RADIO FUNDAMENTALS

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Radio Library

Vol. I

Radio Fundamentals

ELEMENTS OF
RADIO COMMUNICATION

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SOURCES OF ELECTROMOTIVE FORCE

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PREFACE

The Radio Library is an outgrowth of a large demand on the part of those who are not students of the International Correspondence Schools for an authoritative, comprehensive, and readily understood treatise on radio communication. It consists of five volumes each of which is a distinct and complete treatise on the subject or subjects under consideration. Volume I, entitled Radio Fundamentals, consists of two chapters, one on Elements of Radio Communication and the other on Sources of Electromotive Force. Volume II contains instruction on Radio Tubes and Antennas. Volume III, on Radio Transmitters and Carrier Currents; Volume IV, on Radio Receivers and Servicing; and Volume V, on Radio Measurements.

Radio Fundamentals serves as a review of electrical principles, a knowledge of which is necessary for a thorough understanding of radio communication. This volume contains a chapter on the Elements of Radio Communication by H. F. Dart, and a chapter on the Sources of Electromotive Force by A. G. Zimmerman and C. H. Vose.

The original manuscripts were edited by J. F. Witkowski, Principal of our School of Telephony, Telegraphy, and Radio, with the cooperation and under the supervision of Francis H. Doane, Director of our Electrical Schools.

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RADIO WAVES

INTRODUCTION

The term radio communication is applied to communication employing electromagnetic waves, or currents, at radio frequencies. The range of frequencies employed in radio is very large, and starts with a high frequency of something over 300,000,000 cycles, or current changes per second. The wave band covers all frequencies down to about a practical limit of 20,000 cycles per second. The frequencies just mentioned represent a range that may be easily radiated or sent out by a suitable radiating, or antenna, system. The usefulness of the band is somewhat limited by, or dependent on, the generating equipment, interference, service, and various intervening conditions as well as by the receiving apparatus.

ETHER

The transfer of radio energy takes place through a medium called the *ether*. This medium, which forms an important element in radio discussions, is a convenient name applied to a medium supposed to permeate all matter and which is used as a basis for explaining many radio, light, and other energy-transfer phenomena. This ether, if it exists at all, and some claim it does not, does not affect any of the senses of man directly. The ether acts, in a modified way, like a highly developed means of transportation in that it carries minute parcels of energy through long or short distances, and does not change the main characteristic of that energy, namely, its signal individuality.

RECEIVED SIGNAL STRENGTH

The transfer of energy from point to point, does diminish the amount of energy delivered, as the energy is divided up and made available simultaneously at a constantly increasing number of places. The radio energy decreases very rapidly as the distance between the transmitter and receiver stations increases. Expressed as a formula, the amount of current picked up at any point by a simple flat-top antenna from one of similar general design would be

$$I_r = \frac{188 h_s h_r I_s}{R \lambda d}$$

in which I_r = current in receiving antenna, in amperes;
h_s = effective height of sending antenna, in meters;
h_r = effective height of receiving antenna, in meters;
I_s = current in sending antenna, in amperes;
R = resistance of receiving antenna, in ohms;
λ = wave length of signal, in meters;
d = distance between the two antennas, in meters.

This formula should have a correction factor applied when the transmission is for long distances and particularly if the path lies over a surface that absorbs some of the energy.

RATE OF TRAVEL

Radio waves are carried by the ether, or some other means, with the speed of light, namely, at approximately 186,000 miles, or 300,000,000 meters, per second. So far as distances on the earth are concerned, the rate of travel may be considered as instantaneous. There is no appreciable time error, therefore, in making clock settings from signals transmitted by stations even thousands of miles away. The rate of signal transmission between radio stations, is also not limited by the connecting medium, but rather by the sending and receiving equipment. Great strides have been made in the mechanical and electrical development of such apparatus, but further progress is undoubtedly possible.

CHARACTERISTICS OF RADIO WAVES

The basic principle of radio communication, so far as the connecting medium is concerned, is that electrical energy is radiated into and conducted through the ether. This electrical current is alternating or reversing, just like that in most house-lighting systems, except at a much higher rate or frequency. The radio frequency current or signal is modulated, or modified, at the sending station so as to possess the desired telegraph or telephone characteristic which gives that signal its individuality. So far as is known the ether does not alter the signal's characteristic except to diminish its amount or strength as the distance traveled increases. The fact that the signal is not essentially altered by distance is a very desirable characteristic, as it means that communication will be possible over relatively long distances with as good results as over much shorter distances, so far as the quality of the signal is concerned. This, of course, is dependent on other factors, such as interference and the ability of the receiving set to convert the signal into sound without introducing distortion.

Radio waves may be compared, to use the often quoted example, with waves on the surface of water. The surface is normally quiet until some energy is expended and transferred to the water. A dropping stone possesses considerable energy, due to its motion, some of which is used in displacing and disturbing the water. This disturbance causes circular waves to be formed, which gradually travel out from the center of the disturbance. To an observer the waves seem to travel rather slowly, and in fact they are relatively slow when compared with radio waves in the ether. The waves also appear to diminish in size or height as they travel from the center point. The most important reasons are that the wave front is extending over a rapidly increasing area and there is some energy expended in moving the water into the different positions that it assumes during the progress of the waves.

Radio waves travel through the ether in just the same manner as do the waves over the surface of the water; that is, at the transmitting station disturbances are produced and these travel outward in ever enlarging circles. These radio waves will cause radio-frequency currents in many antennas as the waves advance, just as water waves will cause any leaves floating on the surface of the water to move as they receive and use energy from the expanding rings. The energy in the radio wave at any one point and instant is less than that at a previous position for two reasons. The wave extends over a larger front as it expands, and energy is constantly used up in agitating the conducting medium.

