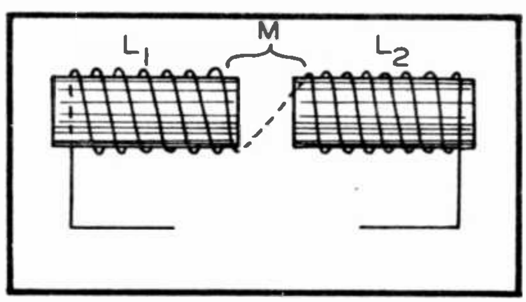

FIG. 13
SERIES-AIDING CONNECTION

Should the same two coils be connected together as illustrated

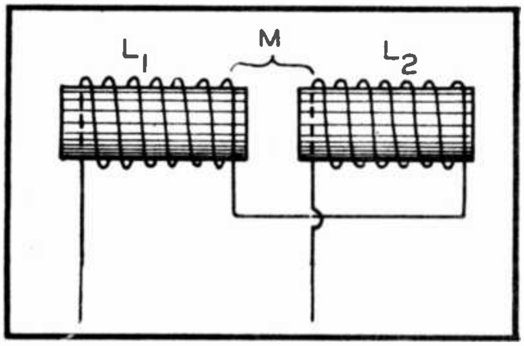

FIG. 14
SERIES-OPPOSING CONNECTION

in Fig. 14 so that their magnetic fields oppose one another, we then say that the coils are connected series opposing. If unity coupling exists under these conditions, and the fields of the two coils are equal in value, the total inductance is zero; because the two fields neutralize each other.

The relation which exists between the two coils when they are connected series-opposing, and the coupling less than unity, is expressed by the formula:

$$L_o = L_1 + L_2 - 2M, \text{ or}$$

$M = \frac{L_1 + L_2 - L_o}{2}$. Here, L_o is the total inductance of the series opposing coils; L_1 is the inductance of coil #1; L_2 is the inductance of coil #2; and M is the mutual inductance.

DETERMINING MUTUAL INDUCTANCE BY MEASUREMENT

The mutual inductance between two coils can be determined by actual measurement with the aid of the Wheatstone Bridge. The set-up for doing this is the same as was already described in a previous lesson for measuring inductance. The two inductively coupled coils under test are considered as a single unknown inductance, and compared with a standard inductance.

First, these two coils are connected in the series-aiding arrangement; and the resulting inductance is measured on the "bridge." This value is called L_a. Then, the two coils are connected in the series-opposing arrangement; and the total inductance is again measured. This is called L_o. The mutual inductance can then be found from the relation:

$M = \frac{L_a - L_o}{4}$. The value of M will be expressed in the same units of inductance as used for L_a and L_o.

A definite relation exists between the coefficient of coupling, between two coupled coils and their individual inductance values; and the mutual inductance between them. This relation is given by the formula:

$K = \frac{M}{\sqrt{L_1 L_2}}$ or $M = K\sqrt{L_1 L_2}$, where K is the coefficient of coupling; M is the mutual inductance between the two coils; while L_1 and L_2 are the inductance values of the two coils, individually.

TUNED POWER PACK FILTERS

In some commercial a-c receivers, you will find the filter of the power pack arranged as illustrated in Fig. 15. You will notice that a fixed condenser C is connected across one of the filter chokes L_1. This connection provides a parallel resonance circuit which will greatly suppress the passage of some unwanted frequency through the filter. For instance, sometimes a 120 cycle power supply hum is quite objectionable in a receiver or amplifier; but by resonating some particular section of the power pack filter to this hum frequency, it can be attenuated.

In order to determine the value of "C" which is necessary to tune the filter section and so reject an unwanted frequency, the following formula may be used:

$C = \frac{25,300}{F^2 \times L_1}$. Here "C" is expressed in microfarads; F is the frequency to be suppressed, in cycles; and L_1 is the inductance of filter choke L_1, expressed in henries.

This formula is only approximate, but nevertheless, sufficiently accurate for practical purposes. This resonance circuit doesn't tune very sharp because of its comparatively high resistance.

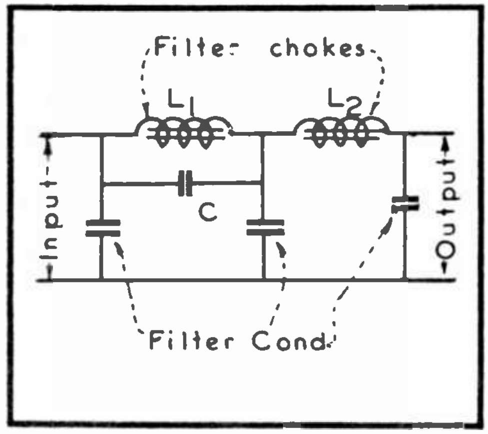

FIG. 15
TUNED FILTER

The reason why a parallel resonance circuit provides maximum impedance towards the resonance frequency can be explained as follows:

By considering the circuit illustrated in Fig. 16, the same a-c voltage is applied across condenser C and inductance L, but the current through each of these two branches is governed by the reactance of that particular branch.

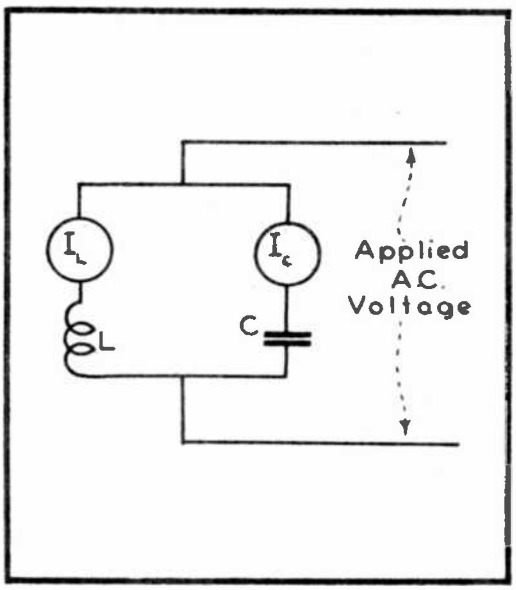

FIG. 16
ANALYSIS OF PARALLEL
RESONANT CIRCUIT

In other words,

$I_L = \frac{E}{X_L}$ and $I_C = \frac{E}{X_C}$. Here, I_L is the current through the inductance; I_C is the current through the condenser; X_L is the inductive reactance; X_C is the capacitive reactance and E is the applied line voltage.

At the resonant frequency, the capacitive reactance is equal to the inductive reactance. So, with a given applied voltage, $I_L = I_C$, at resonance.

In a parallel resonance circuit, the two currents I_L and I_C are out of phase --- I_C having a negative sign and I_L a positive sign. Neglecting resistance, the line current will be equal to the albegraic sum of I_L and I_C, which means that the line current is equal to I_L minus I_C. Then, since $I_L = I_C$ at resonance, the line current will be equal to zero.

The impedance of the circuit, as a whole --- that is, the impedance into which the source of emf forces current --- will be the ratio of the voltage to the current, as usual: or, $Z = \frac{E}{I}$. Therefore, if no current flows, as just shown, we can say that the circuit has infinite impedance.

Actually, there is always some resistance in the circuit. This may be an additional shunt path, or it may exist in one or both of the other branches. For this reason, the current through the circuit does not drop to absolute zero, but reaches a certain minimum value; consequently, the impedance of the parallel resonant circuit does not quite become infinite at the resonant frequency. So, we simply say that its impedance is maximum at the resonant frequency.

WIDTH OF RESONANCE CURVE FOR TUNING CIRCUITS

In Fig. 17, we have a typical resonance curve for a series resonance circuit as used in the tuning circuits of ordinary r-f amplifiers, and with which you are already familiar. Here, the currents through the tuned circuit are plotted on a graph against frequencies, toward both sides of resonance; and with a given applied a-c signal voltage.

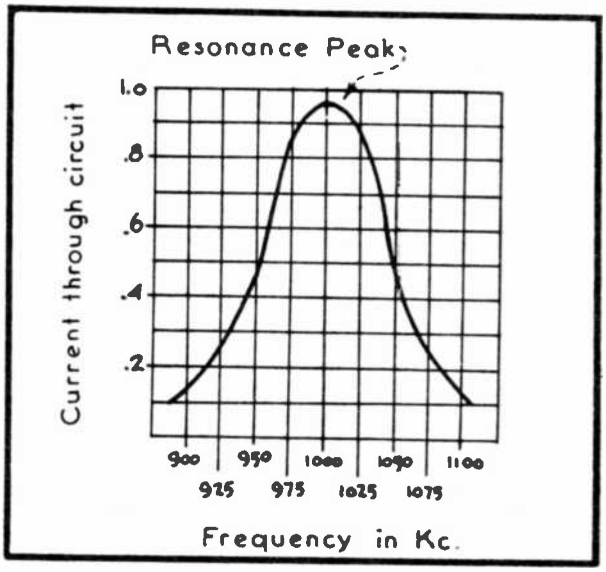

FIG. 17
RESONANCE CURVE

As you will recall, the current flow through a series resonance circuit is maximum at the resonant frequency, and drops off both sides of resonance. The width of such a resonance curve at a point where the current through the circuit is equal to .707 times the current at resonance can be calculated by means of the formula:

$f_2 - f_1 = \frac{Rf_r}{L\omega}$, where f_2 is the frequency above resonance, in cycles; f_1 is the frequency below resonance, in cycles; R is the d-c resistance of the tuning circuit; f_r is the resonant frequency in cycles; L is the inductance of the tuned winding expressed in henries; and ω is equal to $2\pi f$.

As a typical example, let us assume that the tuned winding of a certain circuit in an r-f amplifier has an inductance of 250 microhenries, that the d-c resistance of the tuning circuit is 10 ohms, and that the resonant frequency is 600 kc.

The width of the resonance curve at a point equivalent to .707 times the current at resonance would then be calculated as follows:

$$f_2 - f_1 = \frac{Rf_r}{L\omega} = \frac{10 \times 600{,}000}{.00025 \times 6.28 \times 600{,}000} = \frac{6{,}000{,}000}{942} = 6{,}369 \text{ cycles,}$$

approximately. In other words, the width of the resonance curve, or the width of the frequency band passed at this point, will be about 6.4 kc.

Having completed this lesson, you should now have a good understanding of the different types of filter systems --- including their theory of operation, application and basic design formulas. All of this information is of great value, and should help you tremendously towards reaching the higher ranks of the radio profession.

EXAMINATION QUESTIONS

LESSON NO. 57

1. - What is the basic formula for calculating the inductance value of a single-section T or PI high-pass filter?

2. - What is the basic formula for calculating the capacity value of a single-section T or PI high-pass filter?

3. - What is a band-pass circuit expected to do?

4. - What is the basic formula for calculating the capacity value "C" of a band-pass circuit?

5. - What is the basic formula for calculating the inductance value "L" of a band-pass circuit?

6. - What is meant by the expression "coefficient of coupling"?

7. - How can the coefficient of coupling in a band-pass circuit such as illustrated in Fig. 6 of this lesson be determined?

8. - How can you calculate the width of the band passed by a circuit such as illustrated in Fig. 6 of this lesson?

9. - How can the higher and lower frequency peaks for a band-pass circuit be calculated?

10. - How can the mutual inductance between two inductively coupled coils be determined by measurement?

THERE is no moment like the present. The man who will not execute his resulutions when they are fresh upon him can have no hope from them afterward; they will be dissipated, lost, and perish in the hurry and scurry of the world, or sunk in the slough of indolence.

There is but one straight road to success, and that is merit. The man who is successful is the man who is useful. Capacity never lacks opportunity. It cannot remain undiscovered, because it is sought by too many anxious to use it.

J. A. Rosenkranz

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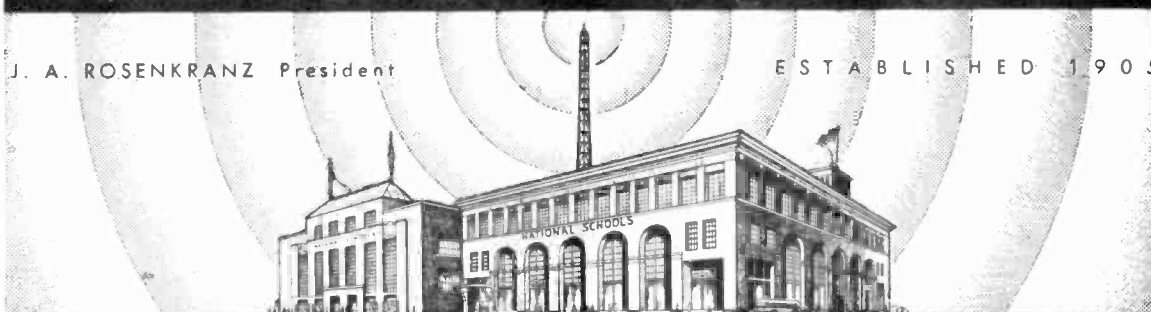

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LESSON NO. 58

SIGNAL TRACING

The art of diagnosing receiver troubles by the Signal Tracing method dates back as far as the first defective radio receiving set. In those days, the only signal source available to the serviceman was the broadcast signal itself; which he utilized by applying the antenna lead-in wire to the input and output of each r-f stage (starting from the antenna or 1st r-f stage and working toward the detector stage), until the signal was heard in the headphones or loudspeaker.

In the absence of a signal, or if one of the i-f or a-f stages was suspected of being faulty, the serviceman frequently resorted to the "finger test". That is, he applied a finger to the control-grid of the tube (or removed the grid cap from the tube) and listened for a humming noise. Absence of this humming noise informed him that the defect was probably in that particular stage of the receiver.

Before the electric type of phonograph pickup was developed, it was not an uncommon practice for the serviceman to connect a headphone or microphone across the input of an a-f stage (or the output of the stage preceding it). Speaking into the headphone or microphone, he was able to tell whether or not the a-f stages were functioning and how well they were operating. When the electric type

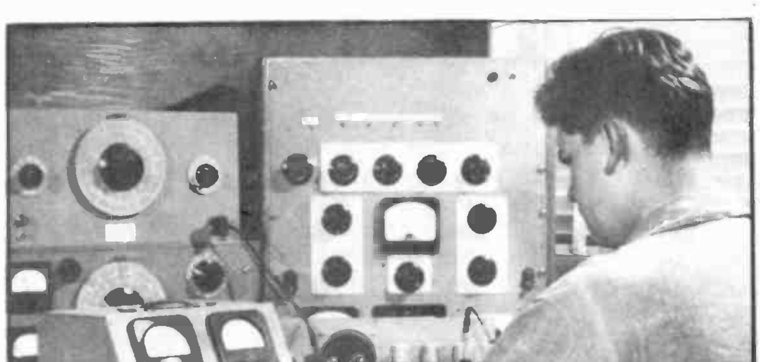


FIG. 1
TRACING AN A-F SIGNAL

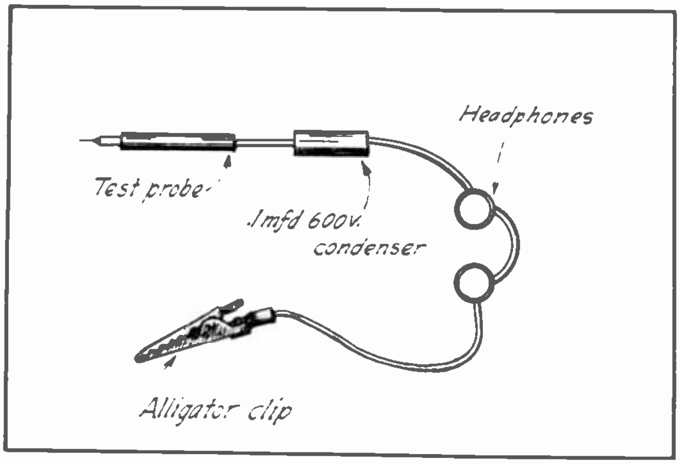


FIG. 2
SIMPLE A-F TRACER

of phonograph pick-up came into popular use, servicemen substituted it---in conjunction with a test phonograph record---for the microphone.

Later, when Signal Generators became part of the service shop's testing equipment, the serviceman soon learned to utilize its signals as a signal source for the signal-tracing method of diagnosing receiver troubles. The advantages of this method soon became obvious to various manufacturers of test equipment---thereby bringing about the development of Signal Tracers as we know them today.

The principles and procedures for operating the various types of Signal Tracers will be discussed at this time.

METHODS OF TRACING

A signal may be traced: (1) Audibly; or, (2) Visually. To trace a signal audibly, we employ an indicating device that will furnish a sound to our ears---that is, a reproducing device such as a pair of headphones or a loudspeaker. Visible tracing, on the other hand, requires the use of an indicating device that will inform us of the presence (and intensity) of the signal through the medium of our eyes. Visual indicators such as a voltmeter, output meter, tuning-eye (electron-ray) indicating tube, oscilloscope, etc., are generally employed for this purpose.

By comparison, each of the above two methods has its own distinct advantage. The audible method is generally preferred when it is desired to determine the presence of extremely weak signals or to judge the tonal quality of the signal. The visual method of tracing, on the other hand, is preferred when it is desired to compare or measure volume intensities with accuracy---since the eye has the ability to detect changes in intensity levels more accurately than can the ear.

A-F TRACER

Regardless of the type of indicator employed, the Signal Tracer is, essentially, nothing more than a receiving set. More specifically, a receiving set that obtains its input signal from the receiver under test, rather than from an antenna.

The simplest type of Signal Tracer is the one used for tracing a-f signals. For this purpose, we require little else than a pair of headphones connected between ground (the chassis) and the input or output of the a-f amplifying stage. However, since a d-c potential also, generally, exists between these points, it is necessary

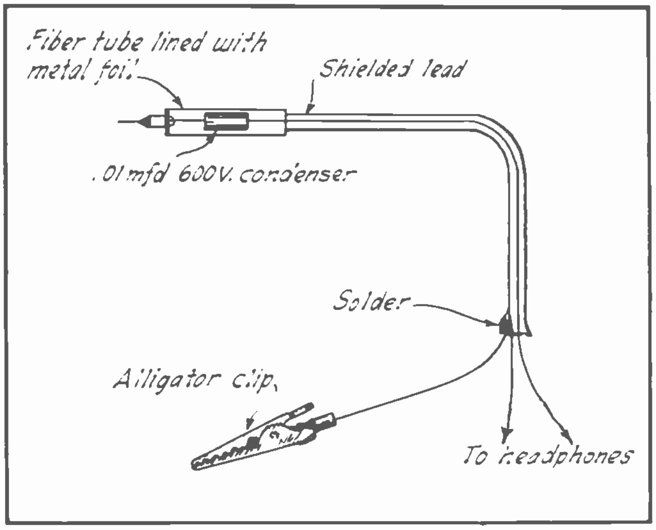


FIG. 3
IMPROVED CONTRUCTION OF THE A-F TRACER

to insert a blocking condenser of from .006 to .1 mfd in series with the headphones to prevent damaging them, as shown in Fig. 2.

A more convenient and efficient form of this type tester is shown in Fig. 3. In this case, the blocking condenser is mounted inside of a test-probe made of fiber tubing whose dimensions approximate 3/4" x 6 1/2". The inner surface of this tubing is lined with a metal foil (tin, copper or aluminum) that is electrically connected to the metal covering of a shielded lead which is used as the means of connection between the probe and headphones. Thus, the probe is internally shielded against stray r-f fields.

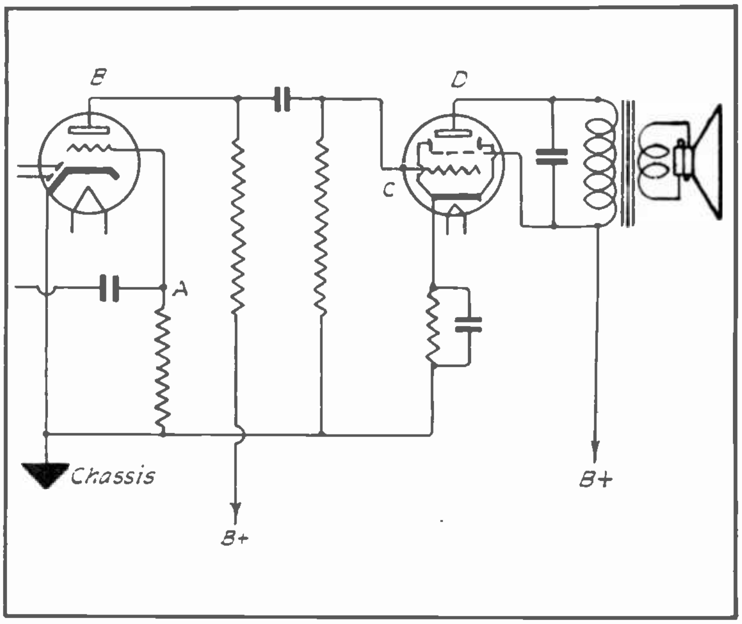


FIG. 4
TYPICAL A-F CIRCUIT

The manner in which this device may be used to trace a-f signals is illustrated in Fig. 4. With the metal, alligator clip fastened to the chassis, the test-probe is then applied to points A, B, C and D, progressively. Since point A is at the input of the 1st a-f stage, the signal will be comparatively weak here. At B, the signal will be much stronger in volume (this being the output of the stage). At C (the input of the power amplifier stage), the signal intensity will be approximately the same as at B. At D, however, a tremendous increase in volume should be obtained since this is the output of the power amplifier stage.

R-F TRACER

For tracing r-f signals, a "de-modulator" or detector will have to be added to the headphone circuit. Although the conventional type crystal detector may be used for this purpose, the "germanium" (1N34) fixed crystal has enjoyed considerable success in this role. The circuit diagram of such type Tracer is shown in Fig. 5.

An example of how a vacuum tube and 0-1 ma. meter may be incorporated into an efficient and useful Signal Tracer, is shown in Fig. 6. This is a circuit diagram of the Model CA-11 Signal Tracer manufactured by the Superior Instrument Company.

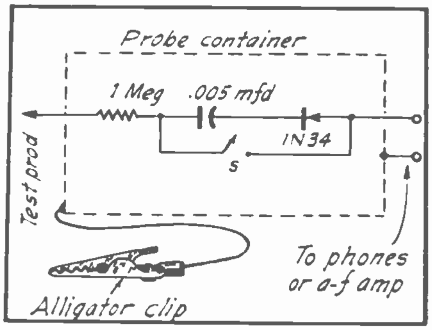
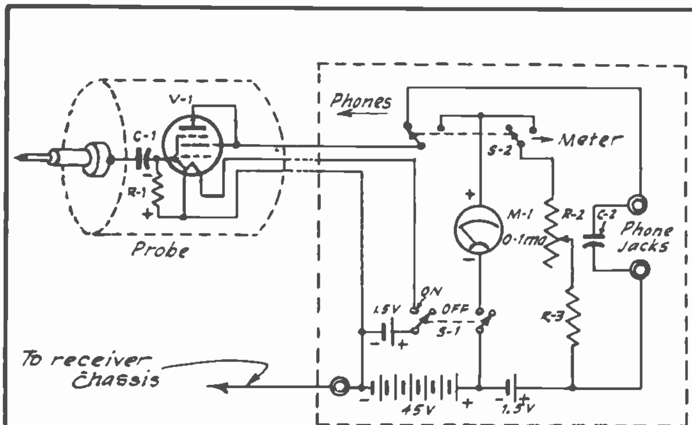


FIG. 5
IN34 CRYSTAL SIGNAL TRACER
(THE SWITCH S SHORTS OUT THE CRYSTAL DETECTOR FOR A-F TESTS)

Upon analyzing the diagram of this Tracer, you will note that the circuit is comprised of little else than a vacuum tube functioning as a grid-leak detector used in conjunction with a pair of headphones for audible tracing; and, a 0-1 ma. d-c meter for visual tracing. To insure efficient operation at the extremely high frequencies, the tube, grid-leak resistor (R-1) and grid condenser (C-1) are enclosed within the probe. A "bantam" type tube was selected; and, although it is of the pentode class, the screen grid is tied to the plate so that it functions as a triode; thereby providing bet-



C-1	300 MMFD, MICA	R-3	600 OHMS, 1/2-WATT
C-2	.002 MFD, PAPER	S-1	DPST SWITCH
M-1	0-1 MILLIAMMETER	S-2	DPDT SWITCH
R-1	20 MEGS, 1/2-WATT	V-1	1T4 TUBE
R-2	300-OHM RHEOSTAT		

FIG. 6
SCHEMATIC DIAGRAM OF "SUPERIOR" CA-11
SIGNAL TRACER

ter operation for this purpose. Connected in series with the probe tip and the control-grid of the tube, the 300 mmfd grid condenser (C-1) serves as a d-c blocking condenser as well as an "isolation" condenser, to prevent the input capacity of the Tracer from affecting the receiver circuit under test.

The meter, batteries, meter-zeroing rheostat, operating switches and phone jacks are all contained in an attractive wooden case, as shown in Fig. 7. A three-foot flexible cable extends from the probe to the case. The probe and cable are contained in the rear compartment of the cabinet when the instrument is not in use.

METER-ZEROING CIRCUIT

When no signal is being impressed on the control-grid of the tube, this electrode is (theoretically) neither positive nor negative. Since the "B" battery applies a positive potential to the tube's plate, the latter attracts electrons toward itself without any interference from the control-grid. Consequently, under no-signal conditions, plate current flows through the milliammeter (M-1). So that the meter will read zero under these conditions, this current flow is "bucked out" by means of the additional 1.5 volt battery. "Zero-ing" of the meter is accomplished by adjusting the variable rheostat R-2.

However, when a signal is impressed upon the control-grid of the tube, this electrode attracts electrons towards itself during each positive-half of the signal cycle. Consequently, grid current flows through resistor R-1. This produces a voltage-drop across R-1; and, since the direction of current flow through this resistor is from the control grid toward the cathode, the control grid is now more negative than the cathode---which, in turn, means that the control-grid has a biasing effect at this time; thereby reducing the flow of plate current through the tube. Consequently, when a signal is impressed on the control grid, less current flows through the plate circuit---the stronger the signal, the less plate current will flow. This upsets

FIG. 7
SUPERIOR MODEL CA-11 SIGNAL TRACER

or opposes the "bucking" circuit so that more current is now permitted to flow through the meter. As a result, the pointer of the meter swings up-scale.

(Note: When employing headphones for signal tracing, it is important that the magnetic type be used, since the tube's plate-current must flow through the field windings of the headphones in order to complete the circuit. In addition, the headphones should, preferably, be of the high impedance type. Under no circumstances should crystal type headphones be used, for they will be damaged!)

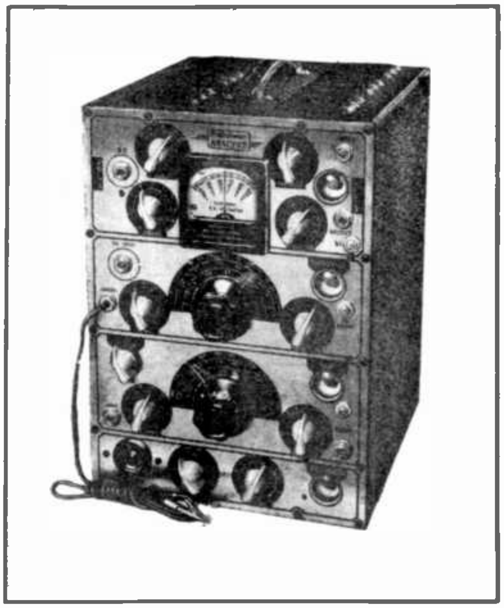


FIG. 8
THE MEISSNER "ANALYST"

MULTI-CHANNEL SIGNAL TRACERS

Before discussing the actual servicing procedure by the signal tracing method, we will study, first, the features of the more elaborate signal tracing instruments; that is, the "multi-channel" types. Typical of such tracers are the "Analyst" in Fig. 8 (manufactured by the Meissner Manufacturing Company, Mount Carmel, Illinois), and the "Chanalyst" in Fig. 9 (manufactured by the Radio Corporation of America, Camden, New Jersey). The circuit diagrams of these instruments are shown in Figs. 14 and 15.

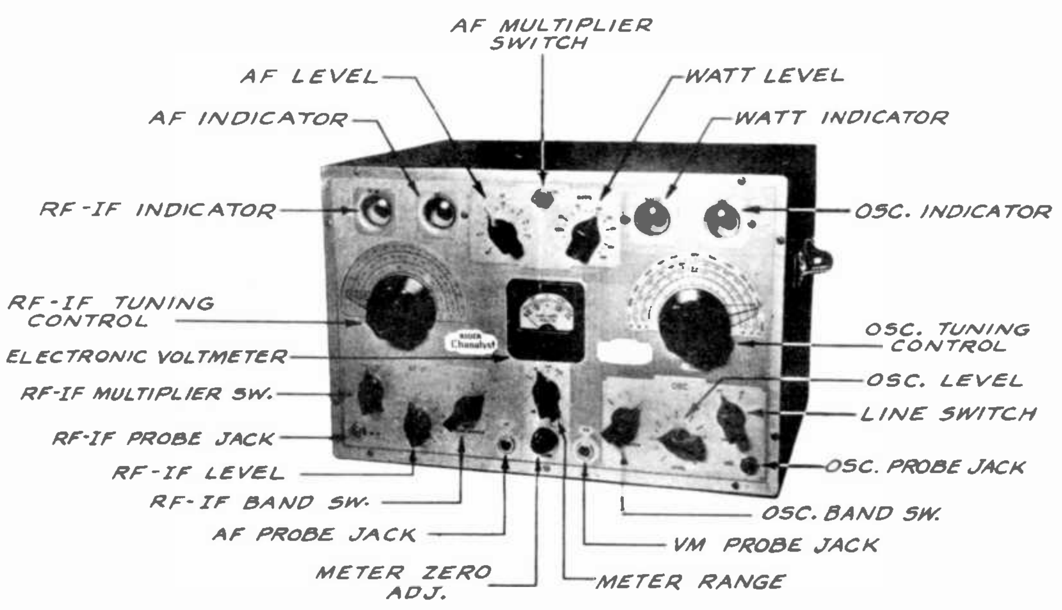


FIG. 9
THE R. C. A. CHANALYST

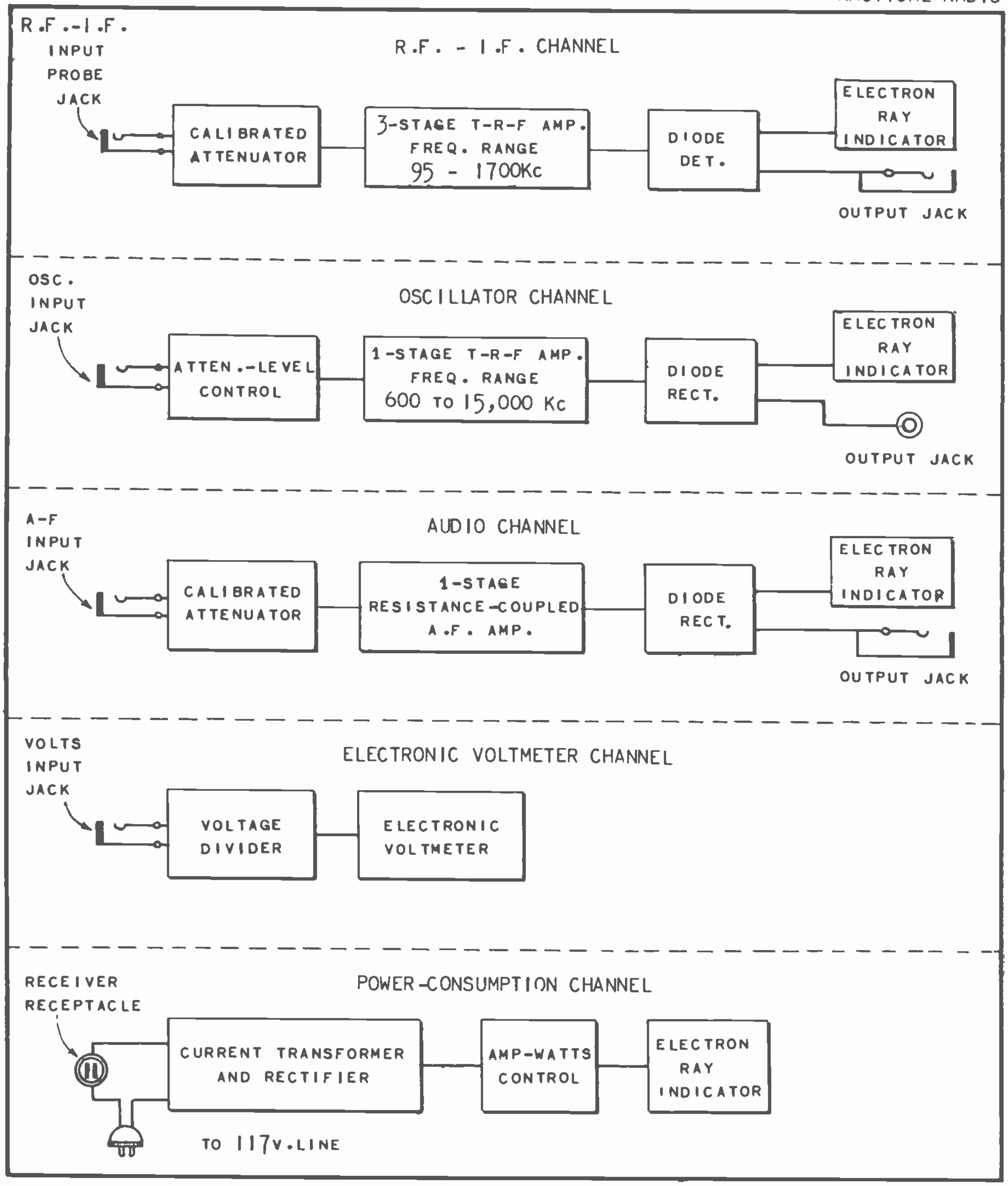


FIG. 10
BLOCK DIAGRAM OF TYPICAL MULTI-CHANNEL SIGNAL TRACER

The channel layout of the typical multi-channel signal tracing instrument is illustrated in block diagram form in Fig. 10. The features outlined in this layout may be considered as being representative of the various models produced by different manufacturers. Referring to this block diagram, you will note that the uppermost section represents the R.F.-I.F. Channel. This section is utilized when tracing signals whose frequencies range from 95 to 1700 kc. In other words, we would employ this particular Channel of the instrument when tracing i-f and r-f signals whose frequencies do not extend beyond 1700 kc. This range of frequencies is, generally, covered in three steps by means of a band-switch mounted on the panel of the instrument.

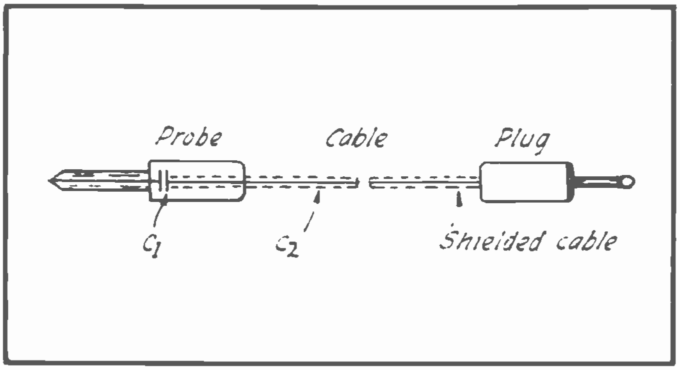


FIG. 11
R.F.-I.F. AND OSCILLATOR PROBE,
CABLE AND PLUG

THE R.F. - I.F. PROBE

The probe and cable for the R.F. - I.F. Channel (which also serves as the probe for the Oscillator Channel) are constructed in the manner shown in Fig. 11. The capacitance of C1 is, generally, approximately 1 mmfd; which, in some cases, is formed by merely separating the probe-tip slightly from the shielded cable conductor within the probe.

The purpose of this series capacitance (C1) is to reduce the overall capacity of the shielded cable. Without this series condenser, the total capacity of the cable (plus the input capacitance of the R.F. - I.F. Channel) would be in the neighborhood of 100 mmfd. This means that each time the probe were applied to a tuned circuit (for the purpose of making a test), a capacity of 100 mmfd would be shunted across the tuned circuit---thereby de-tuning the circuit to the extent that no reliable test could be made. However, with the 1 mmfd condenser inserted in series with this capacity, the overall capacity of the cable, plus the Channel input capacity, is reduced to such small proportions that its de-tuning effect upon the circuit-under-test becomes negligible.

Assuming that the sum of the probe-capacitance and the Channel input capacitance equals 99 mmfd. (C2 in Fig. 12), inserting a capacity value of 1 mmfd (C1) in series with this sum reduces the total capacity to .01 mmfd, in the manner shown below:

$$C_{TOTAL} = \frac{C_1 \times C_2}{C_1 + C_2} = \frac{1 \times 99}{1 + 99} = \frac{99}{100} = .99 \text{ mmfd.}$$

Note: $\frac{99}{100} = 100 \overline{)99.00}$ = .99
90 0
9 00
9 00

R.F.-I.F. CHANNEL AMPLIFIER

Referring again to the block diagram of the Signal Tracer in Fig. 10, you will note that a 3-stage t-r-f amplifier is employed in conjunction with a diode detector in the R.F. - I.F. Channel. The reason for this number of stages is to obtain an average amplification gain of 100,000. With this amount of gain, a 50 microvolt signal fed into the input grid of the Channel amplifier will produce a 5 volt signal at the diode detector--which is sufficiently powerful to operate almost any type of indicating device satisfactorily.

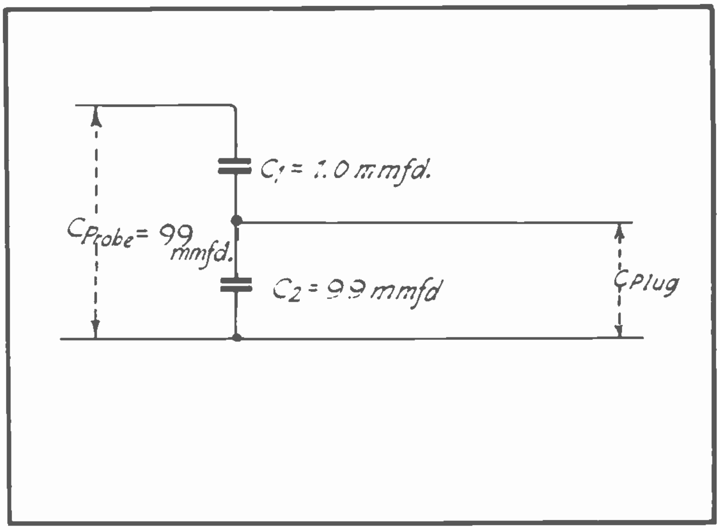


FIG. 12
THE PROBE CAPACITANCE IS REDUCED BY INSERTING A SERIES CAPACITOR

THE CALIBRATED ATTENUATOR CONTROL

A calibrated attenuator control precedes the t-r-f amplifier. In the majority of cases, this control is comprised of two units known as the "multiplier" and "attenuator" or "level" unit (which, for our purpose, we will refer to as the "attenuator-level" control). These two units provide a means for determining the amplification gain afforded by each stage in the receiver under test. Whereas the multiplier control measures the amplification gain in major steps---that is, in steps of 1/10/100/1000; the attenuator-level control provides a finer measurement ratio of from 1 to 10.

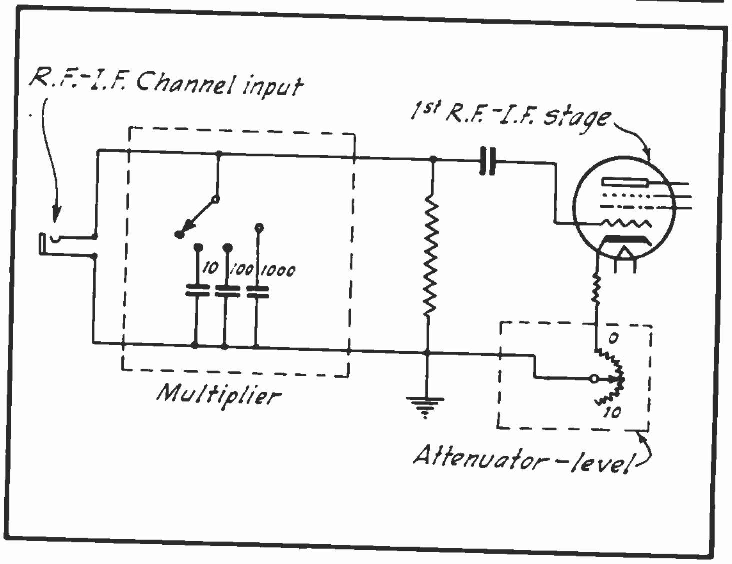


FIG. 13
MULTIPLIER AND ATTENUATOR-LEVEL CONTROL IN THE R.F. - I.F. CHANNEL

The manner in which the multiplier control functions, is as follows: Referring to Fig. 12, we find that when the series capacity (C1) is 1 mmfd and the cable+Channel input capacitance (C2) is 99 mmfd, the signal voltage reaching the input of the R.F. - I.F. Channel will be 1/100th of the voltage existing at the probe-tip, since the voltage is divided in proportion to the ratio of:

$$\frac{C1}{C1 + C2}$$

Consequently, if a 50-microvolt signal is required at the Channel input to provide a maximum reading on the output indicator, a 5,000-microvolt signal will be required at the probe-tip. This is the usual reference level used for the signal fed to the antenna and ground terminals of the receiver.

As the signal travels from stage to stage through the receiver and undergoes amplification, some means of accurately determining this amount of amplification is required. In the majority of the multi-channel Signal Tracers, this is accomplished by shunting specific values of capacities across the Channel-input (plus cable) capacitance (C2), as shown in Fig. 13. Thus, if C2 is 100 mmfd and we increase its capacity to 1000 mmfd., by shunting a 900 mmfd. condenser across it, the signal reaching the R.F.-I.F. Channel input control-grid is reduced to 1/1000th of that at the probe-tip. By using other shunting condensers, in a like manner, additional multiplier ranges are obtained.

The attenuator-level control, on the other hand, as shown in Fig. 13, is a precision type variable rheostat (generally wire-wound) that is inserted in series with the cathode of the first R.F.-I.F. Channel amplifying tube. By varying this control, the sensitivity of the R.F.-I.F. Channel is varied over a 10 to 1 ratio. The dial of this control is calibrated from 1 to 10, so as to facilitate measurement of gain.

Although the average gain of the Channel amplifier may vary (normally) from one end of its tuning range to the other end, the fact that the calibrated attenuator controls are in the input circuit of the channel, make the gain measurements at any one frequency independent of the variations in gain of the amplifier.

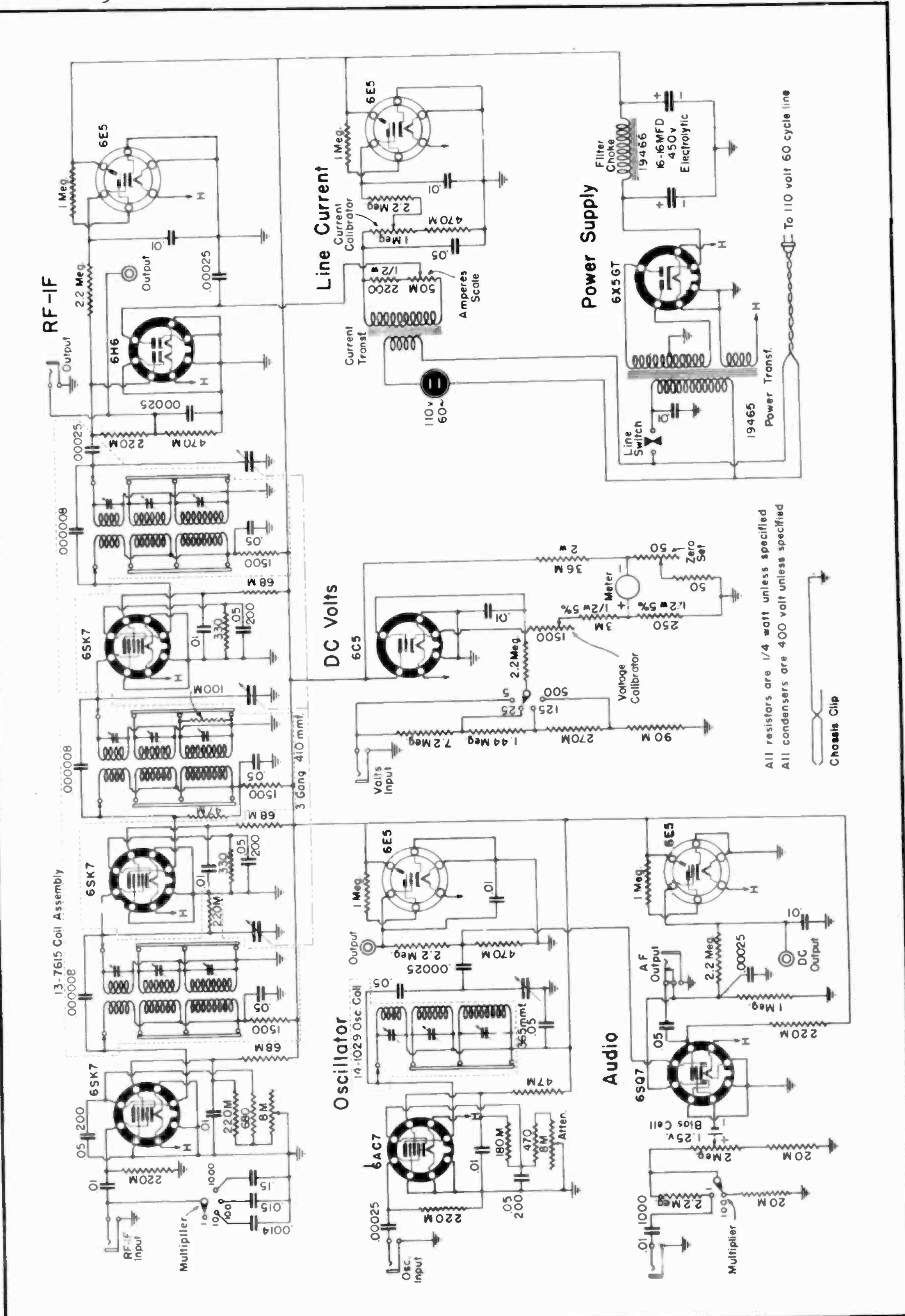


FIG. 14
CIRCUIT DIAGRAM OF THE MEISSNER ANALYST

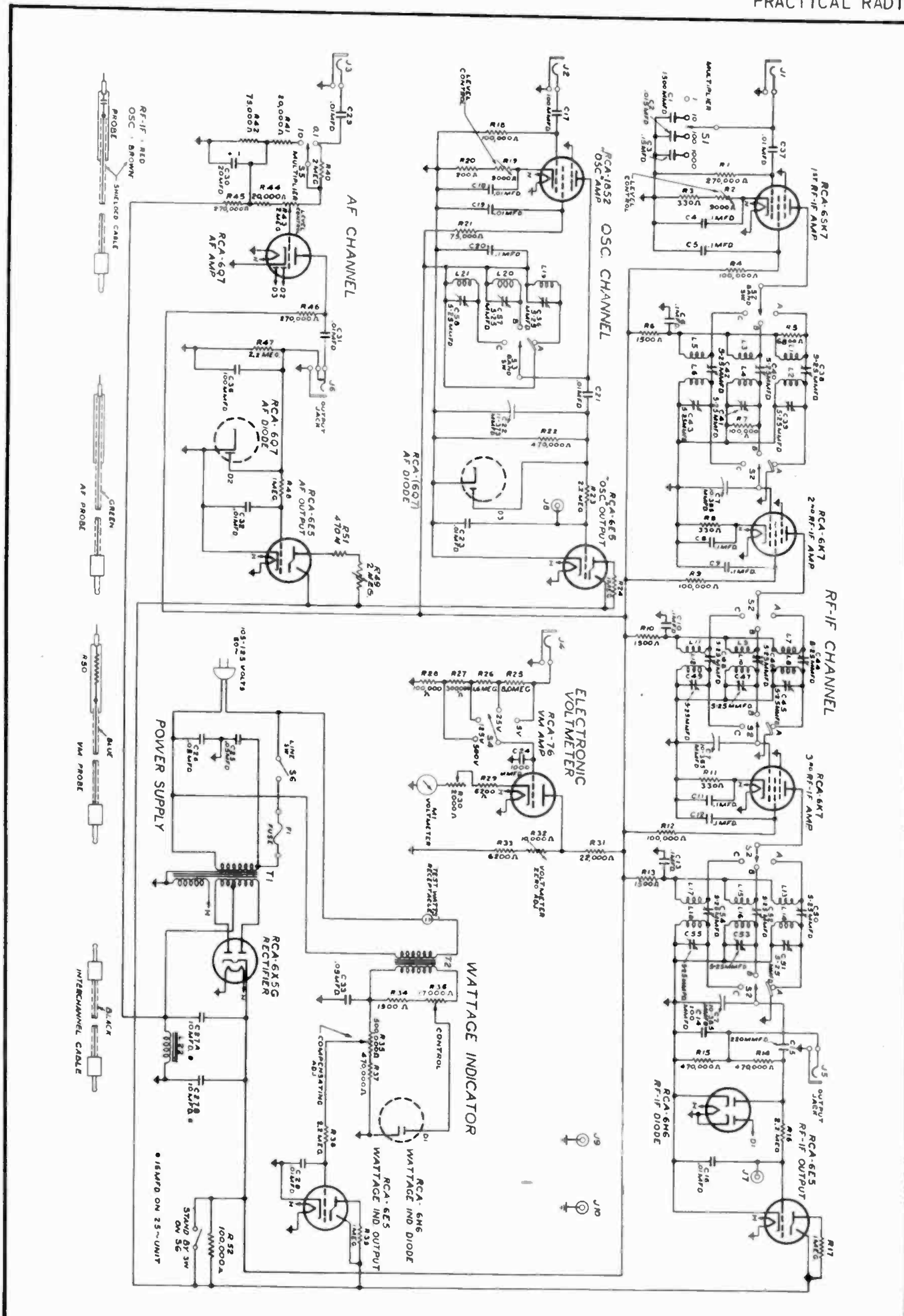


Fig. 15
Circuit Diagram of the RCA Chanalyst

In the output of this Channel (Fig. 10), an electron-ray indicating tube is provided to indicate the presence of the signal; which, in conjunction with the calibrated attenuator control, permits the measurement of the input signal. Besides this, an "output" jack is provided to permit the use of phones or any other audible or visual indicating device. The manner in which the calibrated attenuator control is used in conjunction with the electron-ray indicating tube will be explained later in this lesson.

THE OSCILLATOR CHANNEL

The Oscillator Channel (Fig. 10) is NOT an oscillator--nor is it a Signal Generator! Rather, this channel is merely a one tube t-r-f amplifier, covering a frequency range of from 600 to 15,000 kc. (Generally, this frequency range is covered in three steps).

When the probe is applied to (or placed adjacent to) an oscillating circuit and the Channel tuning dial adjusted to the frequency of the oscillating circuit, the presence and intensity of the receiver's oscillator signal will be indicated on the electron-ray indicator tube, which is connected to the output of the Oscillator Channel. Should the receiver's oscillator frequency drift, a change in the indication will occur; and, if the Oscillator Channel is then re-tuned to this new frequency, the extent of the frequency-drift may be ascertained.

At the input of this Channel, an attenuator-level control (only) is provided. (No multiplier control is supplied for this Channel). Inserted in series with the cathode of the amplifier tube, the attenuator-level control serves to reduce the sensitivity of the Channel when the oscillator signal voltage is more than sufficient to close the "eye" of the electron-ray indicating tube. An additional output jack permits the use of any other type indicating device such as a vtvm, oscilloscope, etc.

THE AUDIO-FREQUENCY CHANNEL

In the majority of multi-channel Signal Tracers, the A-F Channel consists of a single resistance-coupled amplifier stage which feeds into a diode rectifier. Thus, when an a-f signal is applied to the input of this Channel, it first undergoes a-f amplification in the single resistance-coupled stage and is then rectified by the diode. From here, it is fed into the control-grid of the electron-ray indicating tube to give a visual indication of the signal.

An output jack is also supplied so that either a pair of headphones (of the high impedance or crystal type) may be plugged in, to furnish an audible check on the signal (for distortion, hum, etc.); or, a vtvm, oscilloscope, etc., may be plugged in to provide a visual indication or measurement of the signal. When this output jack is used, the diode load is automatically cut out of the circuit so as to avoid introducing distortion because of the loading effect of the diode on the positive-half of the signal wave.

As in the R.F.-I.F. Channel, calibrated attenuation is provided in the form of: 1) a multiplier; and, 2) an attenuator-level control. In this case, the multiplier control is comprised of a SPDT (single-pole, double-throw)type switch that shunts a low-value resistor across the input of the Channel; thereby attenuating the input to the extent marked on the multiplier scale. The attenuator-level control, on the other hand, is a potentiometer whose function may well be compared to the typical volume control in an a-f stage (refer to circuit diagrams of the Analyst and Chanalyst in Figs. 14 and 15).

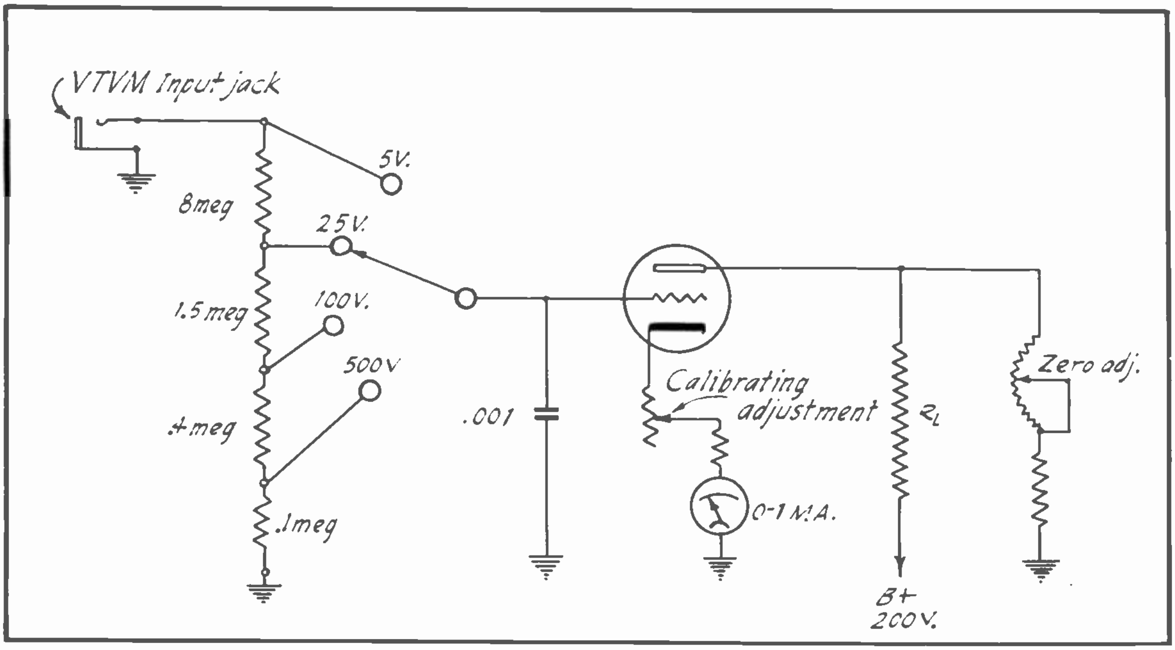


FIG. 16
TYPICAL ELECTRONIC VOLTMETER CIRCUIT EMPLOYED IN MULTI-CHANNEL SIGNAL TRACERS

When used in conjunction with the electron-ray indicating tube, the audio voltage at the probe-tip may be determined by regulating the multiplier and attenuator-level controls until the "eye" just closes. The reading on the attenuator-level control is then multiplied by the value indicated by the multiplier. Audio-frequency voltages ranging from 0.1 to 1000 volts may be checked in this manner with an accuracy of within 15 to 20 per cent.

THE ELECTRONIC VOLTMETER CHANNEL

For the Electronic Voltmeter (VTVM) Channel (Fig. 10), a triode functions as the voltmeter tube in the majority of these instruments. In conjunction with this tube, a voltage-divider system and a d-c milliammeter, calibrated in volts, is used as shown in Fig. 16. In some

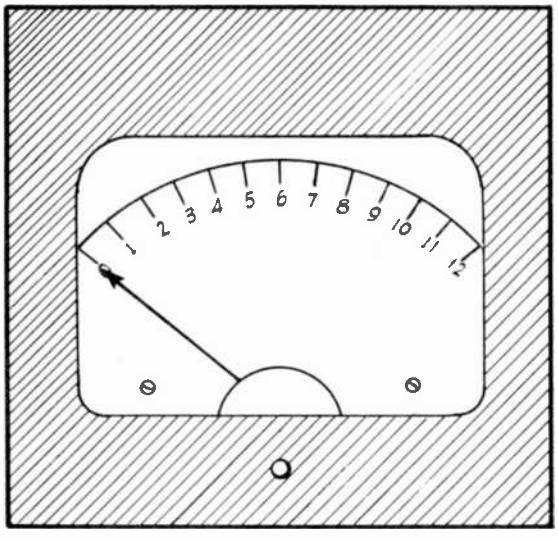


FIG. 17
ZERO AT LEFT OF VOLTMETER SCALE

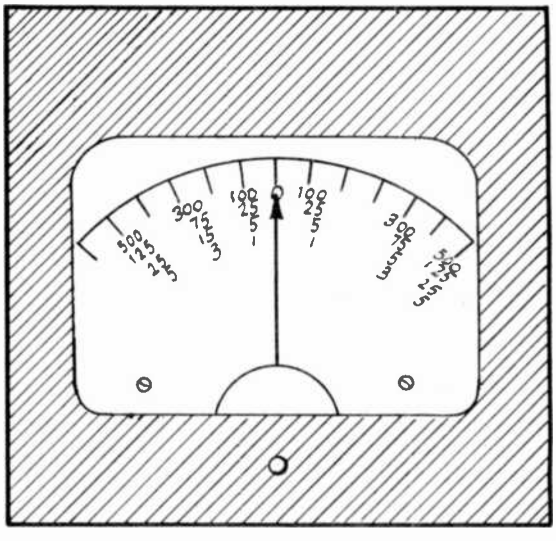


FIG. 18
ZERO AT CENTER OF VOLTMETER SCALE

models, the voltmeter "0" mark is at the conventional position; that is, at the extreme left of the meter-scale, as shown in Fig. 17.

In other Tracer instruments, the meter-pointer rests at zero in the center of the meter-scale, as shown in Fig. 18. All of the negative voltage calibrations are on the left side of this center zero mark; whereas, the positive voltage calibrations are on the right side of the zero mark. The advantage of having the scale calibrated in this manner is that positive or negative voltages may be checked without the need for switching the voltmeter test-prods, or the use of a "polarity-reversing" switch. The disadvantage of this type of scale is that the voltage ranges of the meter can only be spread over one-half of the scale----since this same range (of opposite polarity), must be spread over the opposite half of the scale, also. Because of this, the space allowed between the voltage graduations is reduced by one-half. To offset this disadvantage, the total range of 0 - 500 volts is divided up into four steps: 0/5/25/125/500 volts.

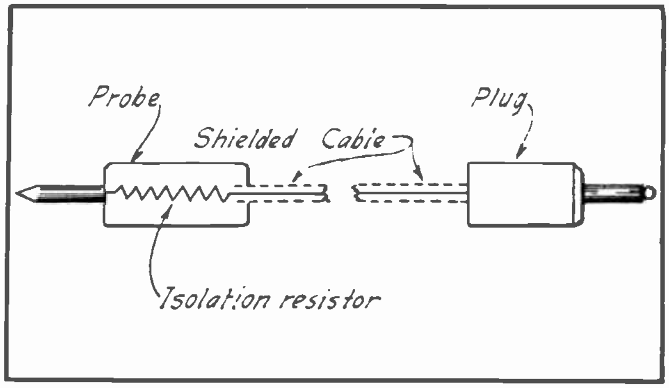


FIG. 19
VOLTMETER CABLE AND PROBE

A voltage-divider having a total resistance of approximately 10 megohms is employed in the input circuit of this Channel. A "meter-range" switch selects any one of the four voltage ranges listed above. A special probe, fitted with a 1-megohm isolation resistor, as shown in Fig. 19, serves to isolate the capacity of the shielded cable from the circuit under test; thereby, allowing d-c voltages of tuned circuits to be measured, as well as all other d-c voltages.

Since the total input resistance is approximately 11 megohms (10 megohms plus the 1-megohm probe resistance) the sensitivity of the voltmeter is approximately 2,200,000 ohms-per-volt on the 5 volt range; and,

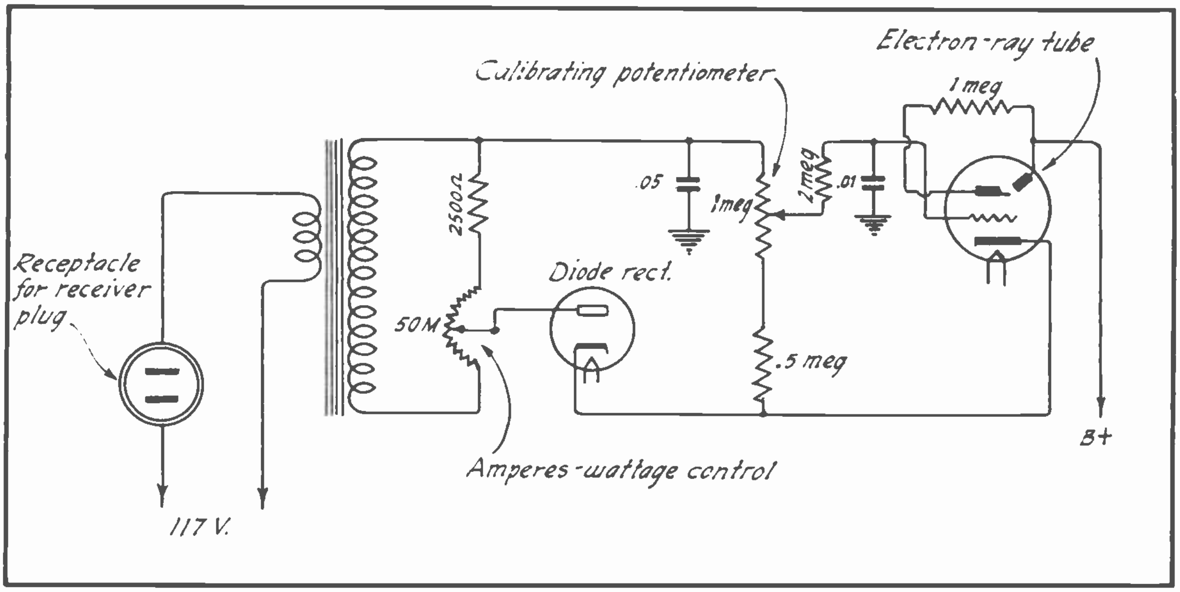


FIG. 20
TYPICAL POWER CONSUMPTION CHANNEL CIRCUIT

on the higher voltage ranges, the input resistance of the voltmeter is sufficiently great to permit accurate measurements on high impedance control-grid, plate and screen-grid circuits.

THE POWER CONSUMPTION INDICATOR CHANNEL

The function of the Power Consumption Indicator Channel, commonly referred to as the "Line Current Channel" or "Wattage Indicator Channel", is to indicate the amount of wattage or electrical power that the radio receiver consumes during operation. The circuit diagram of a typical Power Consumption Indicator Channel is shown in Fig. 20.

The purpose of this Channel is to afford a quick means of informing the serviceman whether any major shorts or open circuits exist in the receiver. Thus, if the power consumption of the receiver is two or three times the normal value, a serious short circuit in the power supply of the receiver may be suspected. On the other hand, if the wattage consumption indicated is considerably lower than normal, an open circuit or failure in the power-supply circuit may be suspected.

This Channel is automatically placed in operation when the electric plug of the receiver is inserted into the a-c receptacle provided on the panel of the instrument. By referring to the diagram of this Channel in Fig. 20, you will note that this section consists, essentially, of a current transformer which feeds a diode rectifier. The primary of this current transformer is in series with the power line; hence, when the receiver is plugged into the receptacle, the current drawn by the receiver passes through the primary of the current transformer. This induces a voltage into the secondary of the transformer which is applied to the diode rectifier and load circuit. The resultant rectified voltage appears across the diode load network (comprised of the .5 megohm resistor and the calibrating potentiometer). A portion of this voltage is then applied to the control-grid of the electron-ray indicator tube.

The use of this Channel, during actual servicing of the receiver, will be outlined in the following chapters---"Preliminary Tests" and "Signal Tracer Servicing Procedure".

PRELIMINARY TESTS

First, turn the Signal Tracer on; and, while it is warming up, carry out the first preliminary check on the receiver. This consists of inspecting the receiver's line cord and plug; and testing all of the tubes for quality, shorts, leaks, etc.

POWER SUPPLY TEST

Having assured yourself that the a-c line cord and plug are in good condition and will not blow a fuse, the receiver plug may now be inserted into the Power Consumption Channel receptacle of the Tracer. (In the event that your Tracer does not have a Channel of this type, it will be necessary for you to check the voltage output of the power transformer with an a-c voltmeter and for a short between B+ and B- in the d-c power supply portion of the receiver, before proceeding with the signal-tracing tests).

Turn the receiver on and observe the "eye" of the Channel electron-ray indicating tube. As the receiver warms up, the eye should be maintained at the point where it just closes---as the ampere-watts control is adjusted. The scale over which the pointer of this control-knob travels is calibrated in amperes or watts (depending on the particular brand of instrument being used). The position at which the dial must be set so the eye <u>just</u> closes, indicates the amount of amperage that the receiver is drawing from the a-c line---or the amount of a-c wattage it is consuming. This reading is then compared with the power consumption rating of the receiver under test.