FUNDAMENTALS OF ANTENNAS

An antenna is a conducting network used for sending out or receiving radio waves. When used for sending, the antenna receives the energy from the station and radiates, or throws out, this energy into the ether, or surrounding space, in the form of radio waves. These waves, in their travel through space, strike various receiving antennas and other metallic objects. If these have the proper electrical characteristics, energy variations similar to those in the transmitting antenna are induced in them. The energy induced in the receiving antenna is much less than that in the transmitting antenna, but it possesses all the other characteristics necessary for the proper reproduction of the signal.

By making the transmitting and especially the receiving antenna of special sizes and shapes its effectiveness for certain purposes may be greatly improved. That is, a beam-type transmitter and a wave-length receiver antenna will be much more effective than those not specially designed for efficient communication. These and other points are considered in detail in a later section.

STATIC ELECTRICITY

ELECTRICAL PRINCIPLES

Among the many fundamental principles of radio communication, or those that affect it, are several important essential principles of the broad field of electrical engineering. For a complete understanding of radio it is necessary to consider some of the electrical phenomena that affect radio either directly or indirectly. Some of these go back as far as the elements of matter for a satisfactory explanation. Even then it is often necessary to make speculative guesses, or theories, as to what actually occurs and the means or methods that are employed to make them useful.

Electricity is often considered as a motion of particles of matter. This will be more apparent from a consideration of the elements of matter in a succeeding paragraph. Electricity has never been seen by any one; even an electric spark must have air or other particles of matter as a conveyer. Electricity makes itself known by the effects it produces, or the work it does. By these same means its characteristics are determined with a great degree of precision.

ELECTRICAL CHARGES

Electric charges form a good illustration of a basic principle common to both electrical and radio phenomena. A strip or rod of hard rubber that has been rubbed over a woolen cloth a few times will pick up small pieces of paper from a table top. By a rearrangement of its minute parts or electrons, the hard rubber has accumulated a charge that causes it to attract the elements of the piece of paper with enough force to lift the paper. In becoming electrified the rod has taken on a charge defined as negative, whereas that on the wool is positive. A glass rod rubbed with silk also becomes charged, but here the rod is charged positively and the piece of silk with which it was rubbed is negatively charged.

A small pith ball suspended by a short piece of string will illustrate the laws of static electricity. Suppose the positively charged glass rod is brought near the pith ball. The ball will move toward the rod, owing to the strong field around the electrified rod. When the pith ball touches the rod the ball receives a positive charge, and the two bodies instantly repel each other. The light-weight pith ball moves away from the rod, and tends to keep its distance.

If the negatively charged hard-rubber rod is brought into the vicinity of the pith ball, the ball will tend to move toward the rod. Should the pith ball touch the negatively charge rod, the ball would be negatively charged by enough energy coming from the rod to neutralize the positive charge and give the pith ball a negative charge. The pith ball would then be repelled by the hard-rubber rod and attracted by the glass rod. These experiments show that *like electrical charges repel each other, and unlike electrical charges attract each other.*

A very interesting application of the foregoing principles or laws is found in the three-element radio tube. The action of the grid, or control element, which is ordinarily charged negatively, depends on the practical operation of these laws. By this means the negatively charged electrons are readily controlled in all their operating feats. Thus, the more negative the grid the more will the electrons be repelled or diminished. Should the grid become positive it will instantly start collecting the negatively charged electrons, since opposite charges attract each other.

MAGNETISM

One of the earliest electric phenomena noticed and studied was that certain ores had the unique property of attracting ores of various kinds. Also if a piece of this ore were suspended so that it would rotate, it would always aline itself in a north and south direction. This ore was first found in Magnesia, a province of Asia Minor, hence it was called a *magnet,* and the property of this ore was called *magnetism.* Today, such natural magnets are superseded by relatively strong magnets made by magnetizing or energizing special grades of steel made in any desired shape.

The magnet may be a small bar mounted so as to swing or rotate in a horizontal plane. Such a magnet is commonly called a *compass,* and is a very reliable indicator of directions. If free to move, the compass needle will point north or south toward the magnetic poles, which approximately coincide with the geographic poles of the earth. The pole that points north, or is north-seeking, is arbitrarily called the *north pole;* and, similarly, the opposite, or south-seeking pole, is called the *south pole.*

A fundamental fact, or so-called law, that applies to magnets is, that *unlike magnetic poles always attract,* and *like magnetic poles always repel.* If a bar magnet whose north and south poles have been determined by reference to the earth's magnetism, is brought close to a compass, the foregoing law may be demonstrated. The north pole of the bar magnet will repel the north pole of the compass needle and cause the compass needle to be deflected. The north pole of the bar magnet will, however, offer considerable attraction for the south pole of the compass and draw that pole closer. It is of interest to note that the magnetic pole near the geographic north pole is a south magnetic pole, as it attracts the north magnetic pole of a compass. Popular usage, however, has given the name of north pole to this magnetic pole of the earth and its name is not likely to be changed.

Iron and steel products and, to some extent, nickel and cobalt, are the only materials affected by magnetism. A piece of soft iron will become magnetized if brought into contact with, or even close to, a strong permanent magnet. A magnet that holds its magnetism indefinitely is called a *permanent magnet* and is generally made of a high grade of hard steel. The soft iron previously mentioned is a *temporary magnet,* as its magnetic property lasts only so long as it is under the influence of the permanent magnet.

One of the main properties of a magnet is its ability to attract iron and steel objects and to hold them with considerable force. This principle is made use of in many ways in the commercial field.

Magnetism itself is a force imperceptible to man except by its effects on magnetic materials. A very small compass such as is shown in Fig. 1, held near a bar magnet tends to show that the attracting or pulling force seems to converge or concentrate at points near the ends of the bar. The magnetic force is sometimes represented by lines that are pictured as continuous from pole to pole outside the magnet, as illustrated beside the magnet in Fig. 1. These are useful in determining the path or way the magnetism passes from one pole to the other. The paths or lines could be obtained by determining the directions shown by a very small compass in various positions in the vicinity of the poles. The space through which magnetism acts is commonly called the *field* or *magnetic field* of a magnet.