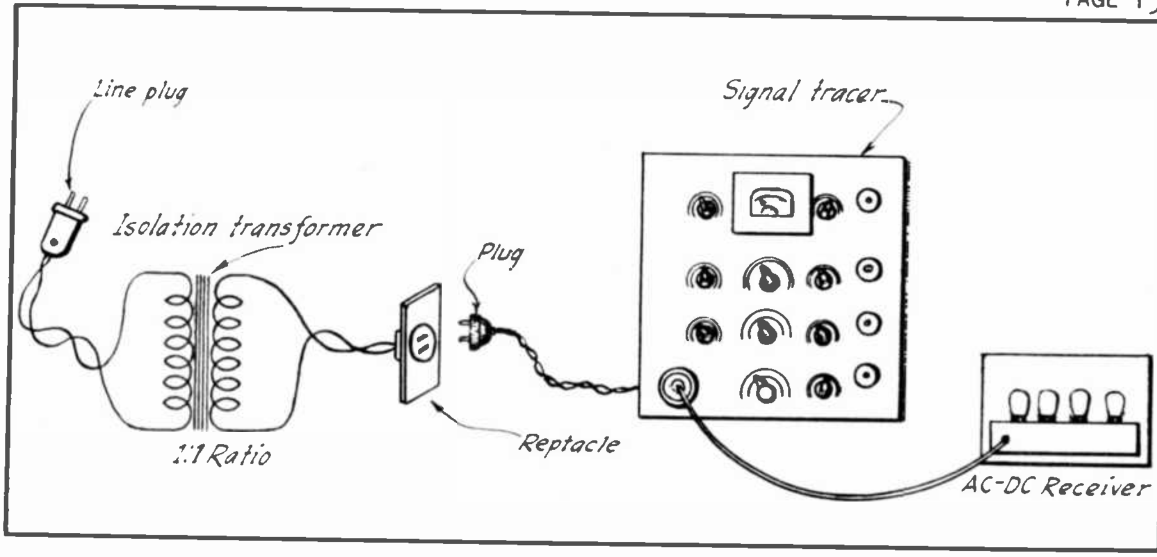


FIG. 21
ISOLATION TRANSFORMER USED WHEN TESTING AC/DC RECEIVERS

If the name-plate on the receiver does not specify the power consumption of the receiver in watts, but rather in terms of amperes, a satisfactory estimate may then be made of the normal operating wattage of the receiver by multiplying this amperage value by 9/10 of the operating voltage specified on the name-plate. For example, if a receiver is rated at drawing .3 ampere and the a-c operating voltage of the receiver is 117 volts, nine-tenths of 117 equals 105.3 volts. $(9/10 \times 117 = \frac{1053}{10} = 105.3 \text{ volts})$

Now multiplying by .3 ampere:

$$\begin{array}{r} 105.3 \\ \times\ .3 \\ \hline 31.59 \end{array} \text{ watts}$$

The wattage consumption of this receiver during normal operation is, thus: 31.59 watts. (Note: The, factor 9/10ths, represents the power factor of the average receiver; hence, is included in the formula.)

On the other hand, if the name-plate specifies this value in watts and the Signal Tracer indicates the amperage drawn by the receiver, a satisfactory estimate of the amount of amperage that the receiver should draw during normal operation may be obtained quickly, and with sufficient accuracy, by dividing the wattage specified by 100. Thus, if the name plate specifies a rating of 50 watts, the normal line-current of this receiver would be .5 ampere $(50 \div 100 = .5$ ampere.).

In the majority of receivers, the power consumption of the receiver (in watts) is provided on the name-plate of the receiver; on a label fastened to the cabinet; or, in the factory service notes or circuit diagram pertaining to the receiver. When this information is not available, the normal wattage-consumption of the receiver may be estimated to be approximately 10 watts per tube.

AC/DC RECEIVERS

When checking AC/DC receivers, obtain the line current or wattage reading with the receiver plugged in. Then reverse the plug in the receptacle and note whether a different reading is obtained. If so, take an average between the two readings.

It is also a wise precaution to remember that one side of the a-c line constitutes B- in this type of receiver; consequently, the ground clip of the Signal Tracer should never be connected to the B- of the receiver when the Signal Tracer is resting on a metal table---or when you are standing on concrete or damp flooring. To insure freedom from danger and electrical shock, the manufacturers of these instruments recommend that an "isolation" transformer be used; that is, a transformer having a 1:1 ratio (117v. to 117v). This transformer should be inserted between the a-c line and the instrument; thereby isolating both the instrument and the AC/DC receiver from ground, as is shown in Fig. 21.

OVERLAPPING "EYE" INDICATION

If, when the receiver is plugged into the Channel receptacle, the indicator "eye" closes to the extent that the illuminated areas overlap, this is, generally, an indication that the receiver is drawing an excessive amount of line current. In that case, a defect in the line-plug, cord, or power-supply of the receiver should be suspected.

One method of localizing the source of such trouble is to remove the rectifier tube from its socket. Normally, this procedure should produce a 2/3 drop in the power consumption of the receiver---since the d-c power-supply portion of the receiver draws approximately two-thirds of the total rated power consumed by the receiver. If the defect lies in the d-c power supply, the eye will open when the tube is removed. On the other hand, if no appreciable change is observed in the indicating eye, a defect in the a-c portion of the power supply may be suspected (such as a short in the power transformer windings or wiring,rectifier tube socket,heater or filament circuit, etc.).

From the above, it is obvious that an open in the a-c portion of the power-supply circuit will be indicated by the eye remaining open; and, if the eye indicates that the receiver is drawing approximately 1/3 its normal load, this, generally, signifies that the rectifier is not functioning or that an open exists in the d-c power supply circuit.

CIRCUIT VOLTAGE TESTS

Assuming that the receiver passes the Power Consumption Channel tests satisfactorily, a voltage check of all plate, screen-grid, avc, control-grid circuits, etc., is now recommended. If the Signal Tracer has an electronic voltmeter (vtvm) incorporated within it, these voltage checks may be made with this instrument. If the Signal Tracer you are using does not incorporate such type of voltmeter, any other voltmeter of sufficient sensitivity may be used for this purpose.

VARIABLE CONDENSER CHECK

Up to this point in our servicing procedure, we have checked and corrected all faults that existed in the power-supply and voltage distribution to the tubes. With the tubes operating at their normal voltages, we are now in a position to allow the receiver to remain turned on for as long a period of time as is necessary to conduct all other tests---without endangering the life of the tubes or other components in the receiver.

With the receiver warmed up to normal operating temperature, and the conventional antenna connected to it, rotate the tuning condenser to observe if any noise is apparent. If such is evident,the first step is to blow out all dust and remove all particles from between the plates. If small metallic particles persist in remaining between the condenser plates after given this treatment, they may be removed with a strip of stiff paper cut out from an old business or playing card. Where considerable space exists between the condenser plates, a smoker's pipe-cleaner may be used to advantage.

At this time, also note if the rotor plates are short-circuiting to the stator plates at any point of condenser rotation. Should the condenser assembly require tightening, do it carefully, and tighten to the point where the rotor plates are centered between the stator plates. Finally, apply a drop or two of "contact cleaning" fluid or paste to the bearings and at all points where the rotor shaft makes a "wiping" contact to the frame of the condenser. (Note: Contact cleaning fluid and paste may be obtained at any radio supply store).

OSCILLATION

If the receiver tends to oscillate, it is a good policy to check each by-pass condenser in the circuit---from the antenna, straight through each r-f, i-f, and audio stage and, finally, through the power-supply circuit (a-c, as well as d-c). The most simple means is by the "substitution method"; that is, by shunting a condenser of an equivalent value across each by-pass condenser and noting whether or not oscillation stops. If the oscillation stops when any one of the by-pass condensers are shunted, it indicates that the condenser being shunted is either defective or of insufficient capacity.

If all by-pass condensers check satisfactorily, a condenser of .01 to .1 mfd capacity should be shunted across each electrolytic filter condenser. If oscillation ceases, this, usually, indicates that the condenser has aged to the point where it is unable to by-pass high-frequency currents effectively. The remedy, of course, is to replace the electrolytic condenser.

HUM

If hum is present, and varies in strength when the variable tuning condenser is rotated, it may be due to the receiver's antenna picking up an "induced" a-c current from a nearby electric circuit or electrical appliance which is being operated at the time. (This type of hum is referred to as an "induction" hum). If the volume control is very noisy and the hum stops when this control is rotated to a certain point, the hum may be due to a worn-out volume control.

Should the hum persist, regardless of the position of the tuning condenser or volume control, it may be due to an open or unshielded control-grid circuit in one of the a-f stages; or, poor filtering in the power-supply or voltage-distribution system. If the volume of the hum can be reduced by rotating the volume control to minimum-volume position, an open control-grid circuit in an r-f, i-f or oscillator stage may be suspected.

If the receiver is of the multi-band type, note whether the hum is heard only on one band or on all bands. If the hum is apparent on one band only, the trouble may be attributed to: 1) faulty band-switch contacts for this particular band; 2) an open in one of the coils used on this band; and 3) a defect in any one of the other components associated with the circuit of this band.

SPEAKER DEFECTS

A rattling noise that becomes more evident when the volume of the signal is increased may be due to: 1) defect in the voice coil of the loudspeaker; 2) loose speaker cone; 3) cone rubbing against the iron core; or 4) metal filings lodged between the voice coil and core of the speaker.

SIGNAL TRACER SERVICING PROCEDURE

If the defect in the receiver is not apparent when applying the preceding tests, we may then resort to the signal tracing procedure.

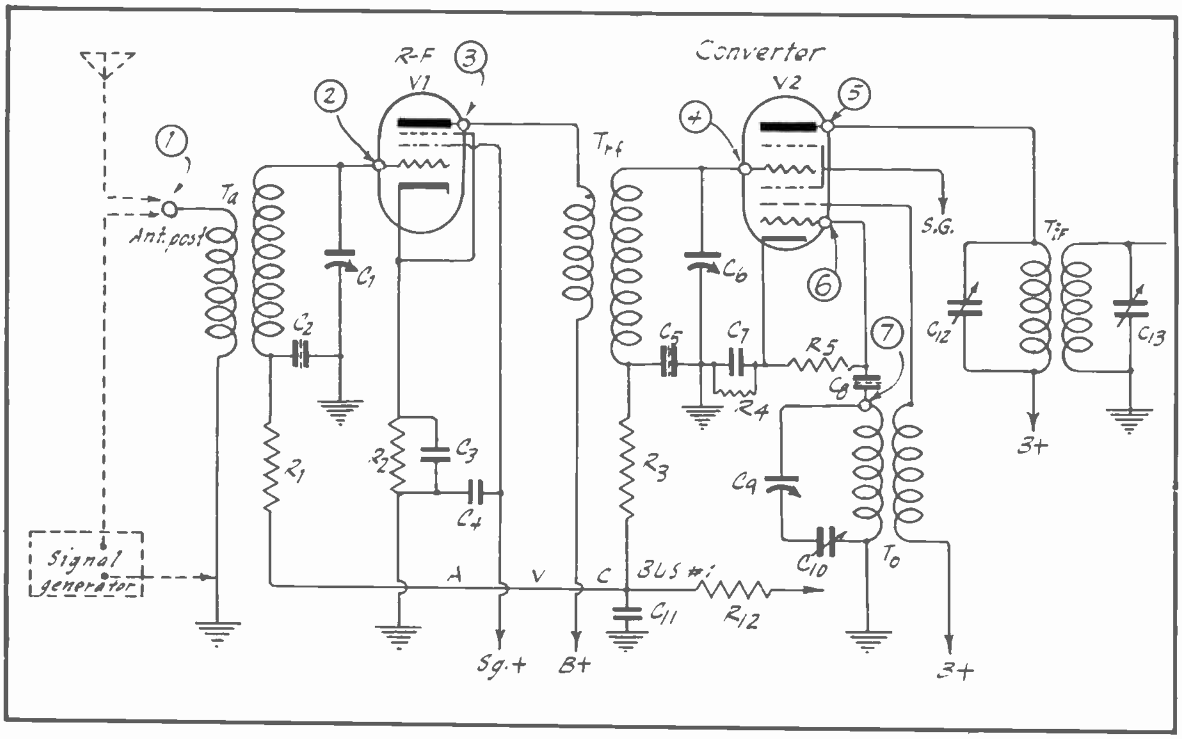


FIG. 22
R.F. - CONVERTER CIRCUIT UNDER TEST

If no sound can be heard from the speaker, or if a signal can be heard only faintly, it is best to employ a Signal Generator as the signal source. However, if the receiver has ample volume, but the sound is distorted, then a broadcast signal may be used as the signal source.

USING SIGNAL GENERATOR AS SIGNAL SOURCE

If a Signal Generator is used, it should be connected to the input (antenna and ground posts) of the receiver in the conventional manner---as prescribed by the manufacturer of the Signal Generator. (Note: If you do not have this information, it is recommended that you write to the manufacturer of the instrument for this data). The frequency of this signal should be high enough so that the rotor plates of the receiver's variable condenser will have to be rotated completely out of mesh with the stator plates. (On the broadcast band, this would be approximately 1700 kc). Also, the signal should be modulated with an a-f tone of approximately 400 to 1000 cycles.

CHECKING THE R-F STAGE

Attaching the ground clip of the Tracer to B- of the receiver, we apply the R.F.-I.F. Tracer probe-tip to the antenna post of the receiver (point "1" in Fig. 22). Using a pair of headphones plugged into the output jack of the R.F.-I.F. Channel, or utilizing the "eye" as the resonance indicator, rotate the tuning dial of this Channel to the 1700 kc position so that the tuning circuit in this Channel resonates to the frequency of the Generator's signal. The output of the Signal Generator is then adjusted so that a satisfactory indication is obtained on the indicator eye of this Channel when the multiplier and attenuator-level controls are set at a low number.

If a very weak--or no indication---is obtained when making this test, increase the output of the Signal Generator. However, if this still does not provide a satisfactory indication, disconnect the Signal Generator from the receiver and check the output of the Generator by applying the

Tracer probe-tip to the output of the Signal Generator directly. If a strong indication is obtained from the Generator when it is disconnected from the receiver, yet an extremely weak (or no) indication is obtained when the Generator is connected (correctly) to the input of the receiver, this generally signifies that the antenna or control-grid circuit of the receiver is shorted. (Many instances are known of where a short circuit in the antenna or grid coil was not revealed by an ohmic resistance test of the coil, but was revealed by the test just described).

The Tracer probe is then transferred to the control-grid of the r-f tube (point "2" in Fig. 22). If an efficient type of antenna transformer is employed in the receiver, a slight gain will be noted, as listed in Table I.

If a satisfactory indication is obtained at this point, the probe is then transferred to the output of the first stage which, generally, is the plate element of the tube (point "3" in Fig. 22). Failure to locate the signal at either point "2" or "3" localizes the fault to the tube or any of the components of the first stage. Besides checking these parts, it is advisable to check also the input and output tuning circuits of this stage which is comprised of the secondary winding of transformer T_a, the variable condenser section C1, coupling condenser C2; and the tuning circuit of the succeeding stage (comprised of the secondary winding of transformer T_{rf}, and condensers C5 and C6). If the presence of the signal is indicated at point "3", the probe is then transferred to the control-grid of the converter tube--which would be point "4". The approximate gains up to these points are listed in Table I.

CHECKING THE OSCILLATOR

At this time, we will test the oscillator circuit of the receiver. To do this, the R.F.-I.F. Channel is tuned to the intermediate frequency of the i-f stages of the receiver. With the probe applied to the plate terminal of the converter tube (point "5" in Fig. 22), the signal should again be intercepted. If the signal does not come through to this point, the oscillator circuit may be suspected of being faulty.

An expedient method of checking the oscillator circuit is to apply the electronic voltmeter probe to the oscillator-grid tube-socket terminal (point "6"). If the oscillator is oscillating, a negative voltage reading will be obtained. If the voltage is zero or of a positive value, this is evidence that the oscillator is not functioning. In that case, the trouble may be due to a poor oscillator (mixer) tube or to a leak or defect in any one of the components in the oscillator circuit (T_o; R5; C8; C9; C10).

As an exception to this rule, it has been found, in certain receivers, that the positive voltage at the converter cathode may exceed the negative voltage at the oscillator-grid; thereby causing a slight positive voltage even though the oscillator is functioning normally. Consequently, as a confirming check, the oscillator circuit may be tested by employing the Oscillator Channel of the Tracer.

Applying the probe to the oscillator-grid of the converter tube (point "6"), the Oscillator Channel should be tuned to the frequency of the r-f circuits PLUS the i-f frequency. Hence, if the r-f circuit of the receiver is tuned to 1700 kc and the i-f frequency of the receiver is 455 kc, the Oscillator Channel should be tuned to 2155 kc (1700 + 455 = 2155 kc). If a signal is obtained at point "6", the oscillator is functioning properly.

LOW-FREQUENCY CHECK

Up to this part of the tracing procedure, we have been working with the 1700 kc signal. Having traced this signal to all points mentioned in

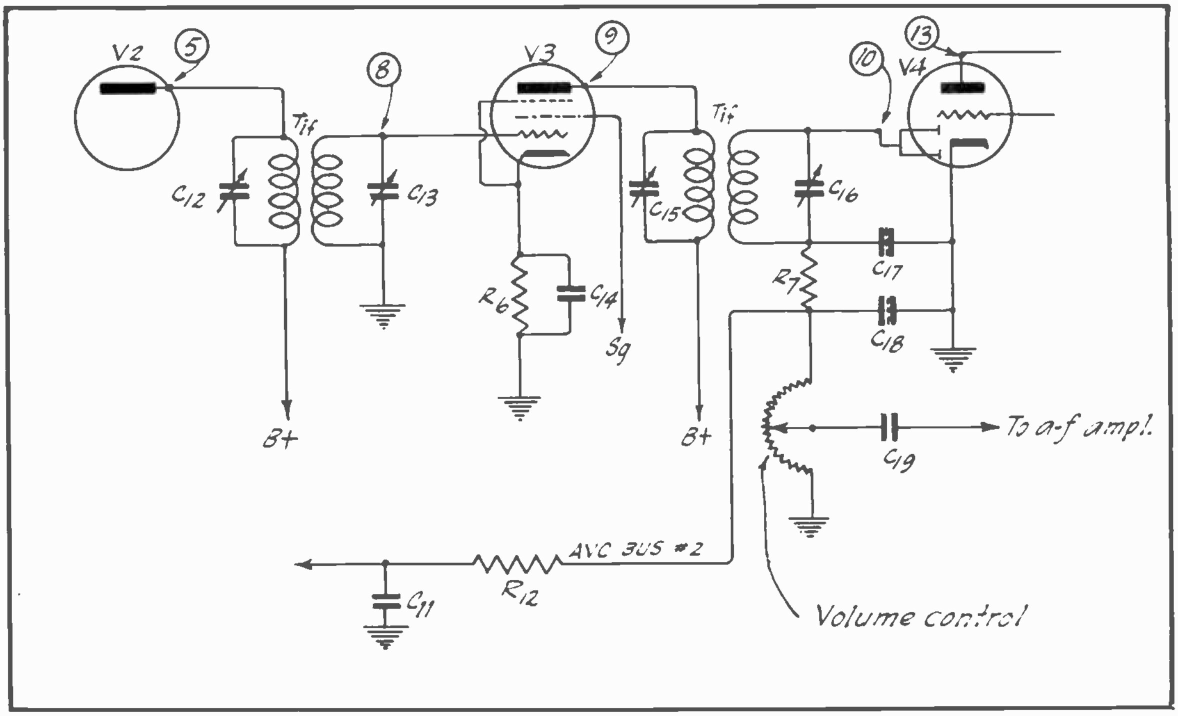


FIG. 23
I.F. CIRCUIT UNDER TEST

the preceding paragraphs--and corrected all existent faults wherever necessary---the frequency of the input signal should now be changed to 600 kc. Tuning the R.F.-I.F. Channel of the Tracer to this frequency, we trace the 600 kc signal from the antenna stage to the converter stage in the identical manner as was done with the 1700 kc signal.

TRACING THROUGH THE I-F STAGES

Having remedied all faults that may have interfered with the passage of the 600 kc signal through the circuit to the output of the converter tube, we may now proceed to trace through the i-f stages.

This is accomplished by tuning the R.F.-I.F. Channel to the i-f frequency of the receiver. Transferring the probe from the control-grid to the plate of each i-f tube, the signal is traced throughout all i-f stages. Referring to Fig. 23, this would be from point "8" to point "10" in this particular circuit. The gains that may be expected in these stages are listed in Table I.

TABLE I

AVERAGE GAIN-PER-STAGE VALUES

R-F SECTION	
Antenna to grid of first tube	2 to 10
Antenna to grid of first tube (auto-radios	10 to 50
R-f amplifier, superheterodynes	10 to 40
R-f amplifier, t-r-f receivers	50 to 100
MIXER SECTION:	
Converter grid to i-f grid (1-stage i-f amp.)	30 to 60
Converter grid to i-f grid (2-stage i-f amp.)	5 to 20
I-F SECTION:	
I-F Stage (1-stage amp.)	40 to 150
I-F Stage (2-stage amp.)	5 to 20
BIASED DETECTOR:	
PENTODES (Types 57, 6C6, 6J7)	
A 1.0 volt rms signal (modulated 20%) at the grid will produce approximately 10 volts rms of a-f at the plate. Higher modulation percentages will produce correspondingly higher a-f voltages. Thus, 40% modulation will produce 20 volts rms of a-f at the plate.	
A-F SECTION:	
MEDIUM-MU TRIODES, RESISTANCE-COUPLED:	
Type 6N7, 6C8 (each section)	20 to 25
HIGH-MU TRIODES, RESISTANCE-COUPLED:	
Type 75, 2A6, 6F5, 6SQ7	40 to 55
PENTODES:	
Type 2B7, 6B7, 6B8	50 to 80
Type 6F6, 2A5, 47, 6V6 6K6. (grid-to-plate gain)	8 to 20
TRIODE OUTPUT TUBES:	
Type 2A3, 45, 71A, 6A5G	2 to 5

CHECKING AVC VOLTAGES

To test the avc voltages in the receiver, it is best to make use of the Electronic Voltmeter Channel or any other suitable voltmeter having sufficient sensitivity. With the positive prod of the VTVM connected to the cathode of the avc-controlled tube, and the negative voltmeter prod applied to the control-grid, the signal intensity of the receiver input signal is varied. The control-grid voltages, thus obtained, should check with those specified by the manufacturer of the receiver. (This information is generally provided in the

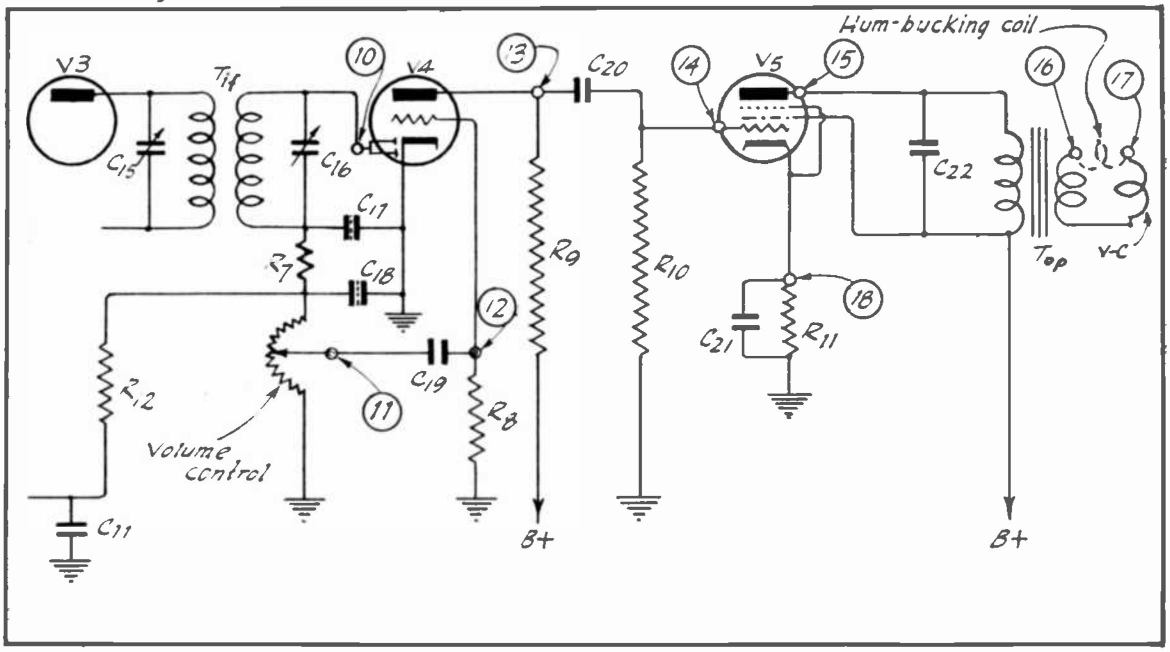


FIG. 24
AUDIO-FREQUENCY CIRCUITS UNDER TEST

circuit diagram of the receiver). Sub-normal avc voltages are usually caused by leaky or defective avc by-pass condensers (C11, C17, C18 in Fig. 23; also, a weak or defective avc tube (V4).

TRACING DISTORTION

Distortion may be traced by means of: (1) the phones; or, (2) an oscilloscope. In the latter case, a visual pattern of the signal is obtained by plugging an oscilloscope into the output jack of the Channel being employed. For the input signal, a high-quality broadcast program may be used; or, the Signal Generator may be modulated with a phonograph record by means of a pick-up and an amplifier whose output is plugged into the proper jack of the Signal Generator. (In most Signal Generators, this jack is marked "External Modulation". To determine which jack to use in your own particular make of Signal Generator, refer to the factory instruction bulletin corresponding to the instrument---or write directly to the manufacturer of the instrument for this information).

Precision tests on distortion may be made by employing an Audio Signal Generator to modulate the R-F Signal Generator, or by connecting the output of the A-F Generator directly to the input of the receiver's a-f amplifier. (This would be directly across the volume control in Fig. 23). The electronic voltmeter or an oscilloscope is then used as the output indicator.

As the audio-frequency input signals are varied by the A-F Signal Generator, an analysis of the wave-form may be made on the oscilloscope; or, if a VTVM is used, voltage measurements of the output are taken at each test frequency, and a graph plotted from this data.

CHECKING AUDIO-FREQUENCY CIRCUITS

Audio amplifiers or circuits are tested in the same manner as prescribed for the r.f.-i.f. circuits. In this case, however, the Audio Frequency Channel of the Signal Tracer is employed.

In a typical receiver, the audio signal is initially developed across the diode load which, in most cases, is the volume control, as shown in Fig. 24.

Assuming that the r-f signal has been traced to the diode of the 2nd detector tube (point "10"), the audio probe is now plugged into the Audio-Frequency Channel of the Tracer and used in place of the R.F.-I.F. probe. This probe employs no isolating resistor or condenser; and consists, merely, of a simple, shielded cable, as illustrated in Fig. 25. Applying the probe to point "11" in Fig. 24, an indication of the signal should be obtained. Now, adjust the volume control until a reference indication is obtained on the output indicator of this Channel.

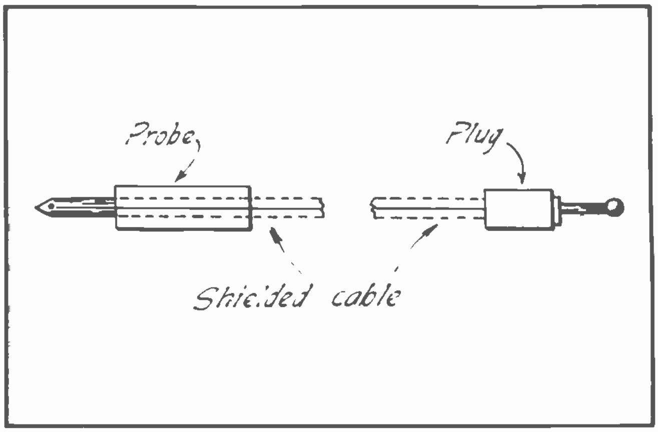


FIG. 25
A-F TRACER PROBE

Failure to obtain a signal at this point indicates an open in either the i-f transformer (T_{if}); the resistor R7; or, the volume control. Other probable causes are a shorted trimmer condenser (C15 or C16) within the i-f transformer, or shorted by-pass condensers C17 or C18. If a shrieking, howling or humming noise is heard when the volume control is rotated, a worn-out volume control may be suspected; although the latter symptoms may also be due to: an open by-pass condenser (C17 or C18); feed-back between the control-grid lead and plate lead; or inadequate shielding of tube V4.

If satisfactory signal-indication is obtained at point "11", the probe is then transferred to point "12". When applying the probe to this latter point, it is best to tap or shake the audio-coupling condenser (C19) slightly. If the volume varies when this is done, it indicates a poor connection between the leads and plates within the condenser (which may be the cause for intermittent radio reception or fading). If a weak signal or no signal is obtained at this point, this condenser may be partially or completely open.

At point "13", a considerable increase in gain should be noted; especially if the triode section of the 2nd detector is of the high-mu type (refer to Table I). Distortion or very little gain may be caused by a shorted or partially shorted audio-coupling condenser (C19 or C20). If C20 is leaky, an insufficient value of biasing voltage will be indicated when the probe of the VTVM is applied to the control-grid of the output tube (point "14"). If this condenser is shorted, a positive voltage will be obtained at point "14"--due to the flow of current from the plate of tube V4 (which is of a positive polarity), through condenser C20 and grid resistor R10.

An insufficient value of grid-biasing voltage may also be due to a partially shorted cathode by-pass condenser (C21). Weak reception at point "14" may also be due to a defective plate-load resistor of the preceding tube (R9); or a defective resistor in the control-grid circuit of the output tube (R10).

Hum and distortion at point "15" may be caused by an open or defective grid resistor (R10); leaky or shorted audio-coupling condenser (C20); or a gassy output tube (V5). If the tube is gassy, the control-grid of this tube will gradually become positive as the tube heats. On the other hand, if the distortion is due to a defective coupling condenser (C20), the temperature of the tube has no effect on the polarity of the control-grid.

Amplification gain of the output tube may also be checked at point "15". Poor gain or excessive bass reproduction may be due to a leaky audio by-pass condenser C22 (or "tone" condenser--as it is sometimes refer red to). If this condenser is open, it may be the cause for audio howl ing, oscillation, poor tone quality and undesirable noise in the form of tube "hiss".

The condition of the output transformer (T_{op}) may be checked by apply ing the probe to point "16". At this point, the signal indication level will take a sharp drop (approximately 1/25 of the reading obtained at point "15")---unless the combined impedance of the indicating circuit and speaker voice-coil match the secondary impedance of the output transformer. Consequently, if a sub-normal indication is obtained at this point, yet the loudspeaker volume is satisfactory, consider this indication to be normal.

If the speaker employs a hum-bucking winding, the effectiveness of this winding may be checked by applying the probe to point "17".

ALIGNMENT PROCEDURE

Aligning the various tuned circuits of the receiver to their proper frequencies is quite a simple procedure with the multi-channel Tracer. In fact, the alignment procedure may be carried out at the time that the signal is being traced from stage to stage.

ALIGNING STANDARD BROADCAST BAND

For example, referring back to Fig. 22, which represents the r.f.-converter portion of the typical superheterodyne receiver, the Signal Generator and the receiver tuning dial are set to 1700 kc. The oscillator tuning condenser C9 is shorted out so that the oscillator will not interfere with the alignment of the r-f stages. The R.F.-I.F. Channel is then tuned to this frequency and the R.F.-I.F. tracer probe is applied to point "3". The trimmer of tuning condenser C1 is now adjusted for maximum closing of the indicating eye.

The probe is then transferred to the control-grid of the converter tube (point "4"); and the trimmer of tuning condenser C6 is adjusted for maximum closing of the indicating eye. Before removing the probe from this point, it is best to go back and re-adjust the trimmer of condenser C1 for a possible increase in indication.

The R.F.-I.F. Channel should then be tuned to the intermediate frequency of the receiver (as specified in the circuit diagram of the receiver). Removing the short-circuit across the oscillator tuning condenser C9, the probe is applied to the plate of the converter tube (point "5")and the trimmer of the oscillator condenser C9 is adjusted for maximum response.

Having aligned the high frequency end of the Broadcast band, we will now line up the low frequency end of this band. First, tune the Signal Generator to 600 kc. With the Channel still tuned to the i-f frequency of the receiver and the probe of this Channel applied to the plate of the converter tube, rotate the gang condenser of the receiver until the 600 kc signal of the Signal Generator is intercepted. If the oscillator circuit has a variable padding condenser (C10 in the diagram), adjust this condenser for maximum indication of the Channel eye. On the other hand, if the padding condenser is of the fixed type (that is, non-adjustable) or no padder condenser is employed, the slotted segments of the oscillator rotor plates are adjusted for maximum indication.

Before proceeding on to the succeeding alignment procedure, it is a good policy to re-check the 1700 kc adjustment once more.

Upon completion of the above operation, the probe is transferred to the plate of the 1st i-f amplifier tube (Point "9" in Fig. 23), and the i-f trimmer condensers C12, C13 and C15 are adjusted. If there is more than one i-f stage in the receiver, the probe is applied to each i-f tube and the i-f trimmers of each stage are adjusted.

To align the 2nd detector stage, the Audio Frequency Channel is employed. Applying the A-F Channel probe to the plate of the 2nd detector tube (Point "13" in Fig. 23), adjust both i-f trimmers of this stage (C15 and C16) for maximum closure of the eye.

SHORT-WAVE ALIGNMENT

Most receiver manufacturers provide a recommended short-wave alignment procedure for their particular type receivers---which is generally included with the circuit diagram and service notes corresponding to the receiver. However, in general, the alignment procedure is identical to that outlined for the broadcast band;with the exception that the variable condensers are first set to the highest frequency of each short-wave band (in that way, the rotor plates are completely out of mesh with the stator plates), and the high-frequency trimmer condensers for that particular band are adjusted for maximum indication. The variable condensers are next rotated to a low-frequency setting (at a frequency so that the rotor plates are approximately 7/8th in mesh with the stator plates) and the low-frequency padder for that particular band is adjusted for maximum response.

When using the Analyst or Chanalyst Signal Tracer, the Oscillator Channel is utilized for this process, since this is the only Channel that responds to frequencies higher than 1700 kc.

EXAMINATION QUESTIONS

LESSON NO. 58

1. When is it preferable to employ: a) an audible indicating device; b) a visual indicating device?

2. What are the essential parts of the simplest type r-f Signal Tracer employing an audible indicating device?

3. When the wattage-rating of a receiver is not specified by the manufacturer, how may this value be estimated?

4. Is it best to use a Signal Generator in conjunction with the multi-channel type of Signal Tracer; or, does one of the Channels serve this purpose?

5. Briefly, how is the overall cable-plus-input capacity of the tuned Channels in the multi-channel Signal Tracer reduced?

6. List the types of output indicators provided on the Multi-Channel Signal Tracer.

7. List the value of each resistor or condenser contained within each of the various Channel probes.

8. Is it always necessary to make metal-to-metal contact between the metal tip of the Oscillator Channel probe and the lead of a condenser or resistor in the oscillator circuit being tested?

9. If, when the receiver is plugged into the Power Consumption Channel, the indicating eye closes and cannot be opened---regardless of where the "Amperes" or "Wattage" control is adjusted, what does this indicate?

10. If you plan to apply the Channel probe to the plate of the 1st detector (converter) tube of a receiver, to what frequency would it be best to tune the Channel?

NO. 1

PRACTICAL RADIO JOB SHEET

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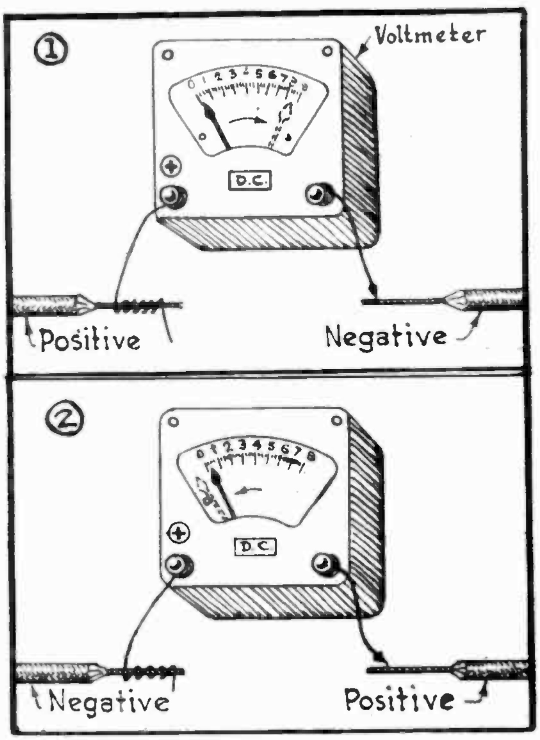
DETERMINING POLARITY OF D.C. CIRCUITS

When engaged in Radio work, the occassion frequently arises where it becomes necessary to determine which side of a D.C. (direct current) circuit is "positive" and which "negative". This can be determined through the use of either a D.C. voltmeter or by means of electrolysis in the manner now to be explained.

THE VOLTMETER METHOD

1. - Use a D.C. type voltmeter whose scale range is sufficiently great to indicate the voltage of the circuit under test.



Voltmeter Method.

2. - Connect one test lead to the positive or (+) terminal of the voltmeter and a second test lead to the other voltmeter terminal as shown in Fig. 1.

3. - Touch the two test points to the two sides of the circuit under test as also shown in Fig. 1 and note the movement of the meter needle as you do so. This connection should be completed for only an instant so as to avoid damaging the voltmeter in case that the needle swings off its scale towards the left of the zero mark.

4. - Should the voltmeter needle swing off its scale towards the left of zero as in Fig. 2, then the test indicates that the positive or (+) terminal of the voltmeter is connected to the NEGATIVE side of the circuit under test. On the other hand, if the meter needle swings across its scale towards the right or in its normal direction, as in Fig. 1, then the test indicates that the positive or (+) terminal of the voltmeter is connected to the positive side of the circuit under test. The other side of the circuit will then naturally be the negative side.

THE ELECTROLYSIS METHOD

If no D.C. voltmeter is available, then the unknown line polarity can be determined through the principle of electrolysis as illustrated in

(over)

FIG. 3. IN THIS CASE, PROCEED AS FOLLOWS:

1. - CONNECT A PAIR OF TEST LEADS ACROSS THE CIRCUIT UNDER TEST AND SUBMERGE THE FREE ENDS OF THE TEST LEADS IN A GLASS OF WATER TO WHICH A LITTLE TABLE SALT HAS BEEN ADDED. AN ALTERNATIVE IS TO SUBMERGE THE BARED COPPER ENDS OF THE CIRCUIT WIRES DIRECTLY INTO THE SALT WATER.

2. - USE CARE THAT THE TWO BARE ENDS OF THE WIRE OR TEST POINTS, WHICH ARE SUBMERGED IN THE SALT WATER, ARE NOT PLACED TOO CLOSE TOGETHER SO AS TO FORM A SHORT CIRCUIT AND WATCH FOR THE FORMATION OF BUBBLES. THE WIRE OR TEST LEAD, AROUND WHICH THE MOST BUBBLES ARE PRODUCED, CORRESPONDS TO THE NEGATIVE SIDE OF THE CIRCUIT.

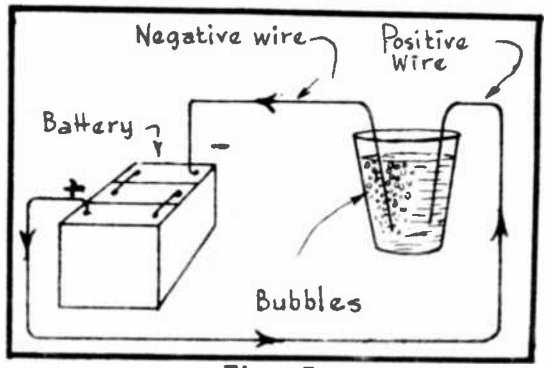


Fig. 3
Electrolysis Method.

3. - WHEN HANDLING WIRES ACROSS WHICH CONSIDERABLE VOLTAGE EXISTS, ALWAYS BE SURE NEVER TO GRASP THE BARE WIRES AT ANY TIME DURING ANY TEST WHILE THE CIRCUIT IS "ALIVE". ONLY GRASP THE INSULATIVE MATERIAL WHICH YOU ARE CERTAIN AS BEING ADEQUATE TO PREVENT YOUR RECEIVING AN ELECTRIC SHOCK.

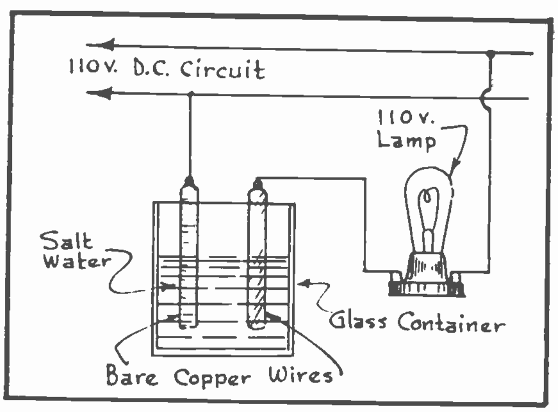


Fig. 4
Limiting The Current Flow.

4. - WHENEVER TESTING CIRCUITS, WHICH HANDLE VOLTAGE OF 110 VOLTS AND UP, A LAMP SHOULD BE CONNECTED IN SERIES WITH THE CIRCUIT BEING TESTED AND THE ELECTROLYTIC POLARITY INDICATOR AS SHOWN IN FIG.4. THE LAMP WILL THUS ACT AS A RESISTANCE AND THEREBY PREVENT SHORT CIRCUITS AND DISASTROUS ACCIDENTS. FOR A 110 VOLT CIRCUIT, A 110 VOLT LAMP SHOULD BE USED AND FOR A 220 VOLT CIRCUIT, A 220 VOLT LAMP. THE LAMP IN EITHER CASE MAY BE RATED AT ABOUT 40 WATTS.

5. - ALL PARTS OUTSIDE OF THE SALT WATER IN THE GLASS CONTAINER SHOULD BE MAINTAINED IN A PERFECTLY DRY CONDITION WHEN USING THIS TESTER, AS SHOULD ALSO THE HANDS OF THE OPERATOR SO AS TO REDUCE TO A MINIMUM THE POSSIBILITY OF RECEIVING AN ELECTRIC SHOCK.

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PRACTICAL RADIO JOB SHEET NO. 2

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DETERMINING A-C OR D-C TYPE OF CIRCUIT

In the majority of cases, it is possible to determine the type of current used by an electrical system simply by referring to the name-plate attached to electrical equipment that is already connected to the system.

The power company's meter at the service entrance of the circuit also carries a plate that specifies the voltage of the circuit, and whether it is of the D-C or A-C type. If such information is not available, the following three methods can be applied.

METHOD NO. 1 - USING WATER

1.- Connect an ordinary incandescent lamp (of the same voltage rating as the circuit) in series with a line plug and two wire leads from whose ends the insulation has been removed. (See Fig. 1.)

2.- Insert the plug in a receptacle that is connected to the circuit being tested and touch the bare ends of the wire leads together. The lamp should burn.

3.- Now, insert the bared ends of the leads into a glass of water, keeping them spaced apart as illustrated in Fig. 1. Observe whether bubbles form around both lead-ends or only around one.

4.- If an equal number of bubbles form around both lead-ends, the current is of the ALTERNATING type. This condition is pictured in Fig. 1.

5.- If numerous bubbles form around one lead and very few or none at all around the other, the test indicates that the circuit is handl-

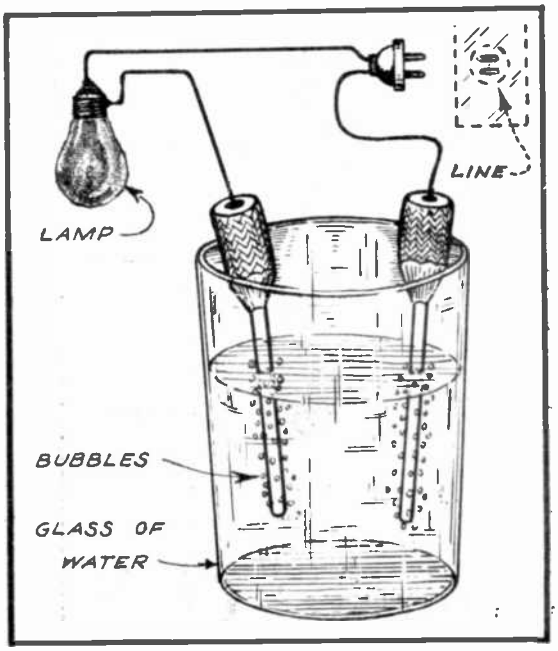

Fig. 1
Water Test for A-C

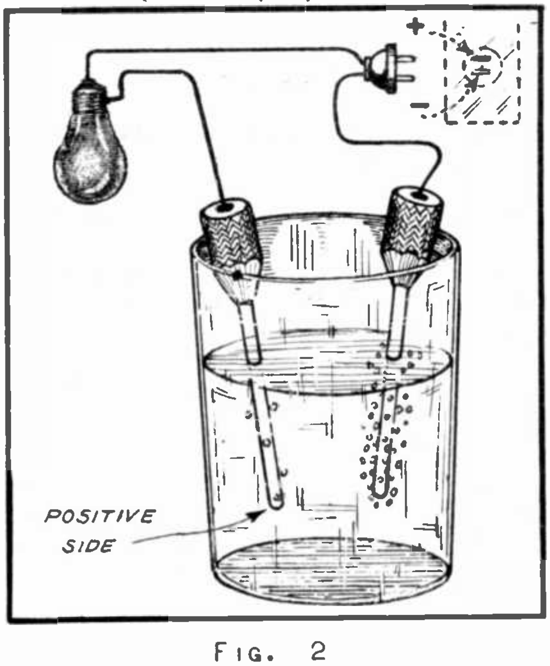

Fig. 2
Water Test for D-C

(OVER)

ING A DIRECT CURRENT. IN SUCH CASE, THE LEAD-END AT WHICH THE MOST BUBBLES OCCUR IS CONNECTED TO THE NEGATIVE SIDE OF THE CIRCUIT. (SEE FIG. 2.)

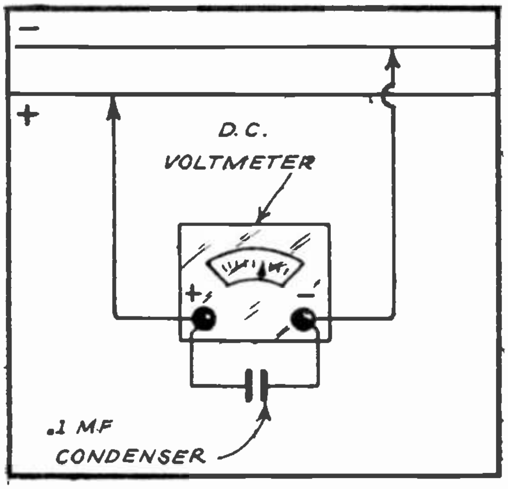

FIG. 3
VOLTMETER TEST

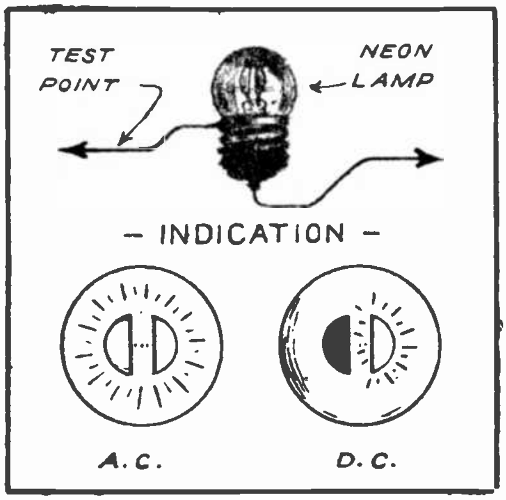

FIG. 4
NEON TUBE TEST

METHOD NO. 2 - USING A D-C VOLTMETER

1.- USE A D-C VOLTMETER WHOSE SCALE IS CAPABLE OF INDICATING VOLTAGES AS HIGH AS THAT HANDLED BY THE CIRCUIT BEING TESTED. FOR EXAMPLE, IF THE CIRCUIT OPERATES AT 110 VOLTS, THE RANGE OF THE METER SCALE SHOULD BE FROM "0" TO ABOUT "150".

2.- CONNECT A BYPASS CONDENSER OF APPROXIMATELY 0.1 MF. ACROSS THE TERMINALS OF THE METER, AND CONNECT A PAIR OF TEST LEADS TO THESE SAME TERMINALS. (SEE FIG. 3.) TOUCH THE FREE ENDS OF THE TEST LEADS ACROSS THE CIRCUIT BEING TESTED, MAKING CONNECTIONS AT A RECEPTACLE OR ANY OTHER CONVENIENT POINT IN THE CIRCUIT. OBSERVE THE MOVEMENT OF THE METER NEEDLE, AND REMOVE THE TEST POINTS FROM CONTACT WITH THE CIRCUIT AS SOON AS THIS OBSERVATION HAS BEEN MADE.

3.- IF THE METER NEEDLE VIBRATES OR DOESN'T MOVE AT ALL DURING THIS TEST, WE KNOW THAT THE CIRCUIT IS OF THE ALTERNATING CURRENT TYPE. IF THE METER NEEDLE MOVES TOWARD THE RIGHT OF ZERO, THE CIRCUIT IS OF THE DIRECT CURRENT TYPE, AND THE POSITIVE METER TERMINAL IS CONNECTED TO THE POSITIVE SIDE OF THE LINE. IF THE NEEDLE MOVES TOWARD THE LEFT OF ZERO, THE METER CONNECTIONS ARE REVERSED.

IMPORTANT: A PERMANENT MAGNET, MOVING COIL TYPE VOLTMETER, SHOULD BE USED IF THE ACTUAL VOLTAGE INDICATION IS TO BE ACCEPTED AS BEING CORRECT. THIS TYPE OF METER MOVEMENT IS EMPLOYED IN INSTRUMENTS OF THE MEDIUM AND HIGH-PRICED CLASS.

METHOD NO. 3 - USING A NEON LAMP

1.- SOLDER ONE END OF AN INSULATED WIRE LEAD TO THE CENTER, INSULATED CONTACT, AND ANOTHER WIRE LEAD TO THE METAL BASE-SHELL OF A 1/4-WATT NEON LAMP, AS SHOWN IN FIG. 4.

2.- CONNECT THE FREE ENDS OF THESE LEADS ACROSS THE CIRCUIT BEING TESTED.

3.- IF BOTH ELECTRODES OF THE NEON LAMP GLOW WITH AN ORANGE COLOR (SEE FIG. 4), THE CIRCUIT IS OF THE A-C TYPE.

4.- IF ONLY ONE OF THE LAMP'S ELECTRODES GLOW, THEN THE CIRCUIT IS OF THE D-C TYPE.

NO. 3

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DIMENSION, WEIGHT & RESISTANCE OF BARE SOLID COPPER WIRE

(Brown & Sharpe Gauge)

B&S WIRE SIZE	DIAM. IN MILS. AT 20°C.	CROSS-SECTIONAL AREA: CIRCULAR MILS.	CROSS-SECTIONAL AREA: SQUARE INCHES	WEIGHT LBS. PER 1000 FT.	FEET PER LB.	RESISTANCE OHMS PER 1000 FEET: AT 20°C. 68°F.	RESISTANCE OHMS PER 1000 FEET: AT 25°C. 77°F.	RESISTANCE OHMS PER 1000 FEET: AT 75°C. 167°F.
0000	460.0	211,600.	0.1662	640.5	1.561	0.04901	0.04998	.05961
000	409.6	167,800.	0.1318	507.9	1.968	0.06180	0.06302	0.07516
00	364.8	133,100.	0.1045	402.8	2.482	0.07793	0.07947	0.09478
0	324.9	105,500.	0.08289	319.5	3.130	0.09827	0.10020	0.11950
1	289.3	83,640.	0.06573	253.3	3.947	0.12390	0.12640	0.15070
2	257.6	66,370.	0.05213	200.9	4.977	0.15630	0.15930	0.19000
3	229.4	52,640.	0.04134	159.3	6.276	0.19700	0.20090	0.23560
4	204.3	41,740.	0.03278	126.4	7.914	0.24850	0.25330	0.30220
5	181.9	33,100.	0.02600	100.2	9.980	0.31330	0.31950	0.38100
6	162.0	26,250.	0.02062	79.46	12.58	0.39510	0.40280	0.48050
7	144.3	20,820.	0.01635	63.02	15.87	0.49820	0.50800	0.60590
8	128.5	16,510.	0.01297	49.98	20.01	0.62820	0.64050	0.76400
9	114.4	13,090.	0.01028	39.63	25.23	0.79210	0.80770	0.96330
10	101.9	10,380.	0.00815	31.43	31.82	0.99890	1.018	1.2150
11	90.74	8,234.	0.00646	24.92	40.12	1.260	1.284	1.5320
12	80.81	6,530.	0.00512	19.77	50.59	1.588	1.619	1.9310
13	71.96	5,178.	0.00406	15.68	63.80	2.003	2.042	2.4360
14	64.08	4,107.	0.00322	12.43	80.44	2.525	2.575	3.0710
15	57.07	3,205.	0.00255	9.858	101.4	3.184	3.247	3.8730
16	50.82	2,583.	0.00202	7.818	127.9	4.016	4.094	4.8840
17	45.26	2,048.	0.00160	6.200	161.3	5.064	5.163	6.1580
18	40.30	1,624.	0.00127	4.917	203.4	6.385	6.510	7.7650
19	35.89	1,288	0.00101	3.899	256.5	8.051	8.210	9.7920
20	31.96	1,022.	0.00080	3.092	323.4	10.15	10.35	12.350
21	28.46	810.10	0.00063	2.452	407.8	12.80	13.05	15.570
22	25.35	642.40	0.00050	1.945	514.2	16.14	16.46	19.630
23	22.57	509.50	0.00040	1.542	648.4	20.34	20.76	24.760
24	20.10	404.00	0.00031	1.223	817.4	25.67	26.17	31.220
25	17.90	320.40	0.00025	0.9699	1031.0	32.37	33.00	39.360
26	15.94	254.10	0.00019	0.7692	1300.0	40.81	41.62	49.640
27	14.20	201.50	0.00015	0.6100	1639.0	51.47	52.48	62.590
28	12.64	159.80	0.00012	0.4837	2067.0	64.90	66.17	78.930
29	11.26	126.70	0.00009	0.3836	2607.0	81.83	83.44	99.520
30	10.03	100.50	0.00007	0.3042	3287.0	103.2	105.2	125.50
31	8.928	79.70	0.00006	0.2413	4145.0	130.1	132.7	158.20
32	7.950	63.21	0.00004	0.1913	5227.0	164.1	167.3	199.50
33	7.080	50.13	0.000039	0.1517	6591.0	206.9	211.0	251.60
34	6.305	39.75	0.000031	0.1203	8310.0	260.9	266.0	317.30
35	5.615	31.52	0.000024	0.0954	10480.	329.0	335.5	400.10
36	5.000	25.00	0.000019	0.0756	13210.	414.8	423.0	504.50
37	4.453	19.83	0.000015	0.0600	16660.	523.1	533.4	636.20
38	3.965	15.72	0.000012	0.0475	21010.	659.6	672.6	802.20
39	3.531	12.47	0.000009	0.0377	26500.	831.8	848.1	1012.0
40	3.145	9.88	0.000007	0.0299	33410.	1049	1069	1276.0

NO. 4

PRACTICAL RADIO JOB SHEET

SPECIALLY PREPARED FOR THE STUDENTS OF

NATIONAL SCHOOLS

Los Angeles California

ALLOWABLE CARRYING CAPACITIES OF COPPER WIRE AND CABLE

B&S SIZE	CIRCULAR MIL AREA	CURRENT CARRYING CAPACITY IN AMPERES		
		RUBBER INSULATION	ENAMELED COTTON COVERED	OTHER INSULATION
18	1,624	3	5	5
16	2,583	6	10	10
14	4,107	15	18	20
12	6,530	20	25	25
10	10,380	25	30	30
8	16,510	35	40	50
6	26,250	50	60	70
5	33,100	55	65	80
4	41,740	70	85	90
3	52,630	80	95	100
2	66,370	90	110	125
1	83,690	100	120	150
0	105,500	125	150	200
00	133,100	150	180	225
000	167,800	175	210	275
	200,000	200	240	300
0000	211,600	225	270	325
	250,000	250	300	350
	300,000	275	330	400
	350,000	300	360	450
	400,000	325	390	500
	500,000	400	480	600
	600,000	450	540	680
	700,000	500	600	760
	800,000	550	660	840
	900,000	600	720	920
	1,000,000	650	780	1,000
	1,100,000	690	830	1,080
	1,200,000	730	880	1,150
	1,300,000	770	920	1,220
	1,400,000	810	970	1,290
	1,500,000	850	1,020	1,360
	1,600,000	890	1,070	1,430
	1,700,000	930	1,120	1,490
	1,800,000	970	1,160	1,550
	1,900,000	1,010	1,210	1,610
	2,000,000	1,050	1,260	1,670

PRACTICAL RADIO JOB SHEET

NO. 5

SPECIALLY PREPARED FOR THE STUDENTS OF

NATIONAL SCHOOLS

Los Angeles California

ALIGNING THE TUNING CIRCUITS OF T.R.F. RECEIVERS - USING BROADCAST SIGNALS

BY "ALIGNING" A RECEIVER IS MEANT THAT THE VARIOUS SECTIONS OF THE GANG TUNING CONDENSER ARE ALL ADJUSTED SO THAT THEY WILL TUNE TOGETHER OR BE IN SYNCHRONISM THROUGHOUT THE ENTIRE TUNING RANGE. THIS PARTICULAR JOB SHEET OFFERS INSTRUCTIONS FOR DOING THIS WORK ON RECEIVERS OF THE STRAIGHT "TUNED RADIO-FREQUENCY" OR T.R.F. TYPE ONLY. LATER JOB SHEETS SUPPLY THE INFORMATION FOR DOING THIS WORK ON SUPERHETERODYNES.

PROPER ALIGNMENT WILL MAKE POSSIBLE A LOUDER AND CLEARER SIGNAL, BETTER TONE QUALITY AND GREATER FREEDOM FROM INTER-STATION INTERFERENCE.

1. - TO ALIGN THE RECEIVER, FIRST TUNE THE SET TO RESONANCE WITH THE SIGNAL OF SOME FAIRLY DISTANT STATION WHICH IS BROADCASTING AT A MEDIUM FREQUENCY (AROUND 1000 KC) AND SET THE VOLUME CONTROL AT THE POSITION OFFERING MEDIUM SIGNAL INTENSITY.

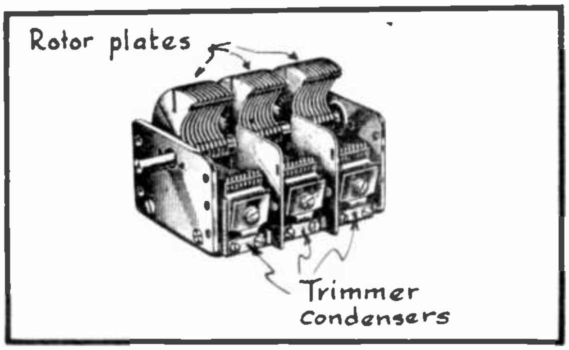

Fig. 1
Three-Gang Tuning Condenser.

2. - WITH THE TUNING DIAL SET TO THE POSITION OFFERING SHARPEST TUNING TO THIS FREQUENCY, ADJUST THE COMPENSATING OR TRIMMER CONDENSER OF THE DETECTOR STAGE UNTIL LOUDEST SIGNAL VOLUME IS EMITTED BY THE SPEAKER. THESE TRIMMERS SHOULD BE ADJUSTED WITH EITHER A BAKELITE SCREW-DRIVER OR BAKELITE WRENCH, WHICHEVER IS SUITABLE FOR THE PARTICULAR DESIGN. DO NOT ALTER THE POSITION OF EITHER THE TUNING OR VOLUME CONTROL WHILE MAKING THE ALIGNING ADJUSTMENTS.

3. - THE TRIMMERS OF THE FOLLOWING STAGES ARE THEN EACH ADJUSTED IN TURN AND SET FOR THE LOUDEST SPEAKER SIGNAL IN THE SAME MANNER AS JUST DESCRIBED.

4. - AFTER THIS AVERAGE SETTING HAS BEEN MADE FOR ALL SECTIONS OF THE TUNING CONDENSER, TUNE-IN ANOTHER SIGNAL AT THE HIGH FREQUENCY END OF THE DIAL OR AT ABOUT THE 1400 KC. POSITION. IF SLOTTED ROTOR PLATES ARE EMPLOYED ON THE CONDENSER, THEN BEND THE LAST SEGMENT OF THE TRAILING END OF EACH CONDENSER SECTION SLIGHTLY ONE WAY OR THE OTHER UNTIL EACH SECTION IS ADJUSTED FOR MAXIMUM VOLUME.

THIS PLATE SEGMENT WOULD CORRESPOND TO SEGMENT #1 AS POINTED OUT IN FIG.2 AND WHICH WILL BE FOUND ON THE OUTER ROTOR PLATES IN EACH SECTION OF MODERN GANG CONDENSERS.

(OVER)

5. - Tune in signals at 1100 - 850 - 700 - 600 and 550 Kc. each in turn and at each setting, bend for loudest signal the last slotted segment of each rotor plate group which came into mesh with the statorplates as the position of the rotor plates was changed.

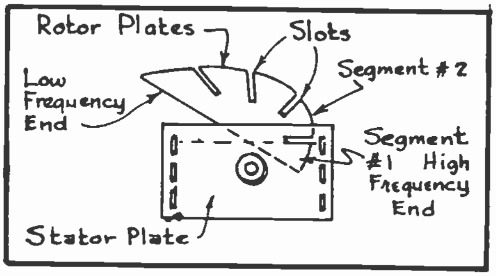

Fig. 2
Provisions For Bending Plates.

In other words, as the dialsettings are gradually changed from the higher to the lower frequencies, rotor plate segments #2 as per Fig. 2 will be adjusted at each section as they follow segments #1 intomesh with the stator plate groups etc., until the final segments at the other extreme position have been adjusted for the lowest frequency settings.

6. - Upon completion of this job, the receiver will be properly aligned throughout its range of tuning and as a final check, stations at various frequencies can be tuned in and the performance of the receiver carefully noted. Any additional adjustment which may be found necessary can then be made.

ALIGNING RECEIVER WITH SERVICE OSCILLATOR

Instead of using a broadcast signal for aligning purposes, the use of a modulated R.F. service oscillator, or signal generator, offers a more accurate method for making the aligning adjustments. This is done in the following order:

1. Disconnect the antenna and ground wires from the receiver.

2. Connect the "Antenna" terminal of the service osicllator to the antenna terminal of the receiver and the "Ground" terminal of the service oscillator to the ground terminal of the receiver, as shown in Fig. 3.

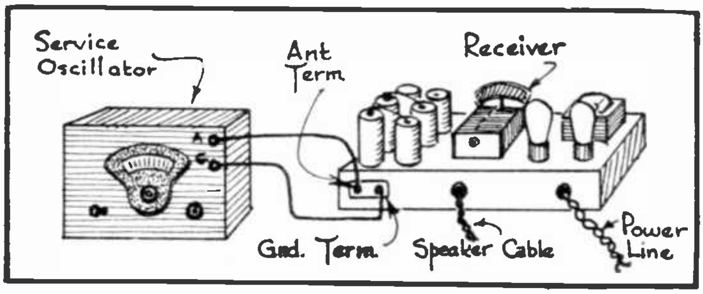

Fig. 3
Set-Up For Aligning Receiver With Service Oscillator.

3. Place the oscillator and receiver in operation, adjust the oscillator to produce a 1000 Kc. signal and tune in this signal on the receiver and adjust the volume control for medium oscillator signal through the loud speaker.

4. Adjust the receiver's tuned circuits for maximum signal in the same order as already described when using a broadcast signal for this purpose.

5. Tune the service oscillator and receiver in turn to 1400-1100-850 - 700 - 600 and 550 Kc. and adjust the tuned circuits for maximum signals in the same manner as already explained when using a broadcastsignal for this purpose.

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PRACTICAL RADIO JOB SHEET

NO. 6

SPECIALLY PREPARED FOR THE STUDENTS OF

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NEUTRALIZING THE R.F. STAGES OF RADIO RECEIVERS

BY NEUTRALIZATION IS MEANT THE PROCESS OF COUNTERACTING THE REGENERATIVE FEED BACK, WHICH FLOWS FROM THE PLATE TO GRID CIRCUITS IN R.F. STAGES, IN WHICH TUBES OF THE NON-SCREEN GRID TYPE ARE USED.

IF AN ADJUSTMENT OF THIS NATURE IS NECESSARY, IT WILL MAKE ITSELF KNOWN BY THE FACT THAT THE RECEIVER, WHEN IN OPERATION, WILL OSCILLATE AND THEREBY CAUSE SQUEALING SOUNDS TO BE EMITTED FROM THE SPEAKER.

1. - TO MAKE A NEUTRALIZING ADJUSTMENT, YOU CAN EITHER USE THE SIGNAL ENERGY SUPPLIED BY A BROADCASTING STATION OR ELSE THE OUTPUT OF A MODULATED OSCILLATOR. THE LATTER IS PREFERABLE.

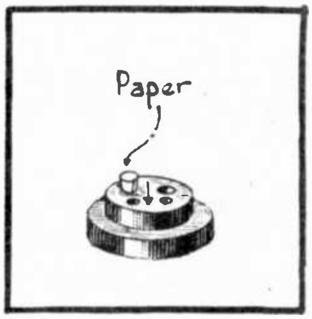

Fig. 1
Insulating The Filament Prong.

2. - TUNE THE RECEIVER TO A SIGNAL FREQUENCY OF ABOUT 1400 KC. AND SET THE VOLUME CONTROL AT ITS LOUDEST POSITION.

3. - REMOVE THE R.F. TUBE PRECEDING THE DETECTOR AND INSERT A PIECE OF PAPER INTO ONE OF THE FILAMENT HOLES OF THIS TUBE'S SOCKET, AS SHOWN IN FIG. 1, SO THAT ONE FILAMENT PRONG OF THE TUBE WILL BE INSULATED FROM THE SOCKET CONTACT WHEN THE BULB IS AGAIN INSERTED, THUS PREVENTING THE FILAMENT FROM BURNING.

4. - INSERT THE TUBE IN ITS SOCKET, LEAVING THE PAPER SLEEVE UNDISTURBED AND NOTE THAT ITS FILAMENT DOESN'T BURN. BE SURE THAT YOU DO NOT DISTURB THE SETTING OF NEITHER THE VOLUME OR TUNING CONTROL DURING THIS WORK AND ONLY USE THE SWITCH AS A MEANS OF STARTING OR STOPPING THE RECEIVER'S OPERATION, OR ELSE CONNECT AND DISCONNECT THE RECEIVER FROM THE LINE IN ORDER TO START AND STOP IT.

5. - WITH THIS "DEAD" TUBE INSERTED IN ITS SOCKET, NO SOUND SHOULD COME FROM THE SPEAKER. IF A SOUND IS HEARD, THEN ADJUST THE NEUTRALIZING CONDENSER FOR THIS STAGE BY MEANS OF A BAKELITE SCREW DRIVER. WITH A PROPER ADJUSTMENT OBTAINED, NO SIGNAL SHOULD BE HEARD AT THE SPEAKER. HAVING NEUTRALIZED THIS R.F. STAGE, OPEN THE SWITCH, REMOVE THE TUBE AND PAPER AND RE-INSERT THE TUBE IN ITS SOCKET.

6. - NOW PERFORM THE SAME ADJUSTING PROCESS WITH THE R.F. TUBE PRECEDING THE LAST R.F. TUBE, AND GRADUALLY CARRY OUT THIS WORK UNTIL YOU HAVE FINALLY ADJUSTED THE FIRST R.F. STAGE IN LIKE MANNER. EACH R.F. STAGE IS THUS NEUTRALIZED IN CONSECUTIVE ORDER FROM THE ONE PRECEDING THE DETECTOR TOWARDS THE ANTENNA.