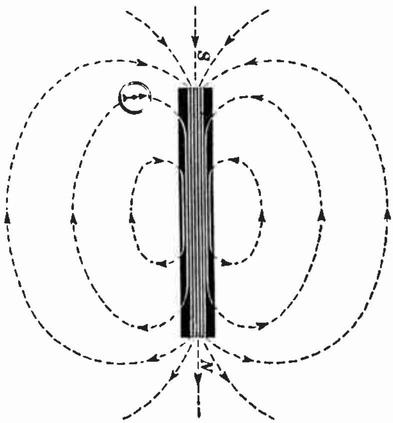


FIG. 1

Magnetism is supposed to affect the material by causing the particles, called *molecules*, to aline themselves in regular fashion so that their individual magnetic effects act in unison. They are normally arranged promiscuously so that they tend to neutralize one another and have no appreciable external magnetic effect. Under the influence of a strong magnet these particles take regular positions so as to combine to produce a strong magnetic effect. Curiously enough, the strength of a magnet of good material decreases very slowly. Permanent magnets that have been carefully handled should keep their magnetic property for years.

DYNAMIC ELECTRICITY

MANIFESTATIONS OF ELECTRICITY

Electric currents are generally thought of as electricity in motion or electric charges in motion as contrasted with static electricity, which is electric charges at rest. Electricity in motion, as an electric current, is a very useful servant of man. Electricity in some form or another is at the bottom of many radio phenomena, and much radio theory is based on electrical laws and principles.

Electricity probably first manifested itself in the spectacular lightning flash. However, the passage of electricity is just as definite in the smaller spark from a man-made source. In any case, the electricity itself is not seen, but what is observed is incandescence caused by the violent agitation of air or other particles in the path. Such manifestations are generally caused by very high electrical pressures, and as such, can produce a great effect on living cells.

The presence of an electric current may also be noted or detected by the magnetic field produced around the wire that carries the current. This magnetic effect or force may be noticed for some little distance by a small compass or other type of magnetic system. This effect is similar to the field around a magnet, and possesses many similar characteristics, as well as some individual ones. This magnetic field is employed in many electrical machines as an active agent in converting electrical energy into mechanical energy, and vice versa.

Another way in which the presence of an electric current may be detected is to note the heat released. Energy is used up in sending an electric current through any material. Some materials will not carry much electricity readily, as will be found later. This energy, sometimes useful, but often detrimental or wasteful, is a manifestation of the presence of electricity, and is, to some degree of accuracy, an indication of the strength of the current.

The foregoing description of the manifestations of electricity constitutes practically the only definition that is known. In a thorough study of electric currents, or electricity in motion, it is necessary to consider the ways in which they behave or act under various influences. By one or another of the preceding methods the laws applying to electric currents are very thoroughly understood and defined.

ELECTRON THEORY

Molecules and Atoms.—In the division of matter a certain limit is reached when the substance that is being divided can undergo no further reduction without changing its identity. The smallest particle of water, if reduced sufficiently, would change the water particle into its component gases, namely, hydrogen and oxygen. The ultimate divisions of any matter not affecting its identity is called a *molecule.* The constituent parts of a molecule are called *atoms.* The water molecule consists of two atoms of hydrogen and one atom of oxygen.

There are about ninety different kinds of atoms in the composition of all matter. The material resulting from any given combination of atoms depends on the relative number of the different kinds of atoms entering into its composition.

Parts of Atom.—Science has found a way of dividing the atom into smaller parts. These are very minute particles of positive and negative electricity. The positive particles are called *protons*, and the negative particles are called *electrons*. Every atom consists of a certain number of electrons and an equal number of protons. The protons of an atom are concentrated in a small *nucleus*, which is held together by some of the electrons. Practically the entire mass of the atom is contained in the nucleus, around which are scattered the additional electrons that render the atom electrically neutral.

The atom of hydrogen (gas) is made up of one proton and one electron. The atoms of other elements are more complex and consist of protons and electrons in complex arrangements. The minuteness of these parts may be realized when the hydrogen atom has a mass of $\frac{1.662}{10^{24}}$ gram. One pound equals 435.59 grams. Most of the weight of the hydrogen atom is due to the nucleus, as one electron weighs only $\frac{1}{1,850}$ part as much as an atom of hydrogen. The electron is so small in weight as compared with the nucleus or the atom's weight that it is often considered as not possessing any weight. The dimensions of these parts of atoms and the spaces they occupy are correspondingly minute. The diameter of the hydrogen atom is about $\frac{1}{300,000,000}$ of an inch, which illustrates the fact that individual atoms are invisible.

Electrons represent a force that is a certain amount or charge of negative electricity. All electrons possess the same amount of negative electricity, namely, the smallest amount that can exist. The nucleus always has a certain number of associated electrons, which number is different for each kind of material or element. In order to maintain its characteristics the nucleus must have a positive charge just sufficient to hold the necessary number of electrons, no more and no less. The atom in its normal state has equal amounts of negative electricity, as represented by the electron charges, and positive electricity, as held by the nucleus. The atom, therefore, does not exhibit any electrified condition.

An electron may become detached from its nucleus or atom, owing to increased agitation caused by heat or other agencies. The atom will then be left with a positive charge, and will attempt to collect any electron that may come within the field of its influence. The electron that is intercepted will attach itself to the system and a stable condition will be restored once more. The negatively charge electron that left the original atom will wander around until it comes within the positive field of either the parent or another atom and attaches itself thereto.

ELECTRIC CURRENTS

Electron Movement.—Electric currents are the result of movements of electrons. As has been mentioned, each electron possesses a certain minute amount of electricity. If these electrons are placed under the influence of an electric potential they may be made to move very rapidly, and combine to transfer considerable amounts of energy. Naturally it requires a stupendous number of electrons to produce an easily observable effect.

The transfer of energy as represented by the electron stream acting under the influence of an electric force or potential is called an *electric current.* The particles of the material carrying this electron current are in particularly rapid motion so as to transfer the electrical energy. The motion of the individual electrons is partly migratory, along the path, and partly oscillatory, with the electrons partly carrying the current and partly handing it on to their neighbors. Electrons in motion, therefore, constitute a flow of electric current.

Voltage.—The difference of potential, or electrical pressure producing the electric current, is commonly called the *voltage.* The voltage has two signs or terminals, namely, *positive* and *negative.* In order to be consistent and uniform, it has been assumed that the current as represented by the movement of electrons, is from positive to negative. The vacuum tube has shown, in its case at least, that the electrons actually travel from a point of negative potential toward one of positive potential. However, the conception that electricity flows from positive to negative is commonly used.

Direct Current.—A *direct current* is an electric current that maintains one direction of flow. The value of the current may be perfectly steady or may have some ripple, but must be unvarying in direction. Such energy would come from a battery or from suitable electrical machinery. The designation direct current is often abbreviated to the initials *d.c.* A machine giving a direct-current output would then be called a d.-c. machine.

Alternating Current.—An *alternating current* is an electric current that continually reverses its direction of flow. Although the alternations are actually caused by reversals in the voltage the identifying term is commonly applied to the current characteristic. Thus an alternating flow of electrical energy would be called an alternating current, which may be abbreviated to *a.c.* The alternations in current usually occur at regular periodic intervals, but this is not a limiting requirement.

The curve of an alternating current is shown in Fig. 2. The straight line *ab* represents the reference, or zero, current line. The curved line shows the current at various instants, sometimes flowing in one direction and part of the time in the opposite direction as indicated by the curved line first on one side and then on the other side of the reference line. Thus the current might increase from point *a* to the value represented by the distance *cd*. It would then decrease to point *e* and increase in the opposite direction to an equal value as indicated by the distance *fg*. The current would next decrease to point *h* and become zero again. In actual practice this curve, or actually the current, would continue indefinitely through other changes as points *i* and *j*.

One complete positive and negative series of events constitute a *cycle*. This might comprise the portion of the

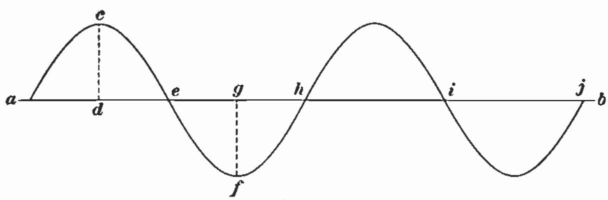


FIG. 2

curve between points *a* and *h* or it might start at, say, point *c* and continue through one full set of values to the corresponding point on the succeeding positive section. The number of cycles per second constitutes the *frequency* of an alternating current or voltage. In some phases of radio work, frequencies of the order of thousands and even millions of cycles per second are encountered. The unit, *kilocycle*, may be used, with the kilocycle defined as 1,000 cycles per second. For still higher frequencies the *megacycle* may serve, and this equals 1,000,000 cycles per second. That is, a current of 3,000,000 cycles per second could be conveniently spoken of as having a frequency of 3 megacycles per second.

CONDUCTORS AND INSULATORS

A current cannot be sent through a material without some opposition. Some materials pass or conduct an electric current quite readily and are commonly classed as conductors. Copper is an example of a good conductor. Other materials offer such high opposition to the passage of electric currents that relatively they are very poor conductors. Such materials are commonly called *insulators*, and are very frequently used to confine electric currents to the desired paths. Air, glass, and porcelain are very good insulators for some types of work, whereas other materials such as mica, oil, and special compounded substances are frequently more suitable for other types of work.

There is no sharp line between the materials classed as conductors and those classed as insulators. For instance, certain gas compounds may serve as a conductor of electricity for some certain purpose, and be considered as an insulator in other cases. Where conductors are desired some of the cheaper metallic materials are commonly selected, whereas for insulators the adaptability of the material is quite as important as the price. In the selection, many other features than those enumerated are generally considered.

ELECTRICAL UNITS

Ampere.—Electricity in motion as electric currents obeys very definite laws. Just as in any other energy transfer, it is convenient to have units for the accurate measurement of the energy. The *ampere* is a unit of current that has been adopted as a standard and is universally used and accepted. For some radio work fractional parts of an ampere are more convenient, such as the *milliampere*, which is one-thousandth part of an ampere, and the *microampere*, which is one-millionth part of an ampere.

The current is commonly read on electrical instruments called *ammeters*. These are made up in different styles and generally depend on the force exerted by the current on a magnetic field to move the indicating needle. Sometimes the expansion in a heated wire is employed to indicate the strength of a current, especially in some phases of radio work. Instruments based on the use of a thermocouple, heated by the current in the main wire, are sometimes used. The voltage generated by the thermocouple affects a measuring instrument the scale of which may be laid out or calibrated to read the milliamperes of current in the main wire. The instrument used to measure these small currents is called a *milliameter*, one of which is shown in Fig. 3. The needle is pivoted on jeweled bearings so that only a very weak current is necessary to produce a deflection. The moving system includes a coil that carries the current to be measured. The electromagnetic field established by this coil acts against a strong field maintained by a permanent magnet mounted inside the protective case. Such instruments may be obtained in various styles of mounting. Instruments for reading other electrical quantities may be obtained with this same size and style of case.

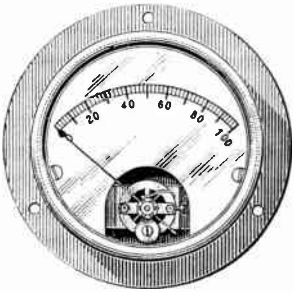


FIG. 3

Ohm.—Electrical resistance is commonly measured in a standardized unit called the *ohm*. This has been standardized as the resistance of a column of mercury of certain definite dimensions. Resistances of 1,000,000 ohms or more are often given the Greek prefix *meg*, meaning a million, and are then expressed as multiples of one *megohm*. The resistance of a circuit may be measured directly by suitable apparatus, but it is more often calculated by the formulas given in succeeding paragraphs.