7. - REMEMBER, THAT THE VOLUME AND TUNING CONTROL SETTINGS SHOULD NOT UNDER ANY CONDITIONS BE DISTURBED FROM THEIR ORIGINAL SETTING UNTIL

(OVER)

THE ENTIRE RECEIVER IS NEUTRALIZED.

8. – WHEN NEUTRALIZING THE R.F. STAGES OF A RECEIVER IN WHICH THE FILAMENTS OF THE VARIOUS R.F. TUBES ARE CONNECTED IN SERIES INSTEAD OF PARALLEL, THEN THE FILAMENT OF THE TUBE BEING NEUTRALIZED CAN BEPREVENTED FROM BURNING BY SHORTING ITS FILAMENT PRONGS CLOSE TO THE TUBE BASE BY MEANS OF A FAIRLY THIN PIECE OF WIRE AS SHOWN IN FIG.2. THIS WILL STILL PERMIT THE TUBE TO BE INSERTED INTO ITS SOCKET, AT THE SAME TIME PUTTING THE FILAMENT OUT OF COMMISSION.

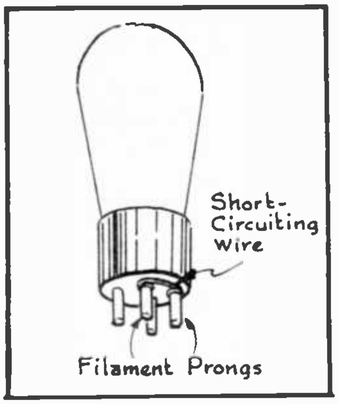

Fig. 2
Short Circuiting
The Filament Prongs.

THE OSCILLATOR METHOD

TO MAKE THESE NEUTRALIZING ADJUSTMENTS, IT IS ALSO POSSIBLE TO USE A MODULATED R.F. SERVICE OSCILLATOR AS THE SOURCE FOR THE SIGNAL AND THIS IS ACCOMPLISHED IN THE FOLLOWING MANNER:

1.– DISCONNECT THE ANTENNA AND GROUND WIRES FROM THE RECEIVER.

2.– CONNECT THE "ANTENNA" TERMINAL OF THE SERVICE OSCILLATOR TO THE ANTENNA TERMINAL OF THE RECEIVER AND THE "GROUND" TERMINAL OF THE SERVICE OSCILLATOR TO THE GROUND TERMINAL OF THE RECEIVER, AS SHOWN IN FIG.3.

3. PLACE THE OSCILLATOR AND RECEIVER IN OPERATION, ADJUST THE OSCILLATOR TO PRODUCE A 1400 KC. SIGNAL AND TUNE IN THIS SIGNAL WITH THE RECEIVER AT HIGH VOLUME.

4.–FROM THIS STEP ON, THE SAME PROCEDURE IS FOLLOWED AS OUTLINED IN PARAGRAPHS #3 TO #8 IN THIS SAME JOB SHEET, WHERE THE BROADCAST SIGNAL IS USED FOR THIS PURPOSE.

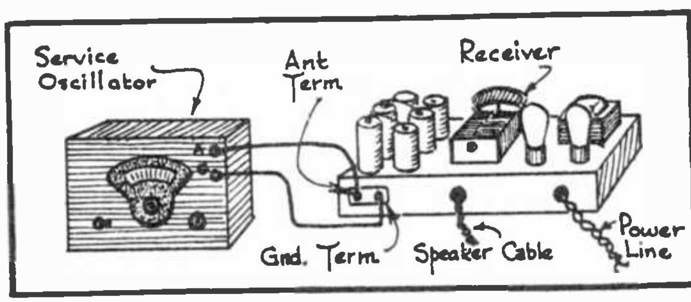

Fig. 3
Set-Up For Aligning Receiver With
Service Oscillator

5.–THE ADVANTAGE OF USING A MODULATED R.F. SERVICE OSCILLATOR FOR SUPPLYING THE SIGNAL FOR TESTING PURPOSES IN PREFERENCE TO BROADCAST SIGNALS IS THAT THE SIGNAL WHICH IS PRODUCED BY THE OSCILLATOR WILL BE STEADY AND OF UNVARYING INTENSITY AS IT IS REPRODUCED BY THE RECEIVER'S LOUD SPEAKER. THE BROADCAST SIGNALS WILL VARY ACCORDING TO THE LOUDNESS AND SOFTNESS OF THE SOUNDS WHICH ARE PICKED UP AT THE MICROPHONE AND THESE SOUND INTENSITIES WILL VARY CORRESPONDINGLY WHEN EMITTED FROM THE LOUDSPEAKER OF THE RECEIVER. THIS NATURAL VARIATION IN THE LOUDNESS OF SOUND MAKES IT SOMEWHAT MORE DIFFICULT TO ASCERTAIN WHETHER THE SOUND AT ANY INSTANT IS BEING AFFECTED BY THE RECEIVER ADJUSTMENT WHICH IS BEING MADE OR DUE TO THE PICK UP OF THE STUDIO MICROPHONE AT THE SAME INSTANT.

PRINTED IN U.S.A.

PRACTICAL RADIO JOB SHEET

NO. 7

SPECIALLY PREPARED FOR THE STUDENTS OF

NATIONAL SCHOOLS

Los Angeles California

COMMON TROUBLES IN BATTERY OPERATED RECEIVERS

TROUBLE	POSSIBLE CAUSE	TESTS
No tubes light.	1. "A" battery run down. 2. Bad connections or open "A" circuit.	1. Test with voltmeter or hydrometer. 2. Inspect wiring and apply continuity tests.
One or more tubes (but not all) fail to light.	1. Defective tubes. 2. Open or short in filament circuit.	1. Try other tubes. 2. Apply continuity tests.
Tubes light but signals are not received.	1. Wrong battery connection. 2. "B" voltage low. 3. Defect in antenna or ground circuit connections. 4. Defective or worn out tube or tubes. 5. Defective speaker or speaker leads. 6. Defective plate or grid circuit.	1. Inspect. 2. Test with voltmeter 3. Inspect. 4. Try other tubes. 5. Try another speaker or headphones. 6. Test socket voltages and apply continuity tests.
Low volume.	1. Run-down battery or batteries or else excessive "C" voltage. 2. Aerial shorter than recommended; defects in aerial or ground system; poor location. 3. Defective tube or tubes. 4. Defective speaker. 5. Receiver out of alignment. 6. Defective audio or radio frequency transformer. 7. Defective connections, bad soldering etc.	1. Test battery voltage with receiver in operation. 2. Inspect aerial and ground system for shorts, opens, bad connections, dirty insulators etc. 3. Try other tubes. 4. Try another speaker. 5. Check alignment. 6. Apply continuity tests. 7. Inspect
Intermittent Reception	1. Loose or broken connection in aerial or ground circuit. 2. Loose or broken connection in receiver.	1. Examine for breaks and poor connections. 2. Check socket voltages and apply continuity tests, jarring receiver while making tests.

(OVER)

(CONTINUED)

INTERMITTENT RECEPTION	3. DEFECTIVE SPEAKER OR SPEAKER CONNECTIONS. 4. DEFECTIVE RESISTOR OR CONDENSER	3. TRY DIFFERENT SPEAKER. 4. CHECK RESISTORS AND CONDENSERS.
UNSATISFACTORY QUALITY.	1. RUN DOWN BATTERIES. 2. DEFECTIVE TUBE OR TUBES. 3. IMPROPER "C" BIAS 4. DEFECTIVE SPEAKER. 5. DEFECTS IN CIRCUIT, GRID LEAK ETC.	1. TEST ALL BATTERIES. 2. TRY OTHER TUBES. 3. TEST "C" BATTERY AND INSPECT CONNECTIONS. 4. TRY ANOTHER SPEAKER. 5. CHECK BY CONTINUITY TESTS, SOCKET VOLTAGES TESTS, AND INSPECTION OF WIRING.
OSCILLATIONS IN NEUTRODYNE RECEIVERS.	1. POOR R.F. TUBES. 2. AERIAL LENGTH DIFFERENT FROM THAT RECOMMENDED FOR RECEIVER OR ELSE A DEFECTIVE GROUND. 3. RECEIVER REQUIRES NEUTRALIZING ADJUSTMENT.	1. TRY CHANGING R.F. TUBES AROUND OR TRY DIFFERENT TUBES IN R.F. SOCKETS. 2. INSPECT 3. CHECK NEUTRALIZATION
OSCILLATIONS IN SCREEN GRID RECEIVERS.	1. AERIAL TOO SHORT OR ELSE AN OPEN IN AERIAL - GROUND CIRCUIT. 2. DEFECTIVE R.F. TUBES OR TUBES WITH TOO HIGH "MU". 3. HIGH RESISTANCE GROUNDS TO CHASSIS. 4. COUPLING BETWEEN SPEAKER LEADS AND ANTENNA OR GROUND WIRES. 5. OPEN OR DISCONNECTED SCREEN-GRID BYPASS CONDENSER.	1. INSPECT AND TRY RECEIVER ON A LONGER AERIAL. 2. TRY OTHER TUBES IN R.F. SOCKETS. 3. TIGHTEN UP ALL CONNECTIONS TO CHASSIS. EXAMINE VARIABLE CONDENSER ROTOR CONNECTION. 4. SEE THAT LEADS ARE AS FAR APART AS POSSIBLE. 5. INSPECT AND CHECK THESE CONDENSERS.
OTHER OSCILLATIONS, SQUEALS, A.C. HUM WITH ELIMINATOR-EQUIPPED RECEIVERS ETC.	1. RUN DOWN "C" BATTERY. 2. MICROPHONIC TUBE. 3. DEFECTIVE GROUND OR AERIAL SYSTEM. 4. DEFECTS IN CIRCUIT, ESPECIALLY IN A.F. TRANSFORMERS. 5. ELIMINATOR OR OTHER A.C. LEADS TOO CLOSE TO RECEIVER. 6. AERIAL TOO CLOSE TO POWER LINES	1. CHECK VOLTAGE WITH RECEIVER IN OPERATION. 2. PREVENT RECEIVER VIBRATIONS OR USE NEW TUBE. 3. INSPECT 4. INSPECT AND APPLY CONTINUITY TESTS. 5. INSPECT. 6. NOTE WHETHER OR NOT DISCONNECTING AERIAL STOPS A.C. HUM.

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PRACTICAL RADIO JOB SHEET

NO. 8

SPECIALLY PREPARED FOR THE STUDENTS OF

NATIONAL SCHOOLS

Los Angeles California

COMMON TROUBLES IN A.C. RECEIVERS

TROUBLE	POSSIBLE CAUSE	TESTS
No tubes light.	1. Power off at socket 2. Fuse blown 3. Open in supply cord or primary circuit of power transformer.	1. Plug in lamp at socket or use voltmeter across line. 2. Try new fuse, noting whether or not tubes light. 3. Test for continuity.
One or more (but not all) fail to light.	1. Burned out tube or tubes. 2. Open in power transformer secondary which supplies filaments. 3. Short or open filament circuit	1. Try other tubes 2. Use voltage test at sockets. 3. Test for continuity.
Tubes light but signals are not received.	1. Antenna, ground or both disconnected, open or shorted. 2. Output to speaker not connected or open in output - speaker circuit. 3. Defect in plate circuit of other tubes, such as open resistor etc. 4. Defects, such as open resistors in grid circuits etc. 5. Defective speaker.	1. Inspect aerial and ground system. 2. Inspect connections and check output plate voltages. 3. Check socket plate voltages. 4. Check voltages of operating grids and screen grids. 5. Try a different speaker.
Unsatisfactory volume.	1. Aerial too short; defects in aerial, ground or both; poor location. 2. Low line voltage. 3. Defective tube or tubes. 4. Improper socket voltages due to defective circuits such as defective resistances etc. 5. Defective speaker. 6. Tuned circuits not aligned. 7. Defective audio or R.F. transformer 8. Defective connections, bad soldering etc.	1. Inspect aerial and ground systems for size, shorts, poor insulation, poor connections etc. If necessary, test same with another receiver. 2. Check line voltage with A.C. meter. 3. Try new tubes. 4. Test to see if "Voltage Limits" are complied with. 5. Try a new one. 6. Check for alignment. 7. Inspect connections and apply continuity tests. 8. Inspect all connections and soldered joints.

(OVER)

(CONTINUED)

INTERMITTENT RECEPTION.	1. LOOSE OR BROKEN CONNECTION IN AERIAL OR GROUND CIRCUIT. 2. LOOSE OR BROKEN CONNECTION IN RECEIVER. 3. DEFECTIVE SPEAKER OR SPEAKER CONNECTIONS. 4. DEFECTIVE TUBE 5. DEFECTIVE RESISTOR OR CONDENSER.	1. EXAMINE THROUGHOUT FOR BREAKS AND POOR CONNECTIONS. 2. CHECK SOCKET VOLTAGES AND APPLY CONTINUITY TESTS JARRING RECEIVER WHILE MAKING TESTS. 3. TRY A DIFFERENT SPEAKER. 4. CHECK TUBES. 5. CHECK SAME.
UNSATISFACTORY QUALITY.	1. DEFECTIVE OR WORN OUT TUBES. 2. WRONG SOCKET VOLTAGES(ESPECIALLY BIAS)DUE TO DEFECTS IN CIRCUIT,DEFECTIVE RESISTORS ETC. 3. DEFECTIVE SPEAKER. 4. TUNING CIRCUITS IMPROPERLY ALIGNED.	1. TRY OTHER TUBES. 2. TEST TO SEE THAT SOCKET VOLTAGES COMPLY WITH "VOLTAGE LIMITATIONS". 3. TRY ANOTHER SPEAKER. 4. CHECK ALIGNMENT.
A.C. HUM.	1. DEFECTIVE TUBE(ESPECIALLY RECTIFIER) OR DETECTOR. 2. POOR GROUND. 3. SHORTED FILTER CHOKE OR OPEN CONDENSER 4. INDUCTIVE PICK-UP OF AERIAL SYSTEM, GROUND WIRE, LEAD-IN ETC. FROM POWER LINE OR A.C. LEADS. 5. OTHER DEFECTS IN CIRCUIT.	1. TRY OTHER TUBES. 2. INSPECT. 3. CHECK SOCKET VOLTAGES AND APPLY CONTINUITY TESTS. 4. INSPECT. SEE IF DISCONNECTED AERIAL OR GROUND STOPS HUM. 5. CHECK SOCKET VOLTAGES AND APPLY CONTINUITY TESTS THROUGHOUT.
MICROPHONISM.	1. JARRING OR VIBRATION OF RECEIVER. 2. DEFECTIVE DETECTOR TUBE.	1. INSPECT FOR CAUSE OF VIBRATION (OFTEN DUE TO SPEAKER VIBRATIONS TRANSFERRED TO SET). 2. TRY ANOTHER DETECTOR TUBE.
OSCILLATION IN NEUTRODYNE RECEIVER.	1. R.F. TUBES 2. IMPROPER AERIAL LENGTH. 3. RECEIVER NOT PROPER NEUTRALIZED.	1. CHANGE TUBES AROUND OR TRY DIFFERENT TUBES IN R.F. SOCKETS. 2. INSPECT. 3. CHECK FOR NEUTRALIZATION.
OSCILLATIONS IN SCREEN-GRID RECEIVER.	1. AERIAL TOO SHORT, OR OPEN IN AERIAL - GROUND CIRCUIT. 2. DEFECTIVE R.F. TUBES OR TUBES WITH TOO HIGH "MU" 3. HIGH-RESISTANCE GROUNDS TO CHASSIS. 4. TOO HIGH LINE VOLTAGE. 5. OPEN OR DISCONNECTED SCREEN GRID BY-PASS CONDENSER.	1. INSPECT AERIAL AND GROUND SYSTEM THROUGHOUT. IF NECESSARY TEST RECEIVER ON LONGER AERIAL. 2. TRY OTHER TUBES IN R.F. SOCKETS. 3. TRY TIGHTENING UP ALL CONNECTIONS. 4. TEST LINE VOLTAGE WITH A.C. METER. 5. INSPECT AND CHECK.

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PRACTICAL RADIO JOB SHEET

NO. 9

SPECIALLY PREPARED FOR THE STUDENTS OF

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Los Angeles California

COMMON POWER PACK TROUBLES

TROUBLE	POSSIBLE CAUSE	TESTS
No D.C. Voltage Available at output of Power Pack.	1. Defective Power transformer.	1. Check suspicious winding for voltage with volt meter and also for continuity.
	2. If tube filaments also fail to burn, look for defective primary winding in power transformer or defective A.C. input line.	2. Check for continuity.
	3. Rectifier tube burned out.	3. Inspect and insert new rectifier tube.
	4. Filter condenser broken down.	4. Rectifier tube's plates will become red hot. Check filter condenser for short.
	5. Open or grounded choke coil.	5. Test for continuity and ground.
Low D.C. Output Voltages.	1. Low A.C. line voltage.	1. Check line voltage with A.C. voltmeter.
	2. Excessive load on D.C. circuit.	2. Check current drain with milliammeter.
	3. Worn out rectifier tube.	3. Try a new rectifier tube.
	4. Excessive D.C. resistance in filter system.	4. Check connections and also measure volt drop across each filter choke.
	5. Shorted divider resistor.	5. Check divider resistors.
Lack of D.C. voltage across a portion of divider only.	1. Shorted by-pass condenser in voltage divider.	1. Test voltage divider by-pass condensers.
	2. An open voltage divider resistor.	2. Check divider resistors for continuity.
A.C. hum, for which power pack may be responsible.	1. Low line voltage.	1. Check voltage with A.C. voltmeter.
	2. Defective rectifier tube.	2. Replace with a new tube.
	3. Shorted filter choke.	3. Test choke for continuity and note meter reading.
	4. An open or poor filter condenser.	4. Check condenser and try a replacement
	5. Open in a voltage divider by-pass condenser or lack of such a condenser.	5. Inspect and check such condensers for continuity
	6. Loose transformer laminations.	6. Listen for rattle.

PRACTICAL RADIO JOB SHEET

NO. 10

SPECIALLY PREPARED FOR THE STUDENTS OF

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Los Angeles California

COMMON TROUBLES IN DIRECT CURRENT RECEIVERS
(110 or 220 Volts)

TROUBLE	POSSIBLE CAUSE	TESTS
No tubes light.	1. One or more tubes "burned out."	1. In some D.C. receivers, all of the tube filaments are connected in series and if one burns out, all will fail to light. In other D.C. receivers, certain groups of tubes are connected in series while others are connected in parallel, so the effect of one open filament will be accordingly.
	2. Power off at socket.	2. Plug in lamp at socket or test with voltmeter across lines.
	3. Fuse or fuses blown.	3. Try new fuse or fuses (some D.C. receivers have 2 fuses, one on chassis and one on supply cord).
	4. Open in supply cord or filament circuit.	4. Test for continuity.
One or more tubes (but not all) fail to light.	1. Burned out tube	1. Possible only in cases where filaments of some tubes are paralleled.
	2. Defect in filament circuit.	2. Note (1) above also applies in this case. Apply continuity tests.
Tubes light but signals are not received.	1. Polarity may be reversed. Other possible causes are the same as those given relative to A.C. receivers in the preceding "Job Sheet".	1. Check polarity of line.
Unsatisfactory Volume.	1. Wrong line voltage. Other possible causes are the same as those given relative to A.C. receivers in a preceding "Job Sheet".	1. Test line voltage with a D.C. voltmeter.
1. Intermittent reception. 2. Unsatisfactory Quality. 3. Microphonism.	4. Oscillation in Neutrodyne Receivers. 5. Oscillation in Screen grid receivers.	The possible causes for these troubles are the same as those outlined with respect to these same troubles for A.C. receivers in a preceding "Job Sheet".

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PRACTICAL RADIO JOB SHEET NO. 11

SPECIALLY PREPARED FOR THE STUDENTS OF

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TROUBLES AND TESTING OF MAGNETIC SPEAKERS

DEFINITION:– SPEAKERS, WHOSE FIELD IS ESTABLISHED BY A PERMANENT MAGNET OR MAGNETS AND WHICH ARE NOT EQUIPPED WITH A MOVING COIL, ARE CLASSIFIED AS "MAGNETIC SPEAKERS." THE BALANCED ARMATURE TYPE SPEAKER, FOR EXAMPLE, WOULD BE INCLUDED IN THIS GROUP. THE TERM "HIGH IMPEDANCE" IS ALSO FREQUENTLY ASSOCIATED WITH THIS CLASS OF SPEAKERS.

CAUTION:– ALL FAULTS INDICATED BY AN IMPROPERLY OPERATING SPEAKER DO NOT INDICATE THAT THE SPEAKER ITSELF IS DEFECTIVE. THE FOLLOWING TABLE ASSUMES THE TROUBLE TO BE WITHIN THE MAGNETIC SPEAKER AND NOT IN THE RECEIVER.

TROUBLE	POSSIBLE CAUSE	TESTS
NO SOUNDS FROM SPEAKER.	1. DEFECTIVE SPEAKER. 2. DEFECTIVE RECEIVER. 3. OPEN OR SHORTED SPEAKER LEADS. 4. OPEN SPEAKER COIL. 5. DEFECTIVE SPEAKER COUPLING.	1&2. CHECK OUTPUT OF RECEIVER WITH A DIFFERENT SPEAKER OR HEADPHONES. 3. TEST LEADS FOR CONTINUITY. 4. TEST COIL FOR CONTINUITY. 5. INSPECT AND TEST COUPLING FOR CONTINUITY.
LACK OF VOLUME.	1. A WEAK SPEAKER MAGNET. 2. AN OPEN SPEAKER COIL. 3. A SHORTED SPEAKER COIL. 4. POOR INSULATION IN CONNECTING CORD.	1. TEST WITH A KNIFE BLADE FOR MAGNETIC ATTRACTION AT POLES. 2. TEST FOR CONTINUITY. 3. TEST FOR CONTINUITY. 4. INSPECT CORD.
WEAK, TINNY SOUNDS.	DAMAGED OR CRUSHED CONE PAPER (ESPECIALLY NEAR APEX).	INSPECT AND REPLACE PAPER CONE WITH A NEW ONE.
LOUD CHATTERING SOUNDS.	ARMATURE STRIKING POLE TIPS.	INSPECT AND ADJUST BY CENTERING ARMATURE IN AIR GAP.
RASPY SOUNDS.	DIRT, IRON FILINGS, OR OTHER SMALL FOREIGN SUBSTANCE LODGED IN NARROW MAGNETIC GAPS.	INSPECT AND REMOVE DIRT BY FORCING A STIFF PIECE OF PAPER BETWEEN ARMATURE AND POLE TIPS.
RATTLING SOUNDS.	LOOSENESS IN SOME PART OF THE DRIVE SYSTEM; PROBABLY A LOOSE DRIVE PIN OR LOOSE CONE ATTACHMENT.	INSPECT

PRACTICAL RADIO JOB SHEET

NO. 12

SPECIALLY PREPARED FOR THE STUDENTS OF

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• TROUBLES & TESTING OF ELECTRODYNAMIC SPEAKERS •

TROUBLE	POSSIBLE CAUSE	TESTS
"DEAD" SPEAKER.	1. NO SIGNAL OUTPUT FROM RECEIVER. 2. LACK OF EXITING VOLTAGE FOR FIELD COIL. 3. OPEN FIELD COIL. 4. SHORTED FIELD COIL. 5. OPEN VOICE COIL. 6. DISCONNECTED VOICE COIL. 7. DEFECTIVE SPEAKER COUPLING.	1&2. CHECK OUTPUT WITH ANOTHER SPEAKER OR PHONES. 2. CHECK VOLTAGE ACROSS FIELD COIL WITH D.C. VOLTMETER. 3. TEST FIELD COIL FOR CONTINUITY. 4. CHECK WITH CONTINUITY TESTER. 5. TEST FOR CONTINUITY 6. INSPECT. 7. CHECK COUPLING.
WEAK, RASPY REPRODUCTION	WEAK MAGNETIZATION OF SPEAKER FIELD (PROBABLY DUE TO LOW EXITING VOLTAGE).	HOLD THE POINT OF A KNIFE BLADE AGAINST THE CENTRAL PORTION OF THE SPEAKER CORE PROJECTING IN APEX OF CONE AND TEST FOR MAGNETIC ATTRACTION WHILE SPEAKER IS IN OPERATION.
DISTORTED OUTPUT.	1. INCORRECTLY CENTERED VOICE COIL. 2. INCORRECT COUPLING UNIT SO THAT IMPEDANCES ARE NOT MATCHED. 3. IMPERFECTLY CENTERED CONE. 4. DAMAGED CONE. 5. EXCESSIVE HUM.	1. INSPECT. 2. CHECK AND TPY A DIFFERENT COUPLING 3. INSPECT. 4. INSPECT. 5. CHECK SPEAKER FOR HUM.
EXCESSIVE SPEAKER HUM.	1. WORN OUT RECTIFIER UNIT. IF SPEAKER IS OF THE A.C. TYPE. 2. POOR OPERATION OF "B" POWER PACK IF SPEAKER IS OF D.C. TYPE. 3. DEFECTIVE HUM BUCKING COIL. 4. SPEAKER LEADS INDUCTIVELY COUPLED TO A.C. LINES.	1. REPLACE RECTIFIER UNIT (SPEAKER CAN BE TESTED FOR HUM BY SHORTING THE PRIMARY TERMINALS OF THE COUPLING TRANSFORMER. ANY REMAINING HUM DOES NOT COME FROM RECEIVER BUT FROM SPEAKER CIRCUIT). 2. INSPECT. 3. INSPECT. 4. INSPECT.
SCRATCHING SOUNDS.	DIRT OR IRON FILINGS LODGED IN AIR GAP BETWEEN FIELD CORE AND APEX SLEEVE OF PAPER CONE.	INSPECT AND REMOVE FOREIGN PARTICLES.

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PRACTICAL RADIO JOB SHEET

NO. 13

SPECIALLY PREPARED FOR THE STUDENTS OF

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METER READINGS AND POSSIBLE RECEIVER TROUBLE

THE OUTLINE HERE GIVEN WILL OFFER YOU A NUMBER OF VALUABLE SUGGESTIONS REGARDING THE MOST COMMON RECEIVER TROUBLES WHICH CORRESPOND TO THE VARIOUS METER READINGS OBTAINED UPON TESTING THE CIRCUITS.

METER READINGS	POSSIBLE TROUBLES
VOLTMETER READS ZERO WHEN CONNECTED ACROSS THE FILAMENT TERMINALS OF THE TUBE SOCKET.	1. DISCHARGED "A" BATTERY IN BATTERY SETS. 2. AN OPEN OR ELSE COMPLETE SHORT IN THIS CIRCUIT. 3. DEFECTIVE TUBE SOCKET. 4. DEFECTIVE FILAMENT CIRCUIT SWITCH. 5. DEFECTIVE POWER TRANSFORMER. 6. PRIMARY CIRCUIT OF POWER TRANSFORMER INCOMPLETE
FILAMENT OR HEATER VOLTAGE TOO HIGH.	1. HIGH LINE VOLTAGE, OR WRONG CONNECTION OF LINE VOLTAGE TAP. 2. HEATER OR FILAMENT BURNED OUT. 3. ONE OR MORE TUBES IN SAME CIRCUIT BURNED OUT, THEREBY DECREASING LOAD ON CIRCUIT. 4. TUBE OF WRONG TYPE FOR SOCKET. 5. PRIMARY WINDING OF POWER TRANSFORMER PARTIALLY SHORTED.
PLATE VOLTAGE LACKING AT ALL TUBES.	1. SHORTED FILTER CONDENSER. 2. OPEN FILTER CHOKE. 3. DEFECTIVE RECTIFIER TUBE. 4. DEFECTIVE POWER TRANSFORMER. 5. PLATE CIRCUIT OF POWER TUBE GROUNDED. 6. OPEN IN MAIN "B" CIRCUIT FEEDING ALL OTHER "B" CIRCUITS.
NO PLATE VOLTAGE ON ONE TUBE AND LOW PLATE VOLTAGE VOLTAGE ON OTHER TUBES.	1. SHORTED BY-PASS OR COUPLING CONDENSER. 2. OPEN R.F. CHOKE. 3. DEFECTIVE TUBE. 4. GROUNDED PLATE CIRCUIT. 5. OPEN RESISTOR.
NO PLATE VOLTAGE ON POWER TUBES BUT PRESENT AT OTHER TUBES.	1. OPEN IN OUTPUT OR SPEAKER COUPLING UNIT. 2. OPEN IN POWER TUBE PLATE CIRCUIT.
LOW PLATE VOLTAGE ON ALL TUBES	1. DEFECTIVE RECTIFIER TUBE. 2. DEFECTIVE FILTER CONDENSER. 3. SHORTED BIAS RESISTOR BY-PASS CONDENSER. 4. SHORTED GRID BIAS RESISTOR. 5. DEFECTIVE BY-PASS CONDENSER. 6. LOW LINE VOLTAGE. 7. DEFECTIVE VOLTAGE DIVIDER. 8. DEFECTIVE FILTER CHOKE. 9. DEFECTIVE POWER TRANSFORMER.

(OVER)

(CONTINUED)

HIGH PLATE VOLTAGE.	1. HIGH LINE VOLTAGE. 2. SHORTED FILTER CHOKE. 3. SHORT CIRCUITED RESISTOR. 4. WORN OUT TUBES PLACING INSUFFICIENT "B" LOAD UPON POWER SUPPLY. (OPEN IN "B" CIRCUIT OF POWER STAGE WILL INCREASE THE "B" VOLTAGE AT TUBES IN THE OTHER STAGES). 5. EXCESSIVE GRID BIAS RESISTANCE IN POWER STAGE.
EXCESSIVE PLATE CURRENT.	1. EXCESSIVE PLATE VOLTAGE. 2. EXCESSIVE SCREEN GRID VOLTAGE. 3. OPEN GRID CIRCUIT. 4. NOT ENOUGH GRID BIAS. 5. GASEOUS TUBE.
LOW PLATE CURRENT WITH NORMAL PLATE VOLTAGE.	1. DEFECTIVE TUBE. 2. TOO MUCH BIAS RESISTANCE. 3. LOW FILAMENT VOLTAGE. 4. LOW SCREEN GRID VOLTAGE.
NO SCREEN GRID VOLTAGE.	1. SHORTED SCREEN-GRID BY-PASS CONDENSER. 2. DEFECTIVE TUBE. 3. DEFECTIVE RESISTOR. 4. OPEN SCREEN GRID CIRCUIT.
NO GRID BIAS.	1. OPEN GRID CIRCUIT. 2. GROUNDED CATHODE. 3. GROUNDED FILAMENT. 4. SHORTED GRID BY-PASS CONDENSER.
LOW GRID BIAS.	1. LOW PLATE CURRENT. 2. OLD TUBES. 3. DEFECTIVE BIAS RESISTANCE OR ONE OF INCORRECT VALUE. 4. DEFECTIVE BIAS RESISTOR BY-PASS CONDENSER.
HIGH GRID BIAS.	1. EXCESSIVE PLATE CURRENT. 2. BIAS RESISTOR OF TOO MUCH VALUE. 3. DEFECTIVE BIAS RESISTOR.

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NO. 14

PRACTICAL RADIO JOB SHEET

SPECIALLY PREPARED FOR THE STUDENTS OF

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HOW TO INSTALL AN ADDITIONAL SPEAKER

TO PROVIDE AN ADDITIONAL LOUDSPEAKER FOR A RADIO RECEIVER, IT IS POSSIBLE TO USE EITHER A CONVENTIONAL ELECTRODYNAMIC SPEAKER OR A PERMANENT MAGNET (P-M) DYNAMIC SPEAKER. HOWEVER, THE LATTER IS PREFERABLE BECAUSE NO DIRECT CURRENT SUPPLY IS REQUIRED TO EXCITE ITS FIELD.

USING AN ELECTRODYNAMIC SPEAKER

FIG. 1 ILLUSTRATES THE CIRCUIT CONNECTIONS WHEN USING AN ELECTRODYNAMIC SPEAKER, HAVING A FIELD COIL RESISTANCE OF 1500 TO 2500 OHMS.

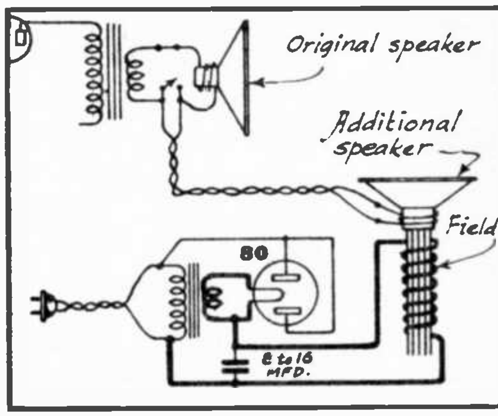

FIG. 1

TO MAKE THE INSTALLATION, PROCEED AS FOLLOWS:

1. - INSTALL THE PARTS COMPRISING THE RECTIFIER IN A METAL BOX; PLACING IT NEAR THE ADDITIONAL SPEAKER. NO SWITCH FOR THE A-C CORD IS SHOWN IN FIG. 1; HOWEVER, IF DESIRED, IT CAN BE CONNECTED IN SERIES WITH THE A-C LINE AND THE PRIMARY WINDING OF THE TRANSFORMER.

IF NO SUCH SWITCH IS USED, THE PLUG WILL HAVE TO BE REMOVED FROM THE LIGHTING CIRCUIT OUTLET WHENEVER THE ADDITIONAL SPEAKER IS NOT BEING USED. ALL OTHER CIRCUIT CONNECTIONS SHOULD BE MADE AS ILLUSTRATED IN FIG. 1.

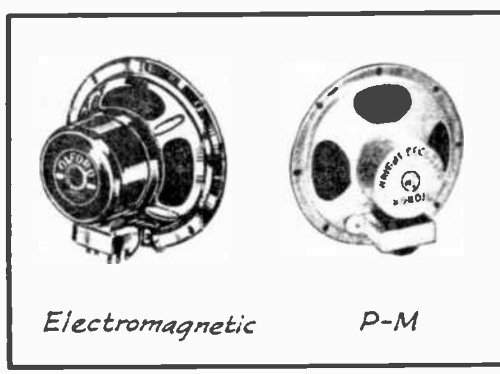

FIG. 2

2. - DISCONNECT ONE OF THE LEADS BETWEEN THE VOICE COIL AND SECONDARY WINDING OF THE SPEAKER COUPLING TRANSFORMER ALREADY BEING USED WITH THE RECEIVER. CONNECT THE SINGLE-POLE SWITCH BETWEEN THESE TWO PARTS.

3. - EXTEND A TWO-WIRE TWISTED LEAD BETWEEN THE EXISTING SPEAKER AND THE ONE BEING INSTALLED, CONNECTING ONE END OF THIS DUAL LEAD ACROSS THE SWITCH TERMINALS AND THE OTHER ACROSS THE VOICE COIL TERMINALS OF THE ADDITIONAL SPEAKER. BOTH SPEAKERS WILL THEN OPERATE WHEN THIS SWITCH IS OPEN; ONLY THE REGULAR SPEAKER WILL OPERATE WHEN THIS SWITCH IS CLOSED.

- OVER -

USING A PERMANENT-MAGNET DYNAMIC SPEAKER

1. - MOUNT THE SPEAKER AT THE DESIRED LOCATION AND CONNECT ITS VOICE COIL TO THAT OF THE EXISTING SPEAKER IN THE SAME MANNER AS ILLUSTRATED IN FIG. 1. THE SWITCH IS ALSO EMPLOYED IN THIS CASE.

2. - IT WILL BE OBSERVED IN FIG. 2 THAT PERMANENT-MAGNET DYNAMIC SPEAKERS ARE QUITE SIMILAR, IN GENERAL APPEARANCE, TO ELECTRODYNAMIC SPEAKERS. HOWEVER, SINCE THEY EMPLOY NO FIELD COIL, NO RECTIFIER NOR FIELD COIL CONNECTIONS ARE REQUIRED.

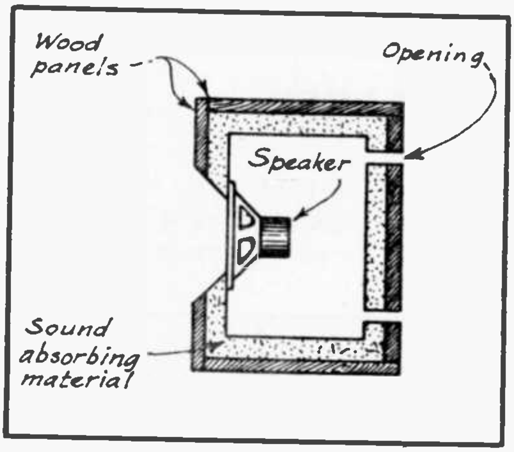

FIG. 3

SPEAKER MOUNTING

1. - THE ADDITIONAL SPEAKER, REGARDLESS OF THE TYPE BEING USED, SHOULD BE INSTALLED IN A SUITABLE CABINET. FACTORY-BUILT METAL CABINETS, DESIGNED FOR CONVENIENT MOUNTING IN PRACTICALLY ANY LOCATION, ARE AVAILABLE FOR THIS PURPOSE.

2. - AS AN ALTERNATIVE TO THE FACTORY-BUILT CABINET, YOU CAN CONSTRUCT ONE OF WOOD BY FOLLOWING THE SUGGESTIONS GIVEN IN FIG. 3.

THE INTERIOR OF THIS CABINET SHOULD BE LINED WITH SOME SOUND ABSORBING MATERIAL AS FELT -- OR SLABS OF CELOTEX, FIRTEX, ETC.

3. - THE OPENINGS AT THE BACK OF THE CABINET SHOULD BE ABOUT 1" IN DIAMETER NOT MORE THAN FOUR BEING REQUIRED -- ONE NEAR EACH CORNER. THE OPENING AT THE FRONT OF THE CABINET MAY BE COVERED WITH COPPER SCREEN OR CLOTH OF SUCH WEAVE THAT IT WILL NOT RESTRICT THE PASSAGE OF SOUND WAVES TO AN OBJECTIONABLE EXTENT. THE DIMENSIONS OF THE CABINET MAY VARY TO CONFORM WITH INDIVIDUAL REQUIREMENTS.

4. - ADDING AN EXTRA SPEAKER CAUSES A REDUCTION IN THE MAXIMUM VOLUME OF SOUND PRODUCED BY THE ORIGINAL SPEAKER. THAT IS, THE OUTPUT OF THE AUDIO AMPLIFIER WILL NOW BE DIVIDED BETWEEN THE TWO SPEAKERS SO THAT THE COMBINED VOLUME OF SOUND PRODUCED BY THE TWO OF THEM WILL BE EQUAL TO THAT PREVIOUSLY PROVIDED BY THE ORIGINAL SPEAKER ALONE.

5. - SOMETIMES, THE ADDITIONAL SPEAKER IS EQUIPPED WITH A COUPLING TRANSFORMER, IN WHICH CASE IT MAY BE PREFERABLE TO MAKE THE CIRCUIT CONNECTIONS TO IT INSTEAD OF TO THE VOICE COIL. THIS IS DONE BY FIRST CONNECTING THE PRIMARY TERMINALS OF THE ADDITIONAL SPEAKER'S COUPLING TRANSFORMER ACROSS THE PRIMARY OF THE RECEIVER'S OUTPUT TRANSFORMER. IF THE TONE AND VOLUME OF BOTH SPEAKERS IS THEN SATISFACTORY, THE CONNECTIONS ARE MADE PERMANENT IN THIS MANNER.

OCCASIONALLY, IT IS NECESSARY TO INSERT A .1 MF BYPASS CONDENSER IN SERIES WITH ONE OF THE LEADS INTERCONNECTING THE TWO SPEAKERS.

NO. 15

PRACTICAL RADIO JOB SHEET

SPECIALLY PREPARED FOR THE STUDENTS OF

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• CONTINUITY TESTS •

THE PURPOSE OF THIS JOB SHEET IS TO DESCRIBE SIMPLE BUT ACCURATE METHODS FOR CHECKING THE CONTINUITY OF WINDINGS AND CIRCUITS, AS WELL AS THE METHOD OF TESTING RESISTORS AND CONDENSERS WITH THE AID OF THE MOST INEXPENSIVE EQUIPMENT. LATER JOB SHEETS DESCRIBE MORE ELABORATE TESTS OF THIS NATURE.

CHECKING A WINDING

1. – TO DETERMINE WHETHER OR NOT A WINDING SUCH AS USED IN AN A.F. TRANSFORMER, R.F. TRANSFORMER, CHOKE ETC. IS COMPLETE OR NOT PROCEED AS ILLUSTRATED IN FIG. 1, THAT IS, CONNECT A 4½ VOLT "C" BATTERY IN SERIES WITH A PAIR OF TEST LEADS AND A D.C. VOLTMETER HAVING A RANGE OF 0–10 VOLTS.

2. – TOUCH THE TWO TEST POINTS TO THE TWO TERMINALS ACROSS WHICH THE WINDING UNDER TEST IS CONNECTED. IF THE WINDING IN QUESTION IS OPEN CIRCUITED AS INDICATED IN FIG. 1, THEN THE VOLTMETER WILL OFFER A ZERO READING.

3. – SHOULD THE WINDING UNDER TEST BE INTACT OR COMPLETE, THEN THE VOLTMETER WILL OFFER A READING WHICH IS APPROXIMATELY EQUAL TO THE VOLTAGE OF THE BATTERY BEING USED. THE EXACT READING WILL DEPEND UPON THE RESISTANCE OF THE WINDING THROUGH WHICH THE TEST IS BEING MADE.

CHECKING A CONDENSER

1.– THE METHOD OF CHECKING A CONDENSER SO AS TO DETERMINE WHETHER IT IS SHORTED ("BURNED OUT") OR NOT IS ILLUSTRATED IN FIG. 2. HERE THE SAME TESTING EQUIPMENT IS EMPLOYED AS HAS ALREADY BEEN DESCRIBED RELATIVE TO FIG. 1.

2.– WHEN CONDUCTING THIS TEST, THE TEST POINTS ARE CONNECTED ACROSS THE CONDENSER TERMINALS

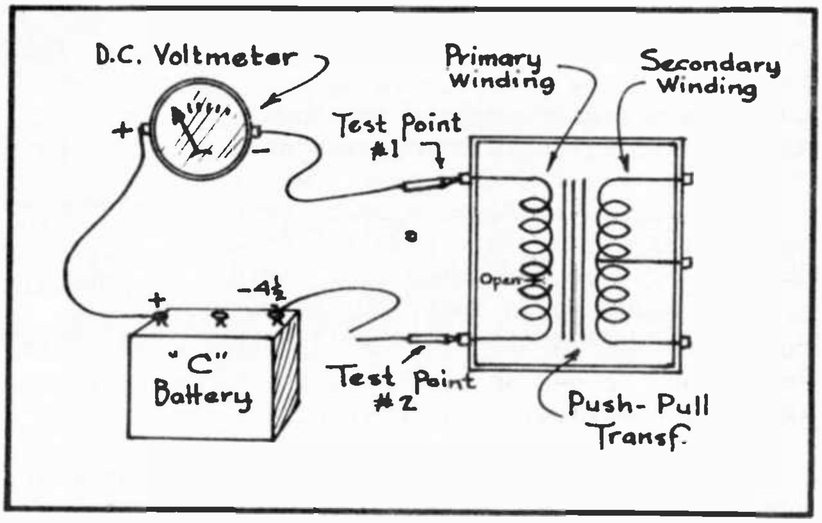

Fig.1
Checking A Transformer.

AND THE ACTION OF THE VOLTMETER CAREFULLY NOTED.

3. — IF THE VOLTMETER INDICATES THE VOLTAGE OF THE "C" BATTERY, THEN THE CONDENSER IN QUESTION IS SHORTED AND SHOULD BE REPLACED WITH A NEW ONE.

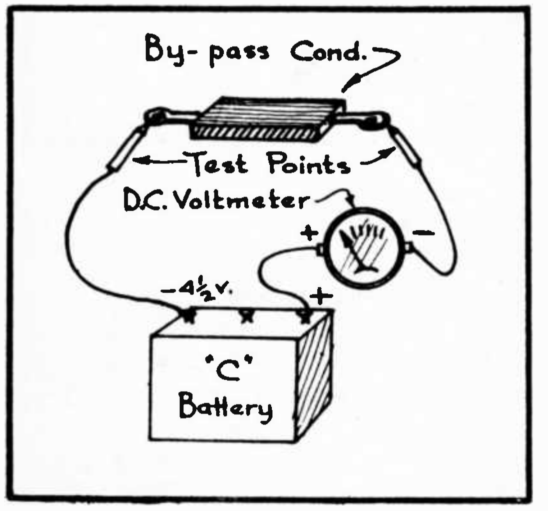

Fig. 2
Testing A Condenser.

4. — IF THE CONDENSER IS IN GOOD CONDITION THEN THE INSTANT THAT THE TEST POINTS ARE CONNECTED ACROSS THE CONDENSER TERMINALS, THE VOLTMETER NEEDLE WILL MOVE VERY SLIGHTLY TOWARDS THE RIGHT FROM THE ZERO MARK BUT ONLY FOR AN INSTANT. THE NEEDLE WILL THEN IMMEDIATELY DROP TO THE ZERO LINE OF THE VOLTMETER SCALE AND AT WHICH POSITION IT WILL REMAIN AS LONG AS THE TEST POINTS ARE HELD IN PLACE.

CHECKING RESISTORS

1. — RESISTORS WHOSE NORMAL RESISTANCE VALUE IS NOT TOO HIGH CAN BE CHECKED FOR CONTINUITY AS PER FIG. 3.

2. — IF THE RESISTOR IS OPEN CIRCUITED, THE VOLTMETER READING WILL BE ZERO. IF THE RESISTOR IS IN A GOOD CONDITION, A METER READING WILL BE OBTAINED — THE EXACT READING DEPENDING UPON THE RESISTANCE VALUE OF THE RESISTOR UNDER TEST.

3. — FOR RESISTORS OF HIGH OHMIC VALUE, THIS TEST ISN'T RELIABLE IN THAT THE RESISTANCE MAY NORMALLY BE SUFFICIENTLY GREAT SO THAT 4½ VOLTS IS NOT ABLE TO FORCE SUFFICIENT CURRENT THROUGH THE UNIT TO OFFER A LEGIBLE READING. AN OHMMETER RESISTOR CHECK IS MORE DESIRABLE AND IS FULLY EXPLAINED IN A LATER JOB SHEET.

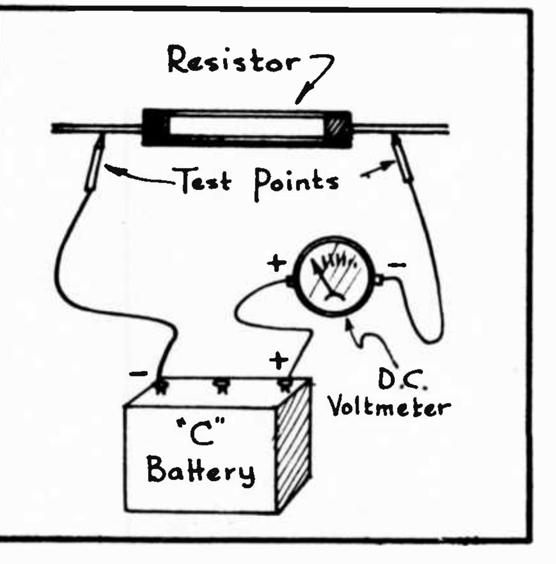

Fig. 3
Checking The Resistor.

NOTE: WHEN PERFORMING THE CONTINUITY TESTS AS DESCRIBED IN THIS JOB SHEET, IT IS ADVISABLE THAT THE UNIT WHICH IS BEING TESTED BE DISCONNECTED FROM THE RECEIVER CIRCUITS DURING THE TIME THAT THE TEST IS CONDUCTED. IN THIS WAY, YOU ARE CERTAIN THAT YOU ARE NOT TESTING THRU AN EXTERNAL CIRCUIT RATHER THAN THROUGH THE UNIT ITSELF.

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PRACTICAL RADIO JOB SHEET

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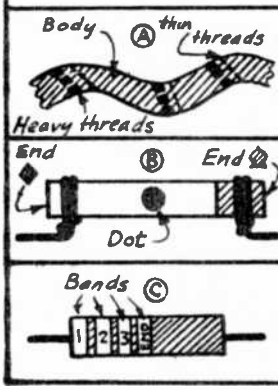
Resistor Color-Code Chart

TYPES	RESISTOR COLOR CODES (VALUES IN OHMS)			
FLEXIBLE (A)→	BODY	HEAVY WOVEN THREAD	THIN WOVEN THREAD	
RADIAL (B)→	BODY	END ♠	DOT OR BAND	END ♦
AXIAL (C)→	1ST BAND OR DOT	2ND BAND OR DOT	3RD BAND OR DOT	END BAND



COLOR	VALUE	COLOR	VALUE	COLOR	VALUE	COLOR	TOLER.
BLACK	0	BLACK	0	BLACK	NONE	GOLD	± 5%
BROWN	1	BROWN	1	BROWN	0	SILVER	±10%
RED	2	RED	2	RED	00	NONE	±20%
ORANGE	3	ORANGE	3	ORANGE	000		
YELLOW	4	YELLOW	4	YELLOW	0000		
GREEN	5	GREEN	5	GREEN	00000		
BLUE	6	BLUE	6	BLUE	000000		
VIOLET	7	VIOLET	7				
GREY	8	GREY	8				
WHITE	9	WHITE	9				

HOW TO USE CHART (EXAMPLES)

FLEXIBLE WIRE TYPE (A): SILK OR COTTON COVERING OF RESISTOR (BODY COLOR) = 1ST SIGNIFICANT FIGURE. HEAVY, COLORED THREAD INTERWOVEN AT FREQUENT INTERVALS INTO WEAVE OF BODY = 2ND SIGNIFICANT FIGURE. THIN, COLORED THREAD, CLOSE TO HEAVY THREAD SIGNIFIES HOW MANY ZEROS ARE TO BE ADDED. EXAMPLE: BODY COLOR, RED; HEAVY THREAD, GREEN; THIN THREAD, BLACK, WOULD HAVE A RESISTANCE VALUE OF 25 OHMS.

RADIAL TYPE (B): BODY-COLOR = 1ST SIGNIFICANT FIGURE; END-COLOR (♠) = 2ND SIGNIFICANT FIGURE; DOT-COLOR DENOTES HOW MANY ZEROS ARE TO BE ADDED. OPPOSITE END-COLOR (♦) IS REFERRED TO AS THE "TOLERANCE COLOR"; WHICH WOULD EITHER BE SILVER, GOLD OR THE SAME COLOR AS THE BODY (IN WHICH CASE, IT WOULD BE CONSIDERED AS HAVING "NO" COLOR). EXAMPLE: BODY-COLOR, BROWN; END-COLOR, BLACK; DOT-COLOR YELLOW; AND WHOSE OPPOSITE END-COLOR WERE THE SAME COLOR AS THE BODY (BROWN) WOULD HAVE A RESISTANCE VALUE OF 100,000 OHMS WITH A TOLERANCE OF ± 20%.

AXIAL TYPE (C): NOTE WHICH ONE OF THE BANDS IS COLORED EITHER SILVER OR GOLD. THIS IS BAND NO. 4 AND IS REFERRED TO AS THE "TOLERANCE BAND". THE BAND TO THE EXTREME LEFT OF THE TOLERANCE BAND WOULD THEREFORE BE BAND NO. 1. IF A TOLERANCE BAND IS NOT PAINTED ON THE RESISTOR, BAND NO. 1, 2 AND 3 ARE CROWDED TO ONE SIDE OF THE RESISTOR SO THAT IDENTIFICATION OF EACH OF THESE BANDS IS OBVIOUS. EXAMPLE: BAND NO. 1, ORANGE; BAND NO. 2, BLACK; BAND NO. 3, RED; BAND NO. 4, SILVER --- WOULD HAVE A RESISTANCE VALUE OF 3,000 OHMS WITH A TOLERANCE OF ± 10%.

PRACTICAL RADIO JOB SHEET

NO. 17

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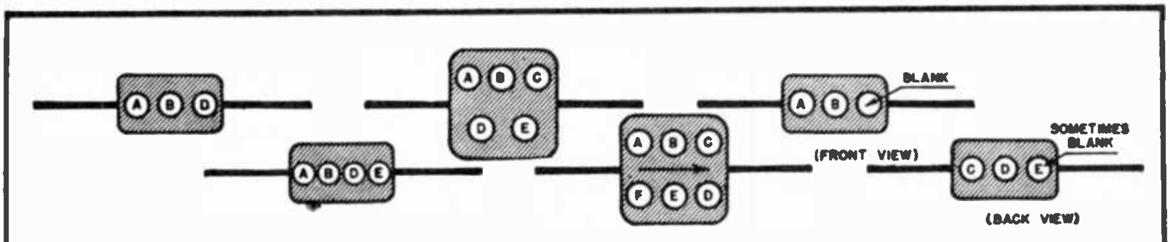
Condenser Color-Code Chart



CAPACITANCE IN MICROMICROFARADS ($\mu\mu$f.)

DOT COLOR	SIGNIFICANT FIGURES A	B	C	DECIMAL MULTIPLIER D	CAPACITIVE TOLERANCE E	DC TEST VOLTAGE F	DOT COLOR
BLACK	0	0	0	-	---	---	BLACK
BROWN	1	1	1	10	± 1%	100	BROWN
RED	2	2	2	100	± 2%	200	RED
ORANGE	3	3	3	1,000	± 3%	300	ORANGE
YELLOW	4	4	4	10,000	± 4%	400	YELLOW
GREEN	5	5	5	100,000	± 5%	500	GREEN
BLUE	6	6	6	1,000,000	± 6%	600	BLUE
VIOLET	7	7	7	10,000,000	± 7%	700	VIOLET
GRAY	8	8	8	100,000,000	± 8%	800	GREY
WHITE	9	9	9	1,000,000,000	± 9%	900	WHITE
GOLD	-	-	-	0.1	± 5%	1,000	GOLD
SILVER	-	-	-	0.01	±10%	2,000	SILVER
NO COLOR	-	-	-	-	±20%	500	NO COLOR

HOW TO USE CHART (EXAMPLES)

IF A CONDENSER IS COLOR-CODED IN THE FOLLOWING MANNER:

EXAMPLE 1: (A) GREEN; (B) BLACK; (C) NO COLOR; (D) BLACK; (E) GOLD; (F) BLUE. THE CAPACITY OF SUCH A CONDENSER WOULD BE DECIPHERED AS 50 MMFD WITH A ± 5% TOLERANCE AND RATED AT A WORKING VOLTAGE OF 600 VOLTS.

EXAMPLE 2: (A) RED; (B) GREEN; (C) BLACK; (D) GOLD; (E) NO COLOR; (F) GREY. THE CAPACITY OF THIS CONDENSER WOULD BE 250 (ABC) x .1 (D) = 25 MMFD WITH A TOLERANCE OF ± 20% AND A RATED WORKING VOLTAGE OF 800 VOLTS.

NO. 18

PRACTICAL RADIO JOB SHEET

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IDENTIFYING POWER TRANSFORMER TERMINALS

AS A GENERAL RULE THE TERMINALS OF POWER TRANSFORMERS ARE NOT MARKED BY THE MANUFACTURER FOR IDENTIFICATION PURPOSES. IN SUCH CASES, THE METHOD AS DESCRIBED IN THIS JOBSHEET CAN BE EMPLOYED SO THAT ONE CAN ASCERTAIN DEFINITELY WHICH OF THE TRANSFORMER WINDINGS ARE CONNECTED TO THE VARIOUS TERMINALS.

1. – FIRST CONNECT A 110 VOLT–25 WATT INCANDESCENT LAMP IN SERIES WITH THE 110 VOLT LIGHTING CIRCUIT AND A PAIR OF TEST POINTS AS SHOWN IN THE ACCOMPANYING ILLUSTRATION. NATURALLY, IF A 220 VOLT TRANSFORMER IS INVOLVED, A 220 VOLT LAMP AND CIRCUIT WOULD BE USED.

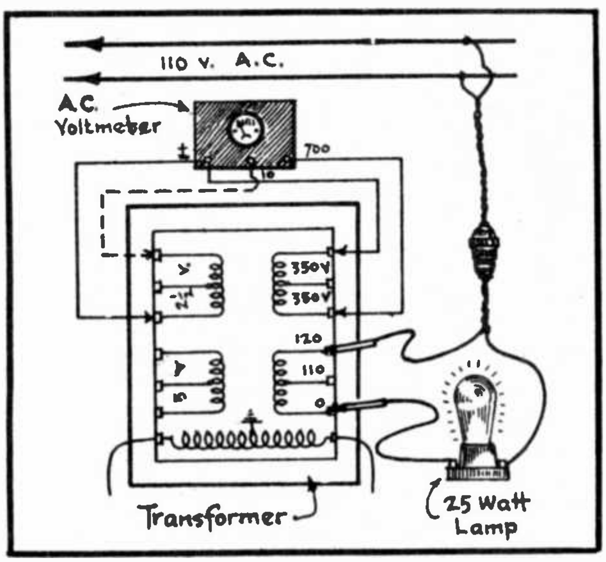

Fig. 1
Testing The Transformer.

2. – WITH THE LAMP CIRCUIT TEST POINTS, TEST BETWEEN THE VARIOUS TERMINALS UNTIL YOU LOCATE A PAIR WHICH CAUSE THE LAMP TO BURN VERY DIM. THESE TERMINALS HAVE THE PRIMARY WINDING CONNECTED TO THEM.

3. – CONNECT THE LAMP CIRCUIT ACROSS THESE PRIMARY TERMINALS AND WITH AN A.C. VOLTMETER OF SUITABLE RANGE TEST BETWEEN THE REMAINING TERMINALS UNTIL READINGS CORRESPONDING TO THE HIGH VOLTAGE WINDING ARE OBTAINED. FOR INSTANCE, IF THE HIGH VOLTAGE WINDING IS RATED FOR 700 VOLTS ACROSS ITS EXTREMETIES, THEN A VOLTMETER READING OF THIS VALUE WILL BE OBTAINED WHEN CONNECTED ACROSS THESE TWO CORRESPONDING TERMINALS. A READING OF ONE-HALF THIS AMOUNT WILL BE OBTAINED BETWEEN EACH END TERMINAL OF THIS WINDING AND ITS CENTER TAP.

4. – USING THE LOW RANGE A.C. VOLTMETER SCALE, CONTINUE TESTING FOR THE TERMINALS OF THE LOW VOLTAGE WINDINGS, AGAIN REMEMBERING THAT BETWEEN THE CENTER TAP OF ANY OF THESE WINDINGS AND EITHER END TERMINAL, THE READING WILL BE ONE-HALF THAT OBTAINED ACROSS THE TWO ENDS OF THE SAME WINDING. ALSO MAKE IT A PRACTICE TO CONSIDER THE TRANSFORMER CORE AS A TERMINAL WHILE TESTING.

5. – IF THE PRIMARY WINDING IS DESIGNED FOR HIGH AND LOW LINE VOLTAGE, THE LAMP WILL BURN DIM WHEN ONE TEST POINT IS HELD IN CONTACT WITH ONE END OF THE PRIMARY AND WITH THE OTHER TEST POINT IN CONTACT WITH EITHER OF THE TWO REMAINING PRIMARY TERMINALS.

PRACTICAL RADIO JOB SHEET

NO. 19

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APPLICATION OF A LINE VOLTAGE REGULATOR

IN SOME LOCALITIES IN WHICH A.C. RECEIVERS ARE OPERATED, THE LINE VOLTAGE VARIES TO SUCH AN EXTENT THAT THE VOLTAGE AT TIMES BECOMES SUFFICIENTLY GREAT TO BURN OUT THE RECEIVER TUBES OR ELSE DAMAGE THE POWER PACK.

1. – TO REMEDY SUCH A CONDITION A LINE VOLTAGE REGULATOR CAN BE CONNECTED IN SERIES WITH THE A.C. LINE AND THE PRIMARY WINDING OF THE RECEIVER'S POWER TRANSFORMER AS SHOWN IN FIG. 1.

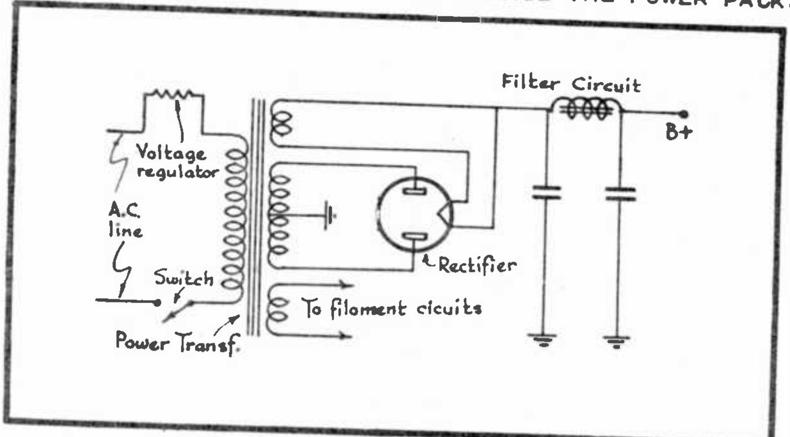

Fig. 1
Installation Of Voltage Regulator In Circuit.

2. – TWO POPULAR LINE VOLTAGE REGULATORS ARE SHOWN IN FIG. 2. THE ONE AT THE LEFT IS A "CLAROSTAT" AND CONSISTS OF A PERFORATED METAL CONTAINER IN WHICH A SPECIAL RESISTANCE ELEMENT IS CONTAINED. ITS DESIGN IS SUCH THAT IT CAN BE INSERTED INTO AN ORDINARY SCREW TYPE PLUG OR CONVENIENCE OUTLET OF THE LIGHTING CIRCUIT. THE PLUG WHICH IS ATTACHED TO THE RECEIVER'S POWER CORD IS THEN INSERTED IN THE TWO HOLES PROVIDED FOR THIS PURPOSE ON THE REGULATOR.

3. – THE TUBE TYPE REGULATOR ("AMPERITE") ALSO SHOWN IN FIG. 2 CAN BE MOUNTED AT ANY CONVENIENT POINT IN THE RECEIVER CABINET SO THAT THE UNIT WILL BE IN SERIES WITH THE A.C. LINE AND THE RECEIVER.

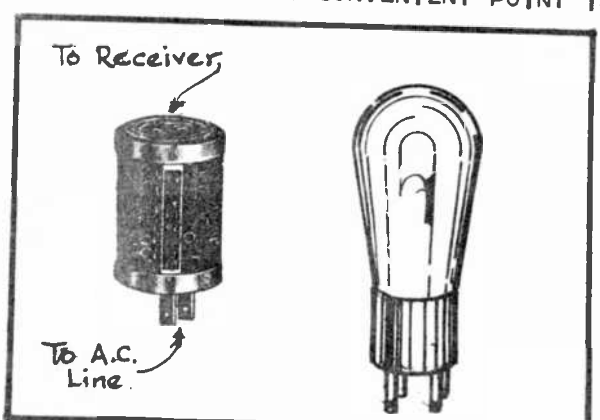

Fig. 2
Typical Voltage Regulators.

4. – FOR 110 VOLT RECEIVERS THESE REGULATORS WILL MAINTAIN THE RECEIVER VOLTAGE VERY NEARLY CONSTANT EVEN THOUGH THE LINE VOLTAGE MAY VARY BETWEEN 95 AND 140 VOLTS. WHEN ORDERING SUCH A REGULATOR FROM A DEALER, IT IS IMPORTANT TO SPECIFY THE VOLTAGE AND POWER CONSUMPTION RATING OF THE RECEIVER.

5. – WHEN PURCHASING A REGULATOR REPLACEMENT ALWAYS SPECIFY THE NAME AND MODEL OF RECEIVER.

PRACTICAL RADIO JOB SHEET

NO. 20

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COMMON TROUBLES IN BROADCAST SUPERHETERODYNE RECEIVERS

IN THIS JOBSHEET ONLY THE MORE COMMON TROUBLES PECULIAR TO SUPER-HETERODYNES ARE CONSIDERED. GENERAL CIRCUIT TROUBLES SUCH AS DEFECTIVE TUBES, RESISTORS, CONDENSERS ETC. WHICH MAY OCCUR IN ANY RECEIVER RE-GARDLESS IF IT BE OF THE T.R.F. OR SUPERHETERODYNE TYPE ARE NOT TREATED HERE.

WEAK SIGNALS THROUGHOUT TUNING RANGE

1. – IMPROPER ADJUSTMENT OF I.F., OSCILLATOR, MIXER OR R.F.TRIMM-ERS OR A DEFECT IN ANYONE OF THESE UNITS.

2. – DEFECTIVE ANTENNA OR GROUND SYSTEM.

3. – DEFECTIVE R.F., MIXER, OSCILLATOR, OR I.F. TRANSFORMER.

4. – DEFECTIVE A.V.C. SYSTEM.

5. – POOR OSCILLATOR TUBE, OR CIRCUIT CONDITION IS SUCH THAT LOW OSCILLATOR OUTPUT IS FURNISHED.

WEAK SIGNALS OVER A PART OF TUNING RANGE

1. – IMPROPER ALIGNMENT OF R.F., MIXER, AND OSCILLATOR TRIMMERS OVER THAT PART OF THE BAND WHERE THE RECEIVER AFFORDS LOWOUT PUT

2. – POOR OSCILLATOR TUBE.

3 – DEFECTIVE COUPLING BETWEEN OSCILLATOR AND MIXER TUBES.

4. – WRONG VOLTAGE SUPPLIED TO OSCILLATOR.

5. – UNSATISFACTORY ANTENNA SYSTEM.

RECEIVER INOPERATIVE OVER A PORTION OF DIAL

1. – POOR OSCILLATOR TUBE.

2. – OSCILLATOR TUBE BEING OPERATED WITH WRONG VOLTAGES APPLIED TO IT.

3. – HIGH RESISTANCE IN TUNED CIRCUITS OF OSCILLATOR OR MIXERTUBE.

4, - R.F., MIXER, OR OSCILLATOR TRIMMERS NOT PROPERLY ADJUSTED.

5, - DEFECTIVE OSCILLATOR COIL.

6. - DEFECTIVE COUPLING BETWEEN OSCILLATOR AND MIXER.

7. - LEAK OR SHORT CIRCUIT BETWEEN TUNING CONDENSER PLATES AT CERTAIN POINTS OF THEIR TRAVEL.

DEAD RECEIVER

1. - DEFECTIVE OSCILLATOR TUBE.

2. - DEFECTIVE OSCILLATOR CIRCUIT OR COMPONENT THEREOF, SUCH AS THE COIL, CONDENSERS, ETC.

3. - DEFECTIVE A.V.C. SYSTEM.

4. - ALIGNMENT OF TUNING CIRCUITS COMPLETELY DISTURBED.

5. - DEFECT IN R.F. OR MIXER CIRCUIT (SAME AS COMMON TO T.R.F. RECEIVERS).

6. - DEFECT IN I.F. CHANNEL AS SHORTED TRIMMER CONDENSERS, OPEN OR SHORTED I.F. TRANSFORMER WINDINGS, ETC,

7. - DEFECT IN SECOND DETECTOR CIRCUIT OR A.F. CHANNEL.

8. - ANY OTHER DEFECT COMMON TO BOTH T.R.F. AND SUPERHETERODYNES SUCH AS DEFECTIVE POWER PACK, OPEN FEEDER CIRCUITS, GROUNDED CIRCUITS ETC.

HETERODYNE WHISTLE AS EACH STATION IS TUNED IN

1. - AN OSCILLATORY CONDITION IN THE R.F., I.F., OR MIXER TUBE CIRCUITS.

2. - INCORRECT LOCATION OF CONTROL GRID OR PLATE LEADS IN R.F., MIXER, OR I.F. CIRCUITS.

3. - OPEN BYPASS CONDENSERS IN A.V.C. VOLTAGE FEED CIRCUITS.

4. - SHORTED GRID FILTER RESISTORS IN R.F., MIXER, AND I.F. CIRCUITS.

5. - OPEN CONDENSERS IN R.F., MIXER, I.F., OR SECOND DETECTOR CIRCUITS.

6. - SHIELDS NOT PROPERLY GROUNDED.

WHISTLE OR GROWL BACKGROUND TO ALL STATIONS

1. - OSCILLATORY CONDITION IN I.F. OR A.F. AMPLIFIER.

2. - IMPROPER OPERATION OF OSCILLATOR CIRCUIT.

3. - EXCESSIVE RESISTANCE IN GRID CIRCUITS.

4. - IMPERFECT BIAS RESISTORS.

5. - IMPERFECT BYPASS CONDENSERS ACROSS BIAS AND GRID FILTER RESISTORS.

WHISTLE WHEN TUNING IN CERTAIN STATIONS ONLY

1. - INSUFFICIENT SELECTIVITY IN TUNING CIRCUITS PRECEDING THE MIXER TUBE.

2. - IMPROPER ALIGNMENT OF I.F. TUNING CIRCUITS.

3. - TRIMMERS OF R.F., OSCILLATOR, AND MIXER CIRCUITS NOT PROPERLY ADJUSTED FOR THAT PARTICULAR SECTION OF THE BAND.

4. - EXCESSIVE SIGNAL STRENGTH OF INTERFERING STATION PRECEDING THE MIXER CIRCUIT.

5. - UNDESIRED COUPLING BETWEEN ANTENNA OR GROUND LEADS AND SECOND DETECTOR CIRCUIT.

6. - POOR SHIELDING.

REPEAT POINTS (STATION RECEIVED AT MORE THAN ONE POINT ON DIAL)

1. - OSCILLATOR TRIMMER ADJUSTMENT NOT CORRECT.

2. - R.F. TUNING CONDENSER TRIMMER ADJUSTMENT NOT CORRECT.

3. - EXCESSIVE PICK-UP FROM STATION.

4. - MIXER CIRCUIT TRIMMER NOT PROPERLY ADJUSTED.

5. - INCORRECT LOCATION OF AERIAL LEADS.

6. - IMPERFECT SHIELDING.

7. - EXCESSIVE CONTROL GRID BIAS ON R.F. AND MIXER TUBES.

DISTORTION ALTHOUGH ALL CIRCUIT CONSTANTS ARE NORMAL

1. - R.F. MIXER OR OSCILLATOR CIRCUITS NOT PROPERLY ALIGNED.

2. - I.F. TRIMMERS OUT OF ALIGNMENT.

3. - OVERLOADING OF TUBES.

4. - EXCESSIVE CONTROL GRID BIAS WHEN RECEIVER IS OPERATED AT LOW VOLUME.

5. – Improperly designed or operating A.V.C. system

6. – Defective tube or tubes.

7. – Defective transformer in R.F., mixer, or oscillator circuit.

8. – Excessively sharp tuning.

9. – Insufficient strength of heterodyning signal.

FREQUENT NEED FOR RETUNING

This condition is generally due to oscillator frequency drift and which means that the oscillator output changes after the receiver has been in use for a while although the operator has made no change in the setting of the tuning dial. Most probable causes for this trouble are:

1. – Imperfect mounting of tuning condenser or slipping tuning condenser drive in which case too much play may cause a slight shift in the setting of the tuning condenser because of the vibrations created by operation of the speaker in the same cabinet.

2. – Imperfect mounting of oscillator coils or imperfect coupling between oscillator and mixer circuit.

3. – Flustrations in the applied operating voltage.

4. – Imperfect ground connection to tuning condenser rotor of the oscillator.

5. – If shield is used on oscillator coil, it may not be grounded properly.

6. – Defective resistor in oscillator circuit, especially in the grid circuit. Any variation in resistance during the course of operation will produce a change in the frequency output of the oscillator.

7. – Defective (leaky) bypass condensers connected across the various resistors which are related to the oscillator circuit.

INTERFERING SIGNAL APPEARS AFTER RECEIVER HAS BEEN IN OPERATION FOR SOME TIME AND DISAPPEARS IF SHUT OFF FOR AWHILE AND THEN AGAIN PLACED IN OPERATION.

Same troubles as listed under the heading FREQUENT NEED FOR RETUNING.

PRACTICAL RADIO JOB SHEET

NO. 21

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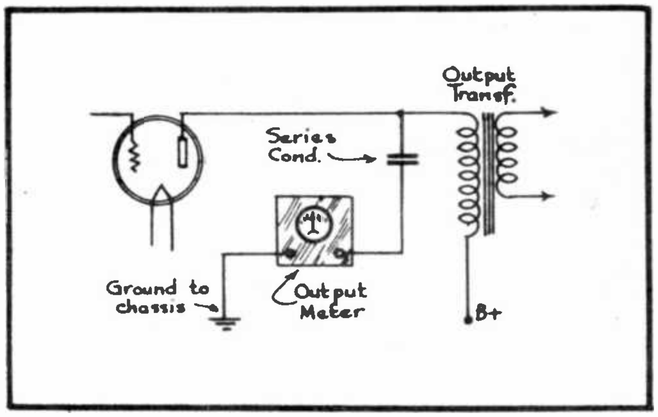
OUTPUT METER CONNECTIONS

WHEN ALIGNING THE TUNED CIRCUITS OF RECEIVERS AS WELL AS WHEN CONDUCTING OTHER TESTS IN WHICH THE OUTPUT OF THE SET IS TO BE CHECKED, OUTPUT METERS ARE USED EXTENSIVELY. THE PURPOSE OF THIS JOBSHEET, THEREFORE, IS TO FAMILIARIZE YOU WITH THE PROPER METHODS OF CONNECTING THE OUTPUT METER TO RECEIVERS EMPLOYING VARIOUS TYPES OF OUTPUT CIRCUITS.

SINGLE TUBE OUTPUT

1. — IN FIG. I YOU ARE SHOWN THE PROPER METHOD OF CONNECTING THE OUTPUT METER TO A RECEIVER WHICH IS EQUIPPED WITH AN OUTPUT STAGE EMPLOYING A SINGLE POWER TUBE AND WHERE A DYNAMIC SPEAKER IS USED.



FFig. 1
Meter Connection For Single Tube Output.

2. — THE OUTPUT METER IN THIS CASE IS CONNECTED BETWEEN THE PLATE TERMINAL OF THE POWER TUBE'S SOCKET AND THE CHASSIS. A CONDENSER HAVING A CAPACITY FROM .I MFD. TO 2 MFD. IS CONNECTED IN SERIES WITH THE OUTPUT METER IN ORDER TO PREVENT ANY DIRECT CURRENT FROM FLOWING THROUGH THE METER. IN THIS WAY ONLY THE ALTERNATING COMPONENT OF THE SIGNAL VOLTAGE IS PERMITTED TO ACT UPON THE METER. IN MOST COMMERCIAL OUTPUT METERS, THIS SERIES CONDENSER IS ALREADY INCLUDED IN THE UNIT.

3. — TO FASCILITATE THE METER CONNECTION TO THE PLATE CIRCUIT OF THE POWER TUBE, THE PLATE CIRCUIT CONNECTION CAN BE MADE AT THE PROPER TERMINAL OF THE RECEIVER'S OUTPUT TRANSFORMER WHEN CONVENIENT, OR ELSE THE POWER TUBE CAN BE REMOVED FROM ITS SOCKET, AN ADAPTER CLIP SLIPPED OVER ITS PLATE PRONG AND AFTER WHICH THE TUBE CAN BE RE-INSERTED IN ITS SOCKET.

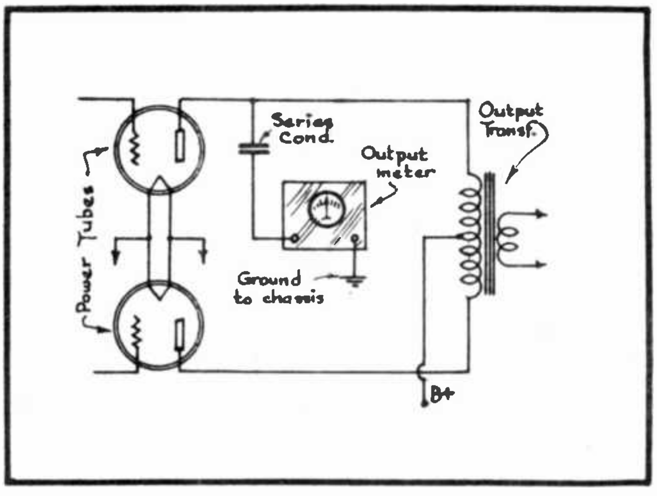


Fig. 2
Meter Connection For Push-Pull Output.

PUSH-PULL OUTPUT

1. — ON RECEIVERS WHICH EMPLOY A PUSH-PULL OUTPUT CIR-

CUIT, THE OUTPUT METER SHOULD BE CONNECTED BETWEEN THE CHASSIS AND THE PLATE TERMINAL OF EITHER ONE OF THE TWO POWER TUBES. IN THIS CASE ALSO, A CONDENSER SHOULD BE INSERTED IN SERIES WITH THE OUTPUT METER.

2. — ALTHOUGH IT IS POSSIBLE TO CONNECT THE OUTPUT METER DIRECTLY ACROSS THE PLATES OF THE TWO POWER TUBES THROUGH THE SERIES CONDENSER, YET THIS ARRANGEMENT WILL NOT PROVIDE METER DEFLECTIONS AS GREAT AS WILL THE CONNECTIONS ILLUSTRATED IN FIG.2.

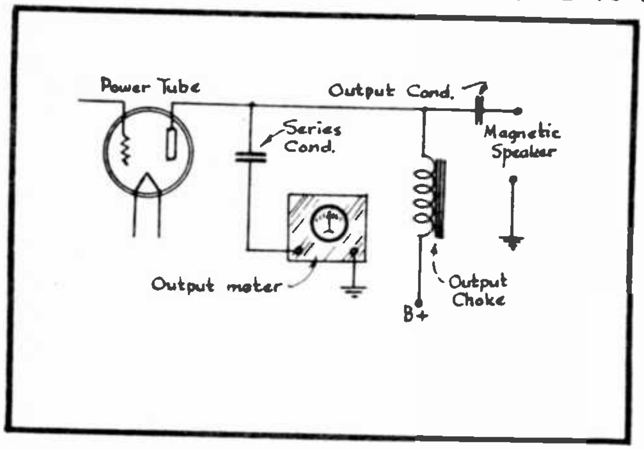


Fig. 3
Meter Connection When Using Magnetic Speaker.

OUTPUT FOR MAGNETIC SPEAKER

1. — IF A MAGNETIC SPEAKER IS BEING USED WITH A RECEIVER AND THE CIRCUIT ARRANGEMENT IS SUCH AS ILLUSTRATED IN FIG.3, THEN THE OUTPUT METER CONNECTION AS ALSO SHOWN IN THIS SAME DIAGRAM CAN BE USED.

EMERGENCY REPAIR OF A.F. TRANSFORMER

IN RECEIVERS WHERE AN A.F. TRANSFORMER IS USED AS A MEANS OF COUPLING BETWEEN THE A.F. STAGES, AS ILLUSTRATED IN FIG. 4, ONE OF THE WINDINGS SOMETIMES BECOMES OPEN CIRCUITED AFTER THE UNIT HAS BEEN IN SERVICE. IN THE EVENT THAT A NEW TRANSFORMER CANNOT BE OBTAINED READILY, AN EMERGENCY REPAIR CAN BE MADE IN THE FOLLOWING MANNER:

1. — IF THE PRIMARY WINDING IS OPEN CIRCUITED, THEN CONNECT A 25,000 OHM RESISTOR ACROSS THE PRIMARY TERMINALS OF THE TRANSFORMER AND CONNECT A .05 MFD. CONDENSER BETWEEN THE PLATE (P) AND THE GRID (G) TERMINAL OF THE TRANSFORMER AS SHOWN IN THE UPPER ILLUSTRATION OF FIG.4.

2. — SHOULD THE SECONDARY WINDING BE OPEN CIRCUITED, THEN CONNECT A 75,000 OHM RESISTOR ACROSS THE SECONDARY TERMINALS OF THE TRANSFORMER AND AN .05 MFD. CONDENSER BETWEEN THE PLATE AND GRID TERMINALS OF THE TRANSFORMER AS SHOWN IN THE LOWER ILLUSTRATION OF FIG.4.

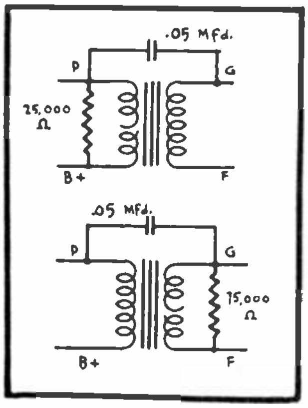


Fig. 4
The Connections.

3. — IF EITHER OF THESE TWO WINDINGS IS DEFECTIVE TO THE EXTENT OF BEING NOISY (CAUSING FRYING AND CRACKLING SOUNDS) THEN IT IS BEST TO DISCONNECT THAT WINDING FROM THE CIRCUIT ENTIRELY AND USE THE PROPER RESISTOR IN ITS PLACE.

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INTERMEDIATE FREQUENCY TABLE

MODEL	K.C.
AIR KING	
37-39-52-54	456
ALLIED	
Knight 118 AVC	175
" 8 tube	175
" 7 tube	175
" P	175
" P9541	175
" P9616	175
" E9830	177.5
" E9831	177.5
" 12 tubes	177.5
" P9660	177.5
" P9640	177.5
" P9505	456
" P9511	456
" P9515	456
" P9531	456
" P9591	456
" P9501	456
" P9571	456
" P9631	456
" P9610	485
ATWATER KENT	
137	125
91-91B-91C	262.5
81-155-246-266	262.5
555-636-756-756B	262.5
1650-5250	264
217-427-667-217D	264
427D-667D-275-387	264
4270-424-425-665	264
534	450
480-708-808-711	472.5
808A	472.5
93 Converter	1000
All Other Models	130
ALL AMERICAN MOHAWK CORP.	
See R. Wurlitzer	
ANSLEY RADIO CORP.	
All Models	175
AUDIOLA RADIO CO.	
1931 Super-Hete	175
5W-3374-3385	456
3387-338105W-3488LW	456
3356P-34C5AC-DC	456
3455AVC	456
All Others	177.5
BALKEIT RADIO CO.	
L7-L8-55-85-100	175
BELMONT RADIO CORP.	
81	105
625-650-660	175
670-750-1050	175
71C	175
775	370
525-530-540	456
550	456
BOSCH RADIO CO.	
See United American Bosch	
BROWNING DRAKE RADIO CORP.	
40-80	175
BRUNSWICK	
11-12-16	175
33AC-17-24-25	175
3NC8-5NC8	180
3NW8	180
BULOVA WATCH CO.	
All Models	175
CAPEHART CORP.	
All Models	180
CLARION RADIO	
See Transformer Corp. of America	
COLONIAL RADIO CORP.	
Laboratory Models 132 & 139	450
15C	480
55	1000
All Others	175
COLUMBIA PHONOGRAPH CO., INC.	
All Models	175
CROSLEY RADIO CORP.	
120-121-122-123-124	175
124-1—125-126-126-1—127	175
127-1—128-131	175
148-154-155-156-159	456
163-166-167-169-172	456
173-173-5—174	456
All Others	181.5
DELCO APPLIANCE CORP.	
32 Volt DC Super 110 Volt AC Super	175
DELCO RADIO	
3026	175
De WALD	
AC746-7M - EAM-62	175
PLG	115
800A	130
58R-60-81-81P	456
55X 58EX-59-61-583	456
570-630	456
ECHOPHONE RADIO MFG. CO., LTD.	
62-72-92	115
All Others	175
ELEC. RESEARCH LAB., INC. Erla -- Sentinel	
1020A-1030A	115
513-570*	262
560-561-510-263	265
540-589-600-602	265
501-502-570*	465
622-623-634-635	465
5000-5010-6101-6102	465
6317-6321	465
All Others	175
ELEC. AUTO LITE	
062A-072A	262
EMERSON	
L-755 - 50-L	115
375-LW	126
35-30-250-300-810	172.5
H5-77-667-678-965	172.5
J8-KS-CB-M-AC-7-B-AC-10	175
40-375-M-755-60M	175
350-LW - H5L - 30LW	132
250LW-321LW	152
AW55	445
26-30AW-33AW	456
250AW-321AW-350AW	456
39-59-71-770-8-755	456
550	456
ERLA	
See Electrical Research Lab.	
EMPIRE ELEC. PRODUCTS	
74	462.5
All Others	175
FADA RADIO & ELEC. CORP.	
RX93-RX95-PX	125
RN106-RN107-RN108	470
RY-RS112	470
131-132RU-133-134-135	265
78-10-79-10-97-10-141NA	265
151-152NE	265
All Others	175
FEDERATED PURCHASER	
31-40	175
FORDSON	
F.U.-F.W.-F.P.32V-F.P.	456
FRANKLIN	
63L	130
100-102-200	175
94	450
53-54L	456
FREED TEL. & RADIO CORP.	
76	115
81DC-72-74-MB7-360	175
360X	175
58-70-72-74	177.5
A7-A9-358-368-365X	456
94-55-77	456
78	462.5
JESSE FRENCH	
Models - U-1 up	175
CALVIN MFG. CO.	
J-8-810	175
Dual 6 - Twin 8	262
44-55-66-77-77A	456
GENERAL ELECTRIC CO.	
K64-M65-M68	370
K80-K80X-K85	449
M41-K43-M49	460
All Others	175
GENERAL HOUSEHOLD UTILITIES	
700-701-801-901-902-1101	262
501-502-503	455
GENERAL MOTORS	
281	535
All Others	175
GRAYBAR ELEC.	
340	180
All Others	175
GREBE	
61R	456
All Others	175
GRIGSBY-GRUNOW CO.	
260A-260B	125
44-49-104-440-560	456
566-195-85-89-75	456
116-370-400	456
10	1000
All Others	175
GULBRANSEN CO.	
10-13-20-23-55	175
92-93-322-130-135	175
235-236-237-530-535	175
925-3225-3226	175
3925-8726	175
V622-Z621-382	262
382-06W-3821	262
3825-3622	262
HALSON	
All Models	456
HAMMARLUND MFG. CO.	
All Models	465
CHARLES HOODWIN CO.	
Models 11 tube rec.	485
All Others	175
[illegible]	
56-69-90-70-71-1018	175
102-101-110	175
24-36-58-156-358	456
HOWARD RADIO CO.	
EX	140
G	170
Auto receivers	260
8-3	456
A S W Converter	600
All Others	175
INSULINE CORP.	
AC Super 7L.W.-AC Super 8L.W.	115
Super Conquerer Uni-nine	115
5 tube Uniradio-Elite-Classic	132
Super 7-AVC Super 6	175
INTERNATIONAL	
J8-KS-C8	175
Kaydette A-B-A8-9-10-CM	262.5
A7-PW-CD-D11-I2-14	262.5
AW55	445
JACKSON BELL	
25-27-28-29-69	175
205	465
33	840
KELLER-FULLER MFG. CO., LTD.	
Radiette Models 70-80-90	175
120-508	175

MODEL	K.C.
COLIN B. KENNEDY CORP.	
Model 67 (Export)	110
" 52 (Export)	135
33SW-54SW	1000
54	1525
All Others	175
KOLSTER RADIO, INC.	
All Models	175
LANG RADIO CORP.	
All Models	175
C. R. LEUTZ, INC.	
C10	47
Special Short Wave Receiver	480
LINCOLN RADIO CORP.	
Deluxe SW-33	480
DC-SW10 - R9	480
LYRIC RADIO	
See R. Wurlitzer Co.	
MAJESTIC	
See Grigsby-Grunow	
MID-WEST	
Miraco Pentode 11 tube super.	175
RT9-G9-F9-H9-RT16	456
A16-B16-D16-P.R.16-RH14	456
MISSION BELL	
10A-11-10-19A-25A	262
14-40	456
MONTGOMERY WARD	
62-11-62-12-62-14-62-27	175
62-19-62-20-62-20X-62-23	175
1111-62-1611-611-62-1711	175
62-29-11-12-17-62-1-62-2	175
62-7-62-8-62-9-62-60	175
62-91-62-93-62-103-62-108	175
62-106-62-107-62-121-77	175
95-11-11X-611X-62-14X	175
62-19X-62-60-62-31-62-31X	175
62-54-62-54X-62-56X	175
62-32-62-64-62-64X	175
62-76-62-76X-62-74-62-74X	175
62-80-62-88-62-23-62-41	175
62-83-62-10-62-10X-62-10	175
62-13-62-15-11-12-17	175
22-1040	175
1230-1630-1630X-62-26	262
62-26X-62-46-62-46X-1358	262
1358X-1968-62-22-62-22X	262
62-30-62-30X-62-42-62-42X	262
62-48-62-48X-62-36	262
62-36X-62-34-62-34X-62-38	262
62-38X-62-44-62-44X-62-50	262
62-50X-62-68-62-68X	262
62-21-13-15-16X-16	262
17-18-18X-62-1838	262
62-1955-62-40	262
Auto Radio-62-96-62-98	262
62-97-62-99-62-97X	262
62-99X-62-101-62-101X	262
62-104-87	262
62-70-62-70X-62-72	456
62-72X-62-81-62-81X	456
MOTOMETER GAUGE & EQUIP.	
10A	175
MOTOROLA AUTO RADIO	
See Galvin Mfg. Co.	
NATIONAL CO.	
A.G.S.	500
NOBLITT SPARKS	
10A-30A	175
20A-20B	175
OZARKA	
4 Super	250
PACKARD	
4-24-24C	235
4 tube Super 5	465
85 - 6 tube auto	470
PATTERSON RADIO CO.	
Straight Models	177.5
Amateur	467.5
70AW-107AW-207AW-210AW	262
80AW-84AW-506AW	262
104AW-510AW	262
PHILCO RADIO & TEL. CORP.	
7-A-12-15-17-37-48	175
51-51A-90-90A-111-111A-52	175
112-112A-116-116A-211-	175
211A-212-212A-Broadcast IF.	175
A-10-11-14-91-18-19-128	260
32-35-71-70-70A-270	260
270A-89-19-90-91A (with 2-47)	260
91-121-221-22L-23X 47DC	260
Broadcast I.F. 503	260
700-22-23-36-37-47DC Series	260
43-53-80	450
5-16-34-34A-38-38A	460
44-57-60-61-64-144	460
504-506-80	460
4-470-470A SW-I.R-490 SW-I.F.	1000
4 & 4C Series	3600

MODEL	K.C.
PILOT RADIO & TUBE CORP.	
8-81-10AC-11-20-30-41	115
1010	115
8148-8164-C168-C165	175
C153-C154-140	175
2-82-F14-10-80-D-8	456
81	462
4 tube D.C.	462.5
PLAZA MUSIC (HAMILTON LLOYD RADIOS)	
711 Super-6 tube LW-7 tube Super	175
5 tube Super	456
RADIO BAR	
505	175
508-526-2109-510	262
RADIO CHASSIS	
L6D	115
L6W	125
Auto Set-A6D-L6A5Y	175
AC-36-6AC-36-L6A36	175
L5D	456
RCA-VICTOR CO., INC.	
R7LW	110
R51-62-64	180
121-122-221-Duo 320	370
Duo 321	370
140-141-141E-240-Duo 340	445
9 tube General Purpose-340-340E	445
301	460
SW Adapter	1000
SWA2-RO-23 (SWIP)	1075
All Others	175
RADOLEK	
951	265
956-980	465
RADIOTROPE	
70B-71B-72B-73B	262
REMLER CO., LTD.	
Best 115KC	115
10-15-3-17-19-15-21	180
10-3-21-3	250
21-4-26-30-40-11-18-13	450
REPUBLIC INDUSTRIES	
8L6	115
8L5D-8L6D	175
Sky Hawk Patrician-S.K.PC5-PC6	175
SCOTT LABS., INC.	
All Wave Super	470
SEARS ROEBUCK	
1320-1322-1324-1390-1400	175
1402-1404-1406-1430	175
1462-1480-1482-1484	175
1580-1582-1584-1570	175
1572-1574-1590-1592	175
1630-1640-1700	175
1705	175
1708-1709-1710-1711	175
7090-1712-1713-1714	175
1715-1720-1725-7065	175
1721-1722-1732-1726X	175
1730-1790	175
1704-7070-7071-7072-7073	460
7074-1706-1707-1711A	460
7090A-1760-7075-7076	460
7077-7078-7081-7082	460
7083-7084	460
1600	1000
SENTINEL RADIO	
See Elec. Research Lab.	
SILVER-MARSHALL, INC.	
36A-Bearcat Midget-714	175
716-683-724-726-728	175
773-A-B-C-D-E-G-J-R	175
4801-4802-41-724B-726BW	175
782-1040-F	175
727-729BW-Z10-G-GD-R-RT-V-X-Y	465
Z Deluxe Z13	472.5
738	1000
SIMPLEX RADIO CO.	
B-K-J-L-R-P-G	175
P-AC-P-32V-W	456
V-T	465
SONORA	
70-71-72-73-84-85-86-87	262
SPARKS-WITHINGTON CO.	
10-12-14-15-16-16AW-18-25-26	172.5
26AW-27-27A-30-33-34-36	172.5
45-56-72-74-75-28-30A-35	172.5
61-62-71-71P-81-82-333	456
STEINITE	
All Models	175
STEWART-WARNER	
102A-0 & E-R102-A-B & E	177.5
R104A-B & E Broadcast I.F.	177.5
1090-91-92-93-94-95-96-97-98-1099	177.5
R106-R110-R117-R119-R120	177.5
R111-R115-R112-R116	456
105 (SWIP)	1525
STROMBERG-CARLSON	
33	260
All Others 175 KC	175

MODEL	K.C.
SUPERTONE PRODUCTS	
Superba	465
L. TATRO PRODUCTS	
L-74-N74-AK54-AN54-O94	175
O84-P54	177.5
TRANSFORMER CORP. OF AMERICA	
125 (Export Model	100
80-81-90-90A-91-84-85-94-25-94	175
100-120-139-160-25-16C-220-280	175
280-300-320-340-420	175
422-423-425-440-480	465
240	490
200	600-1000-1500
TRAVELER RADIO & TEL. CO.	
8-8 - 8-9 - 8-10	175
UNITED AIR CLEANER	
All Models	175
UNITED AMERICAN BOSCH	
10-20J-20K-20L-31-32-36-37	175
40-41-92-100 Auto-108-150	175
160-236-237-242-243-250-251	175
312-313-226-313	175
140A-305A-360-500-502	456
305-405-805-117-127-500	456
260-261	517.5
325-20-22-36-40-91	125
100-150-224	125
UNITED MOTORS SERVICE	
2035-4036-4037 & DOP receivers	262
4048	455
U.S. RADIO & TELEVISION	
7-8-10-10C-9-19-12-120	262
69-99-1006-1007-3070-9A-9B	262
12B-19B-120B	262
5A-70-24-25-3040-3056-25A	455
VICTOR RADIO	
See RCA Victor	
WARE MFG. CO.	
All Models	175
WELLS GARDNER, INC.	
00A-02A-06A-07A-022	175
073-092-40-40A-50	175
92-93-502-572	175
05A-05AA-05BA-06W-072	262
052-062-50-V622-V621	262
6V	262.5
7D	456
WESTINGHOUSE	
Flat top in some cases	175
WESTARK RADIO, INC.	
Knight 7 & 9 tube	175
WHOLESALE RADIO	
10-20-L1-80M-80MA	175
L-20 - Auto Radio	262
WILCOX-GAY	
3PA 6-66	115
2S5-2T5-2VA7-3D5	175
3R6-3J8-3H8-37566	175
3T665	175
WONDER BAR RADIO CORP.	
All Models	175
RUDOLPH WURLITZER CO.	
LW5	125
SA-133-SA120-SA99-SA5-SA6	176
S6-SA130-SA110-SA111-SA91	176
SA91A-S50-S63-SA65-S80	175
S7-S6-S8-S10-DC65-S80	175
SA130-460	175
C4-M4-P5-SU5-A60-U500	456
U50-S40	456
SW8-LU5-450	456
SW8-A60-SW80-SW80	465
U60-U58	465
ZENITH RADIO CORP.	
91-92-AH-CH-RH-BH-LH-WH	175
WH-103-210-220-230-240-245	175
Broadcast I.F. 410-411-420-430	175
440-500-501-503-514-515	175
600-604-606-610-616-618-718	175
755-756-474-730-735-740	175
770-760-765-767-475-775	175
780-476-476A-770B-775B	175
215-216-217-221-225-241	172
244-263-271-412-414-441	175
442-443-470-502-516-520	175
521-530-531-532-602-603	175
605-607-608-611-612-614-615	175
617-619-620-621-622-623	175
210-5 - 211-5 - 270-5 - 510-5	125
462-550HD-651HE-660TD	252.5
661TE	252.5
701	456
460-705-706-707-711-517	465
712-750-2056-2056-1	465
518 - 550	465
250-251-252-260-261	465
272-472-473	175 & 1000
CANADIAN RECEIVERS	
Brunswick of Canada	175
Canadian Marconi Co.	175
Canadian Westinghouse Co., Ltd...Models 89, 90, 99, 99A, 110, 120	171
Columnaires 8, 10 and Models 101, 601, 602	175
DeForest Crosley	175
Grimes Radio Corp.	175
C. B. Kennedy of Canada, Ltd.	175
Mohawk Radio Ltd.	175
Northern Elec. Co., Ltd.	175
Rogers Majestic Co., Ltd.	175

NO. 23

PRACTICAL RADIO JOB SHEET

SPECIALLY PREPARED FOR THE STUDENTS OF

NATIONAL SCHOOLS

Los Angeles California

ALIGNING PEAKED I.F. AMPLIFIERS

ALL SUPERHETERODYNE RECEIVERS WHICH DO NOT EMPLOY A SPECIALLY DESIGNED FLAT-TOP OR BAND-PASS I.F. AMPLIFIER USE WHAT IS KNOWN AS A "PEAKED I.F. AMPLIFIER". THE PROCEDURE FOR ALIGNING A PEAKED I.F. AMPLIFIER IS AS FOLLOWS:

1. — FIRST ASCERTAIN THE EXACT INTERMEDIATE FREQUENCY FOR WHICH THE I.F. AMPLIFIER IN QUESTION IS DESIGNED. THIS CAN BE DETERMINED FROM FACTORY SPECIFICATIONS, BY REFERRING TO JOB SHEET #22, OR ELSE BY MEANS OF TESTS WHICH ARE DESCRIBED IN FOLLOWING JOBSHEETS.

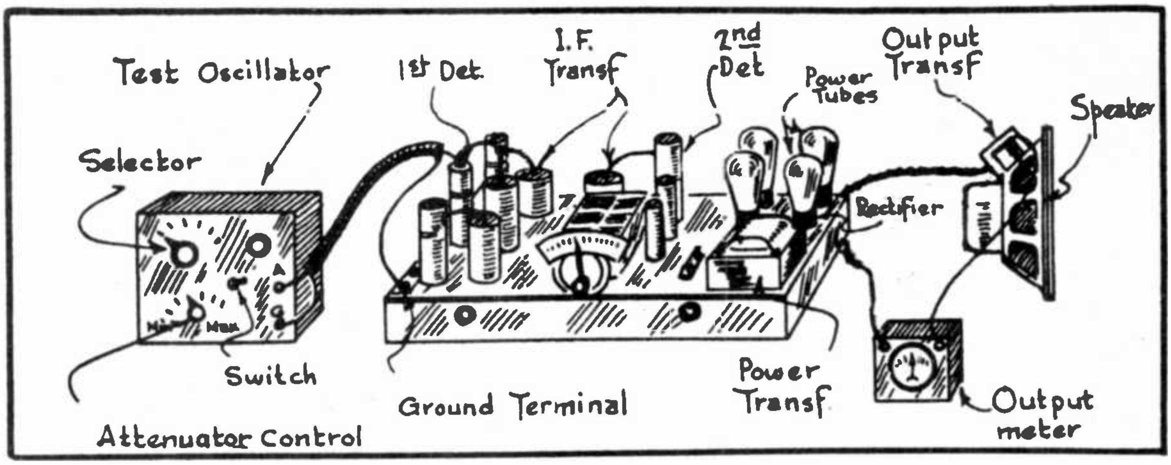

Fig. 1
Set-Up For Aligning The I.F. Stages.

2. — DISCONNECT THE ANTENNA LEAD-IN FROM THE RECEIVER BUT LEAVE THE GROUND WIRE IN PLACE.

3. — CONNECT THE INNER WIRE OF THE TEST OSCILLATOR'S SHIELDED OUTPUT CABLE TO THE CONTROL GRID OF THE FIRST DETECTOR OR MIXER TUBE AS SHOWN IN FIG. 1 AND CONNECT THE OUTER SHIELD OF THIS WIRE TO THE RECEIVER'S GROUND TERMINAL. PERMIT THE CONTROL GRID CONNECTION OF THE MIXER TUBE TO REMAIN IN POSITION AND ALSO PERMIT THE SHIELD OF THIS TUBE TO REMAIN IN PLACE.

4. — CONNECT THE OUTPUT METER TO THE RECEIVER CIRCUIT IN THE PROPER MANNER AND WITH THE TEST OSCILLATOR'S ATTENUATION CONTROL SET AT THE MINIMUM POSITION, ADJUST THE TEST OSCILLATOR FOR THE CORRECT I. F. FREQUENCY OF THE PARTICULAR RECEIVER IN QUESTION.

5. — TEMPORARILY SHORT CIRCUIT THE RECEIVER'S OSCILLATOR TUNING CONDENSER SO AS TO PREVENT ITS OPERATION DURING THE ALIGNING PROCESS. TURN ON BOTH THE RECEIVER AND THE TEST OSCILLATOR, TURN THE RECEIVER'S VOLUME CONTROL TO THE "FULL ON" POSITION AND CAREFULLY ADJUST THE ATT-

enuation control of the test oscillator until the output meter reads about one-half full scale deflection. Be sure that the output signal of the test oscillator is being modulated in the event that a switch for either a modulated or unmodulated signal is furnished on it.

6. – Commencing with the tuning condenser of the secondary winding corresponding to the I.F. transformer preceding the second detector, adjust this condenser carefully with a special insulated aligning tool until the greatest reading is indicated on the output meter. If the indicator exceeds a half-scale reading during the process of adjustment, then readjust the attenuation control of the test oscillator so that the output meter returns to a half-scale reading.

7. – Continue by next adjusting the primary tuning condenser of the same I.F. transformer for maximum reading of the output meter. With this adjustment made, re-check the secondary tuning condenser adjustment because it is frequently affected by any change made in the tuning of the primary circuit. Also re-check the primary circuit tuning after making any change in the secondary tuning circuit.

8. – Repeat the same procedure as just explained for each of the remaining I.F. transformers, gradually working towards the mixer tube. In all cases, always tune the secondary circuit before the primary circuit and then re-check both circuits.

HOW TO OPERATE A 110 VOLT A.C. RECEIVER FROM A 220 VOLT CIRCUIT

Occasionally, the radio technician is confronted with the problem where a receiver which is designed to operate from a 110 volt A.C. line is expected to be operated from a 220 volt A.C. line.

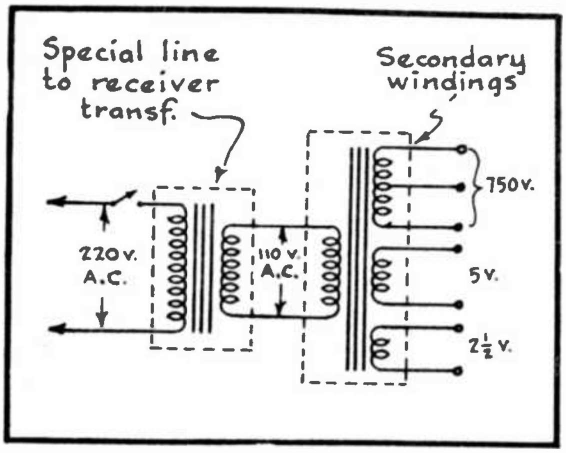

Fig. 2
Transformer Connections.

1. – One method of solving this problem is to remove the power transformer and in its place mount another transformer whose primary winding is designed for 220 volts and which is capable of furnishing the same secondary voltages and currents as the original transformer.

2. – Another solution is to leave the original power transformer in the receiver and to connect a special line transformer between the A.C. line and the primary winding of the receiver transformer as shown in Fig. 2. The primary winding of this special transformer is designed for 220 volts and its secondary for 110 volts. The watt-rating of this special transformer must be at least equal to that of the receiver.

PRACTICAL RADIO JOB SHEET

SPECIALLY PREPARED FOR THE STUDENTS OF

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Los Angeles California

ALIGNING BAND-PASS I. F. AMPLIFIERS

IN SUPERHETERODYNE RECEIVERS OF THE HIGH-FIDELITY TYPE THE I.F. TRANSFORMERS ARE SO DESIGNED AND ADJUSTED THAT THEY ARE RATHER BROAD TUNING SO AS TO AVOID SUPPRESSION OF THE SIDE BANDS AND THEREBY MAKE A BETTER TONE QUALITY POSSIBLE. THESE "FLAT-TOP" TRANSFORMERS HAVE THEIR WINDINGS MORE CLOSELY COUPLED THAN DO THE SHARP TUNING I.F. TRANSFORMERS AND ARE GENERALLY ADJUSTED TO PASS A BAND OF FREQUENCIES FROM 5 TO 7.5 KC. EACH SIDE OF THE MAIN INTERMEDIATE FREQUENCY.

TO ALIGN I.F. AMPLIFIERS OF THIS TYPE PROCEED IN THE FOLLOWING MANNER:

1. - FIRST DETERMINE FROM FACTORY SPECIFICATIONS THE MAIN INTERMEDIATE FREQUENCY BEING USED AND THE FREQUENCY RANGE OVER WHICH THE RESPONSE CURVE IS TO BE "FLAT-TOPPED". EXAMPLE: A CERTAIN RECEIVER REQUIRES THAT ITS MAIN INTERMEDIATE FREQUENCY BE 175 KC. AND THAT ITS RESPONSE CURVE BE FLAT-TOPPED FROM 170 KC. TO 180KC. THIS I.F. AMPLIFIER WOULD BE ALIGNED AS FOLLOWS:

2. - CONNECT A TEST OSCILLATOR AND OUTPUT METER TO THE RECEIVER IN THE SAME MANNER AS EXPLAINED IN JOBSHEET #23. ADJUST THE TEST OSCILLATOR FOR THE UPPER FLAT-TOP FREQUENCY LIMIT OF 180 KC. AND ADJUST FOR HIGHEST OUTPUT THE SECONDARY CIRCUIT OF THE I.F. TRANSFORMER WORKING IN TO THE SECOND DETECTOR. THEN ADJUST THE TEST OSCILLATOR FOR THE LOWER FLAT-TOP FREQUENCY LIMIT, OR 170 KC. IN THIS PARTICULAR CASE, AND ADJUST THE PRIMARY CIRCUIT OF THIS SAME I.F. TRANSFORMER FOR MAXIMUM OUTPUT AT THIS FREQUENCY.

3. - THE SAME PROCEDURE IS CARRIED OUT AT EACH I.F. TRANSFORMER, GRADUALLY WORKING TOWARDS THE MIXER TUBE AND EACH ADJUSTMENT SHOULD BE RE-CHECKED AT LEAST THREE TIMES SO AS TO INSURE AN ACCURATE SETTING.

4. - AS A FINAL CHECK ROTATE THE DIAL OF THE TEST OSCILLATOR THRU THE FLAT-TOP FREQUENCY RANGE CALLED FOR. THE OUTPUT METER READING SHOULD VARY ONLY SLIGHTLY AND THE CHANGE IN READING SHOULD BE THE SAME ON EITHER SIDE OF THE MAIN INTERMEDIATE FREQUENCY.

5. - ANOTHER METHOD WHICH IS SOMETIMES USED IS TO FIRST ADJUST BOTH THE SECONDARY AND PRIMARY OF EACH I.F. TRANSFORMER TO THE MAIN INTERMEDIATE FREQUENCY AND THEN SLIGHTLY DETUNE ONE OF THE WINDINGS ABOVE AND THE OTHER BELOW UNTIL ONLY A SLIGHT VARIATION IN THE OUTPUT METER READING IS OBTAINED UPON ROTATING THE DIAL OF THE TEST OSCILLATOR THRU THE FLAT-TOP FREQUENCY RANGE WHICH IS DESIRED.

NO. 25

PRACTICAL RADIO JOB SHEET

SPECIALLY PREPARED FOR THE STUDENTS OF

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Los Angeles California

DETERMINING AN UNKNOWN INTERMEDIATE FREQUENCY

IN THE EVENT THAT THE CORRECT I.F. FOR A PARTICULAR RECEIVER IS NOT KNOWN AND CANNOT BE OBTAINED BY REFERRING TO ANY SPECIFICATION CHARTS, THEN IT CAN BE DETERMINED IN THE FOLLOWING MANNER:

1. - CONNECT A TEST OSCILLATOR AND OUTPUT METER TO THE RECEIVER IN QUESTION IN EXACTLY THE SAME MANNER AS WHEN ALIGNING THE I.F. AMPLIFIER.

2. - SLOWLY TUNE THE TEST OSCILLATOR FROM ITS LOWER I.F. FREQUENCY LIMIT TOWARDS ITS HIGHER I.F. FREQUENCY LIMIT AND NOTE AT WHICH OF ITS SETTINGS THAT THE OSCILLATOR FREQUENCY IS AMPLIFIED BY THE RECEIVER. ALSO NOTE THE EXTENT TO WHICH THE NEEDLE OF THE OUTPUT METER DEFLECTS.

3. - WE SHALL ASSUME THAT A SIGNAL IS OBTAINED AT THE 87.5 KC AND THE 175 KC. SETTING OF THE TEST OSCILLATOR AND THAT IN ADDITION THE SIGNAL STRENGTH AVAILABLE AT THE RECEIVER OUTPUT IS GREATER WHEN THE TEST OSCILLATOR IS ADJUSTED FOR 175 KC.

4. - UNDER THE CONDITIONS DESCRIBED, IT IS CLEAR THAT WHEN THE TEST OSCILLATOR WAS TUNED TO A FUNDAMENTAL OF 87.5 KC., THE RECEIVER AMPLIFIED ITS SECOND HARMONIC OR 175 KC. FURTHERMORE, THE FACT THAT THE SIGNAL STRENGTH AT THE RECEIVER OUTPUT WAS GREATEST WITH THE OSCILLATOR ADJUSTED FOR 175 KC., THAT THIS SAME VALUE IS AN EXACT HARMONIC OF THE 87.5 KC. SIGNAL AND THAT A FREQUENCY OF 175 KC. IS A STANDARD INTERMEDIATE FREQUENCY FOR SUPERHETERODYNE RECEIVERS, PERMITS US TO COME TO THE CONCLUSION THAT THE PROPER INTERMEDIATE FREQUENCY FOR THIS PARTICULAR RECEIVER IS 175 KC.

5. - SOMETIMES, YOU MAY FIND THAT SIGNALS APPEAR WHEN THE TEST OSCILLATOR IS ADJUSTED TO SOME ODD VALUE. THIS IS QUITE NATURAL SINCE THE FUNDAMENTAL WHICH HAS A HARMONIC EQUAL TO THE I.F. PEAK MAY BE AN ODD FREQUENCY. FOR EXAMPLE, IF THE I.F. AMPLIFIER OF A RECEIVER IS 252.5 KC., THEN A SIGNAL WILL APPEAR WHEN THE TEST OSCILLATOR IS TUNED TO THIS FREQUENCY AND ALSO WHEN IT IS TUNED TO 126.25 KC. LIKEWISE, IF THE I.F. AMPLIFIER IS PEAKED AT 460 KC., SIGNALS MAY APPEAR WITH THE TEST OSCILLATOR TUNED TO 460 KC., 230 KC., 153.3 KC. AND AT 115 KC.

6. - WHEN CONDUCTING TESTS OF THIS NATURE GREAT CARE MUST BE EXERCISED AND HASTY CONCLUSIONS SHOULD BE AVOIDED BECAUSE THE APPEARANCE OF HARMONICS CAN READILY CAUSE CONFUSIONS WHICH LEAD TO ERRORS.

PRINTED IN U.S.A.

NO. 26

PRACTICAL RADIO JOB SHEET

SPECIALLY PREPARED FOR THE STUDENTS OF

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Los Angeles California

Printed in U. S. A.

ALIGNING THE OSCILLATOR AND R.F. SECTION OF SUPERHETERODYNES

NO ATTEMPT SHOULD BE MADE TO MAKE ANY ADJUSTMENT ON THE ALIGNMENT OF THE OSCILLATOR, FIRST DETECTOR OR PRE-SELECTOR STAGE OF A SUPERHETERODYNE RECEIVER UNTIL IT HAS FIRST BEEN DEFINITELY ASCERTAINED THAT THE I.F. STAGES ARE ALL PROPERLY ALIGNED.

ALIGNING THE OSCILLATOR

WITH THE RECEIVER IN AN OPERATING CONDITION, THE PROCEDURE FOR ALIGNING THE OSCILLATOR CIRCUIT IS AS FOLLOWS:

1. - FIRST CONNECT THE SERVICE OSCILLATOR AND OUTPUT METER TO THE RECEIVER AS ILLUSTRATED IN FIG. 1.

2. - THE ADJUSTMENTS FOR THE OSCILLATOR TUNING CIRCUIT IN THE CONVENTIONAL TYPE OF SUPERHETERODYNE RECEIVER ARE POINTED OUT TO YOU IN FIG. 2.

3. - COMMENCE ALIGNING THE RECEIVER'S OSCILLATOR CIRCUIT BY FIRST ADJUSTING THE HIGH FREQUENCY TRIMMER. TO DO THIS, SET THE FREQUENCY SELECTOR OF THE SERVICE OSCILLATOR SO THAT THIS APPARATUS WILL PRODUCE A 1400 KC. SIGNAL FREQUENCY, SET THE VOLUME CONTROL OF THE RECEIVER TO ITS MAXIMUM POSITION AND ITS TUNING DIAL TO THE 1400 KC. POSITION.

4. - TURN "ON" THE SWITCH OF BOTH THE RECEIVER AND THE SERVICE OSCILLATOR AND ADJUST THE ATTENUATOR OF THE SERVICE OSCILLATOR UNTIL A

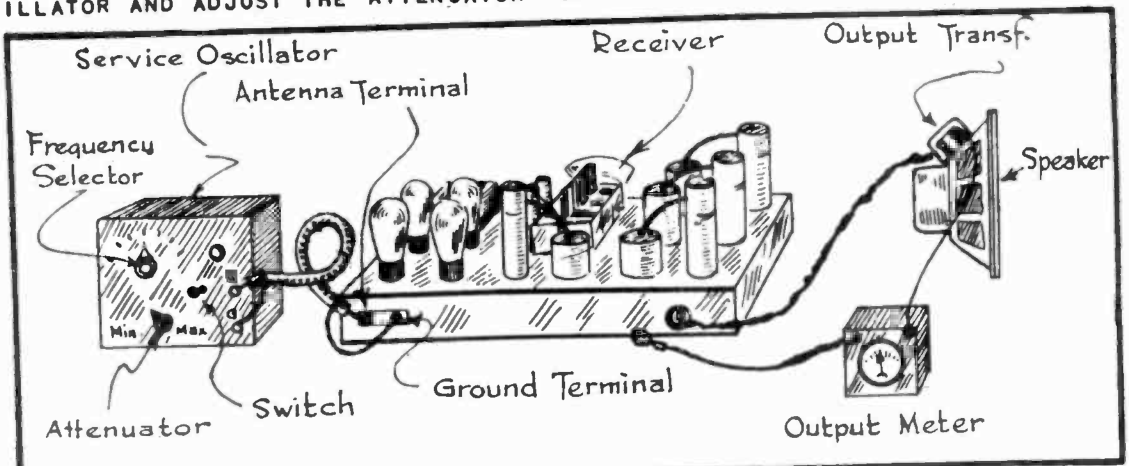

FIG. 1
SET-UP FOR ALIGNING RECEIVER'S OSCILLATOR AND R.F. CIRCUITS.

ONE-HALF SCALE READING IS OBTAINED ON THE OUTPUT METER. IF THE RECEIVER IS BADLY OUT OF ADJUSTMENT, THEN THIS METER READING MAY BE DIFFICULT TO OBTAIN BUT IF SUCH BE THE CASE, THE SIGNAL AS COMING FROM THE SPEAKER CAN BE USED AS A TEMPORARY GUIDE.

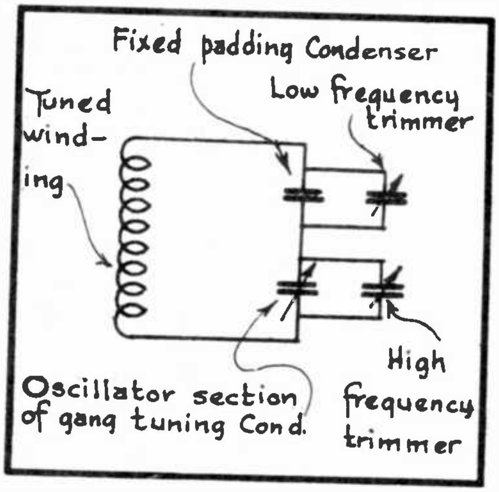

FIG. 2
OSCILLATOR ADJUSTMENTS.

5. - ADJUST THE HIGH FREQUENCY TRIMMER CONDENSER OF THE RECEIVER'S OSCILLATOR CIRCUIT CAREFULLY FOR MAXIMUM READING ON THE OUTPUT METER OR FOR MAXIMUM SIGNAL VOLUME IN THE SPEAKER. AFTER MAKING THIS ADJUSTMENT, TURN THE TUNING DIAL OF THE RECEIVER SLIGHTLY BOTH WAYS FROM ITS 1400 KC. SETTING AND NOTE WHETHER OR NOT ANY INCREASE IN THE METER READING OR SOUND VOLUME IS OBTAINED. IF SO, THEN THE R.F. AND FIRST DETECTOR TRIMMER CONDENSERS MUST BE ADJUSTED AS WILL BE DESCRIBED SHORTLY.

6. - THE NEXT STEP IS TO ADJUST THE RECEIVER OSCILLATOR AT THE LOW FREQUENCY END OF THE DIAL. TO DO THIS, LEAVE THE SERVICE OSCILLATOR AND OUTPUT METER CONNECTIONS JUST AS THEY ARE BUT SET THE FREQUENCY SELECTOR OF THE SERVICE OSCILLATOR TO THE 700 KC. POSITION AND ALSO SET THE TUNING DIAL OF THE RECEIVER TO THE 700 KC. POSITION. NOW ADJUST THE "LOW FREQUENCY TRIMMER" FOR MAXIMUM READING ON THE OUTPUT METER OR MAXIMUM SIGNAL STRENGTH IN THE SPEAKER. IT IS ADVISABLE TO AGAIN RECHECK THE HIGH FREQUENCY ADJUSTMENT IN CASE THAT IT HAS BECOME AFFECTED BY THE LOW FREQUENCY ADJUSTMENT AND TO MAKE ANY FINAL CORRECTION AS FOUND NECESSARY.

ALIGNING THE R.F. STAGES

7. - TO ALIGN THE R.F. AND FIRST DETECTOR STAGES, LEAVE THE SERVICE OSCILLATOR AND OUTPUT METER CONNECTIONS AS THEY ARE AND ALSO LEAVE THE ANTENNA LEAD-IN WIRE CONNECTED TO THE RECEIVER. SET THE FREQUENCY SELECTOR OF THE SERVICE OSCILLATOR TO THE 1400 KC. POSITION AND ALSO SET THE TUNING DIAL OF THE RECEIVER TO THE 1400 KC. POSITION. THEN ADJUST THE TRIMMER OR COMPENSATOR CONDENSERS OF THE R.F. AND FIRST DETECTOR SECTIONS OF THE GANG TUNING CONDENSER SO AS TO OBTAIN THE MAXIMUM READING ON THE OUTPUT METER.

8. - AFTER THE ENTIRE SET HAS ONCE BEEN ALIGNED IN THIS MANNER, IT IS ADVISABLE TO RECHECK THE OSCILLATOR, FIRST DETECTOR, AND R.F. ADJUSTMENTS OF THE RECEIVER OVER THE ENTIRE TUNING RANGE.. IF ANY FURHTER ADJUSTEMNTS ARE REQUIRED IN THE MEDIUM FREQUENCY RANGE, THEY CAN BE MADE BY BENDING THE SLOTTED ROTOR PLATES OF THE TUNING CONDENSER.

PRACTICAL RADIO JOB SHEET
NO. 27
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Aligning Receivers Using A. V. C.

The operation of automatic volume control systems is such that the receiver output is kept practically constant with changes in the input signal intensity due either to signal strength or sensitivity of the circuit. This being true, wide changes in the alignment of the receiver will in some instances not produce any noticeable changes in the indication of the output meter. For these reasons, special precautions must be exercised when aligning superheterodynes which are equipped with an automatic volume control system. The methods used in such cases may be any one of the following:

1. - Use a very weak signal from the test oscillator so that the A.V.C. action does not occur. This applies particularly when delayed A.V.C. is used.

2. - If a separate A.V.C. tube is employed in the circuit, then open the lead which delivers the signal to the control grid of the A.V.C. tube. This lead should remain open during all aligning procedures.

3. - In systems where a single tube functions as an A.V.C. tube as well as a second detector (also as an A.F. amplifier in some instances), disconnect the lead which picks off the A.V.C. voltage from the A.V.C. circuit and delivers it to those tubes of the circuit which are controlled by A.V.C. action.

4. - In some receivers of the type mentioned in note #3, the receiver will not operate properly due to lack of sufficient bias voltage for some of the R.F. tubes. If this is true, the normal bias can be furnished by connecting the end terminals of a 100,000 ohm potentiometer across the terminals of a 45 volt B battery. Connect the positive B battery terminal to the receiver chassis, open the same receiver lead as described in note #3 and to the arm terminal of the potentiometer connect that part of the lead which goes to the grid circuits of the controlled tubes. Adjust this potentiometer for normal bias voltage and proceed with the aligning work.

5. - Any one of these methods will make the A.V.C. system inoperative so that accurate output meter indications may be obtained during the process of aligning the receiver.

NO. 28

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TESTING ELECTROLYTIC CONDENSERS

1. - WHEN IN DOUBT AS TO THE CONDITION OF AN ELECTROLYTIC CONDENSER, THIS TYPE OF CONDENSER CAN BE TESTED BY MEANS OF THE CIRCUIT SHOWN IN FIG. 1.

2. - A COMPLETELY SHORTED OR OPEN CONDENSER CAN OF COURSE BE DETERMINED VERY QUICKLY, SIMPLY BY MAKING A CONVENTIONAL CONTINUITY TEST THROUGH THE CONDENSER BUT THIS CRUDE METHOD DOES NOT TELL ONE HOW GOOD AN ELECTROLYTIC CONDENSER IS.

3. - NOTICE IN FIG. 1 THAT A D.C. VOLTAGE OF ABOUT 400 VOLTS SHOULD BE AVAILABLE AND THIS CAN BE IN THE FORM OF SERIES CONNECTED "B" BATTERIES OR ANY FILTERED "B" POWER SUPPLY. THE POSITIVE END OF THE BATTERY MUST BE CONNECTED TO THE POSITIVE SIDE OF THE CONDENSER. THE 2000 OHM RESISTOR IS USED SOLELY AS A PRECAUTIONARY MEASURE IN ORDER TO PROTECT THE METER IN CASE THE CONDENSER SHOULD BECOME SHORT CIRCUITED.

4. - IF THE CONDENSER HAS BEEN OUT OF USE FOR SOME TIME, IT IS ADVISABLE TO FIRST CONNECT THE BATTERY ACROSS IT WHILE THE METER IS DISCONNECTED FROM THE CIRCUIT. THE CONDENSER SHOULD BE CHARGED IN THIS MANNER FOR AT LEAST 5 MINUTES, SO THAT A GOOD DIELECTRIC WILL BUILD UP.

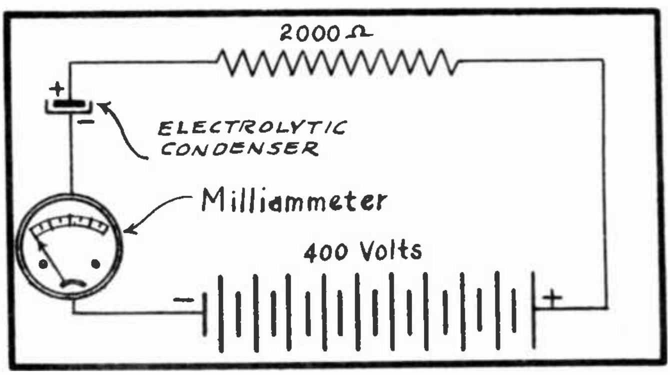

FIG. 1
SET-UP FOR TEST.

5. - WITH THE CIRCUIT CONNECTED AS SHOWN IN FIG. 1, THE MILLIAMMETER SHOULD REGISTER A LEAKAGE CURRENT OF FROM 0.05 TO 0.5 MILLIAMPERE PER MICROFARAD. THAT IS, IF AN 8 MFD. CONDENSER IS BEING TESTED IN THIS MANNER AND THE LEAKAGE CURRENT IS FOUND TO BE ANYWHERES BETWEEN .4 AND 4 MILLIAMPERES, THEN THE CONDENSER CAN BE CONSIDERED AS BEING IN A GOOD CONDITION.

6. - THE LEAKAGE CURRENT GENERALLY DECREASES TO ITS MINIMUM VALUE AFTER THE CONDENSER HAS BEEN WORKING FOR A CONSIDERABLE TIME.

NO. 29

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AUTOMATIC VOLUME CONTROL TROUBLES

WEAK RECEPTION

1. - POOR A.V.C. TUBE -- IT MAY BE GASSY OR SUPPLY TOO HIGH AN EMISSION. CHECK FOR THIS CONDITION BY TUNING IN A WEAK STATION AND THEN WITHDRAW A.V.C. TUBE FROM ITS SOCKET. IF THE VOLUME INCREASES CONSIDERABLY, REPLACE THIS TUBE WITH A NEW ONE. QUITE OFTEN, SEVERAL TUBES OF THE SAME TYPE MUST BE TRIED UNTIL SATISFACTORY OPERATION IS OBTAINED.

2. - IF A.V.C. TUBE IS O.K., CHECK GRID VOLTAGE AND PLATE CURRENT OF A.V.C. TUBE. IF GRID VOLTAGE IS TOO LOW, THIS TUBE WILL PASS PLATE CURRENT WHEN NO SIGNAL VOLTAGES ARE APPLIED TO ITS GRID AND THUS DELIVER AN EXCESSIVE BIAS VOLTAGE TO THE CONTROLLED TUBES, THEREBY REDUCING THE VOLUME.

3. - CHECK BIAS VOLTAGE OF CONTROLLED TUBES WHEN TUNED TO A STATION. IF THIS VOLTAGE IS EXCESSIVE, SUSPECT A LEAKY BY-PASS CONDENSER BETWEEN GROUND AND THE A.V.C. LEADS TO THE GRID CIRCUITS OF THE CONTROLLED TUBES.

NO RECEPTION

1. - CHECK GRID BIAS OF CONTROLLED TUBES. IF THIS IS EXCESSIVE, THERE IS A POSSIBILITY OF A LACK OF BIAS VOLTAGE AT THE A.V.C. TUBE DUE TO AN OPEN RESISTOR IN THE GRIDCIRCUIT OR LEAKY BY-PASS CONDENSERS.

2. - DEFECTIVE A.V.C. TUBE.

3. - OPEN CIRCUITED A.V.C. COUPLING CONDENSER.

INTERMITTENT A.V.C. ACTION

1. - IF RECEPTION IS NORMAL FOR A MINUTE OR TWO AFTER FIRST TURNING ON RECEIVER AND THE VOLUME THEN GRADUALLY DECREASES UNTIL EVEN POWERFUL STATIONS ARE RECEIVED WEAKLY, THEN THE GRID BY-PASS CONDENSERS OF THE A.V.C. SYSTEM SHOULD BE CHECKED FOR LEAKAGE.

2. - IF RECEPTION HAS BEEN NORMAL FOR AN HOUR OR TWO AND THEN GRADUALLY FADES, LEAKY A.V.C. GRID BY-PASS CONDENSERS SHOULD BE SUSPECTED.

ABRUPT A.V.C. ACTION

IF STATIONS ARE TUNED IN WITH A SUDDEN "PLOPPING" SENSATION SO AS TO MAKE IT DIFFICULT TO TUNE THE RECEIVER TO A POINT OF RESONANCE, THEN THIS MAY BE DUE TO ANY ONE OF THE FOLLOWING CONDITIONS: (A) EXCESSIVE HEATER VOLTAGE FOR THE A.V.C. TUBE; (B) PLATE RESISTOR OF TOO HIGH VALUE USED IN A.V.C. CIRCUIT.

DISTORTION

DISTORTION CAUSED BY OVERLOADING OF R.F. OR I.F. STAGES, POOR A.V.C. CONTROL, OSCILLATION, AND MOTOR-BOATING MAY BE CAUSED BY A LEAKY OR SHORT CIRCUITED BY-PASS CONDENSER IN THE GRID-RETURN CIRCUITS OF THE R.F. AND I.F.STAGES TO WHICH THE A.V.C. ACTION IS APPLIED. FADING, WEAK,UNSTABLE, AND INTERMITTENT OPERATION MAY RESULT FROM THIS SAME CONDITION.

NO CONTROL OF VOLUME

IN SOME RECEIVERS EMPLOYING A.V.C. THE VOLUME IS NOT AFFECTED WHEN OPERATING THE VOLUME CONTROL. THIS IS ONLY THE CASE IF THE VOLUME CONTROL IS LOCATED IN SOME PART OF THE A.V.C. CIRCUIT AND NOT IN THE AUDIO PORTION OF THE RECEIVER. THIS CONDITION MAY BE DUE TO ANY ONE OF THE FOLLOWING REASONS:

1. - WEAK A.V.C. TUBE

2. - LEAKY BY-PASS CONDENSERS IN THE CONTROL GRID RETURN CIRCUITS OF A.V.C. CONTROLLED TUBES.

TIME LAG

MOST A.V.C. SYSTEMS ARE DESIGNED FOR OPERATION WITH A "TIME LAG". IN THIS WAY THE A.V.C. ACTION IS PREVENTED FROM BEING ABRUPT IN ACTION AND THUS ELIMINATES EXCESSIVE NOISE BETWEEN STATIONS WHEN OPERATING THE DIAL AT A REASONABLE SPEED. IF THE TIME LAG IS EXCESSIVE, SO AS TO MAKE IT DIFFICULT TO TUNE STATIONS TO THE POINT OF RESONANCE, THEN IT CAN BE REDUCED BY LOWERING THE VALUE OF THE BY-PASS CONDENSERS OR ISOLATING RESISTORS IN THE A.V.C. SYSTEMS.

NO. 30

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SERVICING SILENT TUNING SYSTEM

In Figs. 1 and 2 are shown two typical circuits which include the features of both the duplex diode type tube and noise suppression. By using these as examples, the following trouble analysis can be made.

INTER-STATION NOISE

In a system of the type illustrated in Fig. 1, this condition may be due to any one of the following causes:

1. - Arm of potentiometer R_2 shorted to chassis.

2. - Open screen grid resistor in silencing tube circuit.

3. - Defective silencing tube.

In the case of the circuit appearing in Fig. 2 this condition may be due to:

1. - Shorted or leaky 0.1 mfd. condenser by-passing the cathode of V_3.

2. - Leakage between cathode and heater of V_3. This same condition will cause a hum when the receiver is tuned to resonance and no A.V.C. action will occur.

DISTORTION

In the arrangement illustrated in Fig. 1, distorted or a choked-reproduction may be due to:

1. - Faulty adjustment of

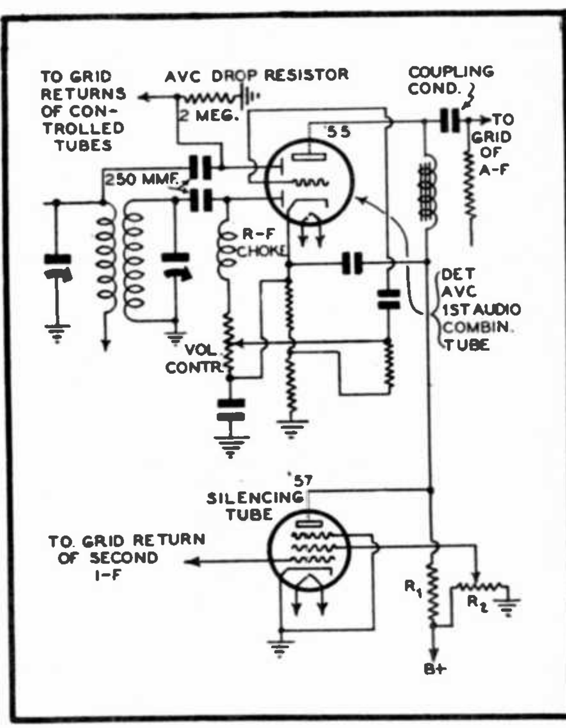

Fig. 1
A.V.C. With Noise Suppression.

R_2 OR WRONG RESISTANCE VALUE AT THIS POINT.

2. - GROUNDED SILENCING TUBE CONTROL-GRID LEAD.

3. - LEAKY BY-PASS CONDENSER IN THE A.V.C. CIRCUIT TO WHICH THE CONTROL GRID LEAD IS CONNECTED.