Volt.—The voltage, or difference of potential, is measured in a unit called the *volt*. It may be defined as the electrical pressure necessary to send a current of one ampere through a resistance of one ohm. The voltage may be read on a *voltmeter* such as is shown in Fig. 4. The one illustrated has two scales with suitable binding posts and internal construction so that voltages over a wide range of values may be read very accurately. A push button is also provided so that the instrument may be connected in the circuit as desired. This instrument has a moving coil, which reacts on the field established by a permanent magnet. The deflection of the coil thus causes the needle to give a reading that is a measure of the applied voltage.

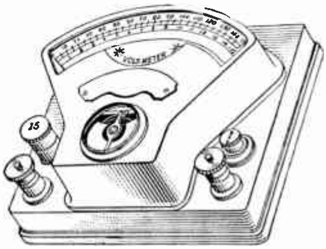


FIG. 4

Watt.—Electrical power is measured in a unit called the *watt*. The power may be considered as the rate at which work is done or used up. It may actually be expressed by two methods, which are, however, related mathematically.

$$P = EI \text{ or } P = I^2R$$

in which
P = power, in watts;
E = potential, in volts;
I = current, in amperes;
R = resistance, in ohms.

With a current I of 1 ampere and a potential E of 5 volts, the power P will be

$$P = EI = 1 \times 5 = 5 \text{ watts}$$

Or suppose a current I of 5 amperes is sent through a resistance R of 6 ohms. The second formula will give

$$P = I^2R = 5^2 \times 6 = 5 \times 5 \times 6 = 150$$

the rate, in watts, at which energy is expended in the resistance unit.

The power passing a certain given point in a circuit may be measured by means of a *wattmeter*. Such an electric instrument has potential and current connections and may be calibrated to read directly in watts.

Where relatively large amounts of power are involved it is convenient to refer to a larger unit of power, namely, the *kilowatt*, which equals 1,000 watts. The power in watts may be calculated in the usual manner, and the result divided by 1,000 to give the answer in kilowatts. The term kilowatt may be abbreviated to *kw*.

Some types of electrical apparatus, as used with alternating-current circuits, may produce effects so that the preceding formula for power is not correct.

Coulomb and Joule—Another electrical unit and one that is not used so very often, is the coulomb. A *coulomb* is the quantity of electrical energy transferred in one second by a current of one ampere. Still another useful unit is the joule as a measure of work. A *joule* is the amount of work done in one second by a current of one ampere in a resistance of one ohm.

ELECTRIC CIRCUITS

TYPES OF CIRCUITS

An *electric circuit* is considered as a system of interconnected paths for the passage of electric currents. The circuit or path usually comprises one or more sources of electricity, as batteries, apparatus or equipment to which the energy is supplied, and a suitable system of interconnecting conductors or wires.

A *series circuit* is one in which the electric current passes first through one device or part of the circuit and then on through the remainder of the parts of the circuit in succession. Two devices, or parts of a circuit, are said to be connected *in series* when all the current that passes through the one passes through the other. Two devices, or parts of a circuit are *in parallel* when the current divides, part passing through each device or part of the circuit. Within reasonable limits any number of devices may be connected in either a series or parallel arrangement or as a combination of these two systems of connection.

Voltages in series add; that is, they all combine and add together to give a higher voltage. The resultant voltage E_R will be the sum of the individual voltages E_1, E_2, E_3 and so forth. That is

$$E_R = E_1 + E_2 + E_3$$

With three 1.5-volt dry cells in series the total voltage will be $E_R = 1.5 + 1.5 + 1.5 = 4.5$ as the total available potential. This law holds, whether the voltages are equal or not. Several voltages, or rather sources of voltage, in parallel do not change the effective or line voltage, but merely reduce the energy drain of each unit.

OHM S LAW

Ohm's law gives the relation between the voltage, the current, and the resistance in a direct-current circuit. If any two of these values are known, the third is found by solving the simple equation of their relation. This law expressed in the form of equations is as follows

$$I=\frac{E}{R}$$

$$E=IR$$

$$R=\frac{E}{I}$$

in which I = current, in amperes;
E = electromotive force, in volts;
R = resistance, in ohms.

These equations show that as the voltage is increased the current is increased by a proportionate amount. Similarly, as the resistance is decreased the current is increased by a proportionate amount.

EXAMPLE 1.—Suppose it is desired to find the current sent through a 5-ohm resistance by a 10-volt battery. The problem is to find the current I when the voltage $E=10$ and the resistance $R=5$ is known.

SOLUTION.— $I=\frac{E}{R}=\frac{10}{5}=2$, or the resulting current will have a value of 2 amperes. Ans.

EXAMPLE 2.—With a resistance of 275 ohms what voltage will be required to produce a current of .4 ampere?

SOLUTION.—The unknown voltage E may be calculated from the known resistance $R=275$ and the required current $I=.4$ by Ohm's law in the form $E=IR=275\times.4=110$, which value is 110 volts. Ans.

EXAMPLE 3.—With a 6-volt storage battery, what resistance is necessary to insert in the line to a tube that takes .25 ampere at 5 volts?

SOLUTION.—Here the voltage is the difference between 6 and 5, or $E=6-5$, and the other known value is the current $I=.25$, while the resistance R may be found by $R=\frac{E}{I}=\frac{6-5}{.25}=\frac{1}{.25}=4.$

The necessary resistance is 4 ohms. Ans.

Resistances in series add; that is, resistances in series combined in their effect to oppose the passage of electric currents. The formula to express this effect is very much like that for other similar cases.

$$R_r=R_1+R_2+R_3$$

in which R_r = resultant resistance in ohms
R_1, R_2, and R_3 are the resistances in ohms of the various units. Other resistance units, if such were present, would also be added.

EXAMPLE.—Consider a case with four resistance in series with the following resistances in ohms, 7, 146, 1.5, and 33. Find the total resistance.