HEADPHONE CONNECTIONS

QUITE OFTEN, IT IS DESIRABLE TO CONNECT A SET OF HEADPHONES TO A MODERN RECEIVER WHICH IS BEING USED IN CONJUNCTION WITH A LOUD SPEAKER. THIS CAN BE DONE IN THE FOLLOWING MANNER:

1. - THE CIRCUIT AT "A" OF FIG. 3 ILLUSTRATES HOW THE HEADPHONE CONNECTION IS MADE ON A RECEIVER EMPLOYING A POWER STAGE WITH A SINGLE TUBE. THE 10,000 OHM POTENTIOMETER SERVES AS A VOLUME CONTROL FOR THE HEADPHONES. A "PLUG-JACK OFFERS A CONVENIENT METHOD BY MEANS OF WHICH THE HEADPHONES CAN BE CONNECTED TO THE CIRCUIT WHENEVER DESIRED.

2. - "B" OF FIG. 3 ILLUSTRATES HOW TO MAKE THE HEADPHONE CONNECTIONS IN A PUSH-PULL POWER STAGE.

3. - THE SWITCH IN THE SPEAKER CIRCUIT CAN EITHER BE USED OR NOT, DEPENDING UPON THE REQUIREMENTS OF THE PARTICULAR INSTALLATION. THE SWITCH IN THE HEADPHONE CIRCUITS AFFORDS A MEANS OF DISCONNECTING THE SHUNTING EFFECT OF THE HEADPHONE CIRCUIT WHEN NOT EMPLOYING HEADPHONE RECEPTION.

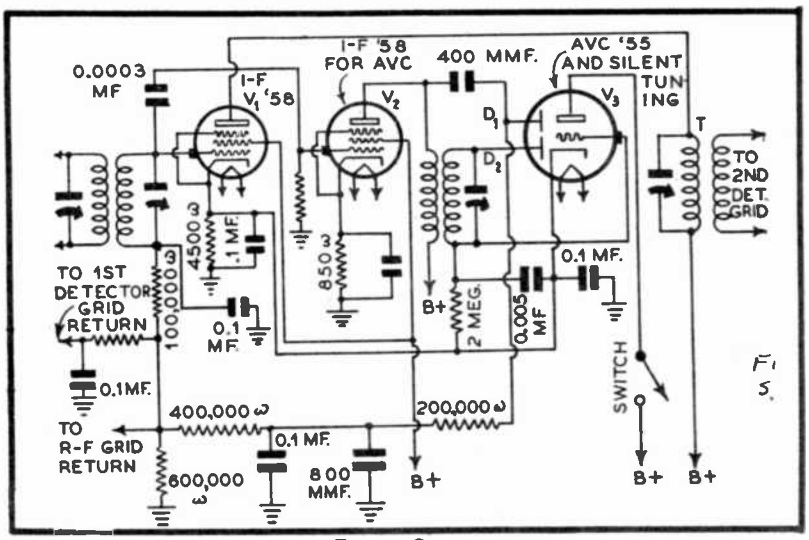

FIG. 2
COMBINATION A.V.C. AND SILENCING TUBE.

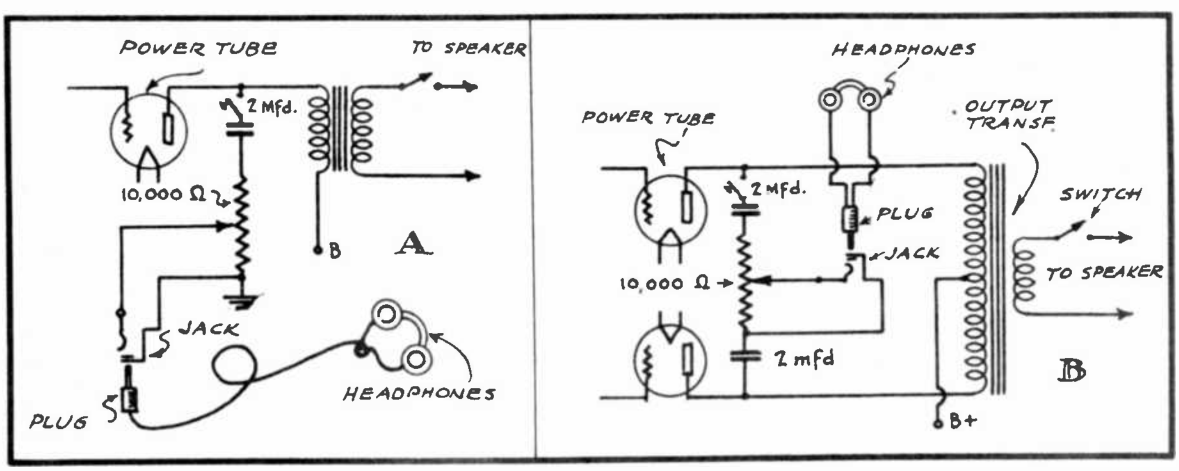

FIG. 3
HEADPHONE CONNECTIONS.

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ALIGNING ALL-WAVE RECEIVERS

IN GENERAL, THE PROCEDURE FOR ALIGNING ALL-WAVE SUPERHETERODYNE RECEIVERS IS THE SAME AS DESCRIBED IN PREVIOUS JOB SHEETS RELATIVE TO THE ALIGNMENT OF BROADCAST SUPERHETERODYNES. THE ESSENTIAL DIFFERENCE IS THAT AFTER ALIGNING THE I.F. STAGES IN THE ALL-WAVE SUPERHETERODYNE, THE OSCILLATOR AND OTHER R.F. STAGES MUST BE ALIGNED IN EACH OF THE FREQUENCY BANDS COVERED BY THE RECEIVER, RATHER THAN IN THE BROADCAST BAND ALONE.

THE FOLLOWING IS THE STEP BY STEP PROCEDURE FOR ALIGNING A TYPICAL ALL-WAVE SUPERHETERODYNE, WHOSE CIRCUIT DIAGRAM APPEARS IN FIG. 1.

1. - ALIGN THE I.F. STAGES IN THE SAME MANNER AS EXPLAINED IN JOB SHEET #23.

2. - ALIGNING THE BROADCAST BAND (BAND "A")

WITH THE RECEIVER'S OSCILLATOR CIRCUIT IN AN OPERATING CONDITION

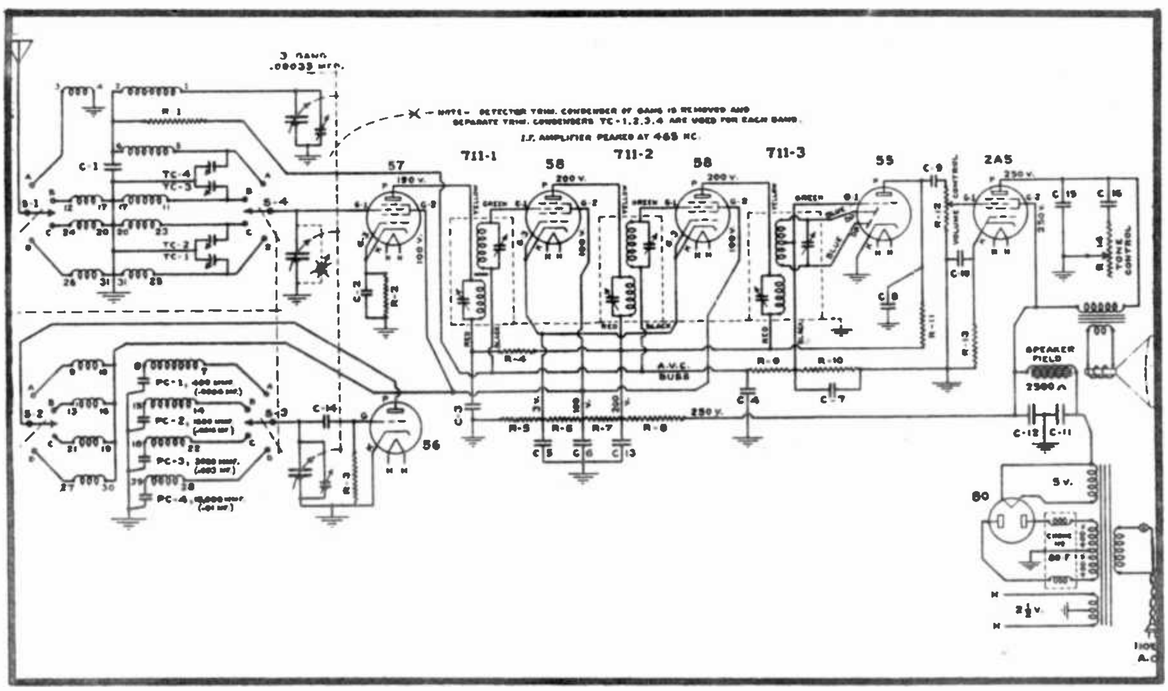

FIG. 1
THE ALL-WAVE SUPERHETERODYNE CIRCUIT.

AND WITH THE BAND SELECTOR SWITCH IN THE BROADCAST POSITION, CONNECT A TEST OSCILLATOR TO THE ANTENNA AND GROUND TERMINALS OF THE RECEIVER. SET THE TEST OSCILLATOR AND RECEIVER TUNING DIAL TO THE 1500 Kc. POSITION.

ADJUST THE TRIMMER CONDENSER ON THE OSCILLATOR SECTION OF THE TUNING CONDENSER FOR MAXIMUM OUTPUT. NEXT, ADJUST CONDENSER TC-4 IN FIG. 1 FOR MAXIMUM OUTPUT (THIS IS A SMALL TRIMMER CONDENSER WHICH REPLACES THE REGULAR TRIMMER ON THE FIRST DETECTOR SECTION OF THE TUNING CONDENSER IN THIS PARTICULAR RECEIVER).

DISCONNECT THE TEST OSCILLATOR FROM THE RECEIVER. CONNECT THE ANTENNA SYSTEM TO THE RECEIVER, TUNE IN A STATION AT THE HIGHEST FREQUENCY END OF THE BROADCAST BAND AND ADJUST THE TRIMMER ON THAT SECTION OF THE TUNING CONDENSER WHICH IS CONNECTED TO THE ANTENNA STAGE R.F. TRANSFORMER.

3. - ALIGNING BAND "B" (1500 Kc. TO 4000 Kc.)

CONNECT THE TEST OSCILLATOR TO THE RECEIVER'S ANTENNA AND GROUND TERMINALS. SET THE RECEIVER'S SELECTOR SWITCH TO BAND B POSITION AND ADJUST THE TEST OSCILLATOR AND THE RECEIVER DIAL FOR APPROXIMATELY 3500 Kc. ADJUST TRIMMER TC-3 FOR MAXIMUM OUTPUT.

4. - ALIGNING BAND "C" (4000 Kc. TO 8600 Kc.)

WITH THE SAME TEST OSCILLATOR CONNECTION, SET THE RECEIVER'S SELECTOR SWITCH TO BAND C POSITION AND ADJUST THE TEST OSCILLATOR AND RECEIVER TUNING DIAL TO APPROXIMATELY 7500 Kc. ADJUST TRIMMER TC-2 FOR MAXIMUM OUTPUT.

5. - ALIGNING BAND "D" (8600 Kc. TO 25,000 Kc.)

WITHOUT DISTURBING THE TEST OSCILLATOR CONNECTION, SET THE RECEIVER'S SELECTOR SWITCH TO BAND D POSITION AND ADJUST THE TEST OSCILLATOR AND RECEIVER TUNING DIAL TO APPROXIMATELY 20,000 Kc. ADJUST TRIMMER TC-1 FOR MAXIMUM OUTPUT. (NOTE: - IT IS IMPORTANT TO LEAVE THE ANTENNA SYSTEM CONNECTED TO THE RECEIVER DURING THE PROCEDURE OF ALIGNING ALL SHORT-WAVE BANDS).

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TESTING WINDINGS

IN ONE OF THE EARLIER JOBSHEETS YOU WERE SHOWN SIMPLE METHODS OF CHECKING WINDINGS AND RESISTORS FOR CONTINUITY WITH THE AID OF A VOLTMETER. IN THIS JOBSHEET A MORE ACCURATE METHOD IS DESCRIBED, AND WHICH APPLIES PARTICULARLY TO UNITS OF RATHER HIGH RESISTANCE RATING.

1. - TO CHECK THE WINDING OF A TRANSFORMER, DISCONNECT THE UNIT FROM ALL OTHER CIRCUITS AND CONNECT AN OHMMETER ACROSS THE WINDING TERMINALS AS SHOWN IN FIG. 1. IF THE METER READS INFINITE RESISTANCE, THEN THE WINDING IS OPEN CIRCUITED. IF A ZERO READING IS OBTAINED, THEN THE WINDING IS COMPLETELY SHORTED.

2. - ANY READING IN BETWEEN THESE TWO EXTREME VALUES SHOULD BE COMPARED WITH THE NORMAL RESISTANCE OF THE WINDING OF A DUPLICATE UNIT WHICH IS KNOWN TO BE IN PERFECT CONDITION.

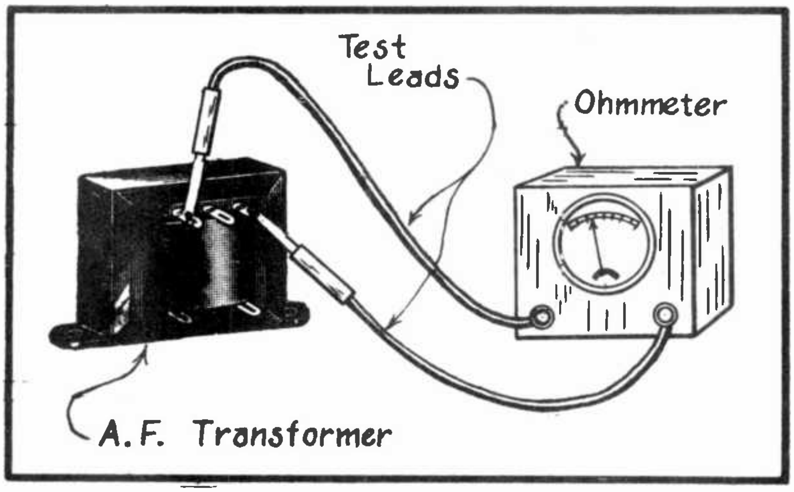

FIG. 1
CHECKING A TRANSFORMER.

3. - A READING WHICH IS LOWER THAN THE NORMAL VALUE INDICATES THAT THE WINDING UNDER TEST IS PARTIALLY SHORT CIRCUITED.

4. - A READING WHICH IS HIGHER THAN THE NORMAL VALUE INDICATES THAT THE WINDING UNDER TEST CONTAINS A HIGH RESISTANCE IN ITS CIRCUIT, AND WHICH IS PROBABLY DUE TO A POORLY SOLDERED CONNECTION.

5. - EVEN THOUGH A DUPLICATE UNIT IS NOT AVAILABLE FOR COMPARISON, YET IN MOST PRACTICAL PURPOSES A SUFFICIENTLY ACCURATE ANALYSIS CAN BE MADE OF A TRANSFORMER OR CHOKE BY COMPARING THE READINGS WITH A UNIT WHICH IS MORE OR LESS SIMILAR TO THE ONE UNDER TEST.

THE OHMMETER METHOD OF CHECKING RESISTORS APPEARS ON THE REVERSE SIDE OF THIS JOB SHEET.

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TESTING RESISTORS

1. - THE APPROVED METHOD OF CHECKING RESISTORS IS ILLUSTRATED IN FIG. 1, AND WHERE IT WILL BE NOTED THAT AN OHMMETER IS CONNECTED ACROSS THE RESISTOR. WHEN CONDUCTING THIS TEST, IT IS IMPORTANT THAT THE RESISTOR BE DISCONNECTED FROM ALL OTHER CIRCUITS.

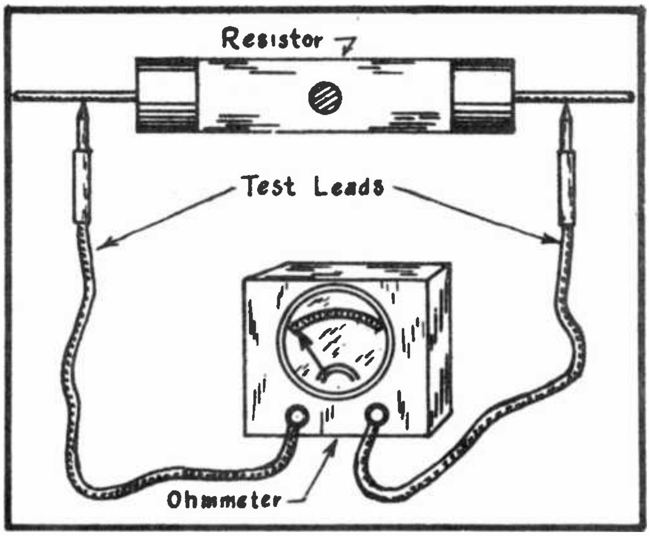

FIG. 1
OHMMETER RESISTOR TEST.

2. - THE OHMMETER SHOULD OFFER A READING WHICH IS REASONABLY CLOSE TO THE RESISTANCE VALUE AT WHICH THE RESISTOR IS RATED.

WHETHER THE DEVIATION IS TOO GREAT FOR SATISFACTORY RECEIVER OPERATION DEPENDS ENTIRELY UPON THE PARTICULAR CIRCUIT IN WHICH THE RESISTOR IS EMPLOYED.

FOR ALL PRACTICAL PURPOSES, IF THE MEASURED VALUE OF THE RESISTANCE IS WITHIN 10% PLUS OR MINUS OF THE "MARKED VALUE", IT MAY BE ASSUMED TO BE SATISFACTORY UNLESS IT IS USED IN A CIRCUIT IN WHICH THE VALUE OF THE RESISTANCE IS CRITICAL.

3. - WHEN CHECKING RESISTORS OF HIGH VALUE WITH A SENSITIVE OHMMETER AND IN SUCH CASES WHERE A HIGH DEGREE OF ACCURACY IS REQUIRED, IT IS PREFERABLE THAT THE RESISTOR BE SUPPORTED BY ITS TERMINAL ENDS ONLY SO THAT ITS BODY DOES NOT TOUCH THE HANDS OR WORK BENCH. ANY SUCH BODY CONTACT WILL OFFER A SHUNT PATH ACROSS THE SURFACE OF THE RESISTOR AND WHICH MAY AFFECT THE INDICATED VALUE APPRECIABLY.

PRACTICAL RADIO JOB SHEET

NO. 34

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CONDENSER LEAKAGE TEST

THE ARRANGEMENT WHOSE CIRCUIT DIAGRAM APPEARS IN FIG. 1 OFFERS AN EXCELLENT MEANS FOR SUBJECTING CONDENSERS TO A LEAKAGE TEST. THE 25,000 OHM RESISTANCE IS AN ADJUSTABLE WIRE-WOUND VOLTAGE DIVIDER RESISTOR, WHOSE CLIPS CAN BE ADJUSTED AS DESIRED.

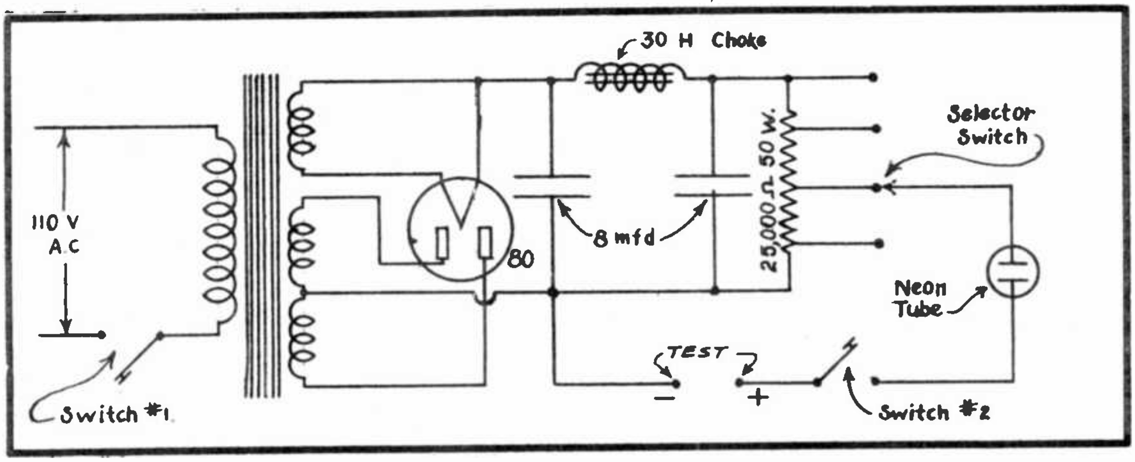

FIG. 1
THE NEON CONDENSER TESTER.

1. - TO TEST A CONDENSER FOR LEAKAGE, CONNECT THE CONDENSER ACROSS THE TERMINALS MARKED "TEST" IN FIG. 1 AND ADJUST THE SELECTOR SWITCH TO THE TEST VOLTAGE FOR WHICH THE CONDENSER UNDER TEST IS RATED.

2. - CLOSE SWITCH #1, AND AFTER THE 80 TUBE HAS HEATED UP TO ITS NORMAL TEMPERATURE, CLOSE SWITCH #2.

3. - OBSERVE THE ACTION OF THE NEON TUBE. A GOOD CONDENSER WILL CAUSE THE NEON LAMP TO FLASH ONLY ONCE AND IMMEDIATELY THEREAFTER NO LIGHT WILL BE EMITTED BY THE LAMP (THIS INITIAL OR MOMENTARY FLASH OF THE NEON LAMP MERELY INDICATES THAT THE CONDENSER HAS BECOME CHARGED.)

4. - IF THE NEON LAMP BLINKS, IT INDICATES CONDENSER LEAKAGE AND THE UNIT IS THEREFORE IN ALL PROBABILITY NOT SUITABLE FOR USE.

5. - IF THE NEON LAMP GLOWS CONTINUALLY, IT INDICATES THAT THE CONDENSER IS SHORTED.

6. - THE NEON LAMP WILL NOT GLOW AT ALL DURING THE SUPPOSEDLY INITIAL CHARGE IF THE CONDENSER IS OPEN CIRCUIT.

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CONSTRUCTION AND USE OF A CAPACITY METER

THE CIRCUIT DIAGRAM OF A SIMPLE BUT EFFECTIVE CAPACITY METER APPEARS IN FIG. 1. THE METER ITSELF CONSISTS OF A 0-1 MA. D.C. MILLIAMMETER USED IN CONJUNCTION WITH AN EXTERNAL COPPER-OXIDE METER RECTIFIER, OR ELSE A SELF-CONTAINED 0-1 COPPER-OXIDE TYPE A.C. MILLIAMMETER MAY BE USED.

WITH THE SWITCH IN THE "UP POSITION", THE RANGE OF THE INSTRUMENT IS FROM 0.001 MFD. TO 0.1 MFD. WITH THE SWITCH IN THE "DOWN POSITION", THE RANGE OF THE METER IS FROM 0.1 MFD. TO 3 MFD.

TO USE THIS CAPACITY METER PROCEED AS FOLLOWS:

1. - SET THE SWITCH FOR THE RANGE DESIRED AND SHORT CIRCUIT THE THE TERMINALS MARKED "TEST". ADJUST EITHER R_1 OR R_2, WHICHEVER IS BEING USED AT THE TIME, UNTIL THE METER READS FULL SCALE.

2. - REMOVE THE SHORT FROM THE "TEST" TERMINALS AND CONNECT THE CONDENSER TO BE TESTED ACROSS THESE TERMINALS. NOTE THE METER READING AND REFER TO A CALIBRATION GRAPH FOR THE CORRESPONDING CAPACITY OF THE CONDENSER.

NOTE: THE CALIBRATION GRAPH MAY BE PREPARED BY NOTING THE METER READINGS WHEN SAMPLE CONDENSERS OF KNOWN CAPACITY ARE CONNECTED ACROSS THE TEST TERMINALS. THE METER READINGS ARE THEN PLOTTED AGAINST CORRESPONDING CAPACITIES, AFTER WHICH THESE POINTS ARE CONNECTED TOGETHER BY A CONTINUOUS LINE TO FORM THE CALIBRATION CURVE.

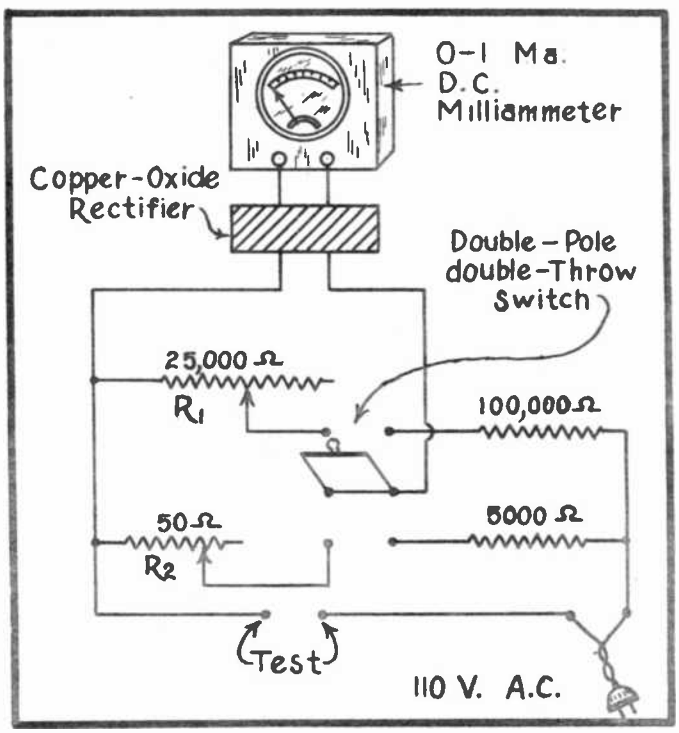

FIG. 1
CIRCUITS OF THE CAPACITY METER.

From the desk of the Chief Engineer

• • • THE RESEARCH DIGEST • • •

RADIO, TELEVISION AND ALLIED ELECTRONICS

NATIONAL SCHOOLS ★ LOS ANGELES 37, CALIF.

PRINTED IN U.S.A.

NEW DEVELOPMENTS ARE BEING MADE CONSTANTLY IN THE FIELD OF RADIO, TELEVISION AND ALLIED ELECTRONICS. IT IS OUR DESIRE TO KEEP YOU, OUR STUDENT, INFORMED ON THE LATEST AND MOST CURRENT SCIENTIFIC PRINCIPLES AND FACTS. THIS IS THE PURPOSE OF THE "DIGEST" WHICH IS SUPPLEMENTARY TO YOUR REGULAR LESSONS. STUDY IT CAREFULLY. SAVE IT FOR FUTURE REFERENCE. THIS INFORMATION IS IMPORTANT.

A DISCUSSION ON TUNED CIRCUITS

Years ago, I witnessed a very interesting scientific demonstration. Our professor, who performed the demonstration, placed an ordinary tumbler upon a small block of tile before a loudspeaker and cautioned everyone to be perfectly quiet. Standing before a microphone, he adjusted a violin under his chin and starting at the lowest note, gradually increased the pitch of the tone, slowly and with much care. When he struck one particular note, I shall never forget the amazed expression that appeared on all our faces when lo-and- behold! The tumbler shattered--as if some magic force had struck it!

> Since the subject we are about to discuss is based upon the above phenomenon, I would suggest that you keep this experiment in mind for it will provide you with a tangible aid that will help you understand the subject of Tuned Circuits (and Resonance) more readily. Consider the violin as being the Transmitter; and the tumbler as being the Receiver.

Every object that we can think of has a natural-vibration-period of its own. The pencil you write with, the table you write upon, the fork or spoon you eat with, the tumbler you drink out of, the glass pane you look through, etc. The vibration period of an object is determined by its <u>physical dimensions</u> and the amount of <u>tension</u> placed upon it.

To demonstrate this, let us suspend a fork and strike it with a rod. Vibrating at its own natural-vibratory-period, we will hear these vibrations in the form of a note--of a particular pitch. Striking a similar fork, we will find that the note given off by this second fork is almost identical to that of the first one. If, however, we now strike a spoon made of the same material, the note will be higher in pitch if the spoon is smaller or of a lower pitch if the spoon is of the large type.

A similar example may be noted by striking two lengths of pipe. Although both are made of the same materials, the longer one will produce a lower note than the shorter one. The shorter one will give off a higher note. This, then, explains how the physical dimensions of the material affects the natural-vibratory-period (n-v-p) of a substance.

Now, we come to the <u>tension</u> placed upon a substance and how this affects the n-v-p. Let us <u>take any</u> of the above mentioned objects and strike them so that they give off a musical "ring" or note. Now let us place a clamp around one end of the spoon or pipe, and you will find that the pitch of the notes is affected.

> Have you ever witnessed a performance wherein the "musician" surrounds himself with a number of tumblers, each filled to a different level with water? By striking each tumbler, he is able to play musical pieces by the various notes each tumbler gives off. The reason for this is that the water acts as a tension upon the glass of the tumbler, thus varying the n-v-p of the tumbler. In that way, each tumbler can be made, to give off a "ring" or musical note of a different pitch and thus provide all of the notes of the musical scale.

Some of you may have had experience with a violin or other stringed musical instrument. To "tune" a violin, guitar, mandolin, cello, etc., the musician adjusts the tension of the strings. As the musician plays, he varies the tension on the strings; thus causing a variation of tones we recognize as "music".

Vibrations of the strings cause corresponding vibrations in the air. The resultant air waves thus produced, come into contact with--and beat against--our ear-drums. Being part of one of the most marvelous mechanisms created upon this Earth (the Human Body), our ear-drums automatically adjust their tension so that they can vibrate in perfect unison or in perfect harmony with the vibration of the air-waves. Nerve-cells, located close to the ear-drum, are thus actuated and relay these vibrations to the brain which interprets them in the form of musical notes.

Our ear-drums then function or play the role of the Receiver. If they were damaged in such a manner so that they were unable to vibrate, we would be unable to hear the speech of another person or the musical notes of an instrument. Such a condition is known as "deafness". We are all deaf to a certain extent, for even though our hearing-mechanism be in perfect condition, the human ear-drum is very much limited to the frequency it can vibrate to.

One example of this is the "dog-whistle". Such a whistle emits a "supersonic" (above-the-human-audible-range) tone that the average human being cannot hear. Dogs can, however, and therefore respond to a seemingly "silent" whistle since their ear-drums are able to vibrate at such a high frequency.

> If dogs or other animals were able to speak to each other at super-sonic frequencies, and then attempted to speak to us at these same frequencies, we would not respond to their conversation; and they would consider us deaf.

At this very moment, there are millions of sounds surrounding us, such as radio-telegraphy, broadcast programs, radio-telephony, etc. Because our ear-drums cannot vibrate at such high frequencies, we are unable to hear them--without the use of accessory devices such as a radio receiver.

RESONANCE

The closer the Receiver is tuned to the frequency of the transmitted wave, the greater will be the response of the Receiver. MAXIMUM RESPONSE WILL BE OBTAINED WHEN THE RECEIVER IS TUNED TO VIBRATE AT THE IDENTICAL FREQUENCY OF THE INCOMING WAVE. Such a condition is referred to as RESONANCE between the Transmitter and Receiver.

In the demonstration given by the professor--with the violin and tumbler--the response or vibration of the tumbler at resonance was so great that it shattered. This also explains why a plate glass window of a store may suddenly shatter when a truck or bus coming down the street creates a vibration of a certain frequency.

When a state of resonance exists between the transmitted wave and the Receiver, the incoming waves encounter no bucking "out-of-step" vibrations to oppose them. This may be compared to a lass sitting on a swing while her little boy-friend swings her.

Let us assume that the little boy develops a rhythm as he pushes the swing. If his rhythm is in complete harmony with that of the back-and-forth motions (oscillation) of the swing, his driving power will be most effective and the swing will rise higher and higher. On the other hand, should his rhythm be out of step---that is, of a different frequency---the swing will not only buck his thrusts, but there will be instances when his hands will not even come in contact with the swing to give it the required push.

At this point, you are probably thinking:

"All fine and dandy--as far as violins, voice and swings are concerned! But how about radio receiving circuits?I've never seen a radio circuit vibrate--or swing back-and-forth".

Radio circuits OSCILLATE! That is the term we use when we want to say that a circuit is vibrating electrically, electronically or radionically.

How radio circuits oscillate will now be discussed.

RADIO OSCILLATIONS

When your gaze is attracted to a piece of wire, it stands out from the surrounding atmosphere as a definitely outlined object. If our power of vision were sensitized to the point where we were able to see what the wire was actually made of, we would soon see that the wire was nothing more than a composition of billions upon billions of small bodies grouped together. We call these bodies molecules. The wire would no longer appear as a sharply defined object but more like a "vein" of small whirling bodies imbedded and surrounded by an immense field of similar bodies, but of a lighter density (the molecules of the atmosphere). Where the molecules of the (copper) wire contact the molecules of the atmosphere we would note a blending of the two--a chemical combination referred to as an "oxide" formation. In the case of copper, this formation is commonly called "tarnish" (cuprous-oxide). In the case of iron, this chemical fusion is referred to as "rust" (ferrous-oxide).

Molecules, as we know, are made up of two or more atoms, just as an "assembly" is made up of two or more persons. An atom, in turn, is represented as a system comprised of a dense core or central body called the Nucleus, about which the electrons revolve. The whole structure is somewhat like a miniature Solar system (the sun and its many planets) in which the sun represents the central core and the planets represent the electrons. Each atom has, in its normal state, a certain number of electrons which rotate about the Nucleus in definite orbits (just as the Earth, Mars, Venus, Jupiter, etc., rotate in their own specific orbits around the sun). These electrons contribute a negative charge to the atom which is offset by an equal positive charge residing in the Nucleus. As a result, the normal atom exhibits no preponderance of either charge, and is electrically neutral.

The electrons are spaced at various distances from the Nucleus just as each of the planets are at different distances from the sun. The Nucleus has a very strong attraction for those electrons closest to it and the weakest attraction for those electrons farthest from it. As a result, should an external force come along, there is a possibility that one or more of the outer electrons may be detached from the atom; thus leaving the atom as a whole with a net positive charge.

And so, as we observe our wire, we recognize the electrons and note that those of the copper wire are on seemingly "unfriendly" terms with those of the atmosphere. A continual exchange of jabs and thrusts seems to be going on between them. On closer inspection it appears that the atmospheric-electrons are the aggressors but, actually, they are only the victims of unfortunate circumstances. If we were to trace the true cause of these unfriendly gestures, we would find that the source of this disturbance was quite distant. The creators of this disturbance are electrons who were agitated into action by the radiation energy released from a transmitting antenna system located a few, or even thousands of miles, away from the wire.

On the other hand, the source of this agitation may have originated only a few feet away from the wire--in the form of an electrical spark that occurred between the brushes and commutator of a vacuum-cleaner or washing-machine motor; between the contact-points of an electrical razor or ignition system; the spark that occurred between the trolley and trolley-wire, etc. From such a source of agitation, there followed an electrostatic* movement of electrons that was relayed through the atmosphere from molecule to molecule; finally reaching and affecting the electrons of the wire.

> This may very well be compared to an over-crowded street car. As a person enters the front of the car, he pushes against the person closest to him who, in turn, pushes the person or persons next to him. A force is thus relayed from person to person which travels from one end of the car to the other end of the car. If you happened to be at the opposite extreme end of the car and the push ultimately reached you, it would be injust to accuse your neighbor of pushing you since he was merely a victim of unfortunate circumstances.

Because the electrons of copper wire are loosely held to their atoms, the jabs and thrusts, thus delivered to them by the neighboring atmospheric electrons, cause them to become detached from their atoms. The mother atoms thus take on a positive charge and pull away electrons from other atoms which are not so strongly attracted or held to their atom. Consequently, a movement of electrons occurs from atom to atom throughout the entire conductor. Since a movement of electrons constitutes a flow of electrical current, we thus have a flow of current going on at all times within all conductors, EVEN THOUGH THEY ARE NOT CONNECTED TO ANY EXTERNAL POWER-SOURCE!

> The above current flow is extremely weak. In fact, so weak that it is not usually perceptible by the ordinary type of instruments; unless, of course, the wire is in close proximity to the transmitter of the agitation (broadcast station, amateur or commercial transmitter, powerful static discharge, lightning bolt, etc.). It is, however, possible for us to detect this current flow by the use of a DETECTOR. If the wire is of sufficient length, the detector may be of the crystal type such as galena, carborundum, etc. Used in conjunction with a sensitive headphone, these agitations may be heard in the form of a broadcast program, telegraphic dots and dashes, static, etc. The wire in such case would be referred to as an ANTENNA. If our antenna was of very short length, or if we wished to increase the volume of these agitations, we could use an amplifying vacuum tube type detector or add stages of amplification to detect extremely weak agitations originating at distant points.

* A TRANSFER OF ELECTRO-MOTIVE-FORCE (ONLY!) THROUGH THE MEDIUM OF A DIELECTRIC (REFER TO YOUR LESSON TREATING CONDENSERS AND CAPACITY). THE DIELECTRIC, IN THIS CASE, IS THE ATMOSPHERE.

This, then, provides us with definite proof that electronic agitations are exerted upon all substances, and that a movement of electrons occurs as a result of them. In a piece of wire to which no power-source is connected, and an open-circuit exists between the two ends, the manner of this current flow is of an OSCILLATORY nature. By this is meant that the electrons first flow in one direction (when they are first dislodged) and then in reverse direction (when they return to their mother atoms). Each such back-and-forth movement is referred to as an OSCILLATION---each complete oscillation constituting one CYCLE. The number of cycles PER-SECOND-OF-TIME is referred to as the FREQUENCY of the oscillation. The oscillations ocurring within a conductor that is not connected to a power-source is referred to as FREE oscillations.

NATURAL-OSCILLATORY-PERIOD OF A CONDUCTOR

The free oscillations occurring within conductors take on a momentum, and soon resolve themselves to a definite rhythm or frequency. The frequency of these oscillations are limited--and therefore determined by the following factors:

1. The physical LENGTH of the wire.
2. The INDUCTIVE REACTANCE (X_L) present in the wire. (Note: the above two are referred to as the Inductance or L of the wire.)
3. The CAPACITANCE REACTANCE (X_c) present in the wire.

The above three factors may be compared to weights that are attached to a clock-pendelum. As any one of the above three factors are increased, the more weighted-down will the pendelum become and the less frequent will be the back-and-forth movements per second of time.

The frequency that the electrons do resolve themselves down to within a conductor which is not connected to any external power-source, is referred to as the NATURAL-OSCILLATORY-PERIOD of a conductor (hereinafter referred to as the n-o-p of a conductor.)

HOW INDUCTANCE AFFECTS THE FREQUENCY

(1): It is obvious how the physical length of the conductor would affect its n-o-p. The longer our length of wire, the longer period of time would it take for the electrons to complete their movement in one direction and back again. Consequently, if it is our desire to have our wire (hereinafter referred to as a TUNED CIRCUIT) tune to a higher frequency, we would shorten our wire. On the other hand, if we wanted our tuned circuit to tune to a lower frequency, we would lengthen our wire.

(2): Electrons in motion always set up a magnetic field about themselves (principle of Electro-magnetism). This magentic field creates an opposing voltage which interferes with the flow of the electrons. The opposition thus offered is referred to as INDUCTIVE REACTANCE. Since this factor has a delaying action upon the flow of electrons within the wire, the more Inductive reactance present in a tuned circuit, the less frequent will be the oscillations.

> Thus, by winding the wire into the form of a coil---or, by introducing an iron-core within the center of the coil--we thereby increase the self-inductive properties of our tuned circuit and automatically decrease the n-o-p of the circuit. (This is the principle of permeability-tuning which will be thoroughly explained, later in the course). On the other hand, by inserting a metal that has a dia-magnetic effect upon the inductance of the coil (such as aluminum, copper, etc.), we reduce the self-inductive properties of the coil, thus increasing the n-o-p of the coil.

To summarize the foregoing: The natural-oscillatory-period of a conductor or tuned circuit is INVERSELY proportional to the INDUCTANCEof that conductor or tuned circuit.

HOW CAPACITY AFFECTS THE N-O-P OF A TUNED CIRCUIT

As stated before, the electrons of all conductors are constantly being subjected to electrostatic jabs and thrusts from the surrounding electrons of the atmosphere--or insulation, if the conductor happens to be encased in such. On the other hand, the movement of the conductor-electrons (resulting therefrom) has a similar (reciprocal) effect upon the atmospheric-electrons (hereinafter referred to as dielectric-electrons).

If the wire is wound in the form of a coil, the electrostatic force thus created will be relayed through the medium of the dielectric-electrons to the adjacent turns of the wire. Conductor-electrons within the adjacent turns of the wire will thus be jabbed and consequently dislodged from their atoms. The flow of electrons resulting therefrom also acts as interference to the flow of electrons already in oscillatory motion within the conductor.

> The electrostatic effect between the turns of wire of a coil is referred to as the DISTRIBUTED CAPACITY of a coil; and, since this slows down the movement of electrons, the n-o-p of a coil or tuned circuit would be INVERSELY proportional to the distributed capacity of that coil or tuned circuit.

Capacity not only exists between the adjacent turns of a coil, but also between the ends of the coil. The two ends of the coil function as the two opposing plates of a condenser, the atmosphere between acting as the dielectric. The larger the capacity between the two ends of the coil, the more electrons will be "stored" before they are discharged back to their mother atoms. Thus, the larger the capacity or condenser-effect between the two ends of the coil, the slower will be the frequency of the n-o-p.

> By connecting a condenser of fixed capacity value between the ends of the coil, we can tune our coil or circuit to a definite frequency. By connecting a variable condenser between the two ends of a coil, we can vary the frequency to which our circuit will tune. Such provides a very convenient method of tuning from one broadcast station to another---which is the purpose of the variable tuning condenser.

To summarize the above: The n-o-p of a tuned cirucit is inversely proportional to the CAPACITY contained within the tuned circuit.

TUNING AND SELECTIVE PROPERTIES OF A CIRCUIT

Now that we are a little more familiar with the tuning properties of a circuit, let us follow an incoming signal and see what happens as it encounters a tuned circuit.

> If the back-and-forth (oscillatory) movement of the signal is at the same freqeuncy as that of the n-o-p of the tuned circuit, the two current flows will combine in complete harmony and be additive in strength to one another. Should the frequency of the incoming signal be different than the n-o-p of the tuned circuit, we will have a bucking or opposing effect between the two; with the net result that little or no signal will be admitted into the tuned circuit.

If, however, the strength of the incoming signal is greater than the strength of the n-o-p current-flow within the tuned circuit, the signal current will force the n-o-p current to flow at the frequency of the signal oscillations. Such is referred to as FORCED OSCILLATIONS and explains the unselective nature of tuned circuits in close proximity to powerful broadcast stations, interference from neighboring amateur stations, etc. This is the reason for resorting to such measures as loosening the coupling between the primary and secondary windings of the antenna transformer, or introducing resistance in the antenna circuit to attenuate (reduce) the strength of the incoming signal so as to eliminate intolerable interference from such sources.

It is obvious, then, that a tuned circuit is only selective to the extent of the SIGNAL STRENGTH vs. the N-O-P STRENGTH. Hence, the selectivity of a tuned circuit may be increased by strengthening the n-o-p wave. One method of accomplishing this is by means of REGENERATION. By feeding the output energy back to the tuned circuit, the strength of the n-o-p wave of the tuned circuit is thereby increased--which explains why a regenerative circuit becomes more and more selective as the feed-back is increased.

SUMMARY

The frequency of the notes emanating from musical instruments, vocal chords, etc., is dependent upon and determined by the physical length and mechanical tension placed upon the strings, reeds, chords, etc. The frequency of the waves emanating from an electronic transmitter (Radio, Television, etc.) is determined by the physical length and electronic tension placed upon the tuned circuit.

To receive such waves, the receiver must be tuned to the identical frequency of the incoming (transmitted) wave. When the transmitted wave is of an identical frequency to that of the receiver, we say that a state of resonance exists between the two. Maximum reception is realized when the receiver is adjusted so that it resonates to the frequency of the transmitted wave.

Whereas the human ear has the ability to automatically adjust its own tension to receive the sound waves, receiving instruments and devices have to be adjusted and tuned to the desired frequency. In electronic receiving circuits, this is done by adjusting the inductive reactance (X_L) and capacitive reactance (X_C) of the tuned circuit. Adding either of these decreases the frequency to which the circuit will tune; while subtracting either of these will increase the frequency to which the circuit will tune. This may be compared to adding or subtracting weights of a clock-pendelum to adjust the number of times it will oscillate back and forth per second of time.

All tuned circuits oscillate at their own "natural" oscillatory period (frequency). Such oscillations are referred to as FREE OSCILLATIONS. If the oscillation period of the incoming wave is in resonance with the n-o-p of the tuned circuit, it encounters no opposition; the two combine in complete harmony and are additive to each other's strength. On the other hand, if the two are out of resonance with one another, they will buck each other, and the strength of the incoming signal is thereby reduced or completely nullfied.

Tuned circuits are therefore selective in nature. This quality, however, is limited to the extend of SIGNAL strength vs. N-O-P strength. If the magnitude of the incoming wave is such that it is able to overpower the strength of the n-o-p wave, the former will force the latter to oscillate at its own frequency. Such a condition is referred to as FORCED OSCILLATIONS and may be remedied by attenuating the strength of the incoming signal by interposing additional tuned circuits or by the use of variable-mu, "remote cut-off" type tubes.

Another method of increasing the selectivity of a tuned circuit is by means of counteracting the strength of the undesirable incoming wave. Such may be accomplished by augmenting (increasing) the strength of the n-o-p wave so that it has the power to completely neutralize or nullify the strength of the non-resonating, interfering signal wave. In an amplifying system, part of the energy is fed back from the output circuit to the tuned (input) circuit; thus, increasing the strength of the n-o-p current flow of the tuned circuit. This method is referred to as regeneration and explains why a tuned circuit becomes more and more selective as the regeneration is increased. Also, why a one-tube regenerative receiver may compare favorably to the selective qualities of a set employing two or more stages of non-regenerative amplification. Although superior in efficiency, regenerative circuits have a tendency towards instability (circuit oscillation), etc,and the values of the parts are quite critical. This is one of the reasons why regenerative type receivers do not enjoy much popularity with manufacturers of radio receiving sets.

CONCLUSION

This treatise represents a discussion on the subject of Tuned Circuits. We do not ask that you accept this presentation as THE theory of Tuned circuits. We merely want you to consider it as another version which may help enlighten you upon problems dealing with the natural-oscillatory-period of conductors and tuned circuits.

Note: Some of the terms used in this discussion may be unfamiliar to you at this particular time. Do not be too concerned about that now, for they will all be thoroughly explained to you in your forthcoming lessons. Keep this RESEARCH DIGEST issue filed for future reference so that you may refer back to it throughout the entire Course.

When you are climbing up be sure to help some one else up, too:— that may prove to be your best assurance that you will continue to stay up.

J. A. ROSENKRANZ

From the desk of the Chief Engineer

* * * THE RESEARCH DIGEST * * *

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SUPPLEMENTARY TREATISE ON CONDENSER FUNCTION

Since the theory of condenser function is somewhat complex, we are hereby presenting this subject from another angle. This is one of our methods of providing our students with maximum assistance wherever possible.

As you progress with the course, you will receive the benefits of many other services of a similar nature that have been incorporated in NATIONAL TRAINING to help make the learning of Radio easy and intensely interesting.

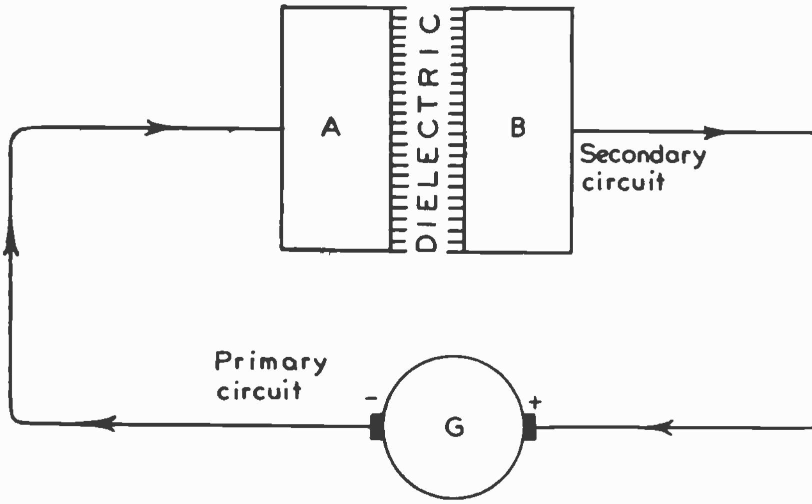
WATER ANALOGY

In beginning this discussion, let us first refer to Fig. 16 of Lesson No. 5. Here, you will note, we have a water tank comprised of two chambers; these two chambers being separated by a flexible (rubber) diaphragm. We will use this illustration as a water analogy to explain the function and action that takes place within the electrical condenser. (Electro-static Induction).

As the piston is pushed inward, ("A" of Fig. 16) we have a rush of water in the direction of the pointing arrows. This causes the diaphragm to flex, as shown in the illustration. As this diaphragm flexes, it applies a pressure to the water in the lower water-chamber so that we now have a flow of water occurring in this chamber back to the piston as indicated by the arrows.

> The point to note and keep in mind is that although NO WATER FLOWED FROM ONE CHAMBER INTO THE OTHER CHAMBER, we did cause the water in the lower chamber (secondary water circuit) to flow by the transfer of PRESSURE (only!) through the medium of a flexible diaphragm.

In the electrical condenser, we have the same action. Referring to Fig. 1, you will note that we have here a condenser connected to a generator. The electrical pressure (voltage) developed in the generator causes a flow of electrons (current) from the negative terminal of the generator to the condenser plate "A". As more and more of these electrons accumulate upon this condenser plate, they exert a pressure (e.m.f. or voltage) upon the insulator (dielectric)-atoms that are sandwiched between the two opposing condenser plates ("A" and "B").



The atoms within insulators differ electrically from the atoms of conductors. This difference lies in the fact that the electrons of the conductor-atom do not cling as strongly, or are not attracted as strongly, to their nucleus -- as are the electrons of the insulator-atoms. Therefore, as voltage is applied to the atom of a conductor, some of its electrons will be torn away; which accounts for the reason why we have a flow of electrons (current) within a conductor. On the other hand, the electrons of insulator-atoms cannot be torn away unless a very high voltage (electro-motive-force) is applied upon them, and therefore we do not have a flow of electrons (current) through an insulator.

Although the electrons of insulator-atoms cannot ordinarily be torn loose from their atoms, they do stretch away from their normal position (orbit) within the atom when an electrical pressure (voltage) is applied to them. The higher the voltage exerted upon them, the further are they stretched away from their normal position. In this abnormal position, we then say that the insulator is undergoing "dielectric stress or strain".

Should too much pressure (voltage) be applied to the electrons within the insulator, they will be torn loose from their atoms and we will then have a flow of electrons through the insulator. The resultant current flow will be so great (because of the tremendous pressure behind the electrons) that an intense heat is created, thus damaging the insulation material permanently. We then say that the condenser has been "punctured" or "burned out"; and it is worthless as such from then on.

However, in normal operation, we never exceed the rated voltage that should be applied to the condenser. Therefore, the electrons of the dielectric are never torn loose from their atoms, but are merely stretched away from their normal orbit in relation to their nucleus. As they are made to yield from their normal position they, in turn, exert a force (voltage) upon the conductor-electrons of the opposing condenser plate "B", tearing these loose from their atoms -- which results in a flow of current in the secondary circuit (from condenser plate "B" to the positive terminal of the battery).

CHARGE AND DISCHARGE OF CONDENSER

In the process of stretching away from their normal position, we call this process "charging the condenser".

Should the charging pressure (voltage) be reduced -- as happens with pulsating d-c or a-c during its cycle -- the dielectric-electrons now exert a back-pressure against the "charging" electrons and push them back into the circuit (Filtering action of a condenser). This process is referred to as "discharging" the condenser; and when all of the charging electrons have been pushed back into the circuit and the dielectric-electrons have completely returned to their normal position within their atoms, we then say that the condenser is "discharged".

CAPACITY OF A CONDENSER

The further the electrons are stretched away from their normal position, the greater will be the force (voltage) exerted upon the conductor-electrons of the opposing condenser plate (Plate "B" in the diagram). The greater, also, will be the "re-bound" force of the dielectric-electrons when the charging force is reduced or removed. This explains the greater current flow (amperage) in the secondary circuit obtained by the use of a condenser of higher capacity, and also the need for higher capacity in filter condensers of power supplies delivering greater amounts of d-c current.

The capacity of a condenser refers to the proportional amount of current that can bemade to flow in the secondary portion of a capacitively-coupled circuit by the application of an electro-motive-force to the primary condenser plate ("A" in our diagram). From the foregoing explanation, it is obvious that the strength (value) of the applied e.m.f. to the primary condenser plate "A" would be a governing factor in determining the resultant current flow that will take place in the secondary circuit; therefore, we will list this as Factor 1.

Factor 2 would be the surface area of the conducting plates in contact with the dielectric. The greater the area, the greater will be the number of electrons involved; therefore, the greater the resultant current flow in the secondary circuit.

Factor 3 would be the distance between the two conducting plates (thickness of the dielectric). In stretching the dielectric-electrons from their normal orbits, force is expended (used up). The thicker the dielectric, the more layers of electrons will have to be stretched. Therefore, more force is used up, leaving us with a lesser amount of force to be exerted upon the conductor-electrons of the secondary plate and circuit, which means that less current will flow in this circuit.

Factor 4 is the type of insulating or dielectric material used. The electrons of certain dielectrics can be made to yield and stretch away from their normal position more easily than can the electrons of other insulating materials. The ease with which electrons of various types of insulating materials can be made to yield from their normal orbits is expressed in the form of a "constant" -- in a table of dielectric comparisons. The dielectric having the highest constant would be the better dielectric, since less force is used up within the dielectric itself; leaving more pressure to be exerted upon the electrons of the secondary circuit.

In conclusion, it is well to remember that whereas, Electro-magnetic Induction is the transfer of electrical energy from one circuit to another circuit by the medium of magnetic lines of force, Electro-static Induction is, on the other hand, the transfer of electrical energy from one circuit to another by the medium of the flexibility of the dielectric-electrons which act in the identical manner as the rubber diaphragm in our water analogy. The only difference is that the rubber diaphragm stretches mechanically, whereas the dielectric diaphragm stretches electronically.

AT NO TIME, HOWEVER, DO ELECTRONS FLOW THROUGH THE DIELECTRIC. In other words, AT NO TIME DOES CURRENT FLOW THROUGH THE DIELECTRIC. We merely have a transfer of e.m.f. (only!) through the medium of the electronic diaphragm that exists between the primary and secondary circuit of a capacitively-coupled circuit.

BY-PASSING EFFECT OF A CONDENSER

The by-passing effect on a condenser may well be exemplified and explained by analyzing the circuit appearing as Fig. 2.

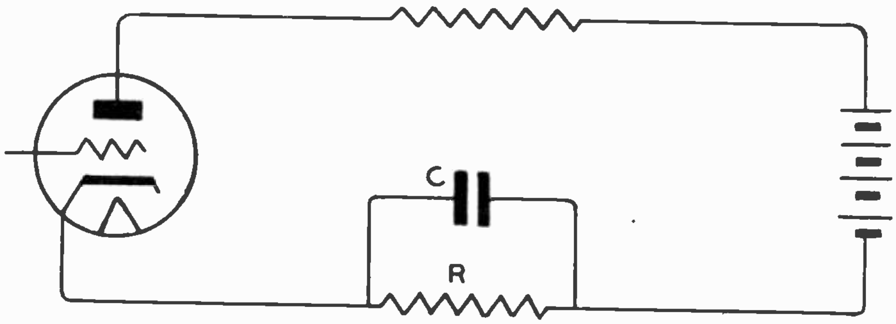


FIG. 2

In this circuit, we have a divided path for the r-f energy to flow through: (1) the resistor "R" and, (2) the by-pass condenser "C". From our lessons covering parallel circuits we have learned that, as the flow of current increases through one branch of a parallel circuit, we have a corresponding decrease of current-flow in the other branch of that parallel circuit. Therefore, if we were to select a condenser that offers a less opposing (less reactive) path to the r-f current than the resistor does, we would then have a greater flow of energy through this branch rather than through the resistor.

Why does the condenser offer less opposition to the flow of higher-frequency current than to low frequency current? One theory states it thus:

> From the science of Physics we learn that Force is a product of speed and distance. In increasing the speed of our oscillations (frequency) we thereby increase the force of our pulsations so that when the molecules of the dielectric are encountered, the electrons within these molecules are more readily "budged" or made to yield out of their normal position; hence, a much greater force is transferred through the dielectric of the condenser. This, in turn,causes a much greater flow of energy in the secondary circuit of the condenser.

Since high-frequency currents are able to cause a much greater movement of the electrons than low-frequency currents, why does not the same hold true for the resistor in parallel with the condenser? This may be readily answered by observing the construction of a condenser in comparison to that of a resistor. In the condenser, we have two comparatively large conducting surfaces between which is sandwiched a dielectric.

Since the opposition offered by the dielectric is inversely proportional to the increase in frequency,we find that the dielectric becomes almost a conductor at very high frequencies; and because of the physical size of the conducting area of the resistor, this becomes a much more desirable -- and much less opposing path -- to high-frequency currents.

Thus, the theory of the by-passing effect of condensers.

From the desk of the Chief Engineer

* * * **THE RESEARCH DIGEST** * * *

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A DISCUSSION ON TRANSFORMERS

WATTAGE INPUT = WATTAGE OUTPUT

As you probably are aware, the function of a transformer is to "transform" or to "re-arrange" the value of the voltage applied to the primary circuit. For instance, if we use a step-up transformer having a step-up ratio of 10 to 1 (10:1) this means that we have ten (10) turns on the secondary for every one (1) turn on the primary. This also means that we will have ten (10) volts in the secondary for every one (1) volt in the primary. The voltage will thereby be increased 10 times.

If, on the other hand, the transformer is of the step-down type and has a step-down ratio of 10:1, the voltage furnished by the output or secondary of the transformer will be 10 times less that of the primary.

What happens to the current in the meantime?

Obviously, you would think that the current would also be increased with an increase in voltage; or decreased---in the case of the step-down, transformer. For, doesn't Ohm's Law state that the voltage and current are in direct proportion or relationship with one another (hand-in-hand)? In other words, as one is increased, the other is also automatically increased--or vice versa.

In the case of the transformer,however, WE ARE NOT DEALING WITH OHM'S LAW. Instead, we are dealing with the LAW OF ENERGY!

Let us quote the Law of Energy, to refresh the minds of those of us who may have forgotten it. This law states in brief:

ENERGY CAN NEITHER BE CREATED NOR DESTROYED

This Law applies to ELECTRICAL energy, as well as to all other forms of energy! This means that we can only take out that amount of energy that we put into the transformer.

Electrical energy is measured in the unit of WATTS. The Watt (W) is equal to the product of the voltage x amperage. Mathematically: $W = E \times I$. Consequently, when using an electrical transformer, WE CAN ONLY GET OUT

AS MUCH WATTAGE AS WE PUT INTO THAT TRANSFORMER. In other words, the wattage-output can NEVER exceed the wattage-input! (If we will remember this simple little rule, we will never have any difficulty in understanding this characteristic of a transformer).

This means that if we use a step-up transformer to obtain a higher voltage from the secondary or output winding, the amperage is thereby automatically (compensatively) decreased. By the same token, if we use a step-down transformer, and thereby "re-arrange" the volts to a lower value, the amperage output of the transformer is automatically increased.

> Thus, in the transformer, we find a complete reversal of Ohm's Law. In this case, the output current of a transformer is INVERSELY proportional to the output voltage of a transformer.

For example: If we have 110 volts and one (1) ampere flowing through the primary of a transformer that has a step-up ratio of 10:1, the voltage would thereby be increased to 1100 volts. The maximum amount of current that we can ever hope to obtain from such a transformer would be:

a. Primary (Input) Wattage $W_p = E_p \times I_p = 110 \times 1 = 110$ watts

b. Secondary current $I_s = \frac{W}{E_s} = \frac{110}{1100} = 0.1$ ampere

On the other hand, if the transformer were of the step-down type and a step-down ratio of 10:1, our output voltage would be 11 volts and the current capacity of the output winding would then be:

a. $W_p = E_p \times I_p = 110 \times 1 = 110$ watts

b. $I_s = \frac{W}{E_s} = \frac{110}{11} = 10$ amperes

Incidentally, welding transformers are designed upon this principle. Welding, as you probably know, requires a heavy amperage to fuse the metals together. Therefore, if we step the voltage down to a low value, we are then able to obtain a heavy amperage. For example:

> Using a step-down transformer having a ratio of 22:1, our output voltage is stepped down to 5 volts. Our transformer is then capable of supplying us with:

$$I_s = \frac{110}{5} = 22 \text{ amperes}$$

Note: Of course, from the output current values stated above, we have to deduct transformer inefficiency losses (which are converted into heat). These losses were omitted in the above computations to avoid confusion.

The subject of transformers will be treated in greater detail in future lessons.

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A DISCUSSION ON AMPERAGE --- THE IMPORTANT FACTOR

A very interesting question was submitted to me recently by one of our students. Attached to the Consultation Service Form was this very neatly drawn diagram and the following question:

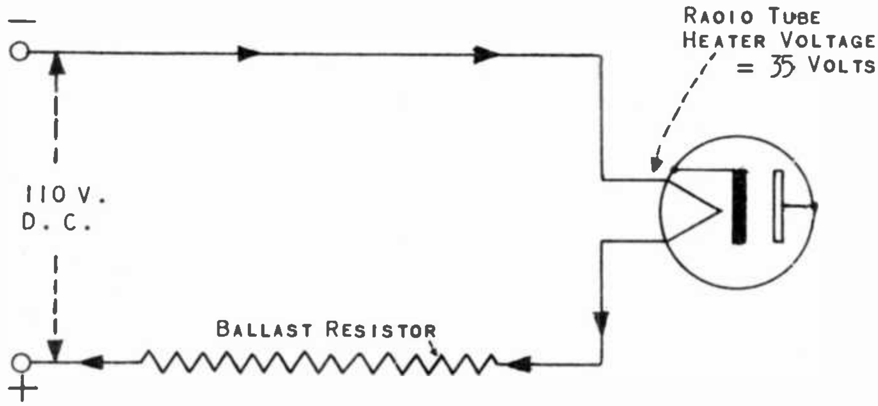

FIG. 1

Dear Sir:

In our Course, we are taught that electrical current flows from negative to positive. In that case, the 110 volts of electrical pressure, in the diagram above, would cause the current to start out from the negative side of the line and flow through the 35-volt heater of the tube; thus burning out the heater before the ballast (voltage-dropping) resistor had a chance to drop the voltage down to 35 volts.

It seems to me that the ballast resistor should be placed BEFORE the tube's 35-volt heater instead of AFTER it, as shown in the diagram.

However, I must be wrong, for I see many heater circuits wherein the ballast resistor is placed in the positive side of the line, and the tube's heater does not burn out. I have conducted experiments to this effect and find that no matter in which side of the circuit the ballast resistor is placed, the heater comes up to normal operating temperature and does not burn out.

Just exactly, where does the flaw in my theory exist?

Before answering this question, I would like to point out that this is a logical deduction -- and a very common one! It shows, however, that most of us do not, as yet, have the proper conception of electrical current flow. And so, to clarify the above common mis-conception, let us go back and do a little REVIEWING OF FUNDAMENTALS -- which is the best policy, in all cases.

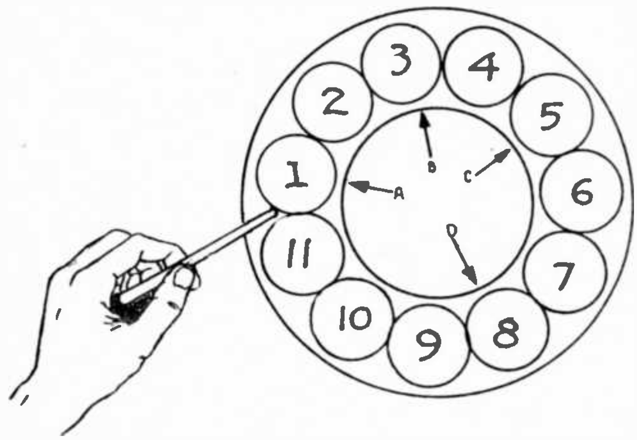

FIG. 2

In Fig. 2, we show an analogy to the manner in which current flows through an electrical circuit.

Instead of a complete circuit of wires, we illustrate a complete circuit (circle) of marbles that are contained within a circular form.

If we jab or push any one of the marbles, the ENTIRE series of them will move.

If we were to mark off various reference points around the circle by means of arrows and label each one of these arrows "A", "B", "C", "D" etc., we would note that ALL marbles moved at the same RATE.

Rate, as you know, is defined as Quantity per time. Mathematically, this is expressed as:

$$\text{Rate} = \frac{\text{Quantity}}{\text{Time}}$$

Therefore, if a marble passed point "A" each SECOND, we would say that the rate of (marble) flow was one marble per second. What is the rate of flow at point "B"? "C"? "D"?

AT ALL OF THESE POINTS, THE RATE OF MARBLE FLOW IS IDENTICAL!

(If there is any confusion in this regard, stop right now, before going any further, and review the above thoroughly until you are completely satisfied and in complete accord with this statement).

The faster or greater the rate of marble flow through the above "circuit", the more FRICTION will be produced. This, in turn, causes more HEAT to be generated.

If we were now to substitute a few iron marbles for some of the glass marbles in our circuit, what would happen to the rate of marble flow? Since the iron marbles are much heavier and harder to push, the rate of flow of ALL marbles would thereby be decreased. The iron marbles act as an opposition or RESISTANCE to the flow of ALL of the marbles in the ENTIRE series circuit.

THE ELECTRICAL CIRCUIT

In our electrical circuit, we are not dealing with marbles, but with ELECTRONS which act in a similar manner to the marbles. In co-relating the marble analogy to our electrical circuit, we may list the characteristics of an electrical circuit as follows:

1. Electrons do not move unless those preceding them also move.

2. A movement of electrons constitutes a flow of current.

3. In a series circuit, the identical amount of current flows throughout the entire circuit!

4. The rate of electron flow (current flow) is defined as $\frac{\text{Coulomb}}{\text{second}}$ in which COULOMB represents the QUANTITY of electrons (six quintillion of them) passing a given point in the circuit per SECOND of time.

   The rate of electron flow is expressed by the unit, Ampere. One ampere represents a flow of six quintillion electrons per second of time past any given point in the circuit.

5. The rate of current flow or amperage in a circuit is dependent upon the amount of (electro-motive) force behind the electrons and the resistance of the circuit (Ohm's Law).

6. Resistance offers opposition to the flow of electrons. If certain types of metals are used whose electrons do not move readily (resistors), greater force must be used to move them.* Much friction is created here; and since heat is a product of friction x quantity, the greatest amount of heat will be developed at this point.

However, the most important factor in producing heat resolves itself down to quantity. The more electrons we have flowing, the more friction is present and the greater is the resultant heat.

We might then say that it is the AMPERAGE in an electrical circuit that determines the amount of heat that will be produced.

This can be proven by the simple circuit shown in Fig. 3.

1. As the resistance is REDUCED, the amperage is increased (as noted on the ammeter) and the lamp lights up brighter. We might then say that the heat developed in a circuit is DIRECTLY proportional to the AMPERAGE in the circuit.

2. As the RESISTANCE is increased, the lamp becomes dimmer, indicating a DECREASE of heat. Hence, we cannot say that as the resistance is increased, the heat is increased.

*****

* Should we insert a substance in series with the circuit whose electrons WILL NOT MOVE (insulators), these prevent all of the electrons within the entire series circuit from moving. Thus, no current flows in a circuit when an insulator is placed in series with an electrical circuit. This would be just as if we cemented one or more of the marbles down so that they were immovable. Because of this, none of the other marbles would move when our force was applied.

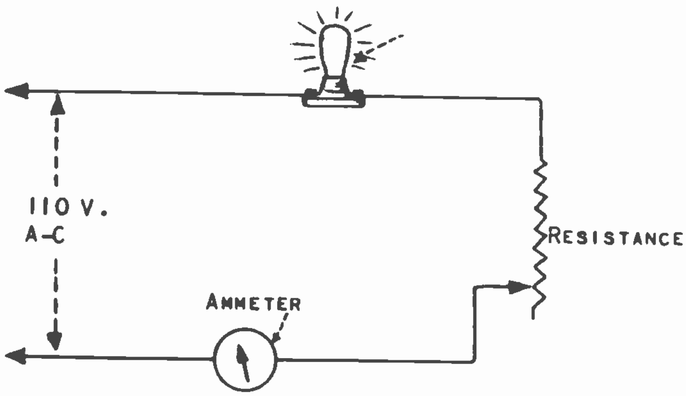

FIG. 3

3. Nor is VOLTAGE the essential factor in respect to HEAT. This point may be effectively demonstrated by the use of an Induction Coil and a 110-volt lamp.

An Induction Coil has a primary-to-secondary ratio of approximately 2500 to 1. When used with six-volts on the primary winding, the secondary or output voltage is stepped up to approximately 15,000 volts.

It would seem disastrous to apply such a high voltage to a 110-volt bulb. When connected in this manner, however, the bulb DOES NOT EVEN LIGHT UP, let alone BURN OUT! The reason? The Induction Coil does not put out enough AMPERAGE!

On the other hand, if we have a sufficiently high amperage flowing through a circuit, we can create enough heat to fuse and WELD two pieces of the toughest metal together.

Electric (arc) welders operate on a very low voltage (as low as 5 volts). However, the amperage ranges from 50 to 200 amperes.

SUMMARY

In summarizing the foregoing, let us always remember that the AMPERAGE in the circuit is the important factor in respect to heat. This is the component of the circuit that does the heating for us (or WORK -- for that matter!). It is the AMPERAGE that determines whether a tube's heater or filament will light up to normal brilliance or burn out!

Let us now refer back to Fig. 1 and re-analyze this circuit on the basis of AMPERAGE, rather than VOLTAGE. We can disregard the voltage required by the heater of the tube and instead refer to a Tube Manual to find out how much CURRENT the heater draws.

Referring to the Tube Manual CHARACTERISTICS of this particular type tube, we note that the heater requires .15 ampere. Since the amperage flowing through the entire (series) circuit is identical at any point of the circuit, we must design our entire circuit so that .15 ampere flows through it!

WORKING OUT THE PROBLEM

In this particular case, the voltage is 110 volts. To limit the current flow through the circuit to .15 ampere, the resistance of the circuit will have to be:

(Ohm's Law) $R = \frac{E}{I}$, in which R = the amount of resistance required; E = the voltage of the SOURCE and I = the required amount of current flow through the heater of the radio tube.

Substituting our values for the symbols in the above formula:

$$R = \frac{110}{.15} = .15\overline{)110} = 15.\overline{)11000.}$$

```
          733.33 ohms
15. ) 110 00.
      105
        5 0
        4 5
          50
          45
          etc.
```

(NOTE: THE ABOVE DOTTED ARROWS SIGNIFY THAT THE DECIMAL POINT IS MOVED OVER TWO PLACES.)

The answer thus obtained is 733.33 ohms. This means that we must have a total resistance of 733.33 ohms in the circuit, in order for .15 ampere to flow through it. Hence, we insert a ballast resistor of 500 OHMS in the circuit.

Why 500 ohms--when the required amount of resistance is 733.33 ohms?

The reason for this is that the heater of our tube also has resistance. The amount of resistance offered by the heater may easily be determined by referring again to the Tube Manual. The Manual tells us that at a voltage of 35 volts, this particular tube will draw .15 ampere. With E and I thus known, we can now solve for the R (resistance) of the tube's heater:

$$\text{(Ohm's Law) } R = \frac{E}{I} = \frac{35}{.15} = .15\overline{)35.} = 15.\overline{)3500.} \quad 233.33 \text{ ohms (ans.)}$$

Since the tube's heater contributes a resistance of 233.33 ohms, and the total value of resistance required in the circuit is 733.33 ohms, it will be necessary to merely add 733.33 minus 233.33 or 500 ohms--in the form of an additional resistor (which we term a "ballast" resistor)--in series with the tube's heater.

Now that we have a current flow of .15 ampere throughout the entire circuit, it is permissible to insert the tube's heater AT ANY POINT within the circuit without fear of burning it out.

In conclusion, I would suggest and heartily recommend that you thoroughly review the FUNDAMENTAL PRINCIPLES covered in this edition of the RESEARCH DIGEST and to co-relate them with your earlier lessons for a more comprehensive understanding of this subject.

****

The best way to
improve the world
is to improve
ourselves.

JR

From the desk of the Chief Engineer

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UNITS OF MEASUREMENT IN RADIO AND ELECTRONICS

In radio and electronics, we are often dealing with UNITS, SUB-UNITS, and GROSS UNITS. Here are some comments which should prove helpful to you in converting between units, sub-units, or gross units.

UNITS: Fundamentally, all electrical and radio measurements are made in terms of basic units. Some of these basic units, and the electrical or electronic characteristics which they measure are:

UNIT	CHARACTERISTIC
VOLT	ELECTROMOTIVE FORCE
AMPERE	CURRENT
OHM	RESISTANCE
HENRY	INDUCTANCE
FARAD	CAPACITY
CYCLE	FREQUENCY
MHO	CONDUCTANCE
METER	LENGTH

These are basic units. Nearly all electrical and radio formulae are set up for the use of these basic units only. Thus, if we have a value expressed in sub-units, or gross units, we must nearly always convert it back to the basic unit before working a problem in which it is involved. For example: Microfarads must be changed to farads, millihenrys to henrys, milliamperes to amperes, etc.

SUB-UNITS: When we are dealing with quantities which are less than the basic unit, or with quantities which are a fraction of the basic unit, such as .125 amperes, .2 volts, .00005 henrys, etc, it is usually more convenient to express these values in terms of sub-units, which are a fraction of the main unit. We do this by putting a metric prefix in front of the main unit, as we write or speak. The three most common metric prefixes for sub-units are: Milli, Micro, and Micro-micro. Milli means one-thousandth. Micro means one-millionth. Micro-micro means one-millionth of one-millionth. Another prefix, "Centi", is sometimes used in connection with measures of length. Centi means one-hundredth. Some of the popular sub units and their basic units are:

SUB-UNIT	FRACTION OF BASIC UNIT
CENTIMETER	1/100 METER
MILLIAMPERE	1/1000 AMPERE
MILLIVOLT	1/1000 VOLT
MILLIHENRY	1/1000 HENRY
MILLIMETER	1/1000 METER
MICROAMPERE	1/1,000,000 AMPERE
MICROVOLT	1/1,000,000 VOLT
MICROHENRY	1/1,000,000 HENRY
MICROFARAD	1/1,000,000 FARAD
MICRO-MICROFARAD	1/1,000,000,000,000 FARAD

GROSS UNITS: Just as was the case when dealing with very small quantities, it is customary when expressing very large quantities to use a unit which is larger than the basic unit. We call such units GROSS UNITS. The word "gross" means large, or larger than normal, in this case. We do this by use of two other metric prefixes: kilo, and mega. Kilo means thousand, while mega means million. Thus, instead of writing 450,000 cycles, it is usually more convenient to use the gross unit, Kilocycle, which is 1000 times as great as the basic unit,cycle. Thus, 450,000 cycles may be conveniently expressed as 450 kilocycles

Or, instead of saying 220,000,000 cycles, we could more conveniently say 220 megacycles. Here are the gross units as commonly used in radio:

GROSS UNIT	REPRESENTS
KILOCYCLE	1000 CYCLES
KILOVOLT	1000 VOLTS
KILOMETER	1000 METERS
MEGACYCLE	1,000,000 CYCLES
MEGOHM	1,000,000 OHMS

A HANDY CONVERSION TABLE

Since it is essential that every student learn the proper procedure for making conversions from sub-units or gross-units, to the basic unit, which is needed for most formulas, these methods are outlined in the lessons where they apply. However, our engineers and technicians have found the following table to be very handy for making rapid and accurate conversions without the necessity of any figuring or computation.

ORIGINAL VALUE	*DESIRED VALUE*							
	Mega	Kilo	Units	Deci	Centi	Milli	Micro	Micromicro
Mega		3→	6→	7→	8→	9→	12→	18→
Kilo	←3		3→	4→	5→	6→	9→	15→
Units	←6	←3		1→	2→	3→	6→	12→
Deci	←7	←4	←1		1→	2→	5→	11→
Centi	←8	←5	←2	←1		1→	4→	10→
Milli	←9	←6	←3	←2	←1		3→	9→
Micro	←12	←9	←6	←5	←4	←3		6→
Micromicro	←18	←15	←12	←11	←10	←9	←6	

TO USE THE TABLE: Use of this table is simple in the extreme.

1. Find the metric prefix (milli, mega, micro, etc) in the column at the extreme left, under ORIGINAL VALUE.

2. Move your eye straight across the table to the right until you come to the column which is headed with the prefix which you wish to convert to.

3. Read the figure in the box, and note the direction in which the arrow is pointing. The figure indicates the number of places the decimal point is to be moved---the arrow indicates the direction it is to be moved. Thus: ← 3, indicates that the decimal point should be moved 3-places to the left.

EXAMPLES

MILLIAMPERES TO AMPERES: To convert 150 milliamperes to amperes, locate the prefix "milli" at the extreme left of the table under "Original Value." Read to the right across the table until you are under "Units". Read "3" as the number of places you must move the decimal point, and note that the arrow tells you to move it to the left. Doing this, 150 milliamperes becomes .150 ampere.

MILLIVOLTS TO MICROVOLTS: To convert 50 millivolts to microvolts, start in the "milli" box at the extreme left under "original value", and read to the right across the table until you are in the column headed "micro," and read: 3 →. This means that you must move the decimal point 3-places to the right. Thus, 50 millivolts becomes 50,000 microvolts.

MICROFARADS TO FARADS: Suppose we have a value of .005 microfarads and we wish to convert this to the basic unit of farads. To do this, locate "micro" at the extreme left of the table. Read straight across the table until you are in the column headed "Units" Read: ← 6, which tells you to move the decimal point 6-places to the left. Thus, .005 microfarads becomes .000000005 farads.

KILOCYCLES TO CYCLES: To convert 450 kilocycles to cycles per second, find "kilo" at the extreme left of the table. Read straight across the table until you are in the column headed "Units." Read: 3 →, which means that you will move the decimal point 3-places to the right. Thus: 450 kilocycles becomes 450,000 cycles.

MEGOHMS TO OHMS: To convert 5.5 megohms to ohms, find "Mega" at the extreme left of the table. Read straight across the table until you are in the column headed "Units." Read 6 →. Thus, 5.5 megohms becomes 5,500,000. ohms.

OHMS TO MEGOHMS: To convert 2.2 ohms to megohms, find "Units" at the extreme left of the table. Read straight across the table until you are in the column headed "Mega". Read: ← 6. Thus, 2.2 ohms equals .0000022 megohms.

DECIMAL POINTS IN WHOLE NUMBERS

In most instances, whole numbers, or numbers which do not contain a fraction---such as 1 15 622 1000995 etc.---are not written or shown with a decimal point. But in all cases, a decimal point belongs, and may properly be placed, at the extreme right of the figure. Thus, 1 is actually 1. with a decimal at the extreme right. Also, 15 is 15. 622 is 622. ; 100995 is 100995. etc.

PLACING THE DECIMAL POINT IN WHOLE NUMBERS: From the above, you can see that if you are dealing with a whole number, you must mentally place a decimal point at the extreme right of the number before you can move the decimal point in accordance with the data obtained from the table.

For example: Suppose you wish to convert 100 milliamperes to amperes. The figure 100 being a whole number is usually not written with a decimal point. But, you will mentally place a decimal point at the extreme right, so that the number now looks like this 100. to you. Then you will refer to the table and find that you will have to move this decimal point three places to the left to get amperes. Doing this, your 100. becomes .100 or .1 ampere. The same procedure is followed in the case of all whole numbers.

SUPPLYING EXTRA ZEROS: Often, you will have to move the decimal point more places than there are figures in the number you started with. In such cases, you will add enough zeros to enable you to move the decimal point the required number of places. For example: To convert 1.2 milliampere to amperes, we must move the decimal point three places to the left. However, there is only one place to the left of the decimal in the figure 1.2 as it is written here, and you need three places---or two more places than you have available. Therefore, we would supply two zeros and place them to the left of the 1 thus getting the required three places. So: 1.2 milliamperes becomes .0012 amperes by means of two extra zeros and the movement of the decimal point three places to the left.

Another example of adding zeros to get the required number of decimal places, would be in the conversion: .05 henrys to millihenrys. The table says to move the decimal point three places to the right. We do this by supplying one extra zero and placing it to the right of the 5 thus making the number .050 instead of .05 . We then move the decimal point three places to the right, and find that we have 050. or 50 millihenrys.

Converting is easier if the number is first jotted on scratch paper, the decimal point placed, and then moved to its new position (adding zeros where necessary).

REMEMBER: A thing is only complicated when you consider it as a whole, or in its entirety. The individual parts of the most complex piece of machinery are each usually quite simple when considered as individual parts.

The same is true in the problems you are encountering in radio. Each individual procedure is simple and easy to learn. The most complex problem is made up of several of these individual procedures and if each individual procedure is completed properly, then the entire problem is complete and correct. The data in this DIGEST is for the purpose of smoothing the way for you by making it easier for you to take care of the individual operations---and thus prepare yourself for a successful career in radio. STUDY IT AND RE-STUDY IT---IT WILL HELP YOU!

ESTABLISHED 1905 J. A. ROSENKRANZ, *Pres.*

NATIONAL SCHOOLS

• Pioneers of Practical Training •

LOS ANGELES, CALIFORNIA

MATHEMATICS

LESSON NO. M-1

BASIC ARITHMETICAL PROCESSES

Your lessons thus far have contained no mathematics; however, to advance yourself in the industry, it is necessary that you also become familiar with the practical application of certain fundamental calculations applied therein.

In this special series of lessons, it is not our intention to discuss engineering mathematics, but rather to provide instruction in

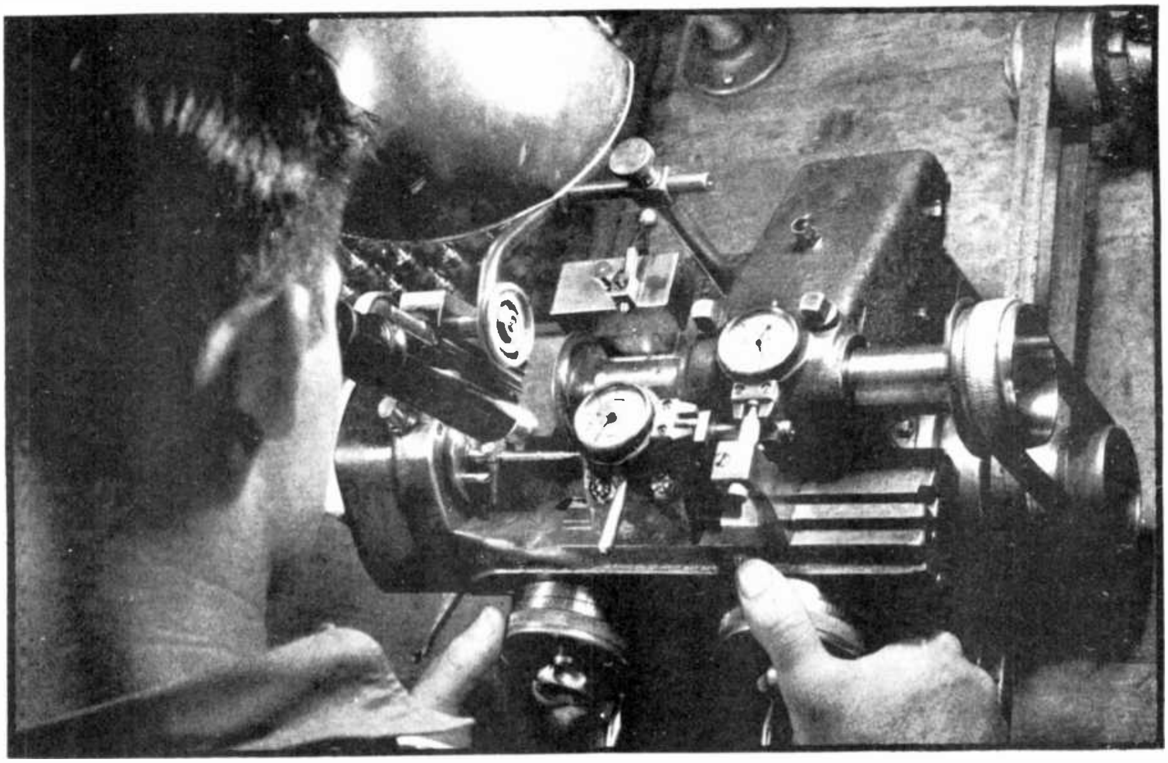


FIG. 1
SKILLED CRAFTSMEN WHO WORK WITH PRECISION EQUIPMENT MUST HAVE A PRACTICAL KNOWLEDGE OF MATHEMATICS

calculation such as is used by skilled craftsmen and technicians in the field or shop. The material presented in this first lesson of the series will consist of the elementary arithmetical processes which must be thoroughly understood before proceeding with the study of the more advanced subjects. To some students it will provide new instruction; to others it will serve as a review; to all it will furnish a foundation for what is to follow.

The importance of this series of lessons cannot be overemphasized in its relation to the practical man who, through the knowledge to be gained herein, will be able to read correctly scales that are calibrated in fractions of an inch and to make simple calculations involving addition, subtraction, division, common fractions, decimals, principles of geometry, etc., as required to do his work efficiently.

This knowledge is essential to skilled workers in practically all branches of the mechanical and electrical industries. Also, it is applicable, in a great measure, to problems that arise in everyday life.

ROMAN NOTATION

Seven letters are used in Roman notation. These seven are listed below at (a), together with their Arabic equivalents. Methods of writing numbers according to Roman notation are shown at (b). Notice that where a smaller value appears ahead of a greater value, the difference is read. Thus, IV is five minus one, or four. When a greater number appears ahead of a smaller value, they are added. Thus LX is equal to 60.

ROMAN	ARABIC
I	1
V	5
X	10
L	50
C	100
D	500
M	1000

(a)

I ----	1	XIX ----	19
II ----	2	XX ----	20
III ----	3	XXV ----	25
IV ----	4	XXXVIII ----	38
V ----	5	XL ----	40
VI ----	6	XLIX ----	49
VII ----	7	LXX ----	70
VIII ----	8	XC ----	90
IX ----	9	CC ----	200
X ----	10	DC ----	600
XI ----	11	CM ----	900
XIV ----	14	MCXX ----	1120
XV ----	15	MD ----	1500

(b)

It is advisable that you give some careful study to the Roman notation appearing in (b), so that you will be able to read such values without difficulty.

ARABIC NOTATION

Arabic notation employs ten characters or figures, as follows: 1, 2, 3, 4, 5, 6, 7, 8, 9, 0. The first nine are called <u>digits</u>. The cipher is called <u>naught</u> or <u>zero</u>, because it expresses nothing.

PROPER READING OF VALUES

It is often easy to err in reading numbers of a magnitude not ordinarily encountered in every-day practice. It will therefore be well to clarify this point before proceeding with arithmetical processes. Such groups of figures as 21; 375; 7,294, present no particular problem to the average person and are read "twenty-one," "three hundred seventy-five," and seven thousand, two hundred ninety-four," respectively.

However, a numeration such as appears in the following statement is not quite so obvious: "The major oil reserves of the United States lie in some 1,126,400,000 acres of lands underlain by sedimentary rocks."

You will note that a comma is used to separate each group of three figures or digits in the above number, which greatly simplifies its reading. This grouping of digits begins at the last figure on the right of the number and continues through to the left, each group being named as shown in the following table:

trillions			billions			millions			thousands			hundreds		
hundreds	tens	units	hundreds	tens	units	hundreds	tens	units	hundreds	tens	units	hundreds	tens	units
1	4	2,	7	5	3,	9	1	4,	1	9	6,	3	5	2

The value of each figure is determined by its location in the group;these locations being listed as units, tens, and hundreds. Since the third figure from the right in the group farthest the right is in the hundreds location, we read this portion of the number as three hundred fifty-two. This number could be read: three hundreds, five tens, and two units, but it would be too lengthy and awkward for practical use.

We find the next group toward the left to be "thousands" and it also has three figures, the values again being determined by their location as to hundreds, tens, and units. The following groups are called the millions, billions, and trillions, respectively; the figures in each being dealt with as in the first two groups.

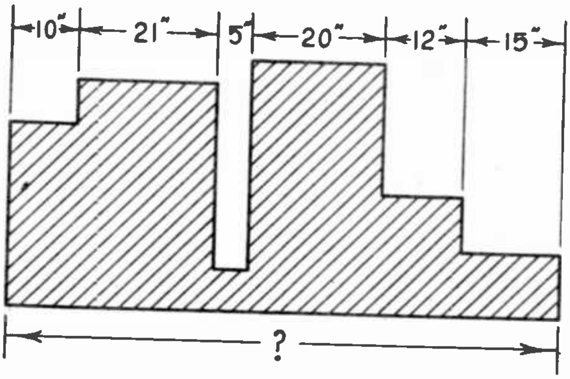
In reading any number, large or small, always begin at the left and read the group as if it were alone, adding the group name. Then read the next group to the right alone and add the group name,continuing in this way to the end,but omitting the name of the last, or units group. The number presented in the table just given is read as follows: One hundred forty-two trillion, seven hundred fifty-three billion, nine-hundred fourteen million, one hundred ninety-six thousand, three hundred fifty-two. Note that the name of the last group is omitted as is the word "and" when reading such numbers.

We occasionally encounter a number such as 14,000,003,067. Applying the above-mentioned rules, we read it as follows: Fourteen billion, three thousand, sixty-seven. You will observe that the millions group was not mentioned in this case due to the fact that there were no significant digits (numbers from 1 to 9)appearing in the millionths group.

With the matter of reading numbers refreshed in your mind,we are now ready to consider elementary arithmetical processes.

ADDITION

The first arithmetical process to be considered is addition. To illustrate this, let us look at the illustration below.



Here we have a sheet-steel plate of irregular contour, the partial dimensions of which are given in the drawing. The problem is to determine the total width of this plate, so we resort to the process of addition. That is, we must find the sum, or add together the dimensions, 10 inches, 21 inches, 5 inches, 20 inches, 12 inches and 15 inches. Note that in this drawing "inches" are designated by the sign (").

To find this sum, we arrange the figures in a vertical column as at (a) below, and draw a horizontal line below the column.

(a)	(b)	(c)
10	10	10
21	21	21
5	5	5
20	20	20
12	12	12
15	15	15
	3	83

Now the right-hand column of figures under (a) is the "units" column, whereas the left-hand column of figures under (a) is the "tens" column; therefore, note that the single figure 5 must be placed under the UNITS column. When writing down a column of figures for the purpose of adding them together, be sure to arrange them in as nearly a vertical line as possible and so that the unit figures will be in a straight units column, the tens figures in a straight tens column, etc. Many errors will be eliminated through close adherence to this matter by preventing the addition of figures in the units column to those in the tens column. Errors will also be prevented by employing extreme care in writing down the figures so that they will be easily read by yourself and others.

We commence by adding the figures in the right-hand column under (a), beginning from the bottom thus, 5 + 2 + 0 + 5 + 1 + 0 = 13. This number 13 is, in reality, 1 ten and 3 units; we therefore place the 3 below the horizontal line under the units column as at (b), and carry the 1 over to the tens column.

Now, adding the tens column, we have the 1 which was carried over plus 1 + 1 + 2 + 2 + 1, giving us the sum of 8. The 8 is now placed directly below the tens column and below the horizontal line, thus giving a result of 83 as shown at (c).

The answer obtained from the process of addition is called the TOTAL or SUM, and since the numbers just added represent inches, our answer will also be expressed in inches. That is, the total width of the steel plate is 83 inches. Remember that you can only add quantities of the same kind, or LIKE QUANTITIES; that is to say, you cannot add inches to feet and obtain a correct answer. The inches would first have to be changed to feet, or the feet to inches.

For instance, should you be required to calculate the total amount of fuel used by a certain engine over a period of one week, you must first decide whether you want this total in quarts, gallons, barrels, etc. You must then be sure that the daily quantities of fuel used are expressed in the same terms. Let us consider such a problem where the following quantities expressed in gallons must be added: 210; 196; 203; 214; 198; 199; 205. The first step is to arrange these numbers in a vertical column as shown at (a), drawing a horizontal line below them and then carrying the work through the following processes as shown in steps (b) and (c).

(a)	(b)	(c)
210	210	210
196	196	196
203	203	203
214	214	214
198	198	198
199	199	199
205	205	205
5	25	1425

The total or sum of this addition then becomes 1,425 gallons. Note that the sign (+) denotes plus or "added to" and the sign (=) denotes "equals" or "is equal to."

The example just given can also be written in the following form: 210 + 196 + 203 + 214 + 198 + 199 + 205 = 1,425.

If the columns of figures on which you are working are quite long and you feel that you should check the answer to be sure that it is correct, you can do this by adding the columns from the top toward the bottom, beginning with the right-hand column, and noting if the results obtained agree with those from the original addition.

PRACTICE PROBLEMS:

Find the sum:

(a)	(b)	(c)
56	467	8,950
49	536	15,765
17	84	7,732
36	705	
21		

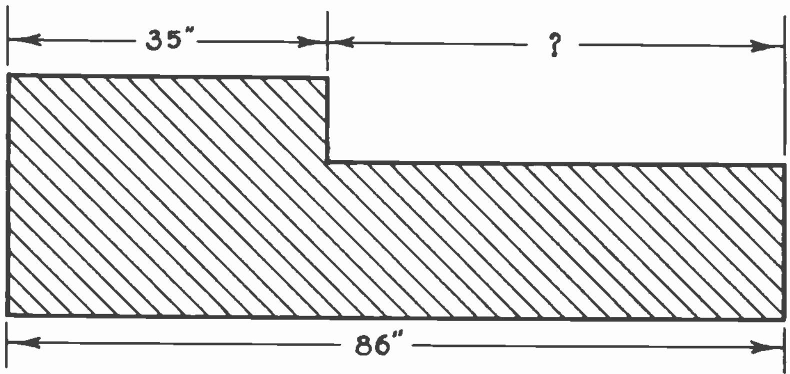
Answers: (a) 179 (b) 1,792 (c) 32,447

SUBTRACTION

Now let us consider briefly the process of SUBTRACTION. In this process we take one number from another to find how much is left, or the difference. To illustrate this process, we again make use of a drawing representing a plate of sheet-steel as illustrated at the top of the next page. The total length of this material is given as 86 inches and the length of one section is indicated on the drawing to be

35 inches. So, to find the length of the section indicated by the question mark, we subtract or take away 35 inches from 86 inches.

The plate is to be cut to the dimensions indicated:



To carry out this process of subtraction, we place the smaller number under the larger one as shown below at (a), drawing a horizontal line below the group.

	(a)	(b)	(c)	
(minuend)	86 in	86 in.	86 in.	
(subtrahend)	35 in.	35 in.	35 in.	
		1	51 in.	(difference)

The upper number is called the MINUEND and the lower one the SUBTRAHEND. We begin our subtraction in the right-hand (units) column as shown at (b), by subtracting 5 from 6. This leaves a remainder of 1 unit, so we place the 1 below the line under the units column. We can now proceed with the next (tens) column, taking 3 from 8 which leaves a remainder of 5 to be placed under the horizontal line in the tens column as shown at (c). The answer or DIFFERENCE thus becomes 51, and since inches were subtracted from inches, the answer will be expressed in inches also.

In subtraction, as in addition, it is permissible to subtract values of LIKE QUANTITIES only. The minus sign (-) indicates the process of subtraction, and the expression given at (c) in the above calculation could also be written as 86 - 35 = 51.

Sometimes, you will be confronted with problems in which there are a greater number of digits (figures) in the minuend than there are in the subtrahend, such as when subtracting 762 from 89,964. In such a case, we arrange this work as:

89,964	
- 762	
89,202	(difference)

If the problem is such that some figures in the minuend are less than those directly under them in the subtrahend, a slight variation in procedure from the foregoing is necessary. For example, if 863 is to be taken away from 1,952, we arrange the work in the usual form as at (a) of the following example.

(a)	(b)	(c)	(d)	
1952	1952	1952	1952	
863	863	863	863	
	9	89	1089	(difference)

In the extreme right-hand column, it is obvious that 3 cannot be taken away from 2, so we mentally take one of the tens from the "tens" column and add it to the 2. This raises the value of 2 to 12, from which number the 3 can now be subtracted, leaving us a remainder of 9 to be placed below the horizontal line under the units column as at (b).

When we come to the next column toward the left, we must remember that one of the tens has been taken away from the 5 in the tens column; we therefore have only a value of 4 left. You will note now that 6 must be subtracted from 4, which cannot be done without raising the value of 4; thus, as in the preceding instance, we must borrow 1 from the next column to the left. In this case, we are taking 1 from the hundreds column and adding it to the 4 in the tens column; this gives us 14 tens, from which we subtract 6 tens and obtain the remainder of 8. The 8 is placed beside the 9 under the horizontal line and directly beneath the tens column.

The next step is to subtract the 8 from the 9, but the 9 has previously been reduced to 8 by the 1 which was taken from it during the preceding step. Now subtract 8 from 8, which leaves us a remainder of 0 (zero). The zero is placed beneath the horizontal line under the hundreds column and next to the 8. There is no number in the thousands column of the subtrahend to subtract from the 1 in the minuend; the 1 is therefore placed below the horizontal line in the thousands column without having had its value changed, as shown at (d).

To check the answer to a problem in subtraction, you can add the remainder or difference to the subtrahend and the result should be a number of the same value as the minuend. For example, in the preceding problem, where 863 was subtracted from 1952, giving a difference of 1089; we can check this work by adding 1089 and 863, which gives us a sum of 1952. This, you will note, is equal to the minuend.

PRACTICE PROBLEMS:

Subtract each number below from 1,000 and check your answers by adding the remainder to the subtrahend:

(a)	225	(d)	499	(g)	900
(b)	314	(e)	725	(h)	931
(c)	216	(f)	328	(i)	653

MULTIPLICATION

The next arithmetical process which we shall consider is MULTIPLICATION. Multiplication is, in effect, a shortened method of performing a certain type of addition where all the numbers to be added are of the same value. Thus, to multiply a number, simply means that it is added to itself as many times as the value of the number by which it is to be multiplied. For example, if 8 is to be added to itself three times, we have 8 + 8 + 8 = 24. This answer is the same as that obtained by multiplying 8 by 3. The expression is written 8 x 3 = 24 and is read "8 times 3 equals 24"-- (x) being the sign denoting multiplication.

Although in a simple problem, as just given, it is perhaps as easy to obtain this answer of 24 by addition as by multiplication, yet when we have a problem where a number such as 36,478 must be added to itself 147 times, the addition would become a long-drawn-out and tedious process. Multiplication, on the other hand, offers a much quicker and easier solution.

A thorough knowledge of multiplication tables is essential in working multiplication problems. These tables are given up to 12 x 12 in Table I, and must be studied until they are known by memory. Each number from 2 to 12 is taken separately so that you can learn its products with numbers from 1 to 12. Begin with the lower number first and gradually increase until you have learned all of them thoroughly.

TABLE I

MULTIPLICATION TABLE

1 x 2 = 2	1 x 3 = 3	1 x 4 = 4	1 x 5 = 5
2 x 2 = 4	2 x 3 = 6	2 x 4 = 8	2 x 5 = 10
3 x 2 = 6	3 x 3 = 9	3 x 4 = 12	3 x 5 = 15
4 x 2 = 8	4 x 3 = 12	4 x 4 = 16	4 x 5 = 20
5 x 2 = 10	5 x 3 = 15	5 x 4 = 20	5 x 5 = 25
6 x 2 = 12	6 x 3 = 18	6 x 4 = 24	6 x 5 = 30
7 x 2 = 14	7 x 3 = 21	7 x 4 = 28	7 x 5 = 35
8 x 2 = 16	8 x 3 = 24	8 x 4 = 32	8 x 5 = 40
9 x 2 = 18	9 x 3 = 27	9 x 4 = 36	9 x 5 = 45
10 x 2 = 20	10 x 3 = 30	10 x 4 = 40	10 x 5 = 50
11 x 2 = 22	11 x 3 = 33	11 x 4 = 44	11 x 5 = 55
12 x 2 = 24	12 x 3 = 36	12 x 4 = 48	12 x 5 = 60
1 x 6 = 6	1 x 7 = 7	1 x 8 = 8	1 x 9 = 9
2 x 6 = 12	2 x 7 = 14	2 x 8 = 16	2 x 9 = 18
3 x 6 = 18	3 x 7 = 21	3 x 8 = 24	3 x 9 = 27
4 x 6 = 24	4 x 7 = 28	4 x 8 = 32	4 x 9 = 36
5 x 6 = 30	5 x 7 = 35	5 x 8 = 40	5 x 9 = 45
6 x 6 = 36	6 x 7 = 42	6 x 8 = 48	6 x 9 = 54
7 x 6 = 42	7 x 7 = 49	7 x 8 = 56	7 x 9 = 63
8 x 6 = 48	8 x 7 = 56	8 x 8 = 64	8 x 9 = 72
9 x 6 = 54	9 x 7 = 63	9 x 8 = 72	9 x 9 = 81
10 x 6 = 60	10 x 7 = 70	10 x 8 = 80	10 x 9 = 90
11 x 6 = 66	11 x 7 = 77	11 x 8 = 88	11 x 9 = 99
12 x 6 = 72	12 x 7 = 84	12 x 8 = 96	12 x 9 = 108

1 x 10 = 10	1 x 11 = 11	1 x 12 = 12
2 x 10 = 20	2 x 11 = 22	2 x 12 = 24
3 x 10 = 30	3 x 11 = 33	3 x 12 = 36
4 x 10 = 40	4 x 11 = 44	4 x 12 = 48
5 x 10 = 50	5 x 11 = 55	5 x 12 = 60
6 x 10 = 60	6 x 11 = 66	6 x 12 = 72
7 x 10 = 70	7 x 11 = 77	7 x 12 = 84
8 x 10 = 80	8 x 11 = 88	8 x 12 = 96
9 x 10 = 90	9 x 11 = 99	9 x 12 = 108
10 x 10 = 100	10 x 11 = 110	10 x 12 = 120
11 x 10 = 110	11 x 11 = 121	11 x 12 = 132
12 x 10 = 120	12 x 11 = 132	12 x 12 = 144

The number which is to be added to itself is called the MULTIPLICAND, and the number denoting how many times the multiplicand is added to itself is called the MULTIPLIER. For example, 7 x 8 = 56. In this case, the number 7 is the multiplicand, 8 is the multiplier, and the answer or PRODUCT is 56.

Let us begin with a simple multiplication problem; say, multiplying 63 by 3. The first step is to write the problem in the form shown at (a). Note that the multiplier is placed below the multiplicand so that the unit figure of one is directly beneath that of the other.

```
                     (a)      (b)

(multiplicand)       63       63
(multiplier)          3        3
                    ---      ---
                      9      189  (product)
```

Now, multiply the 3 of the multiplicand by the multiplier, which gives us 3 x 3 or 9, and since we are multiplying units by units, the 9 is placed below the horizontal line directly beneath the units of the multiplicand and multiplier as at (a). The next step is to multiply the 6 in the ten's position of the multiplicand by the multiplier 3; the resulting value of 18 is, in reality, eighteen tens, or 1 hundred and 8 tens. The 8 is therefore placed in the ten's position below the horizontal line, and the 1 is written in the hundred's position, as shown at (b). The product thus consists of 1 hundred, 8 tens, and 9 units, which you will note is the same as the sum obtained by adding 63 + 63 + 63 = 189. This resulting value is read as one hundred eighty nine.

If a certain number is to be multiplied by another number containing two or more figures, then the work is laid out as follows:

```
 (a)        (b)        (c)        (d)        (e)

 3724       3724       3724       3724       3724
  307        307        307        307        307
 ----      -----      -----      -----      -----
           26068      26068      26068      26068
                      0000       0000       0000
                                11172      11172
                                -----    -------
                                         1143268
```

Note that the units, tens, and hundreds figures of the multiplier are positioned beneath the units, tens, and hundreds, respectively, of the multiplicand.

We now multiply the entire multiplicand by the unit 7 of our multiplier, writing the result of this process in the form shown at (b); the partial product is thus 26,068. With this part of the work completed, we next multiply the multiplicand by the tens figure of the multiplier, which is zero (0). Since zero times any number is zero, we place these zeros under the first partial product as at (c), and since the zero of the multiplier is in the ten's position, the first zero is placed in the ten's column of the partial product.

The following step consists of multiplying the multiplicand by the 3 which is in the hundred's position of the multiplier. We place this resulting partial product of 11,172 under the row of zeros in such a position that the right-hand figure, 2, is in the hundred's column as shown at (d). The partial products are now in their proper positions with respect to their units, tens, hundreds, thousands, etc. values, and may therefore be added together to obtain the total product. A horizontal line is drawn below the last partial product and by addition we find the final or total product to be 1,143,268 which, as explained previously, is read one million, one hundred forty-three thousand, two hundred sixty-eight.

When multiplying by zero, as in the previous example, it is common practice not to write down all of the zeros, but only the first, thus:

```
   3724
    307
  26068
 111720 <---(the zero)
 1143268
```

The product obtained from the next number of the multiplier (3 in this case) is then placed on the same line to the left of the zero which, you will note, is still in the hundreds column so that the result will be the same.

One method of checking a problem in multiplication is to interchange the multiplicand and multiplier, and repeat the process of multiplication. However, a quick check has been developed which is extremely convenient for verifying long multiplication problems. This check which follows should be studied and thoroughly mastered for future use.

(a) Add the digits (figures) in the multiplicand. If this SUM is a number composed of more than one digit, add these. If there are still more than one digit, add them together again until you finally arrive at a number consisting of one digit.

(b) Add the digits of the multiplier in the same manner as described in rule (a) until only one digit remains.

(c) Multiply together the final numbers obtained from rules (a) and (b), and add the digits until a number of 1 digit remains.

(d) Add the digits of the product in the same manner as outlined in rule (a). Now compare the results obtained in rule (c) with those obtained in rule (d). If they are the same, then the work verifies, proving it to be correct.

To illustrate this checking method, let us check our previous computation, where we multiplied 3724 by 307. By adding the digits of the multiplicand, we have 3 + 7 + 2 + 4 = 16, or the two digits 1 and 6; therefore, we add these and get 6 + 1 = 7 as the single digit required by rule (a). By adding the digits in the multiplier we have 3 + 0 + 7 = 10, or 1 and 0. Since 1 + 0 = 1, we have 1 as our single digit as per rule (b).

According to rule (c) we must now multiply the results of steps (a) and (b). That is, 7 x 1 = 7. This done, we add the digits in the product of our previous computation, and find that 1+1+4+3+2+6+8 = 25. Adding the 2 and 5 together, we get the number 7, which checks with the number 7 of step (c). Thus we have proven our calculations to be correct.

In multiplying a number by 10, 100, 1000, etc., it is not necessary to carry the work out in the regular manner. The following method is used in such cases:

To multiply a number by 10, annex 0. (38 x 10 = 380)
To multiply a number by 100, annex 00. (75 x 100 = 7,500)
To multiply a number by 1000, annex 000. (89 x 1000 = 89,000)

PRACTICE PROBLEMS:

(a) Multiply 346 by 47
(b) Multiply 432 by 103
(c) Multiply 2,928 by 364
(d) Multiply 13,456 by 2,004

Answers: (a) 16,262; (b) 44,496; (c) 1,065,792; (d) 26,965,824

DIVISION

Let us now proceed with the process of DIVISION, which consists of finding how many times one number is contained in another. It can also be considered as a process of separating one number into a desired number of equal parts.

Two methods of performing the process of division are available, namely, LONG DIVISION, and SHORT DIVISION. The former is used when large numbers are involved, and the latter may be used with a considerable saving in time when a number of only one or two digits is to be divided into another number. Long division is the more simple of the two methods and will therefore be considered first.

LONG DIVISION: The number to be divided is called the DIVIDEND, and the number by which the dividend is to be divided is called the DIVISOR. The result or QUOTIENT is the number which denotes how many times the divisor is contained in the dividend. For example, if 40 is to be divided by 5, then the dividend is 40 and the divisor is 5. Since 5 will go into 40 just 8 times, the quotient is 8.

The sign for division is (÷) which is read as "divided by". Thus, 40 ÷ 5 = 8 is read as 40 divided by 5 equals 8. This expression may also be written $\frac{40}{5} = 8$, and in this case the 40, or dividend, is placed above the divisor 5, with the horizontal line separating them denoting the process of division. A third method of writing this same expression is 5)40 (8, and is one form in which the problem may be set up to complete the actual process of division.

Now let us work out a problem in division -- as an example, dividing 193,648 by 52. We begin by laying out the problem as at (a).

(a)

```
52)193,648(3___
 ^    ^     ^
  \    \     \
   \    \     `---quotient
    \    `--------dividend
     `------------divisor
```

(b)

```
52)193,648(3724
   156
   ---
    376
    364
    ---
     124
     104
     ---
      208
      208
      ---
      000
```

Note that the divisor is written in a bracket at the left, then the dividend, and finally, a bracket is made at the right which will contain the quotient, or answer.

The first step in this process is to determine the least number of figures in the dividend which will contain the divisor. We see by observation that 52 cannot be divided into 1 or 19, but 193 is of greater magnitude than 52 and so can be divided by the latter. We now must determine how many times 52 is contained in 193, and as an aid to this we will consider only the partial numbers 5 and 19. (Note that the 5 is five "tens", and 19 is nineteen tens.) It is now easily seen that 5 will divide into 19 three times but not four times, so we assume that 52 is contained in 193 three times. We therefore write this 3 as the first digit in the quotient, as shown at (a). Now we multiply the divisor 52 by the partial quotient 3 and obtain a product of 156, which we place directly below the 193.

This done, we subtract 156 from 193, which leaves a remainder of 37 as shown at (b), and to this remainder we annex the figure 6 from the dividend, thus giving us 376. We now determine how many times 52 is contained in 376, and find it to be a little over 7 times; 7 is therefore placed in the quotient bracket after the 3.

We multiply the divisor by this 7, and place the resulting product of 364 under the 376, then subtract. The difference is 12 to which 4, the next number to be taken from the dividend, is annexed, thus giving us 124.

The divisor 52 will go into 124 a little over two times, so we place the 2 after the 7 in the quotient and multiply 52 by 2, placing the product 104 under the 124, as shown at (b). We subtract 104 from 124 and a difference of 20 will remain, to which 8, the last remaining figure in the dividend, is annexed to give us 208. The divisor will go into 208 exactly 4 times, and therefore a 4 is placed as the final number of this quotient. Multiplying the divisor by the 4 will give us a product of 208, which when subtracted from 208 leaves no remainder. Thus the quotient is 3724, meaning that 52 is contained in 193,648 exactly 3724 times.

Quite often, a problem in division does not come out even as, for example, when dividing 2,702,839 by 63. In such a case, place the final remainder over the divisor as a fraction to be annexed to the quotient. This problem would appear as follows:

```
63)2702839(42,902 13/63
   252
    182
    126
     568
     567
       139
       126
        13  (remainder)
```

SHORT DIVISION: When dividing one number by another, and using the process of short division, a considerable amount of the work is done mentally and without writing it down. At (a) is shown the manner in which a problem is set up when short division is to be used.

```
            (a)                                  (b)

divisor→3)2916←dividend                       3)2916
               ←quotient                         972←quotient
```

We first note by observation that the divisor 3 will not go into 2, but will go into the 29 of the dividend a little over 9 times. The number 9 thus becomes the first digit of our quotient and is placed below the horizontal line, directly under the 9 in the dividend. We make a mental note of the fact that 9 x 3 is 27 which, when subtracted from 29, will leave a remainder of 2. Place the 2 mentally in front of the next number, 1, in the dividend; this will give the number 21 which is mentally divided by the divisor 3. The divisor 3 is contained in 21 exactly 7 times, so we place the 7 after the 9 in the quotient.

The number 6 is the only remaining figure in the dividend to be divided and we see that it contains 3 two times. The 2 therefore follows the 7 in the quotient to give us an answer of 972.

A little practice in performing short division will enable you to hold the intermediate values in your mind and make you proficient in the use of this shortened method of division.

One method by which a problem in division may be checked is to multiply the quotient by the divisor and add the remainder (if any) to the product. The final result should be the same as the dividend. For example, to prove our previous problem, where we divided 63 into 2,702,839 and obtained a quotient of $42,902\frac{13}{63}$, we proceed thus:

```
   42902   (quotient)
      63   (divisor)
  ------
  128706
 257412
 -------
 2702826
      13   (remainder)
 -------
 2702839   (dividend)
```

A faster method of checking, similar to that used for checking multiplication, is to apply the following rules as they are given:

(a) Add the digits in the dividend, and if the sum is a number with more than 1 digit, add these digits until a single digit is obtained.

(b) Add the digits in the divisor, and add the digits in the resulting sum until a single digit is obtained.

(c) Add the digits in the quotient, and add the digits in this sum until a single digit is obtained.

(d) Add the digits in the remainder, and add the digits in this sum until a single digit is obtained.

(e) Multiply the result of steps (b) and (c) and annex the result of (d). Then add the digits in this result, which should give the same as the result of (a) if the work is correct.

As an example for the application of this method, let us use it to check our previous division problem, as follows:

(a) The sum of the digits in the dividend is 2+7+0+2+8+3+9 = 31. The digits 3 + 1 give us a single digit of 4.

(b) As per rule (b), the sum of the digits in the divisor is 6 + 3 = 9.

(c) The sum of the digits in the quotient is 4 + 2 + 9 + 0 + 2 = 17 and 1 + 7 gives us a single digit of 8.

(d) The digits of the remainder are 1 and 3, whose sum equals the single digit 4.

(e) By multiplying the results of steps (b) and (c) we have 9 x 8 = 72, and upon annexing to this the result of step (d) which is 4, we have 724; the sum of these digits being 7 + 2 + 4 = 13. Finally, by adding the digits 1 and 3 of this sum, we have a result of 4, the value of which checks with the result obtained in step (a). The work is thus proven to be correct.

PRACTICE PROBLEMS:

(a) Divide 414 by 18
(b) Divide 1,656 by 23
(c) Divide 11,022 by 22
(d) Divide 37,185 by 88
(e) Divide 295,625 by 43

Answers: (a) 23; (b) 72; (c) 501; (d) $422\frac{49}{88}$; (e) 6875.

DETERMINING THE AVERAGE OF SEVERAL NUMBERS

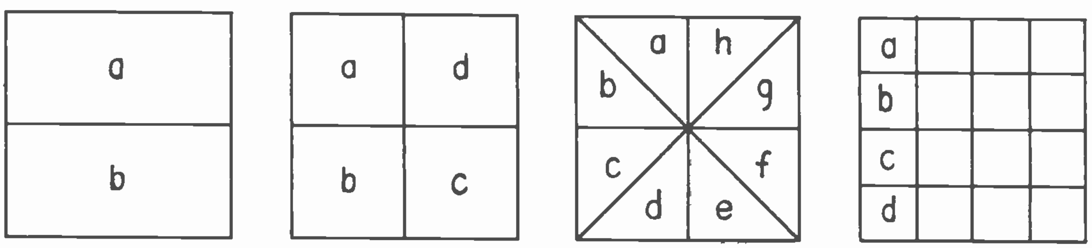
It is sometimes necessary to find the average of several numbers in order to estimate supplies required for a given length of time; to determine the average operating expense over a given period of time, etc

To find the AVERAGE of any group of numbers, it is first necessary to add them together and obtain the sum. Then divide the sum by a value equal to as many numbers as appear in the group. For example: What is the average temperature for 24 hours when the thermometer reads 50 degrees at noon, 30 degrees at 8 p.m., 24 degrees at midnight, and 28 degrees at 8 a.m.?

Solution: 50 + 30 + 24 + 28 = 132. Since 132 is the total, or sum, and there are four numbers in the group, the average will be 132 ÷ 4 = 33. In other words, the average temperature is 33 degrees.

FRACTIONS

We are now ready to give careful consideration to FRACTIONS. A fraction consists of two numbers, one above the other with a line between them, such as $\frac{3}{8}$, $\frac{5}{16}$, 1/2, 3/4, etc. Sometimes, the dividing line is horizontal while at other times it is inclined, but this is simply a matter of choice. From our brief discussion of division, you will recall that a fraction denotes the process of division, and when considered as such, the number below the line tells us into how many equal parts a whole unit is divided, while the number above the line specifies how many of these equal parts are being used. In the case of 5/16, the whole (or the unit 1) is divided into 16 equal parts, but of these only 5 are being used. This can probably be illustrated best by means of the divided squares shown below



(A) (B) (C) (D)

The square at (A) has been divided into two equal parts, where part "a" is 1/2, and "b" is 1/2. Note that the denominator 2 shows the number of equal parts into which the unit has been divided.

The square (B) has been divided into 4 equal parts, and if we take parts a, b, and c, we have taken 3/4 of the square and left 1/4 -- each part is 1/4. Sections "a" and "b" together represent 2/4 or 1/2.

The figure (C) has been divided into 8 equal parts. Each part is 1/8 of the whole square -- a, b, and c together equal 3/8 of the whole.

(D) has been divided into 16 parts of equal size, thus a, b, c, and d are together equal to 4/16, or 1/4.

The number above the line of a fraction is called the NUMERATOR, and the number below the line is called the DENOMINATOR.

Very often, fractions are used together with a whole number, such as $2\frac{1}{4}$, which, by the way, is equivalent to $2 + \frac{1}{4}$. Here, 2 is the whole number and $\frac{1}{4}$ is the fraction, and we call such a number, composed of a whole number and a fraction, a MIXED NUMBER.

If, in a certain fraction, the numerator is less than the denominator, the fraction is called a PROPER FRACTION. Thus, 2/3, 1/2, 2/4,, 5/16, etc., are all proper fractions.

On the other hand, we also have IMPROPER FRACTIONS, in which the numerator is equal to or greater than the denominator. Thus, 13/2, 5/4, 6/5, etc., are all improper fractions.

REDUCING WHOLE OR MIXED NUMBERS TO IMPROPER FRACTIONS

A common function in the manifulation of fractions, which you will need to use quite often, is to reduce a whole or mixed number to an improper fraction. For example, changing 3 to halves, 5 to 6ths, $7\frac{3}{5}$ to 5ths, etc.

Remember that whenever the numerator of any fraction is EQUAL to its denominator, the value of the fraction is equal to unity or 1. That is; 5/5, 3/3, 6/6, 8/8, etc., are all equal to 1.

RULE: To reduce a whole number to a fraction with a given denominator, first multiply the whole number by the given denominator. Then place this product over the denominator.

EXAMPLE: Reduce the number 3 to halves. Here the denominator is to be 2, so our first step according to the rule is to multiply 3 by 2, which gives a product of 6. Placing this product over the denominator gives us the improper fraction of $\frac{6}{2}$, which is the number 3 expressed in halves.

EXAMPLE: Reduce the number 5 to 6ths.

$5 \times 6 = 30$, and $\frac{30}{6}$ is the required fraction.

RULE: To reduce a mixed number to a fraction of a given denominator, first multiply the whole number by the given denominator and add the numerator, then place this sum over the denominator.

EXAMPLE: Reduce $7\frac{3}{5}$ to 5ths.

$5 \times 7 = 35$; $35 + 3 = 38$. $\frac{38}{5}$ is the required fraction.

REDUCING IMPROPER FRACTIONS TO WHOLE OR MIXED NUMBERS

Another common conversion often used in working with fractions is that of reducing an improper fraction to a whole or mixed number.

RULE: To reduce an improper fraction to a whole or mixed number, perform the division indicated by the fraction. The resulting quotient is the number of units in the whole number. If there is no remainder from this division process, the fraction reduces to a whole number only. If there is a remainder from this division process, then the fraction reduces to a mixed number, of which the quotient is the whole number and the remainder becomes the numerator of the fractional part.

EXAMPLE: Reduce $\frac{16}{4}$ to a whole number. The expression $\frac{16}{4}$ is the equivalent of $16 \div 4$, which gives us a quotient of 4. Thus, 4 is a whole number equivalent to $\frac{16}{4}$.

EXAMPLE: Reduce $\frac{46}{5}$ to a mixed number.

$$\frac{46}{5} = 46 \div 5 = 9\frac{1}{5} \text{ (answer)}$$

REDUCING FRACTIONS TO THEIR LOWEST TERMS

When dealing with fractions, it is common practice to reduce them to their lowest terms; that is, if we have a fraction such as 6/8 representing a part of an inch, for instance, we do not leave it in this form, but reduce it to 3/4. A fraction is in its lowest terms when there is no number that will divide into both numerator and denominator. This process makes the fraction look smaller but its value is unchanged.

RULE: To reduce a fraction to its lowest terms, divide both numerator and denominator by the same number. If the resulting quotients can be divided again by a common (same) number, continue in this manner until the fraction reaches its lowest terms.

EXAMPLE: Reduce $\frac{21}{42}$ to its lowest terms. By inspection, it is seen that the numerator and the denominator of this fraction are divisible by 7; thus, by dividing both numerator and denominator by 7, we have 3/6. Again it can be seen by inspection that 3/6 can be reduced to still lower terms because the number 3 is contained in both the numerator and denominator of this fraction. By dividing these two numbers by 3, we have 1/2 as the fraction $\frac{21}{42}$ reduced to its lowest terms.

All of this work could have been accomplished in a single step, due to the fact that the numerator and denominator of the fraction $\frac{21}{42}$ are divisible by 21 which, when carried out, would reduce the fraction to its lowest term of 1/2.

COMMON DENOMINATORS

Before a number of fractions can be added together, or before one fraction can be subtracted from another, it is necessary that they have the SAME DENOMINATOR.

For example, if we are to add together the fractions 1/4, 1/6, 3/8, we must first determine a value for the denominator which can be the same for all three fractions. One way to determine this common denominator is to multiply all of the denominators of the group together. For example, in this particular case, multiply 4 x 6 x 8, which gives a product of 192. This value is called the MAXIMUM COMMON DENOMINATOR and is divisible by each of the denominators without fractional remainders.

To change the fraction 1/4 so that it will have a denominator of 192, proceed by dividing 192 by the original denominator 4 and multiply the resulting quotient by the original numerator 1. Place this product over the denominator desired. The fraction 1/4 is thus transformed to the form $\frac{48}{192}$, which does not change its value.

Applying this method, we find that the fractions 1/4, 1/6, and 3/8 can be written as $\frac{48}{192}$, $\frac{32}{192}$, and $\frac{72}{192}$, the number 192 being the maximum common denominator of this particular group of fractions.

Although any group of fractions can be arranged to have the same denominator as just shown, it is more practical in lengthy calculations to determine the LEAST or LOWEST COMMON DENOMINATOR (LCD) of the group of fractions, so that all of them may have the same but the smallest possible denominators.

REDUCING FRACTIONS TO THEIR LEAST COMMON DENOMINATOR

The least common denominator, or the least common multiple, (abbreviated LCD and LCM, respectively) of a group of fractions can very often be determined by inspection, as in the case of the fractions listed previously (1/4, 1/6, 3/8). By inspection it can be seen easily that each of the denominators will be contained in 24. In other cases, the LCD is less obvious but may be determined by using the following rule:

> Place the denominators in line as shown in the following example. Divide by the smallest number that will go into two or more of the denominators. Bring down the quotient under each denominator that was divisible. Bring down the denominators that were not divisible, just as they were. Divide this second set of numbers by the smallest number that will go into two or more of them, and proceed as before.
>
> Continue this operation of writing new lines and dividing by the smallest number that will go into two or more of the numbers until you cannot divide any more. Then multiply all the divisors and the numbers in the last line together. This product is the LCD.

EXAMPLE: Find the LCD of 1/6, 3/8, 2/9, 5/12, 5/18, 7/24, 1/36.

3	6	(8)	9	12	18	24	36
2	2	(8)	3	4	6	8	12
3	1	4	3	2	3	4	6
2		4	1	2	1	4	2
2		2	1	1	1	2	1
	1	1	1	1	1	1	1

(Note that 8 is not divisible by 3 and is therefore carried forward.)

Multiply together all the divisors at the left side and in the last line. In this case you have 3 x 2 x 3 x 2 x 2 x 1 x 1 x 1 x 1 x 1 x 1 x 1 which is equal to 72, the LCD or the LCM of the denominator.

We now have the LCD of the above fractions, and to reduce each fraction to the LCD, we first divide each denominator into the LCD, then multiply both numerator and denominator by the result as follows, reading across the columns from left to right.

$72 \div 6 = 12 \qquad \frac{1}{6} \times \frac{12}{12} = \frac{12}{72} \qquad \text{so, } \frac{1}{6} = \frac{12}{72}$

$72 \div 8 = 9 \qquad \frac{3}{8} \times \frac{9}{9} = \frac{27}{72} \qquad \text{so, } \frac{3}{8} = \frac{27}{72}$

$72 \div 9 = 8 \qquad \frac{2}{9} \times \frac{8}{8} = \frac{16}{72} \qquad \text{so, } \frac{2}{9} = \frac{16}{72}$

$72 \div 12 = 6 \qquad \frac{5}{12} \times \frac{6}{6} = \frac{30}{72} \qquad \text{so, } \frac{5}{12} = \frac{30}{72}$

$72 \div 18 = 4 \qquad \frac{5}{18} \times \frac{4}{4} = \frac{20}{72} \qquad \text{so, } \frac{5}{18} = \frac{20}{72}$

$72 \div 24 = 3 \qquad \frac{7}{24} \times \frac{3}{3} = \frac{21}{72} \qquad \text{so, } \frac{7}{24} = \frac{21}{72}$

$72 \div 36 = 2 \qquad \frac{1}{36} \times \frac{2}{2} = \frac{2}{72} \qquad \text{so, } \frac{1}{36} = \frac{2}{72}$

Each fraction now has a denominator of 72, yet its value remains unchanged.

ADDITION OF FRACTIONS

In the early part of this lesson it was stated that unlike things cannot be added. The same is true of fractions. Fractional units must be alike, or have a common denominator, in order that they may be added. Therefore, 1/2 and 1/4 cannot be added unless changed to 2/4 and 1/4, respectively. When this is done, however, 2/4 + 1/4 = 3/4.

The rule used in the addition of fractions is as follows: To add fractions which already have a least common denominator, simply add the numerators of the fractions and place their sum over the LCD. If this gives an improper fraction, it should be reduced to a whole or mixed number.

EXAMPLE: Add 3/16, 9/16, 11/16, 13/16. Since all of these fractions have the SAME denominator, or as we might say, the same LCD, we can write the problem in the following form.

$$\frac{3}{16} + \frac{9}{16} + \frac{11}{16} + \frac{13}{16} = \frac{36}{16} = 2\frac{4}{16} = 2\frac{1}{4} \quad \text{(answer)}$$

EXAMPLE: Find the sum of 3/10, 2/11, 3/5, and 3/4. In this problem, we must find the LCD thus:

$$\begin{array}{r|rrrr} 5 & 10 & 11 & 5 & 4 \\ \hline 2 & 2 & 11 & 1 & 4 \\ \hline & 1 & 11 & 1 & 2 \end{array} \qquad 5 \times 2 \times 1 \times 11 \times 1 \times 2 = 220 \text{ (LCD)}$$

By changing the given fractions to values having the least common denominator, we have:

$$\frac{66}{220} + \frac{40}{220} + \frac{132}{220} + \frac{165}{220} = \frac{403}{220} = 1 \text{ and } \frac{183}{220}$$

In adding mixed numbers, we must first add the whole numbers together, then add the fractions together, and finally unite these two sums.

EXAMPLE: Find the sum of $41\frac{1}{2}$, $40\frac{1}{4}$, and $3\frac{2}{3}$. The problem can be conveniently arranged for solution as follows:

$$41 + 40 + 3 = 84 \qquad \frac{1}{2} + \frac{1}{4} + \frac{2}{3} = \frac{6}{12} + \frac{3}{12} + \frac{8}{12} = \frac{17}{12}$$

We now unite (add) the sum of the whole numbers to the sum of the fractions and find ----

$$84 + \frac{17}{12} = 84 + 1\frac{5}{12} = 85\frac{5}{12} \quad \text{(answer)}$$

(Note that the 1 obtained in changing the improper fraction $\frac{17}{12}$ to the proper fraction $\frac{5}{12}$, is added to the sum of the whole numbers.)

SUBTRACTING FRACTIONS

The first rule for the subtraction of fractions is as follows: To find the difference between two given fractions, which already have a common denominator, simply subtract the smaller numerator from the larger one and write the resulting difference over the common denominator. Reduce to lowest terms.

EXAMPLE: Subtract 5/12 from 11/12.

$$\frac{11}{12} - \frac{5}{12} = \frac{6}{12} = \frac{1}{2} \quad \text{(answer)}$$

The second rule for the subtraction of fractions is as follows: To find the difference between two fractions, when they do not have an LCD, first reduce them to a common denominator before subtracting.

<u>EXAMPLE</u>: Subtract 3/34 from 8/17. (The LCM for 34 and 17 is 34.)

$$\frac{8}{17} - \frac{3}{34} = \frac{16}{34} - \frac{3}{34} = \frac{13}{34} \text{ (answer)}$$

The third rule for the subtraction of fractions is as follows: If the numbers are mixed numbers, reduce the fractional parts to an LCD. Subtract the fractional part having the smallest whole number from that having the largest whole number; then subtract the whole numbers and unite the difference with that of the fractions.

<u>EXAMPLE</u>: Subtract $2\frac{3}{5}$ from $8\frac{3}{4}$. The LCD is seen to be 20, thus the fractional parts become $\frac{12}{20}$ and $\frac{15}{20}$. The fractional part $\frac{12}{20}$ has the smallest whole number, therefore the problem is set up as follows:

Subtracting the fractional part -- $\frac{15}{20} - \frac{12}{20} = \frac{3}{20}$

Subtracting the whole numbers --- $8 - 2 = 6$

Uniting the two, we have: $6 + \frac{3}{20} = 6\frac{3}{20}$ (answer)

In case that the fractional part of the subtrahend is greater than that in the minuend, as when subtracting $3\frac{2}{3}$ from $7\frac{1}{2}$, the procedure is as follows:

$$7\frac{1}{2} = 7\frac{3}{6} = 6\frac{9}{6}$$
$$3\frac{2}{3} = 3\frac{4}{6} = \underline{3\frac{4}{6}}$$
$$3\frac{5}{6} \text{ (answer)}$$

In the above, the fractions are first reduced to a common denominator and as can be seen by inspection, 4/6 cannot be subtracted from 3/6. Therefore, 1 whole number is taken away from the 7 of the minuend and is added to its fraction, thereby increasing its value to 9/6. That is, 1 = 6/6 and 3/6 + 6/6 = 9/6. The fraction 4/6 can now be subtracted from 9/6, giving us a fractional difference of 5/6, and upon subtracting 3 from 6 in the whole number column, we obtain a final answer of 3 and 5/6.

MULTIPLYING FRACTIONS

In multiplying fractions, let us first consider multiplying a whole number by a fraction. The rule for this process is as follows:

> To multiply a fraction by a whole number, first multiply the whole number by the numerator of the fraction and then divide this product by the denominator of the fraction.

<u>EXAMPLE</u>: Multiply 8 by 4/5.

$$8 \times \frac{4}{5} = \frac{8 \times 4}{5} = \frac{32}{5} = 6\frac{2}{5} \text{ (answer)}$$

To multiply a fraction by a fraction, apply the following rule: Multiply the numerators together and then multiply the denominators together. Place the product of the numerators over the product of the denominators and reduce to lowest terms, when possible.

<u>EXAMPLE</u>: $\frac{2}{3} \times \frac{5}{7} = \frac{2 \times 5}{3 \times 7} = \frac{10}{21}$ (answer)

To multiply two numbers, one or both of which are mixed numbers, reduce the mixed numbers to improper fractions and then multiply as with proper fractions.

EXAMPLE 1: $6\frac{1}{4} \times 8 = \frac{25}{4} \times 8 = \frac{25 \times 8}{4} = \frac{200}{4} = 50$ (answer)

EXAMPLE 2: $3\frac{2}{3} \times 4\frac{3}{4} = \frac{11}{3} \times \frac{19}{4} = \frac{11 \times 19}{3 \times 4} = \frac{209}{12} = 17\frac{5}{12}$ (answer)

DIVIDING FRACTIONS

When dividing a fraction by a whole number, multiply the denominator of the fraction by the whole number.

EXAMPLE: $2/3 \div 3 = \frac{2}{3 \times 3} = \frac{2}{9}$ (answer)

To divide a whole number by a fraction, invert the divisor and multiply it by the dividend.

EXAMPLE: $7 \div 3/4 = 7 \times \frac{4}{3} = \frac{7 \times 4}{3} = \frac{28}{3} = 9\frac{1}{3}$ (answer)

To divide a fraction by a fraction, invert the divisor and multiply it by the dividend.

EXAMPLE: $3/4 \div 1/3 = 3/4 \times 3/1 = \frac{3 \times 3}{4 \times 1} = \frac{9}{4} = 2\frac{1}{4}$ (answer)

To divide a mixed number by a mixed number, first change them to improper fractions and then divide.

EXAMPLE: $3\frac{2}{3} \div 1\frac{3}{5} = \frac{11}{3} \div \frac{8}{5} = \frac{11}{3} \times \frac{5}{8} = \frac{11 \times 5}{3 \times 8} = \frac{55}{24} = 2\frac{7}{24}$ (answer)

CANCELLATION

Cancellation is the process of dividing one dividend and one divisor at a time by the same factor. (Note: A factor is any number which will divide into another number.)