SOLUTION.—In the formula this would give $R_r=R_1+R_2+R_3+R_4 =7+146+1.5+33$, or $R_r=187.5$; the total resistance, in ohms, is, therefore, 187.5. Ans.

Resistances in parallel reduce the opposition, or resistance effect, of each unit. This relation may be expressed as formula in the form

$$\frac{1}{R_r}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}$$

in which R_r is the resultant resistance and R_1, R_2, and R_3 represent the individual resistance units that are connected in parallel.

EXAMPLE.—With resistances of 2, 12, and 4 ohms in parallel, what is the resultant resistance?

SOLUTION.— $\frac{1}{R_r}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}=\frac{1}{2}+\frac{1}{12}+\frac{1}{4}$ or

$\frac{1}{R_r}=\frac{10}{12}$; solving this gives $\frac{R_r}{1}=\frac{12}{10}$, or

$R_r=1.2$ the total combined resistance effect of the three resistance units in parallel measured in ohms. Ans.

Many combinations of resistances in various series and parallel assemblies are possible. They may be combined in an almost unlimited number of ways, each to perform some particular function. In calculating the resistance of combinations it is necessary to consider small groups and then use these as units in further calculations.

TEMPERATURE COEFFICIENT OF RESISTANCE

The resistance of a conductor increases as the temperature rises, and decreases as the temperature diminishes. The *temperature coefficient of resistance* of a material expresses this change and may be used in a formula to obtain the resistance at any required temperature.

$$R_t = R_o(1+at)$$

in which R_t = resistance, in ohms, at a desired centigrade temperature;
R_o = resistance, in ohms, at at 0° C;
a = temperature coefficient of resistance;
t = desired centigrade temperature.

The temperature coefficient of resistance or specific resistance for copper is .00427 at 0° C. The values for other materials at 20° C. may be found in another Section.

SKIN EFFECT

The electric field acccompanying an electric current in a conductor takes an appreciable time to establish itself through the body of the conductor. If, as in the case with high radio frequencies, the current reverses in direction before it is completely established through the conductor, only the outer section of the conductor will be effective in carrying current. So far as the radio-frequency current is concerned, the conductor might be a thin hollow tube or pipe, as the inner portion is not effective in carrying its share of the current. The resistance of the conductor is thus apparently increased. The *skin effect* of a conductor is its apparent increase in resistance to high radio-frequency currents.

The skin effect may be greatly reduced by making the conductor out of many strands of fine wire, insulated from each other and woven so that there is a large conducting surface able to carry the radio-frequency current well distributed over a large section.

CONDENSERS

PRINCIPLES OF CONDENSERS

A *condenser* is an electrical device formed by two conductors separated by an insulator. In practice the name condenser is applied to a device made with a relatively high condenser value. The chief characteristic for which a condenser is designed is its ability to store up electrical energy. This ability is commonly termed the *capacity* of a condenser, or more strictly the *capacitance*. Except for incidental circuit losses a condenser may be made to give up all the energy it received and stored. A condenser should be thought of merely as a sort of storage reservoir for electrical energy. The condenser is often employed as a tuning device, but even here it must store the energy for short intervals of time to accomplish the desired result.

The actual storage of energy by a condenser occurs in the insulating material called the *dielectric*. The conducting surfaces are commonly called the *plates*, as they often take that form. A condenser may be made up in the form shown in Fig. 5, with plates *a* and *b* separated by the insulating material, or space, *c*. Connections to the electrical source would be by means of conductors *d* and *e*, one connected to each plate. In order to distribute the electrical energy uniformly the plates should be made of good conducting material. When the condenser is connected across a source of electricity, a potential, or voltage, difference is established between the plates, and the plates become oppositely charged. If the material *c* between the plates were a conductor a definite steady current would be established. With the insulating material, which is a requisite of a condenser, there is a momentary rush of current. The applied voltage will establish this current only until the energy stored in the condenser is of the value determined by the voltage. When the condenser has stored this energy and becomes *charged*, as it is called, the dielectric material is actually under an electrical stress.

SPECIFIC INDUCTIVE CAPACITY

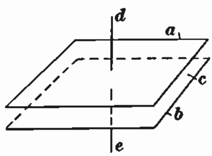


FIG. 5

The capacity of a condenser with dry air as the dielectric is only slightly higher than with a vacuum maintained between the plates. All other insulating materials possess a greater storage capacity than air, other things being equal. It is common practice to refer to the ratio of storage capacity as the *specific inductive capacity*, this being referred to air as 1.0. All other insulator materials have specific inductive capacity values greater than 1, the most common ones ranging from 4 to 8. A table of values for some of the most used dielectric materials is given elsewhere.

FIXED CONDENSERS

The different values of specific inductive capacity indicate that some dielectric materials would make more compact condensers than would others. It is common practice to use these high dielectric materials in condensers whose capacity need not be changed, and which are called *fixed condensers.* There are some other factors that enter into the selection of a dielectric material, especially as made for the commercial field. The dielectric should not be too expensive, should be easy to handle and work to desired size and shape, should resist high-voltage puncture or breakdown, should not be affected by moisture, and should not have high losses. Paper fulfils many requirements and is extensively used in fixed condensers. Mica is more expensive but is the preferred dielectric material. Air for fixed condensers is used only in special cases, owing chiefly to its bulk. Since solid dielectric materials are most common a rigid plate is not required. Copper foil is a very good plate material, since it has good conductivity and occupies little space. Fixed condensers should be solidly assembled and sealed or impregnated so the capacity will remain constant and so there will be no possibility of moisture entering to affect the characteristics.

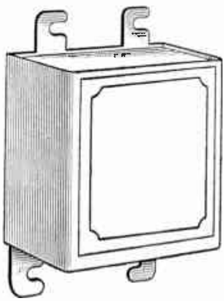


FIG. 6

A commercial fixed condenser embodying many of the principles enumerated above is shown in Fig. 6. The two plates or sides of the condenser end in terminals at the top, to which connections may be made. The lugs at the bottom are suitable for mounting the condenser securely in any convenient position.