When several factors make up the dividend and several make up the divisor, they may be written as follows:

$$\frac{8 \times 4 \times 3}{3 \times 2 \times 8} = \frac{96}{48}$$

Now, if we wish to apply cancellation to the above and so reduce the expression to its lowest terms, we divide the numerators and the denominators mentally, using the same factor for one numerator and one denominator. The quotient of each division is then written in place of the number, and the number is crossed out (cancelled). For example:

$$\frac{\text{dividend}}{\text{divisor}} = \frac{8 \times 4 \times 3}{3 \times 2 \times 8} = \frac{\overset{1}{\cancel{8}} \times \overset{2}{\cancel{4}} \times \overset{1}{\cancel{3}}}{\underset{1}{\cancel{3}} \times \underset{1}{\cancel{2}} \times \underset{1}{\cancel{8}}} = \frac{1 \times 2 \times 1}{1 \times 1 \times 1} = \frac{2}{1} = 2 \text{ (answer)}$$

Generally, the number 1 is not written and this expression becomes ----

$$\frac{\cancel{8} \times \overset{2}{\cancel{4}} \times \cancel{3}}{\cancel{3} \times \cancel{2} \times \cancel{8}} = 2$$

EXAMPLE: Find the quotient of (or divide) $\frac{18 \times 5}{10 \times 3}$

Then, $\frac{18 \times 5}{10 \times 3} = \frac{\overset{6}{\cancel{18}} \times \cancel{5}}{\underset{2}{\cancel{10}} \times \cancel{3}} = \frac{\overset{3}{\cancel{6}}}{\cancel{2}} = 3$ (answer)

In this example, 3 divides into 18 six times, thus the 3 and 18 are cancelled and the quotient 6 is placed above the 18. Then, 5 divides into 10 twice, therefore the 5 and 10 are cancelled and the quotient 2 is placed below the cancelled 10. We now have 6 in the dividend and 2 in the divisor which are cancelled in the next step when 2 is divided into 6. The 3 resulting from this division is placed above the cancelled 6, and as there are no numbers remaining in the divisor, the 3 is thus found to be a whole number and is the expression $\frac{18 \times 5}{10 \times 3}$ reduced to its lowest terms.

EXAMPLE: Find the quotient of $\frac{77 \times 100 \times 18 \times 14}{25 \times 11 \times 49 \times 16}$

Solution:

$$\frac{\overset{7}{\cancel{77}} \times \overset{4}{\cancel{100}} \times \overset{9}{\cancel{18}} \times \overset{2}{\cancel{14}}}{\cancel{25} \times \cancel{11} \times \underset{\cancel{7}}{\cancel{49}} \times \underset{\underset{\cancel{2}}{\cancel{4}}}{\cancel{16}}} = 9 \quad \text{(answer)}$$

Some of the important principles to be remembered in manipulating fractions are:

1. - Multiplying the numerator of a fraction by any number multiplies this fraction by that number.

2. - Dividing the denominator of a fraction by any number multiplies the fraction by that number.

3. - Multiplying the denominator of a fraction by any number divides the fraction by that number.

4. - Dividing the numerator of a fraction by any number divides the fraction by that number.

5. - Multiplying both terms of a fraction by the same number does not alter the value of the fraction.

6. - Dividing both terms of a fraction by the same number does not alter the value of the fraction.

The following suggestions will be helpful in aiding you to tell when your problems are solved by the correct methods. By watching each step carefully, you can tell whether you have made a mistake or not.

1. - When you multiply any number by a proper fraction, the result is less than the number multiplied.

2. - When you multiply any number by an improper fraction, the result is more than the number multiplied.

3. - When you multiply any number by a mixed number, the result is more than when multiplying by the whole number alone.

4. - When you divide any number by a proper fraction, the result is more than the number divided.

5. - When you divide any number by an improper fraction, the result is less than the number divided.

6. - When you divide any number by a mixed number, the result is less than when divided by the whole number alone.

DECIMALS

The decimal system is a convenient method for expressing fractions which have 10 or any multiple of 10 for their denominators. This system is used in connection with measurements in practically all parts of the world, and is also used with the monetary (currency) system in the United States, Canada, and other countries.

When we write fifty cents numerically, as $0.50, we are using the decimal system. The period (.) before the 5 is called the <u>decimal point</u>, and it is this period which determines, to a large extent, the value of the expression. That is, if we were to move the decimal point two places to the right in the above example, we would have fifty dollars ($50.) instead of fifty cents. It is therefore obvious that the utmost care must be given to placing the decimal point.

Fractions having denominators which are multiples of 10, such as 10; 100; 1000; 10,000; etc., may be written in either of two ways: First, as common fractions, having a numerator above the line, and a denominator below the line. Secondly, as decimal fractions, in which a decimal placed before the number indicates that this number is divided by 10 or some multiple of 10, according to the number of figures appearing after the decimal. One figure to the right of the decimal point indicates that the number is divided by 10; two figures to the right of the decimal show that the number is divided by 100; three figures indicate a division of the number by 1000, etc. Thus, 1/10 may be written as .1 in decimal form; 1/100 is the same as .01; 1/1000 is equal to .001, etc.

When there is no whole number in front of the decimal point, as in .1, .01, etc., the quantity is called a PURE DECIMAL. When a whole number and a decimal are written together, as 1.1, 10.5, etc., the number is called a MIXED DECIMAL.

The table below lists the places on each side of the decimal point so that you may know what to call the places when you read them.

Millions	Hundred thousands	Ten thousands	Thousands	Hundreds	Tens	Units	Decimal Point	Tenths	Hundredths	Thousandths	Ten thousandths	Hundred thousandths	Millionths	Ten millionths	Hundred millionths	Billionths
7,	6	5	4,	3	2	1	.	1	2	3	4	5	6	7	8	9

In order to read a decimal, read the number as though it were a whole number, and then call the name of the decimal place of the last right-hand figure according to the above table.

<u>EXAMPLE 1</u>: Read the decimal .68

The last right-hand figure (8) occupies the place of the hundredths in the table, so we add that name to the reading of the number. Thus, 0.68 is read "sixty-eight hundredths."

EXAMPLE 2: Read the decimal .0567

The last figure to the right (7) falls in line with the ten thousandths in the table; thus, .0567 is read "five hundred sixty-seven ten thousandths."

EXAMPLE 3: Read the number 72.093

The whole number is read by itself. In reading the decimal part, we see that the last figure (3) is in the thousandths position in the table, so the number 72.093 is read "seventy-two and ninety-three thousandths."

A thorough mastery of the above is essential if you are to be able to "talk dimensions" in shop language with shop men; you are therefore advised to study the reading of decimals very carefully.

CHANGING COMMON FRACTIONS TO DECIMALS

The first step to be considered in working with decimals is to learn how to change common fractions to decimal fractions. The rule for making this conversion is as follows: Annex zeros to the numerator of the fraction and divide this quantity by the denominator. Then place the decimal point so as to provide as many decimal places in the quotient as there were zeros annexed.

EXAMPLE 1: Change 2/5 to a decimal fraction.

```
5)2.0000(.4000 (answer)
  2 0
  ----
    000
```

That is, 2/5 = .4. (Note that zeros after a decimal number do not change its value and are therefore unnecessary.)

EXAMPLE 2: Change 7/8 to a decimal fraction.

```
8)7.000(0.875 (answer)
  6 4
  ---
    60
    56
    --
     40
     40
     --
     00
```

ADDITION OF DECIMAL FRACTIONS

To ADD DECIMAL FRACTIONS, place the numbers so that the decimal points fall directly under one another. Then add the vertical rows of figures in the usual manner and place the decimal point in the sum directly under the other decimal points.

EXAMPLE: Add 372.431, 27.24, 8374.364, and 1.002

```
 372.431
  27.24
8374.364
   1.002
--------
8775.037 (answer)
```

SUBTRACTION OF DECIMAL FRACTIONS

To SUBTRACT DECIMAL FRACTIONS, write the numbers so that the decimal points are under each other. Then subtract in the customary manner and place the decimal point in the remainder under the other decimal points.

<u>EXAMPLE</u>: Subtract 86.014 from 374.325

```
 374.325
  86.014
 -------
 288.311   (answer)
```

MULTIPLICATION OF DECIMAL FRACTIONS

To MULTIPLY DECIMAL FRACTIONS, multiply in the usual way and then point off as many decimal places in the product as the sum of the number of decimal places in the multiplicand and multiplier.

<u>EXAMPLE</u>: Multiply 436.256 by 4.271

```
      436.256
        4.271
     --------
       436256
     3053792
     872512
   1745024
   ----------
   1863.249376   (answer)
```

The product is thus 1863.249376

DIVISION OF DECIMAL FRACTIONS

To DIVIDE DECIMAL FRACTIONS, proceed as follows: Annex zeros to the right of the decimal point in the dividend, until there are as many, or more, than appear to the right of the decimal in the divisor. Divide as with whole numbers in the usual manner,and point off as many decimal places in the quotient as there are more decimal places in the dividend than in the divisor.

<u>EXAMPLE</u>: Divide 8.7234 by .325

```
.325)8.723400(26.841   (answer)
     6 50
     ----
     2223
     1950
     ----
      2734
      2600
      ----
       1340
       1300
       ----
         400
         325
         ---
          75
```

Note that in this example two zeros were annexed to the dividend so that the problem could be worked out to a greater number of decimal places. Without annexing these two zeros, the answer would be 26.8. Also observe that after annexing the two zeros to the dividend, we have in this number six places to the right of the decimal point. In the divisor there are three places to the right of the decimal point. Therefore, in the quotient there must be 6 minus 3, or three decimal places to the right of the decimal point.

EXAMPLE: Divide 4726 by .034

```
.034)4726.000(139,000   (answer)
      34
      132
      102
       306
       306
         000
```

Since the divisor has three more decimal places than the dividend, we must annex three zeros to the dividend. There are no decimal places in the answer because there are no decimal places in the dividend.

The following suggestions are given as a help in solving problems in decimals:

1. - Read the problem carefully to make sure that you understand what it says and what it asks for.

2. - See how the information given is related to what you are required to find, and decide what process you must use.

3. - Do not simply work with figures and numbers, trying one operation and then another until you arrive at the right answer. You will realize that such a method is of no use unless the answer is known. Avoid such a practice.

4. - Reason out the problem, using the information given in the problem, and put down all statements in logical order. (In making these statements, it is helpful to remember that the number involving the quantity to be found should be put at the end of the line.) If the statements are correct the answer will come of itself.

5. - Do your work carefully and neatly. Check each step to assure accuracy.

6. - Prove your results, by checking, or by reversing the processes.

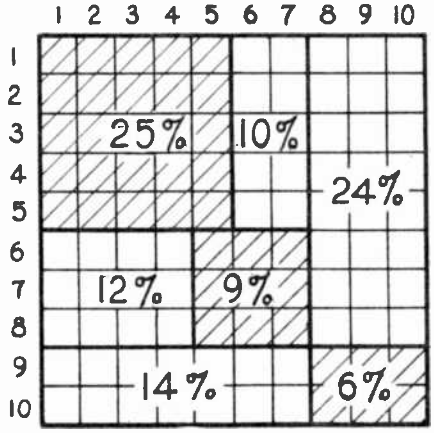
PERCENTAGE

It is a common and convenient practice to express certain values in terms of percentage. This is especially true when referring to the efficiencies of various types of machines and the units with which they are associated.

After having studied fractions and decimals, the matter of percentage should be very easy for you to grasp. Percentage is merely a special case of decimals in which fractional parts are found only in hundredths; it is the process of computing in hundredths.

The words "per cent" are used to indicate the number of hundredths taken, and the symbol is %. Thus, 5% is read "five per cent," and means five-hundredths of the whole quantity (5/100 times the whole quantity). The expression "% of" means the same as hundredths times the quantity, thus 5% of 90 = five hundredths times ninety = .05 x 90 = 5/100 x 90. 23% of 48 = .23 x 48 = 23/100 x 48. You will therefore see that 5%, or any percentage value, can be indicated in three ways; that is, as 5/100, .05, or 5%.

The diagram below will aid you in visualizing percentage more easily.



You will note that the large square is divided into 100 small squares, each one of which will therefore be 1/100 or 1% of the whole. One row of small squares along any side equals 10%, 10/100, 1/10, or .1 of the whole. Two rows equal 20% or 1/5; 5 rows equal 50% or 1/2. The upper left-hand corner, which is shaded, has 5 x 5 small squares and is therefore 25% or 1/4 of the whole. The upper right-hand corner has 3 x 8 small squares, bounded by .heavy lines, and is 24% of the whole. The remaining divisions show 10%, 12%, 9%, 14%, and 6%. If all the percentages in the squares are added together, they will be found to total 100%.

The large square represents the quantity from which the percentage is taken; that is, it is a unit or 1, and in percentage we think of the whole as 100 equal parts or 100/100, or 100%. We can therefore say that the large square represents a box of apples,a hundred dollars, a barrel of oil, or even 100% efficiency of an engine, and each small square represents one one-hundredth part of the whole.

APPLICATION OF PERCENTAGE

Problems involving percentage can be divided into three general groups, or types, as illustrated by the following examples:

Type 1 --- What is 62% of 825?
Type 2 --- 23 is what per cent of 650?
Type 3 --- 64 is 37% of what number?

Before proceeding with the methods of solving these three types, the following definitions must be learned:

(a) The number from which the per cent is taken is called the BASE.

(b) The number of per cent taken is called the RATE.

(c) The part of the base determined by the rate is the PERCENTAGE.

By applying these definitions, we can arrange our three typical problems in the form of three rules or formulas as follows:

RULE I: Percentage = base x rate. This formula is used to solve problems of <u>Type 1</u>.

Example: What is 62% of 825?

Solution: Percentage = base x rate = 825 x 62% = 825 x 0.62 = 511.5 (answer)

RULE II: Rate = percentage ÷ base. This formula is used to solve problems of Type 2.

Example: 23 is what per cent of 650?

Solution: Rate = percentage ÷ base = 23 ÷ 650 = 0.035, which equals 3.5% or 3½%.

RULE III: Base = percentage ÷ rate. This formula is used to solve problems of Type 3.

Example: 64 is 37% of what number?

Solution: Base = percentage ÷ rate = 64 ÷ 0.37 = 172.9.

In the following lesson of this series you will be shown the functions of a few more arithmetical processes and their applications in industry.

We have covered considerable arithmetical territory in this one lesson and it is important that you study it carefully; you will find a knowledge of the material contained herein to be very useful when confronted with problems involving general mathematics.

It is advisable that you keep this, and the following lessons, within reach at all times so that you can refer to them whenever necessary; they will be valuable to you as handbooks in conjunction with your regular studies.

REVIEW PROBLEMS

The problems appearing on this page will give you an opportunity to check up on yourself, to see how well you have mastered the instruction presented in this lesson. We suggest that you solve each of them and compare your answers with those given at the bottom of this page.

If your answer for each problem agrees with that given here, it is sufficient proof that you understand the work involved. If not, review thoroughly that part of this lesson which explains those points on which you are weak.

Do not send your solutions to us for correction.

1. - Multiply 745.36 by 21.5
2. - What is the sum of 432.17; 36.875; 0.062; 3.496 and 20754.182?
3. - Subtract 629.01 from 8,736,294
4. - How many times is 34.02 contained in 7643.096?
5. - Change $\frac{5}{16}$ to a decimal fraction.
6. - What is the product of $\frac{35}{42}$ and $\frac{26}{71}$?
7. - (a) How would you multiply a number by 1000 without going through the actual calculation?
   (b) How would you divide a number by 100 without going through the actual calculation?
8. - Divide 40 x 48 x 54 x 60 by 30 x 24 x 72 x 3, using the method of cancellation.
9. - What is 25% of 200?
10. - What is the sum of 1/2; 7/8; 3/4; and 3/16?

******

ANSWERS: 1. - 16,025.240   2. - 21,226.785   3. - 8,735,664.99

4. - 224.66   5. - 0.3125   6. - $\frac{65}{213}$

7. - (a) Add three zeros to the right of the number, or move the decimal point three places to the right.
(b) Move the decimal point two places to the left.

8. - 40   9. - 50.00   10. - 2 and 5/16

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MATHEMATICS

LESSON NO. M-2

POWERS - ROOTS - EQUATIONS

This lesson is a continuation of the arithmetical processes with which you are required to be familiar in this lesson-series on Mathematics. These processes are of value, also, in solving the more general type of everyday problems and should, therefore, be thoroughly understood by every man in the industry. Application of the functions --

FIG. 1
CRAFTSMEN WHO POSSESS A PRACTICAL KNOWLEDGE OF MATHEMATICS ARE ASSURED OF RAPID ADVANCEMENT IN MODERN PRODUCTION PLANTS

in this lesson will be found in those following, and it is important that you understand each step as it is presented so that a solid foundation will be built for the work which is to follow. You are advised to study this, and the succeeding lessons of this series, slowly and carefully, to be sure of mastering all the information they contain and to prevent any possibility for confusion.

POWERS

When two or more numbers are multiplied together to give a certain product, these numbers are called FACTORS. Thus, in the expression 3 x 4 = 12, the numbers 3 and 4 are said to be factors of 12; in the same way, it will be seen that 5, 6, and 2, are factors of 60, as are 30 and 2, 15 and 4, etc. If, however, all the factors making up a product are equal, then the product is called the POWER.

In the expression 4 x 4 x 4 = 64, the product 64 is the power and the factor 4 is called the base. We can therefore say that 4 is the base of the power 64, and 64 is the power of the base 4. It will be seen that the base multiplied by itself a definite number of times is the power.

When a base is used as a factor just two times, then the product is said to be the second power, or the square, of the base. Thus, 3 x 3, or 9 is the square of 3, and the process of multiplying a number by itself in this manner is called "squaring the number." When the base is used as a factor three times, the resulting product is known as the third power, or the cube, of the base, and the process is known as "cubing the number." Thus, multiplying 5 x 5 x 5 is called "cubing the number 5" and the resulting product of 125 is the cube of 5, or is 5 to the third power.

Squares and cubes are used in calculations by many industries for finding areas and volumes, among other things, as will be shown later.

When the base is used as a factor more than three times, the resulting product is called the 4th power, 5th power, 6th power, etc., according to the number of times it is used.

A small figure, known as the EXPONENT, is used to indicate the number of times the base is to be used as a factor. This small figure is placed above and to the right of the base, as 4^2, 25^4, 6^3, etc. The value 4^2 is read "four squared", or "four to the second power;" 25^4 is read twenty-five to the fourth power; and 6^3 is read six cubed, or six to the third power. Study the following expressions carefully: $4^2 = 4 \times 4 = 16$; $25^4 = 25 \times 25 \times 25 \times 25 = 390,625$; $6^3 = 6 \times 6 \times 6 = 216$.

By using the exponent, we thus have a shortened way of expressing a factor multiplied by itself any number of times, and the process is generally referred to as "raising" the base to the power. We would therefore say of the expression $2^3 = 8$, that 2 raised to the third power equals 8.

Powers of decimals and common fractions may also be expressed in the same manner; that is, $2.45^2 = 2.45 \times 2.45 = 6.0025$. When a fraction is to be raised to a certain power, it is necessary to place a parenthesis around it to indicate that both numerator and denominator are to be raised; otherwise, only the number adjacent to the exponent will be affected.

For example, $(\frac{2}{3})^2 = \frac{2 \times 2}{3 \times 3} = \frac{4}{9}$, but $\frac{2^2}{3} = \frac{4}{3} = 1\frac{1}{3}$.
Note that when the fraction is enclosed by parentheses, the numerator and denominator are each raised to the same power.

It will be seen from the foregoing that raising any proper fraction to any power will decrease its value, and the reverse is true of any improper fraction.

That is, $\frac{2}{3} = \frac{6}{9}$, but $(\frac{2}{3})^2 = \frac{4}{9}$; a decrease of $\frac{2}{9}$.

On the other hand, $\frac{4}{3} = \frac{12}{9}$ but $(\frac{4}{3})^2 = \frac{16}{9}$; an increase of $\frac{4}{9}$.

These same characteristics also apply to decimals; that is, a pure decimal (one having no whole number) will be decreased in value when raised to a power, while the reverse is true of the mixed decimal (one having a whole number). For example, 0.2^2, or .2 x .2 =.04, which is less than 0.2; similarly, 0.3^3, or .3 x .3 x .3 = .027, which is a lesser value than 0.3. However, 2.2^2 = 2.2 x 2.2 = 4.84, which is a greater value than 2.2.

Example 1 -- Find the value of 23^4, or the fourth power of 23.

Solution: 23^4 means 23 x 23 x 23 x 23 = 279,841

Example 2 -- Find the third power of 2.45, or $(2.45)^3$.

Solution: 2.45 x 2.45 x 2.45 = 14.706125

Example 3 -- Find the fifth power of 3/4.

Solution: $\frac{3}{4} \times \frac{3}{4} \times \frac{3}{4} \times \frac{3}{4} \times \frac{3}{4} = \frac{243}{1024}$

ROOTS

Roots are very closely related to powers and will therefore be considered at this time. The process of finding the roots of numbers is just the reverse of determining the powers.

A root of a number is one of the equal factors, which, when multiplied together, give the number. Thus, in the expression 9 x 9 = 81, 9 is the root of 81, and since the factor 9 is used only twice, it is called the SQUARE ROOT. The arithmetical process of determining this root is known as extracting the square root.

When the number is composed of three equal factors, the process of finding this factor is known as extracting the cube root of the number. Thus, in the expression 3 x 3 x 3 = 27, the number 3 is the cube root of 27.

The symbol used to indicate that the root of a number is to be taken is $\sqrt{\ }$ and is known as the radical sign. The number of which the root is to be found is placed under the sign, as $\sqrt{16}$.

The root of the number which is to be taken is indicated by a small figure placed over the radical sign as $\sqrt[3]{\ }$, $\sqrt[4]{\ }$, etc., in which instances the third and fourth are to be taken, respectively When only the square root of the number is to be taken, it is not necessary to indicate the fact by a small figure over the radical, as the sign alone indicates that the square root is to be extracted, thus $\sqrt{25} = 5$.

Only the method of finding the square root of a number will be discussed in this lesson, owing to the complications resulting in the calculations of higher roots, and the fact that there is little application for them on the job. Cube roots, when needed, are most easily obtained through the use of engineering tables.

EXTRACTING THE SQUARE ROOT OF WHOLE NUMBERS

When the square root of any number having only one, two, or perhaps three figures must be found, the value can usually be determined by inspection, provided that you have conscientiously studied your multiplication tables. In such cases, no special process is necessary. However, when the square root must be extracted from larger numbers, a process consisting of certain definite rules must be followed.

In studying the process to follow, you are advised to not merely read the explanation over and then attempt to work a problem, but to write down the steps as they are given, and adhere strictly to the rules. In this way only will you be able to learn the method of finding the square root. No attention need be given to the reasoning underlying the use of the rules -- just take them for granted and memorize the process itself.

EXAMPLE 1: FIND THE SQUARE ROOT OF 1369.

SOLUTION: The solution to this problem is grouped into successive steps as outlined below, and the arithmetical procedure appears to the right of the explanation for convenient reference.

STEP 1:

Starting from the right-hand figure, separate the number into groups of two, indicating this grouping by an apostrophe (') as shown. The number of groups so formed will be the same as the number of figures in the answer.

```
13'69
```

STEP 2:

A vertical line is now drawn at the left of the number, and a bracket is made to the right as shown.

```
|13'69(__
```

STEP 3:

Inspect the first group at the left (13), and determine mentally which is the largest number that, when multiplied by itself, or squared, can be subtracted from this group. In this case, you will see immediately that 3 is the required number, because 3 x 3 = 9, which may be subtracted from 13. The number 4 could not be used, because 4 x 4 = 16, which is of too great a magnitude to be subtracted from 13. We therefore place the 3 in the bracket to the right of the number, and it becomes the first figure of the root.

```
|13'69(3
| 9
|----
| 4 69
```

The number 3 is now squared (3 x 3) and the resulting square (9) is placed under the first group to the left and subtracted as in the process of division. The difference of 4 is placed below the horizontal line, and the next group of figures is brought down beside it as shown above, giving the number 469.

STEP 4:

Take the first figure of the root (3) appearing in the bracket, and multiply it by 2. The result (6) is placed to the left of the vertical line, opposite the 469, in which position it is known as the trial divisor.

```
  |13'69(3
  | 9
  |----
6 | 4 69
```

STEP 5:

Determine by inspection how many times 6 is contained in 46(the first two figures of 469). This is found to be 7 times,as 7 x 6 = 42, which is the largest multiple of 6 that can be subtracted from 46. The 7 becomes the second figure in the root which is placed next to the first figure of the root (3), and also next to the 6 of the trial divisor. This gives a value of 67 in the latter position, which in this case is the complete divisor.

```
  |13'69(37 root
  | 9
67| 4 69
  | 4 69
```

Now multiply the 67 by the seven in the root, and the resulting product of 469 is placed under the number 469 previously obtained. In subtracting, it is found that there is no remainder -- thus the operation is complete, and 37 has been calculated to be the square root of 1369. The calculation shown in Step 5 illustrates the complete operation as it should appear.

The problem may be checked by simply squaring the root; thus, 37 x 37 = 1369, proving the calculation to be correct.

EXAMPLE 2: SOLVE THE PROBLEM $\sqrt{5,317,636}$

SOLUTION: Step 1, as before,is the separation of the number into groups of two figures each -- marking them off from right to left -- the last group to the left will have only one figure.

```
5'31'76'36
```

STEP 2:

Draw the vertical line to the left and the bracket to the right of the number, allowing space for four figures in the root because we have four groups of figures in the number.

```
|5'31'76'36(____
|
```

STEP 3:

The largest number of which its square can be subtracted from 5 (the first group) is 2, and it is therefore placed in the root bracket. The 2 is squared and the product (4) is placed under the 5 of the first group. Upon subtracting,a remainder of 1 is obtained,and the next group,(31) is brought down beside this remainder, as shown.

```
|5'31'76'36(2___
|4
|1 31
```

STEP 4:

The 2 in the root is doubled,or multiplied by 2, and the product 4 is placed to the left of the vertical line and opposite the 131. The number 4 is the trial divisor.

```
 |5'31'76'36(2___
 |4
4|1 31
```

STEP 5:

The trial divisor (4) is found to divide into 13 three times. The 3 is thus placed in the bracket as the next figure in the root, and is also placed after the trial divisor 4. This gives us the number 43 which must be divided into 131, and as we have estimated that it will divide three times,we multiply 43 by 3 and place the product 129 under the 131. The difference upon subtracting, is found to be 2, to which the 76 is brought down to form the next dividend of 276, as shown.

```
  |5'31'76'36(23___
  |4
43|1 31
  |1 29
  |   2 76
```

STEP 6:

Multiply the 23 in the root by 2,and place the product 46 (which becomes the next trial divisor) to the left of the vertical line.

```
    |5'31'76'36(23
    |4
 43 |1 31
    |1 29
 46 |  2 76
```

STEP 7:

In attempting to perform the next process of division, we find that the trial divisor 46 must divide into 27, which of course cannot be done, as 46 is greater than 27. Because it will not divide, we place a zero in the root-bracket as well as behind the 46. We now have a complete divisor of 460 which must be multiplied by 0; the product 000 is placed under the 276. Subtracting 000 from 276 leaves a remainder of 276, to which the next group (36) is annexed.

```
    |5'31'76'36(230
    |4
 43 |1 31
    |1 29
460 |  2 76
    |  0 00
    |  2 76 36
```

STEP 8:

The 230 of the root is now doubled and the product (460) becomes the next trial divisor.

```
    |5'31'76'36(230
    |4
 43 |1 31
    |1 29
460 |  2 76
    |  0 00
460 |  2 76 36
```

STEP 9:

It is seen by inspection that the trial divisor 460 divides into the first four figures of the dividend six times. The 6 thus becomes the last figure in the root and is annexed to the trial divisor 460 also, to give a complete divisor of 4606. This complete divisor is now multiplied by the 6 of the root and the resulting product is subtracted from 27636, leaving no remainder. The number 2306 is therefore the required square root of 5,317,636.

```
     |5'31'76'36(2306
     |4
  43 |1 31
     |1 29
 460 |  2 76
     |  0 00
4606 |  2 76 36
     |  2 76 36
```

EXTRACTING THE SQUARE ROOT OF NUMBERS WITH DECIMALS

When extracting the square root of numbers having decimal fractions, special care must be exercised with the division of the number into groups on each side of the decimal point. However,this is a very simple procedure, and is fully explained in the following examples.

EXAMPLE: FIND THE SQUARE ROOT OF 570.7321

SOLUTION -- Step 1: When the square root of a number containing a decimal is to be found, the number is laid out in groups of two both ways from the decimal point, as shown. In this way, the decimal will not be positioned between any two numbers of one group.

```
5'70.73'21
```

STEP 2:

The vertical line is drawn to the left of the number,and the root-bracket is placed to the right. We now proceed to extract the root as before, disregarding the decimals.

```
|5'70.73'21(
```

STEP 3:

The largest number of which its square can be subtracted from 5 (the first group) is 2, and

```
|5'70.73'21(2
|4
|1 70
```

it is therefore placed in the root-bracket. The 2 is squared and the product (4) is placed under the 5 of the first group. Upon subtracting, a remainder of 1 is obtained, and the next group (70) is brought down beside this remainder, as shown.

STEP 4:

The 2 in the root is multiplied by 2, and the product (4) is placed to the left of the vertical line and opposite the 170. The 4 is the trial divisor.

```
  |5'70.73'21(2
  |4
4 |1 70
```

STEP 5:

The trial divisor (4) is found to divide into 17 four times. It would therefore appear that the second figure of the root is 4, and the complete divisor, 44. However, if we multiply 44 by 4 we obtain a product of 176 which cannot be subtracted from 170, so we must use a smaller number, trying 3. The 3 is thus placed in the bracket as the next figure in the root, and is also placed after the trial divisor 4. This gives us the number 43 which must be divided into 170, and as we have estimated that it will divide three times, we multiply 43 by 3 and place the product 129 under the 170. The difference upon subtracting is found to be 41, to which the group 73 is brought down and annexed.

```
   |5'70.73'21(23
   |4
43 |1 70
   |1 29
   |  41 73
```

STEP 6:

Multiply the 23 in the root by 2, and place the product (46), which becomes the next trial divisor, to the left of the vertical line.

```
   |5'70.73'21(23
   |4
43 |1 70
   |1 29
46    |41 73
      |
```

STEP 7:

The number 46 is found to divide into 417, nine times; however, if 9 is used as the third figure of the root we find (as in Step 5) that the resulting product cannot be subtracted from the minuend. We therefore try 8 as the next figure in the root, and proceed as in Steps 5, 6, and 7 to find the remaining figures in the process, as shown.

```
     |5'70.73'21(23.89
     |4
43   |1 70
     |1 29
468     |41 73
        |37 44
4769    | 4 29 21
        | 4 29 21
```

As you will have observed, the process of finding the square root of a number containing decimals is identical to that followed when working with a whole number. It remains, however, to place the decimal point in the root. This can be done when we remember a very simple fact -- namely, that there will be as many figures before the decimal in the root as there are groups of figures before the decimal in the number itself. Also, there will be as many figures after the decimal point in the root as there are groups of figures after the decimal in the number. In the preceding example, there are two groups of figures before the decimal in the number; therefore, there will be two figures before the decimal in the root. The correct answer is thus 23.89, which can be checked by squaring it and comparing the product with the original number.

If the number of which the square root is to be taken, has an odd number of figures after the decimal, we add a zero to the last figure and thus provide two figures in the last group as in the following example. (Adding this 0 does not change the value of the number in any way because it is preceded by a decimal point.)

EXAMPLE: -- FIND THE SQUARE ROOT OF 2.916

SOLUTION:

```
       |2.91'60(1.70+
       |1
   27  |1 91
       |1 89
  340      |2 60
           |0 00
           |2 60 (remainder)
```

In the above calculation, you will note that we have a remainder of 260. The number 2.916 is therefore not a perfect square, and the root 1.70 will not give the exact product of 2.916 when squared. We then say that 1.70 is the approximate square root of 2.916, or we state the root as being 1.70^{+}.

If it is desired to carry the decimal part of the above root farther than two places, we simply annex groups of zeros to the number, as 2.91'60'00'00, and the process is continued in the regular manner.

EXTRACTING THE SQUARE ROOT OF COMMON FRACTIONS

A problem such as $\sqrt{\frac{625}{2500}}$ is sometimes presented. In such a case, it is only necessary to take the square root of the numerator and denominator separately. Thus, $\sqrt{\frac{625}{2500}} = \frac{25}{50} = 1/2$. (Note that when the numerator and denominator of fractions, from which the square root is to be taken, are not perfect squares, the fraction is first reduced to a decimal number of which the square root is then taken.)

PRACTICE PROBLEMS

To be sure that you can calculate square root correctly, it is advisable that you work the following practice problems and afterward check them with the answers given.

(1) Find the square root of 1444.
(2) Find the square root of 855,625.
(3) Find the square root of 1.8769
(4) Find the square root of 7.365
(5) Find the square root of $\frac{2025}{3000}$

ANSWERS: (1) 38; (2) 925; (3) 1.37; (4) 2.71^{+}; (5) 0.82^{+}

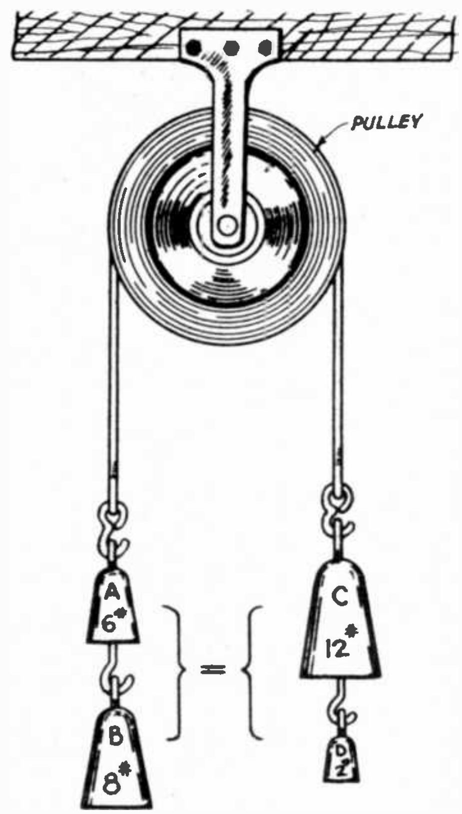
EQUATIONS

Equations are tools which may be used to advantage in mathematics for the solution of problems which would otherwise be very complex. It is therefore essential that a good understanding be had of this method of solving problems.

An equation is a statement of <u>equality</u> between two quantities. This equality is expressed by the equal sign (=) and indicates that the factor, or factors, to the left of the sign are equal to that, or those, to the right of the sign. Equations can be illustrated by a simple mechanical arrangement, as shown on page 9.

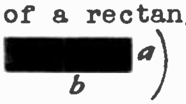
Suppose that attached to a rope laid over a pulley are four iron weights, each of which weighs a different amount as indicated. In this instance, we see that A weighs 6 pounds, B is 8 pounds, C is 12 pounds and D is 2 pounds. (Note that pounds, or lbs, are represented in the illustration by the sign #.)

It is obvious from the illustration that a state of balance exists between the two groups of weights because those on the left side have the same total weight as those on the right (14 pounds in each case). We can therefore form an equation to represent this condition by stating 6# + 8# = 12# + 2#; or, we might use the letters with which the weights are named and obtain the equation A + B = C + D. If we are certain that such a statement is true and if we know the values of all the terms but one, we can easily calculate the value of the one unknown, as will be explained later.



Simple equations are illustrated in the multiplication tables which you studied in the preceding lesson. Thus, $8 \times 7 = 56$ is an equation. Other forms are: $6 + 5 = 11$; $12 - 5 = 7$; $20 \div 5 = 4$; $0.6 \times 0.4 = 0.24$; $\sqrt{4} + 3 = 8 - \sqrt{9}$; $3^2 - 2 = 2^3 - 1$. Thus, equations may have various numbers connected by +, -, x, ÷, root, or power signs.

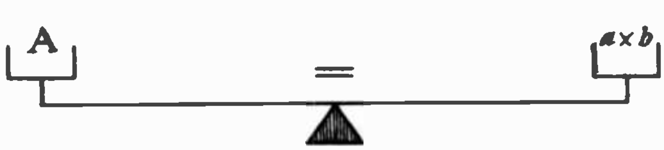
A FORMULA is a certain type of equation which is governed by a rule or principle. When an equation is made up of letters alone, or letters and figures, the letters may represent certain specific things. For instance, to calculate the area of a rectangle (a surface shaped as



) we make use of the statement A = a x b. Here A stands for area, "a" for the length of a vertical side (altitude), and "b" for the length of a horizontal side or base. In such a case where the letters have a definite meaning, the statement is called a FORMULA. If the letters do not stand for certain specific things, the statement is simply an equation.

The above formula might be stated in words as, "The area of the rectangle is equal to the length of the altitude multiplied by the length of the base." Such a statement is too long, however; it is difficult to remember, and is hard to move around -- so we say the same thing by abbreviating it to A = a x b.

The diagrammatically illustrated balance scale below demonstrates the meaning of this formula:



Notice that A balances, or is equal to, a x b. This same condition must hold true when numbers are substituted for the letters; that is, the arithmetical value of the left side must be equal to the arithmetical value of the right side. If not, the formula is not correct.

When all the values are known and substituted for the letters in the formula, this formula is then simply a statement of a fact in abbreviated form. Very often, however, all the values contained in a formula are known with the exception of one; this remaining quantity may then be determined by performing the proper mathematical processes. This is called SOLVING THE FORMULA.

In an equation such as 2 + 3 = 5, we know the value of both members of the equation, and it therefore becomes a simple statement of fact. However, if we have 2 + ? = 5, then we are required to find one unknown value. In this simple example, we of course see immediately that 3 must be added to 2 in order to give the left member of the equation a value equal to 5. Bear in mind that the unknown quantity, which we have designated by the question mark (?), could have been given any other temporary name, such as A, B, C, X, Y, Z, etc. In any case, it still remains simply the unknown quantity. In dealing with equations, we will call everything on the left side of the equal sign (=) the first member, and everything on the right side of the equal sign, the second member.

RULES FOR SOLVING EQUATIONS

There are certain rules which will assist us greatly in solving equations. These rules follow, together with examples to demonstrate their use.

RULE 1: The letters that occur in a formula or equation must be given such numerical values as will make both members numerically equal when these values are substituted in the formula.

Example: A + B = C x D, wherein A = 12; B = 6; C = 2; D = 9. Thus, substituting the numerical values given for the letters, we have: 12 + 6 = 2 x 9
Therefore: 18 = 18

RULE 2: The same quantity may be added to or subtracted from both members without unbalancing the equation.

Example: Add 10 to each side of the equation (18 = 18).
Thus: 18 + 10 = 18 + 10
or: 28 = 28

Example: Subtract 10 from each side.
Thus: 18 - 10 = 18 - 10
or: 8 = 8

RULE 3: Both members of a formula or equation may be multiplied or divided by the same quantity without destroying the balance.

Example: Multiply both sides of the equation by 7.
Thus: 18 x 7 = 18 x 7
or: 126 = 126

Example: Divide both members by 9.
Thus: 18 ÷ 9 = 18 ÷ 9
or: 2 = 2

RULE 4: Both members of a formula or equation may be raised to the same power without destroying the balance.

Example: Raise the equation to the second, third and fourth powers.
$18^2 = 18^2$; $18^3 = 18^3$; $18^4 = 18^4$

RULE 5: The same root may be extracted in both members without destroying the equality.

Example: Take the square, cube, and fourth roots of the equation.

$$\sqrt{18} = \sqrt{18}; \quad \sqrt[3]{18} = \sqrt[3]{18}; \quad \sqrt[4]{18} = \sqrt[4]{18}$$

RULE 6: The order of the numbers or the order of the letters is not important if the proper sign is given to each.

Example: Change the order of the numbers in the first member of the equation $(6 \times 8) - 6 - 20 = 22$

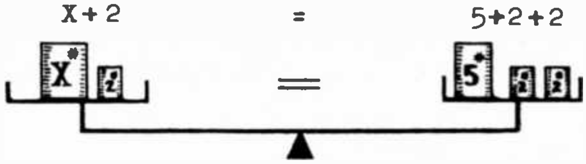
Changing locations:

$$-6 + (6 \times 8) - 20 = 22$$

or: $$-20 + (6 \times 8) - 6 = 22$$

When neither a positive (+) or negative (-) sign is found in front of the letter or number, it is taken for granted that the number is positive; thus, 6 means +6, or 10 means +10.

A common process in working with equations is that of TRANSPOSITION, or transposing of numbers. By transposition is meant the moving of a term from one side of the equation to the other, or from one member to another. This, in reality, is the application of Rule #2, which says that the same quantity may be added to or subtracted from both members without unbalancing the equation. Thus, if it is necessary for us to move a term from one member to another, we proceed as explained in the following paragraphs:



In the above illustration, we have a balancing scale containing two iron blocks in the left-hand tray, and three blocks in the right-hand tray. One of the blocks in the left tray is known to weigh 2 lbs; the weight of the other is not known so we will just call it X. The blocks in the right tray are known to weigh 5, 2, and 2 pounds, respectively. Since the scale is in a state of balance (the total weight of the blocks on each side being the same), we can formulate the equation $X + 2 = 5 + 2 + 2$. Now, we wish to find the weight of X, and in order to do this we must move the 2 from the first member to the other side of the "equal" sign. We begin by subtracting 2 from each member of the given equation as follows:

$$X + 2 - 2 = 5 + 2 + 2 - 2$$

When the minus 2 is subtracted from the plus 2 in the first member, the answer is zero; therefore, we have eliminated the 2 from the first member and we now have: $X = 5 + 2 + 2 - 2 = 7$. Our calculations have thus shown that the weight of X = 7 pounds.

Now, let us refer back to the illustration and see if this solution is born out in actual practice. We subtracted 2 pounds from the first member of the equation, so let us take the 2-pound block from the left tray; this leaves only the block X on this tray. Since we subtracted 2 from the second member of the equation, we also remove one of the 2-pound blocks from the right tray, and the scale will again be in balance because we have removed the same amount from each tray. It is now seen that the block X in the left tray is balancing the two blocks weighing 5 and 2 pounds in the right tray; therefore, $X = 5 + 2$, or 7, which agrees with our calculation.

Instead of subtracting 2 from each side of the equation as we have done, it will be seen that we can accomplish the same thing in a much shorter and easier way. That is, to remove the 2 from the first member of the equation, we simply change the sign in front of the number contained in the first member and move it to the second member of the equation. Thus: $X + 2 = 5 + 2 + 2$

$$X = 5 + 2 + 2 - 2$$
$$X = 7$$

We thus have the handy rule: TO TRANSPOSE ANY TERM FROM ONE SIDE OF AN EQUATION TO THE OTHER, CHANGE THE SIGN IN FRONT OF THE TERM AND MOVE IT (THE TERM) TO THE OTHER MEMBER. (Note: By "changing the sign" is meant to change it to the opposite sign. That is, if the sign is plus, change it to a minus; if the sign is minus, change it to a plus; if the sign is multiplication (x), change it to division (÷); and if the sign is division, change it to multiplication, when transposing.)

TYPICAL PROBLEMS INVOLVING EQUATIONS

Find the value of (?) in each equation by the method of leaving (?) by itself.

(1) 5 + 3 + 1 = 8 + ? (See explanation below) Ans. ? = 1
(2) 6 + 1 + 5 = 10 + ? Ans. ? = 2
(3) ? + 7 - 2 = 8 + 0 Ans. ? = 3
(4) ? x 5 x 2 = 4 + 1 (See explanation below) Ans. ? = 1/2
(5) ? ÷ 7 x 6 = 4 x 1 (See explanation below) Ans. ? = 168

Explanation of Problem 1: The equation 5 + 3 + 1 = 8 + ?, can also be stated as 8 + ? = 5 + 3 + 1. Transposing the 8, we have:

$$? = 5 + 3 + 1 - 8$$
$$? = 1$$

Explanation of Problem 4: We have ? x 5 x 2 = 4 + 1, and it is necessary to transpose the terms 5 and 2 in order to find the value of (?) Since the 5 and 2 are connected to the (?) by multiplication signs, we must perform the opposite function to eliminate them from the first member of the equation -- thus, we divide both members by this quantity, 5 x 2. Our equation then appears as follows:

$$? \times 5 \times 2 = 4 + 1$$

Dividing by 5 x 2, $\frac{? \times 5 \times 2}{5 \times 2} = \frac{4 + 1}{5 \times 2}$

Cancelling, we have $\frac{? \times \not{5} \times \not{2}}{\not{5} \times \not{2}} = \frac{4 + 1}{5 \times 2}$

Thus: $? = \frac{4 + 1}{5 \times 2}$

$$? = \frac{5}{10}$$

$$? = \frac{1}{2}$$

Explanation of Problem 5: In this problem we employ a new rule, which says that whenever multiplication and division are indicated without parenthesis in an equation, the process of multiplication is performed first, followed by the process of division. In the case of addition and subtraction, these functions are performed in the order in which they appear in the equation.

Problem 5 presents the equation ? ÷ 7 x 6 = 4 x 1. According to the above rule, we must first multiply 7 by 6. Thus the equation becomes

$$? \div 42 = 4 \times 1$$

or: $$\frac{?}{42} = 4$$

To remove the 42 from the first member, we <u>multiply</u> both sides by 42, thus:

$$\frac{?}{42} \times 42 = 4 \times 42$$

Cancelling, we have: $$\frac{?}{\not{42}} \times \not{42} = 4 \times 42$$
$$? = 168$$

When multiplying two letters together in a formula, or a letter and a number, it is not necessary to use the multiplication sign (x). For instance, the equation A x B x 5 = C x D may be written 5AB = CD (Note that when a number and a letter are multiplied together, the number is written before the letter.)

To be sure that you understand the use of letters in equations or formulas, let us consider the following expression:

$$5 + 3 + 8 - 7 = 9$$

Instead of using the figures 5, 3, 8, 7, and 9, we could have used the <u>names</u> of these figures as: five + three + eight - seven = nine; or, instead of using the full names, we could use just the first letter of each and the equation would read F + T + E - S = N. In the latter case, however, we must not forget that each of these letters has a definite value and stands for a certain number.

This is exactly what is done when writing formulas. We use letters in place of names because they require less time and space to write. The letters represent the quantities or values of the names and are connected by signs of operation such as x, ÷, +, −, and = .

To solve these formulas with letters, we first substitute all known values for the letters, and solve for the letter that remains, just as we solved for ? and X in the preceding examples.

Returning once more to our formula A = a x b, where A is the area of the rectangle, "a" the length of the altitude, and "b" the length of the base -- let us suppose that "a" is 4 inches and "b" is 10 inches. If such be the case, what is the value of A?

Substituting values in our formula, we have A = 4 x 10, or 40 square inches.

Now, suppose we know the value of A to be 40 square inches and "a", 4 inches. What, then, is the value of "b"?

It is apparent that to determine the value of "b", we must first rearrange the formula A = a x b so that we can find what "b" is equal to in terms of A and "a". This is done by first writing the formula in the equivalent form, a x b = A so as to get the unknown value "b" on the left side (first member) of the equation. Then we transpose according to the rule previously given and so move the "a" from the first to the second member by changing the sign, thus:

$$b = A \div a, \quad \text{or } b = \frac{A}{a}$$

We now have the formula in a form in which we can use it, so we simply substitute the known values and solve as follows:

$$b = \frac{A}{a} = \frac{40}{4} = 10 \text{ inches}$$

We can also rearrange our original formula, A = a x b, to obtain the form we can use for finding "a". Starting with the convenient form, a x b = A, transposing "b" to the second member and changing its sign we have:

$$a = A \div b, \text{ or } a = \frac{A}{b}$$

Notice how by substituting the known values of 40 for A and 10 for "b" in this formula, you obtain the value 4 for "a" as originally given ($a = \frac{A}{b} = \frac{40}{10} = 4$) -- thus showing how a condition of balance is maintained by the equation or formula no matter how it be rearranged.

SOLVING TYPICAL PROBLEMS

When you studied percentage in the previous lesson, you learned three rules: One to find the percentage, one to find the base, and one to find the rate. Now that you understand how to solve formulas, you may use only one of the rules and get all three parts from it. The formula is this:

$$\text{Percentage} = \frac{\text{Rate x Base}}{100}$$

or, use just the letters: $P = \frac{R \times B}{100}$

<u>EXAMPLE 1</u> Find P, when R = 15 and B = 5000.

Solution: The formula is $P = \frac{R \times B}{100}$

Substituting the given values for R and B, we have:

$$P = \frac{15 \times 5000}{100}$$

By cancellation and multiplying,

we find: P = 750

<u>EXAMPLE 2</u> When P is 300, B is 15,000. What is R?

Solution: Rearranging the formula to find the value of R in terms of P and B, we first clear the fraction as before, thus:

$$P = \frac{R \times B}{100}$$

$$100P = \frac{100RB}{100}$$

$$RB = 100P$$

Transposing, $R = \frac{100P}{B}$

Substituting, $R = \frac{100 \times 300}{15000}$

Cancelling, $R = \frac{\overset{2}{\cancel{100}} \times \cancel{300}}{\underset{50}{\cancel{15000}}} = 2\%$

EXAMPLE 3 Given: $P = 250$ and $R = 10$. Find the value of B.

Solution: Arranging the formula to find the value of B in terms of P and R, we clear the fractions as before.

$$\text{Then, } 100P = \frac{100RB}{100}$$

$$\text{Cancelling, } 100P = RB, \text{ or } RB = 100P$$

$$\text{Transposing, } B = \frac{100P}{R}$$

$$\text{Substituting, } B = \frac{100 \times 250}{10} = \frac{25,000}{10}$$

$$B = 2500 \text{ (answer)}$$

******

The knowledge which you will acquire from a thorough study of this lesson will help you greatly to master the subject of general arithmetic. Such a background will enable you to advance much farther in the industry than would be possible without your having the ability to solve practical problems relating to mechanics. You will realize this even more after you have advanced a little farther in your studies.

Should you find some of the arithmetical processes described herein to be new to you, thereby requiring more time for study, then we advise you not to concentrate on this lesson for too long a time at one sitting. It is better that you continue your study of the regular Assignments and devote only a part of each day's study-time to this lesson.

REVIEW PROBLEMS

The problems appearing on this page will give you an opportunity to check up on yourself, to see how well you have mastered the instruction presented in this lesson. We suggest that you solve each of them and compare your answers with those given at the bottom of this page.

If your answer for each problem agrees with that given here, it is sufficient proof that you understand the work involved. If not, review thoroughly that part of this lesson which explains those points on which you are weak.

Do not send your solutions to us for correction.

1. - What is the value of 8^4?

2. - What is the square root of 1296?

3. - If R = 30 and B = 10, what is the value of P in the equation (formula) --

$$P = \frac{R \times B}{100}$$

4. - If X + 8 = 12 + 4, what is the value of X?

5. - May the same quantity be added to or subtracted from both members of an equation without unbalancing the equation?

6. - What is the square root of 25/64?

7. - What is the square root of 39.69?

8. - How will an equation be affected if you multiply both sides of it by the same number?

9. - What is the value of $(3/4)^2$?

10. - Find the value of (?) in the equation 2 x ? x 3 = 4 + 2.

******

ANSWERS:

1. - 4096
2. - 36
3. - 3
4. - 8
5. - Yes.
6. - 5/8
7. - 6.3
8. - It will remain balanced.
9. - 9/16
10. - 1

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LOS ANGELES, CALIFORNIA

MATHEMATICS

LESSON NO. M-3

SIMPLIFYING RADIO AND ELECTRONICS CALCULATIONS

(Power of Ten Notation)

At this stage of your training, you have probably observed that workers in the interesting fields of radio and electronics are sometimes called upon to handle problems in which are involved "cumbersome" or "ponderous" numbers. That is, numbers ranging from very small fractions of electrical units, to very large numbers involving millions of units---often in the same problem. With the development of equipment designed to operate on higher and higher frequencies, such as television, F-M, radar, etc, this use of "cumbersome" numbers will increase, rather than decrease.

Now, very few persons care to perform long mathematical computations, or work complicated problems, simply for the joy of "figuring", or because of a love for mathematics itself. The practical man wants concrete answers to his problems, and he is only interested in mathematics because it is a method of obtaining those answers.

FIG. 1
POWER OF TEN NOTATIONS ARE A VALUABLE TOOL TO THE RADIO ENGINEER

You, as a radio and electronics technician can and should use the many handy mathematical "short-cuts" which are available. These include tables, charts, graphs, and special methods which convert what would be rather complicated problems in multiplication and division, into simple problems involving mostly addition and subtraction.

Whenever and wherever possible, these aids have been incorporated in your study material---such as the tables and charts for figuring coils, tables for conversion from units to sub or gross units, etc. In line with this policy, we are now going to introduce the subject of EXPONENTS and POWER OF TEN. The use of Exponents can be one of your handiest mathematical short cuts----as you shall see while reading the following pages.

Many persons seem to think that the study of exponents is difficult---indeed, some misinformed individuals mentally "shy" every time they see the word "exponents" associated with a practical problem in electricity, radio or electronics. This is unfortunate, as only a slight amount of time and effort will enable almost anyone who can add, multiply, and divide, to utilize this easy "short-cut" in practical work.

WHAT YOU CAN DO WITH EXPONENTS

To you,as a practical technician, exponents can:

1. Enable you to solve difficult problems in multiplication and division either in your head, or with a few numbers jotted down on a piece of scratch paper.
2. Enable you to use a very handy type of "short hand" in writing values which would normally contain a great many digits. In other words, it takes the long string of numbers which are hard to read, and converts them into simple and easily written and easily considered values, greatly simplifying many calculations which would otherwise be rather complex.
3. Enable you to read and understand the many technical handbooks and magazine articles in radio and electronics magazines, wherein exponents are used as an easy method of illustrating a principle.

A BRIEF REVIEW

You will recall that in a previous Mathematics Lesson, you learned that an exponent is a small number written to the right, and slightly above another number. For instance, in 7^4, the small figure ^{4} is an exponent. You also learned that the number with which an exponent is combined is called the basic number, or more simply, the BASE. Thus, in the case of 7^4, 7 is the BASE combined with the EXPONENT ^{4}.

Continuing, you have learned that when a BASE is written with an exponent, it means that the base is to be multiplied by itself, and that the number of times it is to be multiplied by itself is indicated by the exponent. Thus, in the case of 7^4 we know that 7 is to be taken as a factor four times. Like this: $7 \times 7 \times 7 \times 7 = 2{,}401$.

When a base number is multiplied by itself one or more times, as is the case with 7 in the above example, the answer is called a POWER. Thus, in the above, the answer of 2,401 is a power of seven. Because the base, or 7, was multiplied by itself four times, we know that 2,401 is the fourth power of seven. Or, to state it in a more scientific manner, "seven to the fourth power equals 2,401." We would write it in this manner: $7^4 = 2{,}401$; or in the reverse manner, $2{,}401 = 7^4$.

FACTOR

Because the series of numbers which are multiplied to secure the answer in a problem of multiplication are often called FACTORS of the answer, the base number which is written with an exponent is often called a factor. Thus, it would be proper to say that in the case of 7^4, 7 is either the base of the power 2,401 or a factor of 2,401. Just remember that when you hear or see the word factor, it refers to the number, or numbers, involved in a problem of multiplication.

Before proceeding further, it is suggested that you work the practice problems in Fig. 2. This is merely to ensure that you do understand the basic principles of exponents and powers, so that you will be fully prepared to proceed to the more interesting parts of this Lesson. Work each example, determining the required value; checking your answer against the correct answers at the bottom of Fig. 2. If you can do them satisfactorily, then you can feel confident of being able to continue in this so valuable a study.

CAUTION: DO NOT HESITATE TO REFER BACK TO AN EARLIER MATHEMATICS LESSON (M-1 OR M-2) SHOULD YOU BE IN DOUBT ABOUT ANYTHING WHICH HAS BEEN PREVIOUSLY COVERED IN THOSE LESSONS.

(A) $6^2 = ?$
(B) IN THE ABOVE, 36 IS WHAT POWER OF 6?
(C) HOW WOULD YOU FIND THE FIFTH POWER OF 5?
(D) $9^4 = ?$
(E) IF 7 x 4 x 9 x 2 = 504, WHAT ARE THE FACTORS OF 504?
(F) THE BASE 5 AND THE EXPONENT 3 ARE EQUAL TO WHAT ?
(G) WHAT IS THE 4TH POWER OF 10 ?
ANSWERS: (A) 6 x 6 = 36; (B) THE 2ND; (C) MULTIPLY 5 BY ITSELF FIVE TIMES, THUS 5 x 5 x 5 x 5 x 5 = 3125; (D) 9 x 9 x 9 x 9 = 6,561 . (E) THE NUMBERS 7, 4, 9, AND 2; (F) = 5 x 5 x 5 = 75; (G) = 10 x 10 x 10 x 10 = 10,000 .

FIG. 2
PRACTICE EXAMPLES---POWERS, BASES AND EXPONENTS

Exponents and Powers of Ten

Undoubtedly, the most useful application of exponents from the standpoint of the radio and electronics worker is the combining of exponents with the figure ten, to form POWERS OF TEN. You will remember that the figure ten is the easiest of all values to use in problems of multiplication and division. You know that you can multiply any number by ten by simply moving the decimal point one place to the right, or you can divide by ten by merely moving the decimal point one place to the left.

For example, to multiply 23,946.35 x 10, it is merely necessary to move the decimal point one place to the right (from in front of the 3 to a position in front of the 5) to get the answer of 239,463.5 (like this: 2 3 9 4 6 3 5).

To divide by ten, you know that it is merely necessary to move the decimal point one place to the left. For example, to divide 1623.54 by 10, you move the decimal point from a place in front of the 5, to a position in front of the 3, to get the answer of .62.355 (like this: 1 6 2 3 5 4).

From the above, you see that you can divide or multiply ANY NUMBER by ten without any figuring or computation whatsoever.

EXAMPLES

Fig. 3 shows a few problems involving the multiplication or division of numbers by ten. Just for the sake of ensuring your complete understanding and appreciation of the easy way in which ten is handled in such problems, it is suggested that you work a few of them, and compare your answers with those at the bottom of Fig. 3.

CAUTION: Remember that in the case of a whole number (a number which does not incorporate a decimal point) the decimal point belongs in back of the number, at the extreme right of the series of numbers, and should be placed there (either mentally or actually) before attempting to work any problem. For instance: the value 1692 is a whole number, and is usually written without the decimal point, but you would insert the decimal point, like this, 1692. before actually multiplying or dividing.

TEN COMBINED WITH EXPONENTS

Just as the knowledge of how to divide and multiply by ten without computation is valuable in simple problems, so is this same handy figure "ten" valuable, when combined with an exponent, and used in even what would ordinarily be highly complex problems---were it not for ten and its exponent.

Naturally, we write the figure "ten" and an exponent just as we would any other base number and an exponent. For example: 10 and the exponent ^{2} are written 10^2; 10 and the exponent ^{6} are written 10^6, etc. You immediately know that 10^2 is equal to 10 multiplied by itself, or 10 x 10 = 100. You also know that 10^6 (or, 10 x 10 x 10 x 10 x 10 x 10) is equal to 1,000,000 .

(A) 10 x 16.94 =
(B) 16.94 x 10 =
(C) 9,954.21 ÷ 10 =
(D) .21 ÷ 10 =
(E) 21 ÷ 10 =
(F) $\frac{983,261}{10}$ =
(G) 10 x 21,429 x 10 =
(H) $\frac{.006421 \times 10}{10}$ =
(I) .00021 ÷ 10 =
(J) $\frac{105,240.005}{10}$ =
ANSWERS: (A) 169.4; (B) 169.4; (C) 995.421; (D) .021; (E) 2.1; (F) 98,326.1; (G) 214.29; (H) .006421; (I) .000021; (J) 10,524.0005

FIG. 3
PRACTICE EXAMPLES ---
MULTIPLICATION AND DIVISION BY 10

A really proper way to state this, in a mathematical sense, is to say, in the case of 10^6, that ten is taken as a factor six times, and the factors then multiplied to get the power, which is 1,000,000 .

From the above, you can see that we can properly call the value 1,000,000 a POWER OF TEN --- the 6th power of ten, to be exact.

THE POWERS OF TEN

Naturally, the first power of 10 is 10. It could be written with the exponent ^{1} like this, 10^1, but it seldom is, as there is obviously no point in using an exponent to indicate that 10 is equal to itself.

The second power of 10, written 10^2, is obviously 100 because 10 x 10 = 100. The third power of 10,

TABLE I POWERS OF TEN			
POWER	EXPRESSED WITH EXPONENT	ACTUAL MEANS OF ARRIVING AT POWER	VALUE OF POWER
FIRST	10^1	10 x 1	10
SECOND	10^2	10 x 10	100
THIRD	10^3	10 x 10 x 10	1,000
FOURTH	10^4	10 x 10 x 10 x 10	10,000
FIFTH	10^5	10 x 10 x 10 x 10 x 10	100,000
SIXTH	10^6	10 x 10 x 10 x 10 x 10 x 10	1,000,000
SEVENTH	10^7	10 x 10 x 10 x 10 x 10 x 10 x 10	10,000,000
EIGHTH	10^8	10 x 10 x 10 x 10 x 10 x 10 x 10 x 10	100,000,000
NINTH	10^9	10 x 10 x 10 x 10 x 10 x 10 x 10 x 10 x 10	1,000,000,000
TENTH	10^{10}	10 x 10 x 10 x 10 x 10 x 10 x 10 x 10 x 10 x 10	10,000,000,000

written 10^3, is obviously 1000 because 10 x 10 x 10 = 1000. Table I shows the powers of ten up to the tenth power, and the basic method of arriving at them.

HOW YOU CAN USE POWERS OF TEN

By this time, you are probably wondering how you can use the principles governing powers of ten, such as you have just studied. That is as it should be, as a practical man does not wish to put in time and effort in learning principles of mathematics, unless he is shown clearly and promptly how those same principles can be of use to him. Following, are explained some easy methods of shortening cumbersome numbers and multiplying and dividing cumbersome numbers by means of exponents---easier and quicker than you could do it by other methods.

Shortening Numbers by Means of Exponents and Powers of Ten

Let us take as an example, the figure for the velocity of radio and light waves, or 300,000,000 meters per second. Now this value, containing as it does, the numeral 3, followed by eight zeros, is what we would call in non-technical phraseology, a "cumbersome" or "awkward value". Setting it up in a problem of multiplication or division can sometimes be quite complicated, and one has to be very careful to see that none of the zeros are omitted in the final answer.

On the other hand, if you just had to deal with the figure 3, and could eliminate the zeros from your problem, you know that it would be very simple. Obviously, a problem in division or multiplication involving just 3 and another equally simple number can be solved easily and quickly.

We can eliminate the zeros by the use of a power of ten, or by the use of 10 and a suitable exponent. This is how it may be done:

TO SHORTEN A NUMBER WHICH CONTAINS A NUMBER OF ZEROS

PROCEDURE: MOVE THE DECIMAL POINT TO THE LEFT UNITL YOU HAVE A VALUE WHICH IS MORE THAN ONE AND LESS THAN TEN. THEN SHOW THE RESULTING VALUE AS BEING MULTIPLIED BY 10, COMBINED WITH AN EXPONENT WHOSE VALUE IS EQUAL TO THE NUMBER OF PLACES THE DECIMAL POINT WAS MOVED.

At the first reading, the above might well sound like "double-talk" to one not accustomed to working with exponents, but it isn't, as you will readily see when we apply the above PROCEDURE to our value of 300,000,000.

Remembering that in any whole number, the decimal point may be properly placed at the extreme right of the number, we regard 300,000,000 as 3 0 0 0 0 0 0 0 0. , with a decimal point following the final zero. Then we move this decimal point to the left, like this:

3. 0 0 0 0 0 0 0 0 x

and discard the zeros. Thus giving us only the number 3., which is a value more than one and less than ten.

Now, while the above is easy to do, it should be remembered that while we don't require the eight zeros which we have discarded, we do have to represent them, or to make a notation after the 3. to show that it was originally followed by eight zeros.

Such a notation is easily made by showing the 3. as being multiplied by 10; like this: 3 x 10, with a suitable exponent. Now, remembering our rule of procedure, you will recall that the exponent must be equal to the number of places the decimal point was moved. Since the decimal point was moved eight places, we know that our exponent must be ^{8} . Thus in its final form, 300,000,000 may be shortened to $3. \times 10^8$ (pronounced: "three times ten to the eighth").

As you will see in future sections of this Lesson, 3×10^8 is much more easily handled than is 300,000,000, because in shortening it, we have changed it from a nine-digit number to a number having only one digit. While it is true that we have added the " $\times 10^8$", you will remember that ten is the easiest of all values to use in multiplication and division, and this is no exception.

Compare the RULE OF PROCEDURE as given, with the actual way in which we shortened 300,000,000 and make certain that you understand all of the operations, and the reasons for doing them.

In a like manner, the number 200,000 can have its decimal point moved 5 places to the left, and it becomes 2×10^5 (pronounced: "two times ten to the fifth"); 50,000 can have its decimal point moved 4 places to the left, to become 5×10^4 (pronounced: "five times ten to the fourth"); 628,000 can have its decimal point moved 5 places to the left to become 6.28×10^5 (pronounced: "six point two eight times ten to the fifth"). Note in this last instance, that while we can't always shorten our numbers so that they contain only one digit, we can shorten them to the extent that they have a total value which is always less than ten. Hence 628,000 in its shortened form, 6.28×10^5, contains three digits (a 6 a 2 and an 8); but because of the placement of the decimal point, the total value of these three digits is less than ten.

Fig. 4, shows a number of examples of values which have been "shortened" or expressed with suitable powers of ten. Go over each example, comparing it with what you have learned in the preceding paragraphs--- and make certain that you understand just how each operation was done, and why.

PRACTICE EXAMPLES

After you have examined the typical worked-out examples in Fig. 4, turn to Fig. 5 and perform the necessary operations on the values given so that they may be expressed in "shortened" form with the aid of power of ten. After you have done this, compare your results with the correct answers given at the bottom of Fig. 5.

CAUTION: Should any of your answers to the examples in Fig. 5 fail to correspond with the correct answers, do not go on until you have learned WHY your answer was incorrect. Do not hesitate to review the earlier parts of this Lesson if necessary.

ORIGINAL FORM		"SHORTENED" FORM
256,000	=	2.56×10^5
160	=	1.6×10^2
450,000,000,000	=	4.5×10^{11}
121.0	=	1.21×10^2
12.10	=	1.21×10^1
1.210	=	1.21×10^0
1210	=	1.21×10^3
670,250.1	=	6.702501×10^5
.670,000.0	=	6.7×10^5
11,000,000	=	1.1×10^7

FIG. 4
SHORTENING VALUES---TYPICAL EXAMPLES

ORIGINAL FORM		"SHORTENED" FORM
(A) 755	=	
(B) 755,000	=	
(C) 75.5	=	
(D) 500,000,000	=	
(E) 10,968	=	
(F) 968	=	
(G) 21.5	=	
(H) 165,000	=	
(I) 3.620	=	
(J) 362.0	=	

ANSWERS:
(A) 7.55×10^2; (B) 7.55×10^5; (C) 7.55×10^1; (D) 5×10^8; (E) 1.0968×10^4; (F) 9.68×10^2; (G) 2.15×10^1; (H) 1.65×10^5; (I) NO SHORTENING POSSIBLE---READ AS 3.62; (J) 3.62×10^2

FIG. 5
SHORTENING VALUES---PRACTICE EXAMPLES

Shortening Numbers Which Are Less Than One, or Decimal Fractions

Remembering from the foregoing explanation, how we took the figure 300,000,000 and called it a "cumbersome" or "awkward" number, because it had so many zeros following its main digit of 3, let us now consider the value .00025. This value, which is so often encountered when working with circuits containing capacity, is also very "cumbersome" because in addition to its two principle digits, the 2 and 5, it contains three zeros.