VARIABLE CONDENSERS

Condensers whose capacity may be readily changed, are called *variable.* Largely for mechanical reasons, air stands unrivalled as a dielectric material. Variable condensers generally consist of two sets of plates so arranged that one may be moved almost entirely within or outside the field established by the other. Aluminum and brass are both very good plate materials and both are largely used in practice. Care should be taken in design and manufacture to produce a type of construction that will offer a low resistance to the currents while the charge is being distributed over the plates with each reversal of the signal current. A good connection should also be provided between any movable set of plates and its binding post or terminal.

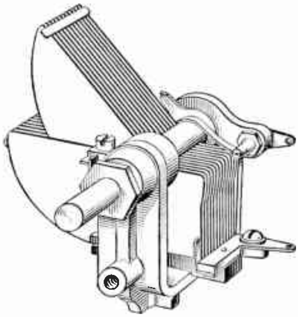


Fig. 7

Extreme care in design is necessary to reduce the losses through the rigid insulating material that supports the movable plates. This support receives the full potential applied across the condenser, and itself acts as a small condenser with its body as a dielectric. It is important that good material be used, and that it be designed so as to introduce as small an effect into the unit as is possible.

Variable condensers may be made in many different styles and shapes. Usually, one set of plates, called the *stator*, is stationary or fixed, while the other, called the *rotor*, is movable. Semicircular plates are most economical of space and material, and are very commonly used. The tuning of a circuit with such a condenser results in a bunching, at the lower condenser settings, of stations equally spaced according to frequency. In order to give equal dial settings on such stations, the rotor or stator plates may be made in special shapes. The construction employed in the variable condenser shown in Fig. 7 gives equal dial spacings for equal frequency tuning changes. Even though the weight is not equally distributed on both sides of the rotor shaft, the difference in weight on opposite sides of the shaft is not so great but that the friction in the bearings or a counterweight may be depended on to hold any desired setting.

CONDENSERS ON DIRECT CURRENT

In the discussion it was stated that the condenser takes current until the dielectric material becomes charged. On a direct-current source, such as from a battery, this is practically the only thing that happens so long as the voltage is maintained constant. There will be a continuous minor supply of current to the condenser to compensate for any leakage or other loss of energy in the condenser. If the current supply is removed the charge will still reside in the condenser. The condenser would retain its charge indefinitely except that with most commercial condensers there is enough leakage to permit the charge to disappear within a few minutes. The condenser may be discharged at once by connecting a heavy wire between the plates. There will be a rush of current as the plates become equal in potential. The energy that was stored in the condenser will all be expended in the wire as resistance loss.

CONDENSERS ON ALTERNATING CURRENT

On alternating current, which constantly reverses, a condenser periodically charges and discharges with each alteration of the current. The condenser will charge in accordance with the polarity of the supply at any one instant. As soon as the next reversal occurs, however, the condenser will first discharge and then assume a charge of the opposite polarity. When the condenser discharges, its energy goes back to the supply line, which, having reversed its polarity, is in a proper condition to receive this energy. The amount of energy returned or discharged to the line is equal to that originally taken as a charge less the circuit and condenser losses. These losses are very apt to increase rapidly with the higher frequencies and to be very important with relatively high-frequency radio signals.

CAPACITY UNITS AND FORMULAS

Farad.—The unit of capacity is the *farad*, which is really a measure of the charge that may be stored in a condenser. A condenser has a capacity of one farad when a potential difference of one volt causes it to have an electrical charge of one coulomb. A condenser with a capacity of one farad would have a monstrous size. A much more convenient and common unit is the *microfarad*, which is one-millionth $\left(\frac{1}{1{,}000{,}000}\right)$ of a farad. Sometimes the *micro-microfarad* is used as a unit, it being one-millionth $\left(\frac{1}{1{,}000{,}000}\right)$ of a microfarad.

Capacity of Two-Plate Condenser.—The capacity of a condenser may be calculated when the dimensions of the plates and the thickness and material of the dielectric are known. For a two-plate condenser the formula is

$$C = .0885\frac{KA}{t}$$

in which C = capacity, in micro-microfarads;
K = specific inductive capacity of dielectric;
A = Area of each plate, in square centimeters;
t = average thickness of dielectric, in centimeters.

A condenser could be made with a mica dielectric which would have a specific inductive capacity, or K, of 6. With 5-centimeter plates the plate area will be $5\times5=25$ square centimeters. A dielectric thickness of .05 centimeter may be used. The capacity of the two-plate condenser will be

$$C=.0885\frac{6\times25}{.05}$$
$$=265.5 \text{ micro-microfarads.}$$

The capacity in microfarads will be one millionth as great; that is, $265.5\div1{,}000{,}000=.0002655$ microfarad.

Capacity of Multiplate Condenser.—A condenser made up of several plates connected in parallel has a large capacity due to the capacity effect between the different sets of plates. For calculating the capacity of such a condenser the formula is

$$C=.0885\frac{KA(N-1)}{t}$$

in which C = capacity, in micro-microfarads;
K = specific inductive capacity;
A = area of each plate, in square centimeters;
N = total number of plates;
t = thickness of the dielectric, in centimeters.

The fact that the part $N-1$ is in marks of parenthesis means that that portion is to be solved first. That is, with a 9-plate condenser and the same dimensions as were used in the preceding case,

$$C=.0885\times\frac{6\times25\times(9-1)}{.05}$$
$$=.0885\times\frac{6\times25\times8}{.05}$$
$$=2{,}124 \text{ micro-microfarads}$$

The capacity in microfarads will be this value divided by 1,000,000 or $2{,}124 \div 1{,}000{,}000 = .002124$ microfarad. This same formula really applies to the preceding example of a two-plate condenser. In that case the number of plates, N, would be 2 and the result would be $2-1$, which would still leave 1. The formula would merely be multiplied by 1, but that would not alter its value in any way.