Fortunately, just as we can shorten a number of 1 or greater, such as 300,000,000, so also can we shorten numbers which are less than one, or which are decimal fractions, such as the value .00025; however, because with all decimal fractions, the decimal point is located at the extreme left of the last digit, it is obvious that to shorten such values, we must move the decimal point to the right, instead of to the left. Here is the RULE OF PROCEDURE in "shortening" decimal fractions:

> <u>PROCEDURE</u>: MOVE THE DECIMAL POINT THE REQUIRED NUMBER OF PLACES TO THE RIGHT SO THAT THE VALUE BECOMES MORE THAN ONE AND LESS THAN TEN. THEN SHOW THE RESULTING VALUE AS BEING MULTIPLIED BY 10, COMBINED WITH A NEGATIVE EXPONENT WHOSE VALUE IS EQUAL TO THE NUMBER OF PLACES THE DECIMAL POINT WAS MOVED.

Now, let us compare the above PROCEDURE with an actual operation; taking as our first example, the value .00025 . First, we will move the decimal point until our value becomes more than one and less than 10; or 2.5 like this:

x.0 0 0 2,5

Note that this requires that the decimal point be moved 4 places. We then show the shortened value, 2.5 as being multiplied by 10 or

2.5 x 10

Since our decimal point was moved 4 places, our exponent will be equal to^4 . Therefore, our notation becomes.

2.5×10^4

However, in "shortening" all values which are less than one, there is one other important item to be placed in the notation. Remember that the RULE OF PROCEDURE for shortening decimal fractions specified the use of a <u>negative</u> exponent. Now, a negative exponent is nothing more than an <u>exponent</u>, written in the usual manner, with a small minus, or negative sign (-) in front of it.

Thus, in its final form, our notation looks like this:

2.5×10^{-4}

(pronounced: "two point five times ten to the negative fourth").

Anyone looking at this value; 2.5×10^{-4}; would instantly realize that the negative sign means that the original value was a decimal fraction having a total value which was less than 1 .

To sum up. Whenever you "shorten" a decimal fraction, or a value which is less than one, place a small negative sign ahead of the exponent, thus making the exponent negative. Whenever you see a value with a notation to a power of ten, with the exponent negative, you will instantly realize that the original value was less than one, or was a decimal fraction.

POSITIVE EXPONENTS

SINCE IN ELECTRICITY AND RADIO WE USUALLY ASSOCIATE THE TERM "NEGATIVE" WITH AN OPPOSITE, OR "POSITIVE" TERM, YOU ARE POSSIBLY WONDERING IF THERE IS SUCH A THING AS A POSITIVE EXPONENT. THE ANSWER, OF COURSE, IS YES. THE POSITIVE EXPONENT IS THE EXPONENT WHICH IS USED IN SHORTENING NUMBERS THAT ARE EQUAL TO ONE OR MORE, SUCH AS 300,000,000 . WE NOTED THIS WITH POWERS OF TEN AS 3×10^8. IN THIS CASE, THE EXPONENT ^{8} IS A POSITIVE EXPONENT, AND COULD ACTUALLY BE WRITTEN SO THAT OUR NOTATION COULD INCLUDE THE POSITIVE SIGN (+) LIKE THIS:

$3 \times 10^{+8}$

HOWEVER, IT IS CUSTOMARY IN MOST INSTANCES TO OMIT THE POSITIVE SIGN IN FRONT OF POSITIVE EXPONENTS, AND TO TAKE IT FOR GRANTED THAT WHEN AN EXPONENT IS WRITTEN WITHOUT A SIGN, IT IS POSITIVE.

RULE: AN EXPONENT WRITTEN WITHOUT ANY SIGN IN FRONT OF IT IS ALWAYS CONSIDERED A POSITIVE EXPONENT. IN OTHER WORDS, USUALLY ONLY NEGATIVE EXPONENTS HAVE THE SIGN IN FRONT OF THEM. THIS, OBVIOUSLY, IS JUST ANOTHER WAY OF SAYING THAT IF AN EXPONENT IS NOT NEGATIVE, THEN IT MUST BE POSITIVE.

FOR EXAMPLE, ALL OF THE EXPONENTS USED IN THE EXAMPLES OF FIGS. 4 AND 5, ARE POSITIVE EXPONENTS, AND MUST BE RECOGNIZED AS SUCH, EVEN THOUGH NO POSITIVE SIGN (+) IS SHOWN.

Continuing with negative exponents: In a like manner, .00035 has its decimal point moved 4 places to the right and is noted as 3.5×10^{-4} (pronounced: "three point five times ten to the negative fourth"); .00000628 has its decimal point moved 6 places to the right and becomes 6.28×10^{-6} (pronounced: "six point two eight times ten to the negative sixth"); .004 is noted as 4×10^{-3}(pronounced: "four times ten to the negative third").

Fig. 6 shows additional examples of decimals which have been shortened by means of 10 and suitable negative exponents. Analyze each example, and make certain that you understand just how each answer was arrived at; reviewing if necessary.

PRACTICE EXAMPLES

After you have examined the typical worked-out examples in Fig. 6, turn to Fig. 7, and perform the necessary operations on the fractional values given, so that they may be expressed in "shortened" form with the aid of powers of ten and suitable exponents; comparing your results with the correct answers given at the bottom of the illustration.

CAUTION: Should any of your answers to the practice examples in Fig. 7 fail to correspond with the correct answers given, do not go on until you have learned WHY your answer was incorrect. Review if necessary.

ABSOLUTE VALUES OF EXPONENTS

In summing up, we can say that the absolute, or numerical value of ANY exponent is determined solely by the number of places the decimal point was moved, without regard to the direction in which it was moved. Thus, if when "shortening" a number the decimal point were moved five places to the left, the exponent would have an absolute value of 5; if it were moved five places to the right, the exponent would also have an absolute value of 5.

However, in the case where the decimal point was moved to the right, the sign of the exponent would be negative or minus. When the decimal point was moved to the left, the sign of the exponent would be positive or plus.

RULE: THE ABSOLUTE (NUMERICAL) VALUE OF AN EXPONENT IS DETERMINED BY THE NUMBER OF PLACES THE DECIMAL POINT IS MOVED. THE SIGN OF THE EXPONENT IS DETERMINED BY THE DIRECTION IN WHICH THE DECIMAL IS MOVED.

	ORIGINAL FORM		"SHORTENED" FORM
(A)	.00065	=	6.5×10^{-4}
(B)	.65	=	6.5×10^{-1}
(C)	.003100	=	3.1×10^{-3}
(D)	.21896	=	2.1896×10^{-1}
(E)	00.65	=	6.5×10^{-1}
(F)	.250025	=	2.50025×10^{-1}
(G)	.00001	=	1×10^{-5}
(H)	.00045	=	4.5×10^{-4}
(I)	.0004	=	4×10^{-4}
(J)	.006	=	6×10^{-3}

FIG. 6
NEGATIVE EXPONENTS----TYPICAL EXAMPLES

Changing Notations With Powers Of Ten Back To Their Original Forms

The changing of a notation with powers of ten back to its original form is equally as simple as the "shortening" of a number. Here is the procedure:

PROCEDURE: IF THE EXPONENT IS POSITIVE, MOVE THE DECIMAL POINT TO THE RIGHT ACCORDING TO THE VALUE OF THE EXPONENT. IF THE EXPONENT IS NEGATIVE, MOVE THE DECIMAL POINT TO THE LEFT ACCORDING TO THE VALUE OF THE EXPONENT.

For example, assume that you wish to change the value:

$$8.56 \times 10^5$$

Since the exponent has no sign in front of it, it is therefore considered to be positive, and indicates that the decimal point is to be moved 5 places to the right (annexing zeros as necessary) like this:

8x5 6 0 0 0.

Thus: $8.56 \times 10^5 = 850,000$

ANOTHER EXAMPLE

Assume that you wish to change the value 5×10^{-3}

Since the sign of the exponent is negative, it indicates that the decimal point is to be moved 3 places to the left (annexing zeros as necessary), like this: .0 0 5x

ORIGINAL FORM		CHANGE TO "SHORT" FORM
(A)	.1691 =	
(B)	.0041 =	
(C)	00.0031 =	
(D)	.2180 =	
(E)	.0007 =	
	.7000 =	
(F)	.004 =	
(G)	.0000008 =	
(H)	.0000000000362 =	
(I)	.000932102 =	
(J)	.9 =	

ANSWERS:
(A) 1.691×10^{-1}; (B) 4.1×10^{-3}; (C) 3.1×10^{-3}; (D) 2.18×10^{-1}; (E) 7×10^{-4}; (F) 4×10^{-3}; (G) 8×10^{-7}; (H) 3.62×10^{-11}; (I) 9.32102×10^{-4}; (J) 9×10^{-1}.

FIG. 7
USE OF NEGATIVE EXPONENTS---PRACTICE EXAMPLES

Thus: $5 \times 10^{-3} = .005$

You will note that the procedure in converting a notation back to its original form is just the reverse of the process which you used when "shortening" a number to a notation with power of ten.

Or, to go back to our original values: 300,000,000 with the decimal point moved 8 places to the left, becomes 3×10^8; while 3×10^8 with the point moved 8 places to the right, becomes 300,000,000.

In the case of our first illustration with negative exponents, .00025 with the point moved 4 places to the right became 2.5×10^{-4}; while 2.5×10^{-4} with the point moved 4 places to the left becomes .00025.

Fig. 8 shows a number of typical notations with power of 10, using both positive and negative exponents. Note the values to which these notations refer, or are equal to.

PRACTICE EXAMPLES

To ensure that you are familiar with this procedure, you are requested to do the conversions required in the examples of Fig. 9, which give you values using both positive and negative exponents with 10 as the base. Convert back into the original form in each instance and compare your answers with the correct answers at the bottom of the illustration.

Shortening Values Which Are Exact Multiples or Sub-Multiples of Ten

A slight variation of the procedures you have just studied is used when the original value you are dealing with is either an even multiple, or an even sub-multiple of ten.

NOTE: NUMBERS SUCH AS 100 1000 10,000 100,000, ETC., ARE CALLED EVEN MULTIPLES OF ONE BY TEN BECAUSE THEY MAY BE SECURED BY MULTIPLING 1 x 10 FOR THE REQUIRED NUMBER OF TIMES. FOR INSTANCE: 1 x 10 x 10 IS 100; THEREFORE, 100 IS AN EVEN MULTIPLE OF TEN.

NUMBERS SUCH AS 0.1, 0.01, 0.001, 0.00001, ETC., ARE CALLED EVEN DIVISIONS OF ONE BY TEN, BECAUSE THEY MAY BE SECURED BY DIVIDING 1 BY 10 FOR THE REQUIRED NUMBER OF TIMES. FOR INSTANCE, DIVIDING 1 BY 10 GIVES YOU .1; DIVIDING 0.1 BY 10 GIVES 0.01; DIVIDING 0.01 BY 10 GIVES 0.0001; ETC. SUCH EVEN DIVISIONS OF 10 ARE OFTEN CALLED SUB-MULTIPLES OF TEN. THE TERM "SUB-MULTIPLE" MEANING THE OPPOSITE OF "MULITPLE".

You will note that if you had a value of, say 1000, which is 1 followed by three zeros, you could shorten it to a one-digit value by making a notation with power of ten like this:

$$1 \times 10^3$$

However, our only aim in using exponents and power of ten is to simplify. A moment's consideration shows that we can even remove the 1; leaving only the power, 10 and the exponent ^{3}, or 10^3. This is possible because multipling 1 x 10 , is done like This:

$$1 \times 10 \times 10 \times 10 = 1000$$

While if we omit the 1, and write the notation as just 10^3, it becomes:

$$10 \times 10 \times 10 = 1000$$

which yields the same answer as when the 1 was included. Therefore, since the 1 is not necessary, it is omitted in our notations. However, like the positive sign in front of the positive exponent, even though the 1 is not actually shown, you must always realize that whenever you see a power of ten notation, such as 10^3, the 1 is always assumed to be

	NOTATION WITH POWER OF TEN		CHANGE TO ORIGINAL VALUE
(A)	6×10^5	=	600,000
(B)	6×10^{-5}	=	.00006
(C)	3.41×10^{-15}	=	.00000000000000341
(D)	2.5×10^{-4}	=	.00025
(E)	3×10^8	=	300,000,000
(F)	4×10^{-3}	=	.004
(G)	5×10^3	=	5,000
(H)	9×10^{12}	=	9,000,000,000,000
(I)	3.16×10^{-6}	=	.00000316
(J)	7.95×10^7		79,000,000

FIG. 8
CONVERTING BACK TO ORIGINAL VALUE
-----TYPICAL EXAMPLES

NOTATION WITH POWER OF TEN		CHANGE TO ORIGINAL VALUE
(A)	5.3×10^8 =	
(B)	9.999×10^{-9} =	
(C)	8×10^{-1} =	
(D)	6.6×10^{-6} =	
(E)	6.6×10^6 =	
(F)	4.50×10^{-3} =	
(G)	1.60003×10^{-4} =	
(H)	5×10^{-2} =	
(I)	1.00×10^5 =	
(J)	1×10^{-1} =	

ANSWERS:
(A) 530,000,000; (B) .000000009999; (C) .8; (D) .0000066; (E) 6,600,000; (F) .0045; (G) .00016003 (H) .05 ; (I) 100,000; (J) .1

FIG. 9
CONVERTING BACK TO ORIGINAL VALUES -----PRACTICE EXAMPLES

present, just as though it were written out 1×10^3; and when converting a power of ten and an exponent back to its original value, you will always first write the 1 down, and then follow it with the proper number of zeros as indicated by the exponent.

Therefore, if you saw 10^3 and wished to convert back to its original form, you would first jot down the 1 which you know is the first digit of the value, like this:

1.

Then, since the exponent is ^{3}, you would move the decimal point the required three places to the right (annexing zeros) like this:

1.0 0 0.

Which would give you the answer of 1000 .

OTHER EXAMPLES

Likewise, 100,000 is noted as 10^5; 100,000,000 as 10^8, etc.

EXPRESSING DECIMALS WHICH END IN ONE

Likewise, in the case of decimals such as .1, .01, .001, .0001, .00001, etc, which have a single 1 in them as the only digit which is greater than zero, we omit the 1 in the notation with power of ten.

For example, .1 would be noted with power of ten by moving the decimal point one place to the right, like this: .1. and making the proper notation, like this: 1×10^{-1}. However, the 1 is almost never put down; merely the notation: 10^{-1} being used. Thus:

$$.1 = 10^{-1}$$

Likewise, .01 would be noted as: 10^{-2}; .0001 as: 10^{-4}; .000001 as 10^{-6}; etc.

In Table II, you are shown all multiples and sub-multiples of 10 from .000001 to 1,000,000 and the way in which they would be noted with power of ten. Observe that in no instance would the digit 1 be included. However, the digit 1 is always assumed to be present, and in converting notations with power of 10 back to their original values, as well as when working problems of division, multiplication, etc, you will always first write the digit 1 down; mentally placing a decimal point to its immediate

TABLE II

MULTIPLES AND SUB-MULTIPLES OF TEN

	NUMBER		POWER OF TEN		EXPRESSED IN ENGLISH	
SUB-MULTIPLES OF TEN	0.000001	=	10^{-6}	=	TEN TO THE NEGATIVE SIXTH	POWER
	0.00001	=	10^{-5}	=	TEN TO THE NEGATIVE FIFTH	POWER
	0.0001	=	10^{-4}	=	TEN TO THE NEGATIVE FOURTH	POWER
	0.001	=	10^{-3}	=	TEN TO THE NEGATIVE THIRD	POWER
	0.01	=	10^{-2}	=	TEN TO THE NEGATIVE SECOND	POWER
	0.1	=	10^{-1}	=	TEN TO THE NEGATIVE FIRST	POWER
	1	=	10^{0}	=	TEN TO THE ZERO POWER.	POWER
MULTIPLES OF TEN	10	=	10^{1}	=	TEN TO THE FIRST POWER.	
	100	=	10^{2}	=	TEN TO THE SECOND POWER.	
	1,000	=	10^{3}	=	TEN TO THE THIRD POWER.	
	10,000	=	10^{4}	=	TEN TO THE FOURTH POWER.	
	100,000	=	10^{5}.	=	TEN TO THE FIFTH POWER.	
	1,000,000	=	10^{6}	=	TEN TO THE SIXTH POWER.	

right. Then move the decimal point according to the value of the exponent (to the right if positive; to the left if negative).

For example: 10^6 is converted to its original value of 1,000,000 by first jotting down a 1 with a decimal point like this:

1.

Then you would move the decimal point the required 6 places---to the right---because the exponent is positive, like this:

1x0 0 0 0 0 0.

If you wished to convert 10^{-6} back to its original value, you would start out just as you did in the above, by jotting the digit 1, with its decimal point, like this:

1.

Then, since the exponent is negative, you would move the decimal the required 6 places to the left, annexing 5 zeros, like this:

.000001x

ZERO EXPONENT

You will note that in Table II the simple numeral I, when expressed with power of ten, is equal to 10^0. This is shown here for reference purposes only; as in simple applications of exponents, such as we are explaining in this Lesson, the zero exponent is not used. Obviously, the figure 1 doesn't require any "shortening" or simplification, to enable you to use it in practically any type of problems with the utmost convenience.

PRACTICE EXAMPLES

So that you may be certain as to your understanding of the proper method of noting power of ten when dealing with even multiples or sub-multiples of 10, you are requested to work the examples in Fig. 10, supplying either the required power of ten notation, or the original value, as the case may be. Check your results with the answers, and re-study the preceding paragraphs if you think it advisable.

How We Talk About Exponents

One thing which you are probably curious about, is the way in which you would speak of exponents and power of ten notations in ordinary speech. For example, you have just studied the mathematical significance of say, 3×10^5 and are perhaps not certain as to how the engineer would speak of such a notation or what he would call it in everyday speech.

Well, if you wished to speak of say 3×10^5, you would just call it:

"three times ten to the fifth power",

Or more simply:

"three times ten to the fifth",

Likewise:

6×10^3 is "six times ten to the third"
8.91×10^6 is "eight point nine one, times ten to the sixth"

In the case of negative exponents, you would speak of them in the same manner, except that you would mention the negative sign. Thus, 3×10^{-5} is expressed as: "three times ten to the negative fifth power".

Or simply: "three times ten to the negative fifth".

Still another way, when dealing with negative exponents, is to use the word "minus" in place of the word "negative". Thus, in the above example, it would be equally correct and permissible to say:

"three times ten to the minus fifth"

or, "three times ten to the minus fifth power".

By the way, the word EXPONENT is pronounced as: ex-po-nent with the "o" having the sound of "oh".

Thus, you see that there is nothing difficult about speaking of exponents, or their functions.

(A) .001 =

(B) 10^{-3} =

(C) 10^{+3} =

(D) 10,000 =

(E) .00001 =

(F) 10^{-6} =

(G) 10^{15} =

(H) 10^{0} =

(I) 10 =

(J) 10^{2} =

ANSWERS:
(A) 10^{-3}; (B) .001; (C) 1000; (D) 10^4; (E) 10^{-5}; (F) .000001; (G) 1,000,000,000,000,000; (H) 1; (I) 10^1; (J) 100.

FIG. 10
EVEN MULTIPLES AND SUB-MULTIPLES OF TEN -----PRACTICE EXAMPLES

Multiplication With Power of Ten

Multiplication can often be greatly simplified by the use of "shortened" numbers and power of ten notations. The steps which one goes through when working a multiplication problem with the aid of power of ten, are as follows:

1. Shorten all numbers so that their value is more than one and less than ten (in accordance with previous instruction).

2. "Set-up" these "shortened" values so that they form a problem in multiplication. This is done in the conventional manner with which you are familiar---with the exception of one slight variation which will be explained.

3. Solve the "multiplication" part of the problem, by means of straight multiplication.

4. Determine the value and sign (positive or negative) of the final exponent, in accordance with instructions which follow.

5. Combine the answer to the "multiplication" part of the problem, with the final exponent. This will give you the answer in "shortened" form.

6. If the full arithmetical value of the answer is required, proceed as previously instructed for converting "shortened" numbers back into their original form.

It is suggested that you re-read the above steps, so that you may have a clear and broad picture which will aid you in the following detailed instructions that follow.

It might be of interest at this point, to emphasize the fact that none of the above steps involve any complex or detailed math problems, and that most of them can be carried out mentally, or "in your head", after you have become familiar with the process. Actually, the paper work involved usually consists of only a few "jottings".

EXAMPLE NO. 1

For a typical problem, we are deliberately going to choose values which are very large, and which contain a great many zeros. This is done so that you may fully appreciate the advantages offered by exponents and power of ten in simplifying multiplication.

Therefore, we will assume that it is desired to multiply 500,000 by 700,000,000. It would be a nuisance to multiply this out in the conventional manner, and great care would be required to ensure that none of the zeros were "misplaced" or omitted from the final answer. However, this is exactly the type of problem which may be excellently handled by means of exponents and power of ten, as follows:

PROCEDURE FOR STEP #1:

Referring to Step #1, you see that the first thing to do is to "shorten" the factors of the problem so that they have values which are between one and ten, with their proper power of ten notations. We do this according to the previously described method. Therefore:

$$500{,}000 = 5 \times 10^5$$
$$700{,}000{,}000 = 7 \times 10^8$$

PROCEDURE FOR STEP #2:

Then, in accordance with Step #2, we set the problem up like this:

$$(5 \times 10^5) \times (7 \times 10^8) =$$

Note that in setting it up, we have used the parenthesis signs () to indicate, or set-off, the two separate notations. This inclusion of the parenthesis or "bracket" signs is not entirely necessary from the strict mathematical standpoint; but their use will help you to visualize the problem, and is recommended by most technical men. Incidentally, this use of the parenthesis signs is the "variation" mentioned in the outline of Step #2.

PROCEDURE FOR STEP #3:

The third step states that you now solve the "multiplication" part of the problem. Every power of ten problem in multiplication consists of two basic parts. One part consists of straight multiplication. This is the part that we will consider now.

As far as this portion of the problem is concerned, the factors which are to be multiplied are the "shortened" values. In this case, the 5 and 7. Therefore, we can mentally multiply 5 x 7 and get the answer of 35, which we will place at the extreme right of our problem as presented above, so that it now looks like this:

$$(5 \times 10^5) \times (7 \times 10^8) = 35$$

Therefore, the first part of our answer is 35. Note that you merely multiply the factors---you do not do anything with the power of ten notations at this stage of the proceedings.

PROCEDURE FOR STEP #4:

The next step is to find the final exponent, or to determine the value and sign of the power of ten notation to use with our answer of 35 in the example. There are two simple and easily memorized rules for determining the sign and value of this final exponent.

RULES FOR DETERMINING FINAL EXPONENT

RULE #1: IF ALL OF THE EXPONENTS IN THE PROBLEM HAVE LIKE SIGNS (EITHER ALL POSITIVE, OR ALL NEGATIVE), YOU ADD THE ABSOLUTE VALUES OF THE EXPONENTS TO GET YOUR FINAL EXPONENT, AND RETAIN THE SAME SIGN. THUS, IF YOU HAD TWO OR MORE POSITIVE EXPONENTS, YOU WOULD ADD THEM, AND YOUR FINAL EXPONENT WOULD BE POSITIVE. IF YOU HAD TWO OR MORE NEGATIVE EXPONENTS, YOU WOULD ADD THEM TO GET THE VALUE OF YOUR FINAL EXPONENT, WHICH WOULD BE NEGATIVE.

RULE #2: IF THE PROBLEM CONTAINS BOTH, POSITIVE AND NEGATIVE EXPONENTS, OR IS COMPOSED OF UNLIKE EXPONENTS, YOU FIRST ADD THE ABSOLUTE VALUES OF ALL OF THE POSITIVE EXPONENTS. THEN YOU ADD THE ABSOLUTE VALUES OF ALL THE NEGATIVE EXPONENTS. THEN YOU SUBTRACT THE SMALLER OF THESE ABSOLUTE VALUES FROM THE LARGER,TO GET THE ABSOLUTE VALUE OF YOUR FINAL EXPONENT; AND GIVE IT THE SAME SIGN AS THAT OF THE EXPONENT IN THE PROBLEM HAVING THE GREATER ABSOLUTE VALUE.

Therefore, we will inspect the sample problem which we are working and note that there are two power of ten notations (10^5 and 10^8),and that both of them are positive. Thus, we can say that the exponents in this problem are ALIKE AS TO SIGN and therefore apply RULE #1 to find the

EXAMPLE: MULTIPLY 500,000 x 700,000,000	
STEP #1 - SHORTEN: 500,000 = 5×10^5 700,000,000 = 7×10^8	CAN BE DONE MENTALLY IN MOST CASES.
STEP #2 - SET UP PROBLEM: $(5 \times 10^5) \times (7 \times 10^8) =$	
STEP #3 - MULTIPLY: $5 \times 7 = 35$	DONE MENTALLY.
STEP #4 - ADD EXPONENTS: $10^{5+8} = 10^{13}$	DONE MENTALLY.
STEP #5 - COMBINE ANSWER TO MULTIPLICATION WITH FINAL EXPONENT TO GET ANSWER: 35×10^{13} (ANSWER---SHORTENED FORM)	DONE MENTALLY.
STEP #6 - CONVERTING FROM "SHORTENED" FORM: 35×10^{13} = 350,000,000,000,000 -----	FINAL ANSWER.

FIG. 11
MULTIPLICATION-----STEP BY STEP PROCEDURE

value of our final exponent. The rule tells us that we add the exponents. Thus, we add ^{5} and ^{8} to get ^{13}, which is the absolute value of our final exponent. It is done like this, either mentally or on paper:

$$10^{5+8} = 10^{13}$$

PROCEDURE FOR STEP #5:

We then combine this final exponent with the answer to the multiplication part of this problem (35); so that in its final form, our problem looks like this:

$$(5 \times 10^5) \times (7 \times 10^8) = 35 \times 10^{13}. \text{ (Answer)}$$

Therefore, our answer (in "shortened" form) is 35×10^{13}.

PROCEDURE FOR STEP #6:

If we desire to know the full arithmetical value of our answer, we proceed as mentioned in Step #6, and convert the answer in "shortened" form to its full value, in accordance with previous instructions, by moving the decimal point thirteen places to the right, like this:

$$35 \times 10^{13} = 35.0000000000000.$$

Thus, our answer to the problem of 500,000 multiplied by 700,000,000 is 350,000,000,000,000 (350-trillion).

If you will refer to Fig. 11, you will see just how this problem would be worked by a practical radio or electronics technician. Note that most of the steps involved would be done mentally, or "in your head"; the time required to complete each step and the amount of "pencil and paper" work necessary being very small indeed. Naturally, we want you to proceed slowly at first; but just as soon as you are accustomed to working with exponents, you will find yourself handling problems of this nature in a very rapid manner, and with a minimum of actual figuring.

Just for comparison, it is suggested that you now set up this problem of 500,000 x 700,000,000 in the conventional arithmetical method, and multiply it out the long way. This should show you the advantages of the shorter and easier method we have just described.

EXAMPLE NO. 2

We will now take another problem---one which you might well encounter in communications work. Let us suppose that it is desired to erect a telephone or other communications line, composed of #16 B & S copper wire, which has a resistance of approximately .004 ohms per foot. If the total length of the wire in this line is 35,000 feet, what is the total resistance of the wire? Obviously, our answer can be secured by multiplying .004 x 35,000. We do it with the aid of exponents in this way:

STEP #1:

$$.004 = 4 \times 10^{-3}$$
$$35{,}000 = 3.5 \times 10^{4}$$

STEP #2:

$$(4 \times 10^{-3}) \times (3.5 \times 10^{4}) = ?$$

STEP #3:

$$4 \times 3.5 = 14$$

STEP #4:

Note that in this problem, one of the exponents ($^{-3}$) is negative, while the other exponent (^{4}) is positive. Thus, the problem contains exponents which are unlike; one being positive, the other negative. We will thus have to apply RULE #2, for finding the sign and value of the final exponent of this problem.

Proceeding according to RULE #2: We subtract the numerically smaller exponent from the numerically larger exponent, like this:

$$10^{4-3} = 10^{1}$$

Thus, the absolute or numerical value of our final exponent is 1.

Note that the 10 is unaffected by this subtraction, but is merely carried over with the final exponent.

Since the rule states that our final exponent takes the same sign as that of the numerically larger of the two exponents in the problem, and since the numerically larger exponent is positive, we can determine by inspection that our final exponent of ^{1} will be positive. Thus, our final power of ten notation will be 10^{1}.

PROBLEM: FIND THE TOTAL RESISTANCE OF 35,000 FT. OF WIRE, WITH A RESISTANCE OF .004 OHMS PER FT.
STEP #1: .004 = 4×10^{-3} 35,000 = 3.5×10^{4}
STEP #2: 3.5 x 4 = 14 — — — — — — — — — — — — — — — — — — — (DONE MENTALLY) 14 IS "JOTTED" DOWN, FOLLOWED BY x 10, THUS: 14 x 10
STEP #3: EXPONENTS ARE SUBTRACTED: 4 - 3 = 1 — — — — — — — — — — (DONE MENTALLY) 1 IS "JOTTED" DOWN AS EXPONENT OF TEN, THUS: 14×10^{1}
STEP #4: INSPECTION SHOWS THAT THE LARGER EXPONENT (4) IS POSITIVE. CONSEQUENTLY, THE EXPONENT 1 IS A POSITIVE EXPONENT.
STEP #5: THEREFORE: 14×10^{1} IS THE ANSWER IN THE SHORTENED FORM.
STEP #6: CONVERT ANSWER IN SHORTENED FORM TO ITS FULL ARITHMETICAL VALUE LIKE THIS: $14 \times 10^{1} = 140$ (DONE MENTALLY) FINAL ANSWER IS 140 OHMS.

FIG. 12
EXAMPLE OF SOLVING PROBLEM INVOLVING POSITIVE AND NEGATIVE EXPONENT

STEP #5:
Combine the value found in STEP #3, with our final power of the notation, thus:

$$14 \times 10^{1}$$

Therefore: $(4 \times 10^{-3}) \times (3.5 \times 10^{4}) = 14 \times 10^{1}$

STEP #6:

$$14 \times 10^{1} = 140 \text{ (ANSWER)}$$

Thus, the total resistance of 35,000 feet of wire will be 140 ohms.

Fig. 12 shows how this might be worked out by one familiar with exponents and power of ten.

EXAMPLE NO. 3

We have measured the current in a certain circuit with a microammeter, and find that there are 3 microamperes of current flowing. The circuit resistance is known to be 120 ohms. We wish to compute the voltage by means of Ohm's Law. Since 3 microamperes equals .000003 ampere, our problem is 120 x .000003 .

STEP #1: $120 = 1.2 \times 10^{2}$
$.000003 = 3 \times 10^{-6}$

STEP #2: $(1.2 \times 10^{2}) \times (3 \times 10^{-6}) = ?$

STEP #3: $1.2 \times 3 = 3.6$ (Answer to multiplication part of problem)

STEP #4: These are unlike exponents, so we subtract the numerically smaller from the numerically larger, or:

$$10^{6-2} = 10^{4}$$

Thus, ^{4} is the absolute value of our final exponent.

Since the numerically larger of the two exponents in the problem is negative, and since our final exponent takes the sign of the numerically larger exponent in the problem, our final exponent is negative. Therefore, our final power of ten notation is: 10^{-4}

STEP #5: $(1.2 \times 10^{2}) \times (3 \times 10^{-6}) = 3.6 \times 10^{-4}$ (Answer in shortened form)

PROBLEM: Find the voltage when the circuit resistance is 120 Ohms, and a current of 3 microamperes is flowing.	
3 Microamperes = .000003 ampere	
$.000003 = 3 \times 10^{-6}$ $120 = 1.2 \times 10^{2}$	
1.2 x3 3.6	(Probably done mentally)
$10^{-6-2} = 10^{-4}$	(Done Mentally)
3.6×10^{-4} volts	(Answer in shortened form)
.00036 volts	(Answer without power of ten notation)

Fig. 13
Another Example of Multiplying, Using Power of Ten Notation

STEP #6: $3.6 \times 10^{-4} =$ .00036 (Answer).

Thus, the e.m.f. applied to this circuit is .00036 volts.

The way in which this problem would be worked in actual long hand, in the shortest possible manner, is shown in Fig. 13.

COMMENTS

You will note from a study of Figs. 11, 12 and 13 that there is no fixed or "formal" manner in which you have to work problems with power of ten. You put down on paper only sufficient calculations for you to arrive at your answer. Much of the calculation can be done mentally (such as subtracting the exponent in Fig. 13). In most instances, you are the only judge of just how much "pencil and paper" calculations you should use---do only enough to ensure that you secure an accurate answer, or to ensure against errors in calculation.

PROBLEMS INVOLVING MORE THAN ONE MULTIPLIER

Working problems which contain more than one multiplier by means of power of ten notations is just as easy as working those which contain but two multipliers---such as those we have discussed up to this point. For a sample problem, we will take:

$$2{,}500{,}000 \times .00025 \times 500{,}000 \times .0001 = ?$$

STEP #1:

$$2{,}500{,}000 = 2.5 \times 10^{6}$$

$$.00025 = 2.5 \times 10^{-4}$$

$$500{,}000 = 5 \times 10^{5}$$

$$.0001 = 1 \times 10^{-4}$$

STEP #2: $(2.5 \times 10^{6}) \times (2.5 \times 10^{-4}) \times (5 \times 10^{5}) \times (1 \times 10^{-4}) = ?$

STEP #3: $2.5 \times 2.5 \times 5 \times 1 = 31.25$

STEP #4:

Finding the final exponent in a problem of this nature becomes merely a matter of taking the sum of all the positive exponents and the sum of all the negative exponents; then subtracting the numerically smaller from the larger. Since the problem contains two positive exponents (10^6 and 10^5), we add them like this:

$$10^{6+5} = 10^{11}$$

The problem also contains two negative exponents (10^{-4} and 10^{-4}) so we add them to get the total negative value, like this:

$$10^{(-4)+(-4)} = 10^{-8}$$

Proceeding: Since the exponent ^{11} is the larger of the two exponents, and the exponent $^{-8}$ is the smaller, and since RULE #2 says that we subtract the numerically smaller from the numerically larger in order to get the value of our final exponent (neglecting signs as we do so), we will subtract the ^{8} from the ^{11}, like this:

$$10^{11-8} = 10^{3}$$

Since the sign of the numerically larger exponent was positive, the final exponent will also be positive. Thus, our final power of ten is 10^3.

Should the nature of the problem have been such that the exponents were $^{-11}$ and ^{8} respectively, then our final power of ten would have been 10^{-3} because the sign of the larger of the two figures is negative.

STEP #5: Our answer in "shortened" form is 31.25×10^3.

Thus: $(2.5 \times 10^{6}) \times (2.5 \times 10^{-4}) \times (5 \times 10^{5}) \times (1 \times 10^{-4}) = 31.25 \times 10^{3}$

STEP #6: Converting this back to its full arithmetical form:

$$31.25 \times 10^{3} = 31{,}250 \quad \text{(ANSWER)}$$

This is shown worked out in long hand in Fig. 14.

PROBLEM: MULTIPLY

2,500,000 x .00025 x 500,000 x .0001

STEP #1:

$2,500,000 = 25.5 \times 10^{6}$

$.00025 = 2.5 \times 10^{-4}$

$500,000 = 5 \times 10^{5}$

$.0001 = 1 \times 10^{-4}$

STEP #2:

```
  2.5          6.25
 x2.5         x   5
 ----         -----
  125         31.25
  50
 ----
 6.25
```

STEP #3:

$10^{6+5} = 10^{11}$

$10^{(-4)+(-4)} = \frac{10^{8}}{10^{3}}$

STEP #4: 31.25×10^{3} (ANSWER WITH POWER OF TEN)

STEP #5: 31,250 (ANSWER)

FIG. 14
SOLVING A PROBLEM IN MULTIPLICATION CONTAINING FIVE FACTORS, USING POWER OF TEN NOTATIONS

If you will just memorize the two basic rules for determining the value and sign of the final exponents, you will not find it difficult to quickly and accurately work even the most complex problem in multiplication.

Ten examples of multiplication with the aid of power of ten are given in Fig. 15. Work these examples, in accordance with the step-by-step analysis of similar problems which you have just studied. Do not hesitate to review the rules and procedure governing multiplication, if necessary. Note, that you are asked to supply the answer to these examples, in their "short" forms only---you have already studied the method of converting the "short" answers to their full arithmetical values, and understand it; so repetition is not necessary at this point. Incidentally, in many cases, this "short" answer is all that is needed in actual work with electronics and radio.

NOTE: The terms "absolute" or "numerical" are used merely to make it technically correct according to the laws of mathematics, for you to subtract an exponent whose sign is positive from an exponent which is numerically larger, but whose sign is negative.

You will remember that a negative exponent actually stands for a value which is less than 1, and a positive exponent stands for a value which is greater than 1, and that it would be mathematically impossible to subtract a value greater than one from a value which is less than one. Consequently, in dealing with exponents having unlike signs---as far as the practical engineer or technician is concerned, the "smaller exponent is always subtracted from the larger exponent" without regard to their signs when actual subtraction is performed. However, the word "absolute" or "numerically" is frequently inserted to prevent any misunderstanding between mathematicians and engineers or technicians.

Therefore, in all parts of this Lesson, when reference is made to the "subtraction of the smaller exponent from the larger exponent," it is numerical or absolute values which are referred to, and you automatically know that the "larger" exponent is the one having the largest number, regardless of whether it is positive or negative. Thus, the exponent $^{-12}$ is larger than ^{8}; the exponent ^{6} is larger than $^{-5}$; etc.

Division With Exponents or Power of Ten

In order to show you the procedure to use in dividing with the aid of power of ten, we will take some simple examples.

EXAMPLE NO. 1

As our first example, let us solve the problem 50,000 ÷ 200. First of all, we nearly always set such problems up by writing the dividend above the divisor, and separate them by means of a horizontal line, like this:

$$\frac{\text{dividend}}{\text{divisor}} = \text{quotient (Answer)}$$

The final answer (quotient)will appear at the extreme right,as indicated.

> NOTE: THE MATHEMATICIAN USES THE TERM QUOTIENT IN PLACE OF ANSWER WHEN SPEAKING OF SUCH PROBLEMS; BUT SINCE QUOTIENT IN A PROBLEM IN DIVISION MEANS THE SAME AS ANSWER, AND AS WE ARE PRACTICAL RADIO AND ELECTRONICS MEN, RATHER THAN MATHEMATICIANS,WE WILL USE THE WORD ANSWER, INSTEAD OF THE MORE PROPER BUT LESS COMMON TERM QUOTIENT.

Accordingly, for our example of 50,000 divided by 200, we will set it up like this:

$$\frac{50,000}{200} = ?$$

Naturally, as we are going to work this example by the easy method of exponents and power of ten, we will first "shorten" the dividend and divisor in the customary manner. Thus:

$$50,000 = 5 \times 10^4$$

$$200 = 2 \times 10^2$$

Proceeding with our problem,you can see that through power of ten, we have simplified our example from one which contained a total of eight digits in the dividend and divisor combined, to one which contains only two digits in the dividend and divisor combined. Or, we have changed our problem from the form:

$$\frac{50,000}{200}$$

to this form:

$$\frac{5 \times 10^4}{2 \times 10^2} = ?$$

In working problems in which, for simplification, we have included power of ten, it is

(A)	$300,000,000 \times 900,000$	=
(B)	$.000016 \times 750,000,000$	=
(C)	$(6 \times 10^8) \times (8 \times 10^2)$	=
(D)	$.0001 \times 300,000$	=
(E)	$(3.5 \times 10^{-4}) \times (2.5 \times 10^{-4})$	=
(F)	$.000014 \times 628,000$	=
(G)	$375,000 \times 250,000 \times 4,000$	=
(H)	$(2.75 \times 10^{-2}) \times (1.25 \times 10^4) \times (1.8 \times 10^{-3})$	=
(I)	$1600 \times 24,000 \times .0001 \times (1.6 \times 10^{-8})$	=
(J)	$.666 \times 10,000 \times .00015$	=

ANSWERS:

(A) 27×10^{13}; (B) 12×10^3; (C) 48×10^{10}; (D) 3×10^1; (E) 8.75×10^{-8}; (F) 8.79×10^0, OR 8.79 ; (G) 37.4×10^{13}; (H) 6.1875×10^{-1} (I) 6.144×10^{-5}; (J) 999×10^0 OR SIMPLY 999.

FIG. 15
MULTIPLICATION-----PRACTICE PROBLEMS

customary to consider the problem in two parts. Just as though it were "split-up" by an imaginary vertical line, like this:

Imaginary line ------→

$$\frac{5 \;\vdots\; \times \quad 10^4}{2 \;\vdots\; \times \quad 10^2} = ?$$

That part of the problem on the left of this imaginary dividing line is the "division" part of the problem, Everything to the right of the line is the "decimal point location" part of the problem, or that part of the problem comprising the powers of ten.

Thus, in the example being considered, our problem has two parts.

1. The problem in straight division, or 5 divided by 2.
2. The manipulation of the power of ten to get the value of the final exponent so that we will know where to place the decimal point in the answer.

Though there is no set rule in this regard, it is customary to first work the division part of the problem. Doing this, we divide the divisor into the dividend (either mentally or by resorting to long division on scratch paper if necessary). In this instance, our divisor is 2 and our dividend is 5, or $\frac{5}{2} = 2.5$; thus, 2.5 is the answer to the "division" part of our problem. We will place this answer to the extreme right of our example, just as we would in the usual division problem.

Thus, our example, as we have worked it so far, appears like this:

$$\frac{\overset{2.5}{\cancel{5}} \quad \times \quad 10^4}{\cancel{2} \quad \times \quad 10^2} = 2.5$$

We can now say that we have worked the left half of the problem, or that part involving division. It now only remains for us to arrive at the value and sign of our final exponent so that we will know where to place the decimal point in our final answer. We will, for convenience, call this last part, "finding the final exponent."

There is a basic, and easily memorized rule for solving the right half of our problem, or for finding the value of the final exponent.

> RULE: MOVE THE POWER OF TEN EXPRESSION IN THE DIVISOR (THE EXPONENT BELOW THE HORIZONTAL DIVIDING LINE) TO A POSITION ABOVE THE LINE, CHANGING THE SIGN AS YOU DO SO. THEN YOU TREAT THE PROBLEM IN EVERY WAY AS THOUGH IT WERE ONE OF MULTIPLICATION.

Now, let's take that rule, and see how it works out with our present example. At this point, we have completed the division part of our example, and it looks like this:

$$\frac{\overset{2.5}{\cancel{5}} \quad \times \quad 10^4}{\cancel{2} \quad \times \quad 10^2} = 2.5$$

Since the first part of our rule for finding the final exponent says to move the power of ten expression in the divisor to a position above the line, we will do this in this manner:

$$\frac{\overset{2.5}{\cancel{5}} \quad \times \quad 10^4 \quad \times \quad 10^2}{\cancel{2} \quad \times \quad \cancel{10}^2} = 2.5$$

This done, note that the next part of our rule says to change the sign as you do so. This means that if the exponent below the line was a positive exponent (as is the one in our example), it is always converted into a negative exponent when moved above the line. On the other hand, if the exponent below the line is a negative exponent, then it is converted into a positive exponent when moved above the line. Our present example, then, looks like this:

$$\frac{\overset{2.5}{\not{5}} \times 10^{4} \times 10^{-2}}{\not{2} \times \not{10^{2}}} = 2.5$$

with both power of ten expressions above the line; one of them positive and, the other negative.

The next part of our rule states: Then you treat the problem in every way as though it were one of multiplication.

ACTUALLY, IT HAS TRULY BECOME A PROBLEM OF MULTIPLICATION BY THE TRANSFER OF ALL COMPONENTS ABOVE THE LINE WHICH SIGNIFIED DIVISION.

PROBLEM: DIVIDE 50,000 BY 200

STEP #1: $\frac{50,000}{200}$

STEP #2: $= \frac{5 \times 10^{4}}{2 \times 10^{2}}$ (SET UP IN "SHORT" FORM)

STEP #3: $\frac{5}{2} = 2.5$ (DONE MENTALLY)

STEP #4: $\frac{\overset{2.5}{\not{5}} \times 10^{4} \times 10^{-2}}{\not{2} \times \not{10^{2}}} = 2.5 \times 10^{2}$ (ANSWER WITH POWER OF TEN NOTATION).

STEP #5: $2.5 \times 10^{2} = 250$ (ANSWER WITHOUT POWER OF TEN NOTATION).

FIG. 16
PROBLEM IN DIVISION,
USING POWER OF TEN NOTATIONS

Then, as our final step, we will remember that in multiplication with power of ten: If both exponents are alike as to sign, we add them to get the final exponent, retaining the same sign; and if the exponents are not alike as to sign, we subtract the smaller from the larger, retaining the sign of the larger, in order to get our final exponent. (Review the previous section on multiplication if necessary).

You can see that to secure our final exponent in our present example, we merely subtract the exponent ^{2} from the exponent ^{4}, and retain the sign of the ^{4}, which is positive. This makes our final exponent equal to ^{2}. Accordingly, our problem, in its full solution, looks like this:

$$\frac{\overset{2.5}{\not{5}} \times 10^{4} \times 10^{-2}}{\not{2} \times \not{10^{2}}} = 2.5 \times 10^{2}$$

Thus, 2.5×10^{2} is our final answer. Naturally, you could immediately convert this to its longer form of 250, if desired, since 2.5×10^{2} equals 250 .

The way in which this would be worked out in long hand is shown in Fig. 16. Note that at least one or more of the steps could be done "mentally".

EXAMPLE NO. 2

For a second division problem, we will assume that it is desired to find the wave-length of a radio wave having a frequency of 20,000,000 cycles (20 megacycles). Recalling that our velocity is always constant at 300,000,000 meters per second, we know that our problem is merely a matter of dividing 300,000,000 by 20,000,000. Accordingly, let's solve this with the aid of exponents, in step-by-step procedure:

STEP #1:

$$\frac{300,000,000}{20,000,000} = \frac{3 \times 10^8}{2 \times 10^7}$$

STEP #2:

$$\frac{3}{2} = 1.5$$

STEP #3:

The power of ten expression (10^7) below the line is brought to a position above the line, changing it to a negative exponent in the process. Thus, at this stage of solution, the problem looks like this:

$$\frac{3 \times 10^8 \times 10^{-7}}{2 \times \cancel{10^7}} = 1.5$$

Subtracting the smaller exponent ($^-7$) from the larger, and taking the sign of the larger as explained before, we find that our final exponent has a value of ^{1} and is positive. Thus, our answer is:

$$\frac{3 \times 10^8 \times 10^{-7}}{2 \times \cancel{10^7}} = 1.5 \times 10^1$$

Proceeding one step further, we find that our answer of 1.5×10^1 when carried out to its full arithmetical value, equals 15 meters.

PROBLEM:	Frequency equals 20,000,000 cycles (20 megacycles). Find wavelength in meters.	
STEP #1:	$\lambda = \frac{300,000,000}{20,000,000}$	(Set up in original "long" form)
STEP #2:	$= \frac{3 \times 10^8}{2 \times 10^7}$	(Set up with power of ten to shorten).
STEP #3:	$\frac{3}{2} = 1.5$	(Done mentally)
STEP #4:	$\frac{10^8 \times 10^{-7}}{\cancel{10^7}} = 10^1$	(Done mentally)
STEP #5:	1.5×10^1 meters	(Answer with power of ten notation).
STEP #6:	= 15 meters	(Answer without power of ten notation).

Fig. 17
Solving Another Problem in Division, Using Power of Ten Notation

You have thus been given the formal instructions for working this type of problem. Naturally, if the average technician were working a practical problem of this nature, he would do as little actual formal mathematical work as possible, and would perform many of the operations "mentally" without taking the time to jot them on paper.

Fig. 17 shows you a manner in which this could be done in about 6 steps---at least two of them being "mental steps," without the need of "paper work." While the individual operations performed in the numbered steps in Fig. 17 do not correspond exactly with the operations performed in steps of the same number in the Lesson text, they are equally permissible; and the resultant answer will be the same in each instance.

NOTE: WHEN WORKING PROBLEMS, IT WILL NEARLY ALWAYS BE MORE CONVENIENT IF POWER OF TEN NOTATIONS INVOLVING MULTIPLES OR SUB-MULTIPLES OF TEN ARE WRITTEN WITH THE 1 INCLUDED.

For example, if you were required to divide 10^4 by 2×10^{-2}, and wrote the problem like this:

$$\frac{10^4}{2 \times 10^{-2}}$$

you would have nothing to divide the 2 into. But if you write it like this:

$$\frac{1 \times 10^4}{2 \times 10^{-2}}$$

then you can divide 1 by the 2 so that the problem works out like this:

$$\frac{1 \times 10^4}{2 \times 10^{-2}} = \frac{\overset{.5}{\cancel{1}} \times 10^4 \times 10^2}{\cancel{2} \times \cancel{10^{-2}}} = .5 \times 10^6 = 500,000$$

PRACTICE EXERCISES

Typical examples of division problems are shown in Fig. 18. You are requested to work these out; getting the answer in its "short" form and then comparing your answer with the Correct Answers at the bottom of the illustration.

Complex Problems
Involving Both Division And Multiplication

Here are some suggestions on working problems of a more complex nature, such as those which involve both division and multiplication. As an example, we will take:

$$\frac{0.000644 \times 96,000 \times 3300}{161,000 \times 0.00000120} = ?$$

First, convert all values in the problem to values between 1 and 10, times their proper power of 10, thus:

$0.000644 = 6.44 \times 10^{-4}$

$96,000 = 9.6 \times 10^4$

$3300 = 3.3 \times 10^3$

$161,000 = 1.61 \times 10^5$

$0.00000120 = 1.2 \times 10^{-6}$

In setting these "shortened" values up, we will again make use of our imaginary line, and will set up all of the factors of the multiplication and division part of our problem to the

(A)	$63,000,000 \div 9,000$	=
(B)	$2,800 \div .0001$	=
(C)	$.0015 \div .00025$	=
(D)	$8 \times 10^3 \div 4 \times 10^2$	=
(E)	$8 \times 10^3 \div 4 \times 10^{-2}$	=
(F)	$8 \times 10^{-3} \div 4 \times 10^{-2}$	=
(G)	$16,000 \div .016$	=
(H)	$.016 \div 16,000$	=
(I)	$500,000,000,000 \div 25,000$	=
(J)	$25,000 \div 500,000,000,000$	=

ANSWERS:

(A) $.7 \times 10^4$; (B) 2.8×10^7; (C) $.6 \times 10^1$; (D) 2×10^1; (E) 2×10^5; (F) 2×10^{-1}; (G) 1×10^6 OR JUST 10^6; (H) 1×10^{-6} OR JUST 10^{-6}; (I) 2×10^7; (J) 5×10^{-8}.

FIG. 18
DIVISION-----PRACTICE PROBLEMS

left of this imaginary line, and all of the powers of ten to the right, like this:

Imaginary line

$$\frac{6.44 \times 9.6 \times 3.3}{1.2 \times 1.61} \;\Big|\; \frac{\times\ 10^{-4} \times 10^{4} \times 10^{3}}{\times\ 10^{-6} \times 10^{5}}$$

Note that in setting it up on this manner, everything to the left of the imaginary line consists of straight multiplication and division, while everything to the right consists of the "decimal point location" part of the problem.

In dividing and multiplying, we use cross multiplication or cancellation wherever and whenever possible. Thus, in this example, inspection shows that the only initial cancellation possible is that of 1.61 and 6.44 . Thus, we divide 6.44 by 1.61 to obtain 4.

Inspection then shows that no other cancellation is possible at this point. Accordingly, we begin to multiply the factors above the line, starting at the left and multiplying 4 by 9.6 to obtain 38.4 .

Further inspection shows that another cancellation is now possible, so 38.4 is divided by 1.2 to obtain 32.

No further cancellation being possible, we multiply 32 by 3.3 to obtain a final value of 105.6, with our problem looking like this:

$$\frac{\overset{4}{\cancel{6.44}} \times \overset{\overset{32}{\cancel{38.4}}}{\cancel{9.6}} \times 3.3}{\cancel{1.2} \quad \cancel{1.61}} \times \frac{10^{-4} \times 10^{4} \times 10^{3}}{10^{-6} \times 10^{5}} = 105.6$$

It only remains to find the answer to the "right" half of the problem, or to determine the sign and value of the final exponent. To do this, we move the exponents below the line to positions above the line, changing their signs as we do so. Thus, the exponents which were $^{-6}$ and ^{5} when below the line, become ^{6} and $^{-5}$, when moved above the line. After these exponents have been moved, the "right" half of our problem looks like this:

$$\frac{10^{-4} \times 10^{4} \times 10^{3} \times 10^{6} \times 10^{-5}}{\cancel{10}^{-6} \times \cancel{10}^{5}}$$

Proceeding, we add all of the positive exponents like this:

$$10^{4+3+6} = 10^{13}$$

Now, we add all of the negative exponents like this:

$$10^{(-4)+(-5)} = 10^{-9}$$

Then we subtract the smaller exponent from the larger exponent like this:

$$10^{13-9} = 10^{4}$$

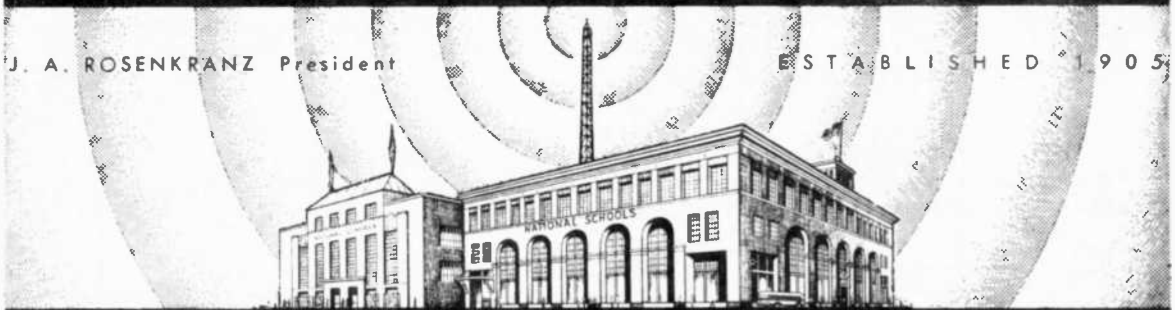
Thus, 10^4 is the value of our final power of ten; and since the larger exponent in the above subtraction (^{13}) was positive, our final exponent is also positive. (Note: Had the larger exponent been negative, then our final exponent would also have been negative).

Therefore, our answer to this problem is 105.6×10^4.

If it were desired to express the answer without the power of ten notation, then 105.6×10^4 would equal 1,056,000 .

Practical Technical Training In
RADIO·TELEVISION
AND ALLIED ELECTRONICS

J. A. ROSENKRANZ President ESTABLISHED 1905



NATIONAL SCHOOLS • LOS ANGELES 37, CALIF.

BUSINESS LESSON #1

HOW TO EARN MONEY IN SPARE-TIME RADIO WORK

Up to this point of your training, you have learned considerably about radio and should by this time have built for yourself a most substantial foundation upon which to plan your future work.

Probably since starting your studies, it appeared as taking you quite awhile until you finally got into the actual practical trouble shooting work;and it is possible that you expected to get into this work sooner. Bear in mind, however, that many years of experience in training men has proved to us that before any man can INTELLIGENTLY perform any kind of service work on even the simplest types of receivers, he must first have a definite amount of technical knowledge to back him up. It is for this reason that we have carefully planned our course of training the way you have found it.

EARN WHILE YOU LEARN

Lessons No. 24 to 32, inclusive, have provided you with much information concerning many different kinds of receiver circuits; and the Manuals have introduced you to service procedures. We urge you to apply this knowledge to practical use immediately for two important reasons: First, it offers you an excellent opportunity for turning your leisure hours into profit. You can still continue with your studies and any other work which you may now be doing to earn a living, and in addition commence earning money on the side through doing radio work among your neighbors, relatives and acquaintances. The second important reason why you should commence doing service work NOW is that through doing so, you will obtain actual PRACTICAL EXPERIENCE working with commercial equipment;and this will in itself be of tremendous value to you. In other words, if you go about this spare-time work in the right way, you will already have a satisfactory amount of experience out in the field by the time you graduate and at the same time be ahead of the game from a financial standpoint.

Furthermore, by breaking into the service game now in a rather small way, you will have the opportunity of contacting a great many people --- all of whom will remain as your steady customers when you finally are prepared to enter the radio business on a larger scale. By starting NOW in your spare time, you should in a few months have all the business you can handle.

You certainly couldn't find a better investment anywhere than honest to goodness radio training which already pays dividends long before you have completed it and which pays for itself so quickly.

GETTING STARTED


Radio Service & Construction Installation of Antennas
Installation, Adjustment & Repair . . all types Receivers

(YOUR NAME HERE)

EXPERT RADIO TECHNICIAN

Endorsed by National Radio & Electrical School
Los Angeles, Calif.

(Your address and phone No. Here) (your city here)

SAMPLE BUSINESS CARD

In order to build up a clientele, the first thing which you will have to do is to let people KNOW that you are in the radio business and qualified to take care of their radio needs. One way of spreading the news is to have some attractive business cards printed, based upon the sample which we are showing you here. These cards are inexpensive and offer a most effective means towards bringing about an introduction between you and your prospective customer.

You can distribute these cards to the homes in your neighborhood, as well as to furnish friends with a supply so that they can in turn distribute them among acquaintances and people whom they contact during their routine of business and social activities.

Another method which will frequently bring results is to canvass the community in person and thus contact the set owner directly.

A simple way to strike up an acquaintance with prospective customers is to take note of all antenna installations in your vicinity --- the majority of them will be crude in construction, inefficient, and thereby offering you an ideal opportunity for engaging the set owner in worthwhile conversation.

Approach the prospective customer in a business-like manner, being certain that your appearance is inviting. Be pleasant and mention the fact that you are actively engaged in the service business in this vicinity and in passing have noticed the appearance of his antenna. Then continue and suggest that you can improve his reception tremendously by installing an efficient antenna system designed especially to best meet his particular requirements.

If he is bothered by interference noises, inform him that you are in a position to clear up the disturbance for him. Tell him about the many features of the static-rejecting antenna systems which were brought to your attention in a previous lesson and explain how his reception will be improved thereby. Let him know that this is something new but backed up by recognized manufacturers and is based upon scientific principles.

Should the set owner reside in a district frequented by electric storms and no lightning arrester is installed in his antenna system, then point out to him the protection which such a unit will afford.

In plain words, the thing for you to do is to CONVINCE the set owner that he needs a first class antenna system and that YOU are the man to do the job.

Having "landed the job", your first step will be to provide yourself with the necessary materials, such as the antenna wire, insulators, lightning arrester, etc., and a complete noise reducing kit if this type of job is sold. All of this equipment can of course be purchased ready for use and it is advisable that you buy it from a large radio supply house whose chief business lies in supplying equipment to the radio trade.

Such concerns are established in all of the larger cities and by making it known to them that you are a radio serviceman, they will allow you an appreciable discount. As a rule, you will be able to purchase your equipment from them at about 40% less than the list price.

Thus you can charge the customer the list price for the equipment and thereby realize a righteously earned 40% from the sale of parts alone. Then in addition, figure your labor charges at an average rate of about $1.00 per hour. So altogether then, you can see that you will make a fair profit on the deal and at the same time be assured of a satisfied customer.

SERVICING RECEIVERS

In the event that a new antenna isn't absolutely essential or you find it impossible to interest the set owner in one, then inquire about the general performance of his set. Perhaps he will complain about weak reception, fading, noisy receptions, lack of selectivity, etc. In fact, if any thing at all is preventing him from enjoying good programs, he won't hesitate to make this fact known,especially so when he has the chance to talk about it to a man whom he is confident of being capable to offer sound advice and assistance.

At any rate. you can offer to check and test his receiver free of charge and honestly advise him as to the receiver's true condition. Then if your inspection thereof should disclose any defects or any form of ofjectionable performance, point out this fact to the owner and explain to him how you can correct the condition.

Quite often, you will come across some minor jobs, such as renewing a connection here or there, installing new tubes, aligning a tuning condenser gang, replacing a noisy volume control or defective switch, etc. All of these are simple jobs but do their part to increase your income, as well as offering you an opportunity to look into all of the different types of commercial receivers so as to familiarize yourself with the many different constructional features incorporated in them.

Whenever you come across a job which requires the removal of the chassis from the cabinet, such as when replacing a transformer, condenser, resistor, etc., then make it a point to take the chassis to your home workshop where you have everything available for doing a first class job. It is never advisable to conduct any form of reconstruction job in the set owner's home for several reasons. (1) All tools etc. are not generally available. (2) There is a possibility of scratching furniture and cluttering up the room with dirt. (3) A partially disassembled receiver doesn't make a favorable impression upon the owner.

Naturally, when you are canvassing a neighborhood in person, you should have your service equipment with you or at least within easy reach so that when you do get a job, you can take care of it immediately instead of stalling off the customer until you get your equipment. Remember that if you keep a customer waiting too long, he is likely to change his mind in the meantime about having the work done.

In the event that you contact the set owner through one of your business cards and he communicates with you by phone, question him concerning the make of his receiver and how it acts. This will enable you to judge what might be wrong before you even see the set, and you can thereby estimate what equipment it will be best for you to take to the job.

INSTALLING RECEIVERS

Many department stores, etc., sell receivers but do not include a radio technician among their employees. They simply sell the set to the customer and let him install it himself as best he can or else expect the driver of the general delivery truck to hook it up for him. In such cases, the antenna generally consists of a piece of hook up wire and sometimes the set isn't even balanced up correctly. The proper use of a long and short antenna terminal is not heeded, etc.

Any new receiver, even though it leaves the factory in perfect condition, is likely to reach the final owner slightly out of adjustment due to shocks received during shipment and it isn't really fair to the final owner if the set isn't first serviced properly before turning it over to him.

Here is another opportunity for you.

The thing for you to do is to contact these concerns which sell radios without offering technical service. Many men have made an agreement with these concerns whereby they take over the responsibility of testing the set before delivery, make any necessary service adjustments and install the set in the new owner's home in expert fashion. For this, they receive a definite fee from the store for each set installed or else the customer is quoted a certain price for the receiver and can at his own choice have the set installed for an additional reasonable fee.

You can do the same thing and many sales organizations will be only too glad to make some such deal with you.

In fact, such an association with any sales organization will place you in an advantageous position to even service receivers sold by them and which develop defects after being in operation for some time. If this happens, it seems to be the natural thing for the set owner to "air his troubles" to the firm from which he purchased the receiver, and the firm can then in turn place the service job in your hands. Such a practice is beneficial to both you and the concern who doesn't have sufficient calls for service work to warrant employing a man solely for this purpose.

Work of this nature is generally handled on a percentage basis in which the service man is given a definite percentage of the money received for the job, the balance being retained by the dealer. In the event that the serviceman sells some additional equipment during a service call, he also receives a percentage from the dealer for his effort.

For most service work, you will generally find it the practice among servicemen to purchase the replacement parts and any other equipment at a 40% discount off the list price and to charge the customer the list price of the unit. For each service call requiring one-half hour of your time, a fee of $1.00 should be satisfactory while labor charges can be figured at the rate of $1.00 per hour.

Naturally, circumstances arise where you may have to adjust the price so as to meet certain special requirements and in this respect you can use your own judgement.

Upon completing a job, always be sure to leave your business card with the set owner upon taking leave. Some servicemen tack their card inside the receiver cabinet so that there will be no possibility of the customer's misplacing it.

If you contact a prospective customer who doesn't require any work at the time, then leave your card with him and tell him that you will appreciate his calling you by telephone when in need of service at any future time.

Adopt the practice of doing your best regardless of how small the job. A satisfied customer will call you again when he needs you and will be more than willing to recommend you to his acquaintances.

Give the customer a SQUARE DEAL, for honesty in service and workmanship always pay bigger dividends in the long run.

Should you be any chance run into a job which you cannot satisfactorily handle, you may feel free to write to us for additional advice. If you do, please give us as much information as possible concerning the job so that we will be better able to give you a most helpful answer.

Naturally, do not deliberately take upon yourself a job of an advanced nature which involves equipment and work about which you have not yet had a chance to study. It is no more than fair that you take this into consideration because you are still in an early stage of your training and must therefore keep your activities in the field within these limits.

EXPERIENCE

Perhaps you intend to ultimately specialize in some branch of this wonderful industry other than radio servicing such as broadcasting, commercial operating, talking pictures, or television. Even if this be the case, you still should make it a point to engage in servicing receivers for the time being at least because of the valuable experience it will give you.

Here is a chance for IMMEDIATE financial returns, whereas you will require considerably more training before becoming qualified to accept a position in the other branches of the industry. Furthermore, the people whom you contact now through service work, may be prospects for a television receiver later on. Then too, some concerns with which you establish dealings now, may be in a position to offer you future opportunities in some other profitable field of radio. You simply must meet these people sometime or other --- so why not now?

Maybe you find yourself in such a fortunate position that you have no special need for spare-time money. Although this may be true, you YOU DO NEED EXPERIENCE, so it is up to you to make the most of the opportunities which we are extending to you in this respect.

The experience which you obtain now will enable my Employment Department to help you more effectively when you graduate. It is for this reason that I want you to mail me a complete report of every Spare-Time Job you do --- describing the job in detail and the price you charged. I expect this report from you and am frank to tell you that all such reports will form a part of my Employment Department records. In this way I can tell at a glance just exactly what practical experience you have acquired during your period of training and can therefore recommend you accordingly to your prospective employer. This is an important matter and I am certain that you realize its value to your self.

When you get a service job, by all means do the work yourself. THIS IS YOUR EXPERIENCE and although you might make a little money on the deal by only "selling the job" and letting someone else do the actual work, yet such a practice would be of no special benefit to you. Remember that we are willing to help you through specific suggestions and advice.

Bear in mind that in this lesson, our suggestions apply particularly to SPARE-TIME work, considering the fact that you are not yet fully trained. However, as you advance with your studies, you will receive additional business suggestions which will assist you materially in conducting a profitable radio business to which you will devote your FULL-TIME.

We hope that you will find the information contained in this special lesson of the business series to be of value to you and that you will take it upon yourself to make the most of your opportunities.