These formulas may be used to calculate other factors than the capacity if only one term is not known. For example, how large will the plates of a 3-plate mica condenser need to be to have a total capacity of .00025 microfarad, if the mica is .01778 centimeter thick? Substituting the value of 4 for K and the other known values in the formula gives

$$1{,}000{,}000 \times .00025 = .0885 \frac{4 \times (3-1) A}{.01778}$$

$$A = \frac{1{,}000{,}000 \times .00025 \times .01778}{.0885 \times 4 \times 2}$$

$$A = 6.278 \text{ square centimeters.}$$

The area of the plate could be made up by using a plate 2.54 centimeters on each side, the area being $2.54^2 = 6.4516$ square centimeters or 1 square inch, approximately.

Capacity of Condensers with Semicircular Plates. Another capacity formula that is applicable to radio apparatus is the one that permits of the calculation of condensers with semicircular plates. This applies specifically to the various types of variable condensers which are made in a variety of shapes to obtain certain tuning effects.

$$C = .139 \frac{K(N-1)(r_o^2 - r_i^2)}{t}$$

in which C = capacity, in micro-microfarads;
K = specific inductive capacity of main dielectric;
N = total number of plates;
r_o = outside radius of plates, in centimeters;
r_i = inside radius of plates, in centimeters;
t = thickness of the dielectric, in centimeters.

Capacity of Condensers Connected in Parallel.—The capacity values of condensers connected in parallel add to give a resultant capacity equal to the sum of all the individual capacity values. This applies to parallel connected plates mounted in one condenser unit as well as separate condensers. The rule holds with any number of plates connected in parallel, and with both large and small sized condensers. Expressed as a formula this would be

$$C_t = C_1 + C_2 + C_3 + C_4 + \text{etc.}$$

in which C_t = total capacity, in microfarads;
C_1 = capacity of one condenser, in microfarads;
C_2 = capacity of second condenser, in microfarads;
C_3 = capacity of third condenser, in microfarads;
C_4 = capacity of fourth condenser, in microfarads.

If there were only two or three condensers, only that number of terms would be considered. Also, if there were more than four condensers in the group, additional terms would be added or the capacity values could be added directly. The capacity values are all give in microfarads, but any other unit might be used all through, such as micro-microfarads. For instance, two condensers of .00015 and .00575 microfarad connected in parallel will give

$$C_t = .00025 + .00575 = .006 \text{ microfarad.}$$

Capacity of Condensers Connected in Series.—The capacity values of condensers in series act to reduce the total capacity of the whole combination. This may best be expressed as a formula with the same symbols and units as were used in the preceding case.

$$\frac{1}{C_t}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+\frac{1}{C_4}+\text{etc.}$$

Additional terms may be added to this formula if there are more than four condensers in the series, or some may be omitted if the number of condensers is less than four. That is, six condensers, each with a capacity of .00012 microfarad, will give

$$\frac{1}{C_t}=\frac{1}{.00012}+\frac{1}{.00012}+\frac{1}{.00012}+\frac{1}{.00012}+\frac{1}{.00012}+\frac{1}{.00012}$$

$$\frac{1}{C_t}=\frac{6}{.00012}=\frac{1}{.00002}$$

or solving algebraically

$$C_t=.00002 \text{ microfarad.}$$

CONDENSIVE REACTANCE

Like other electrical devices, a condenser offers considerable opposition to the passage of electric currents. This opposition, for a condenser, is termed *condensive reactance*, and may be expressed by a formula

$$X_c=\frac{1}{2\pi fC}$$

in which X_c = condensive reactance, in ohms;
π = constant, or 3.1416;
f = frequency of alternating current, in cycles per second;
C = capacity of condenser, in farads.

This formula shows that the reactance or opposition of a condenser decreases directly as the frequency increases, and that it is smaller, the larger the condenser. Sometimes a high reactance is desirable, but to reduce the reactance it is necessary to increase the capacity of the condenser.

ELECTROMAGNETIC AND INDUCTIVE EFFECTS

ELECTROMAGNETIC FIELDS

An electric current is considered as being established in the body of the conductor. As such it produces certain effects inside the conductor. An electric current is also always accompanied by electric forces that surround the conductor. These forces are of a magnetic nature in that they will act and react with magnets. This force or field, because of its electrical origin, is commonly called *electromagnetic*.

The lines of electromagnetic force surround a single conductor and extend for some distance from the conductor. They diminish in strength rapidly as the distance

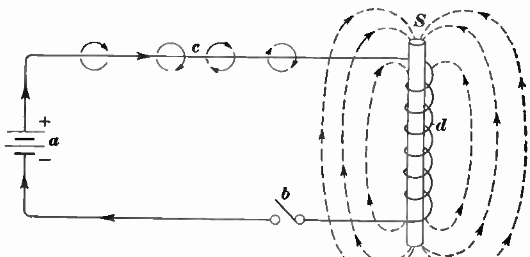


FIG. 8

from the conductor increases. The electromagnetic field may be greatly strengthened by winding several turns of conductor into a coil. The force due to each turn of wire is added to all the others and the several turns in the coil combine to give a relatively strong electromagnetic field. In Fig. 8 the electric circuit is supplied with energy from battery *a*. The switch *b* may be used to close the circuit to establish a current from the positive pole of battery *a* through the straight conductor *c*, the coil *d*, and switch *b* to the negative battery terminal.

As soon as switch *b* is closed the current is established in the circuit and the magnetic field is established uniformly along the conductor. The force around the conductor section *c* is represented by the circular rings enclosing the conductor. The arrowheads indicate the direction of these lines or the direction in which the north pole of a magnet would point. The direction of the lines of force may be determined by grasping the conductor with the right hand, with the thumb pointing in the direction of the current. The fingers will then point in the direction of the lines of force that encompass the conductor. It is well to remember that these lines of force are actually not at all visible. They are merely lines drawn for convenience in studying the fields and forces surrounding conductors. The individual lines of coil *d* have lost their identity and combined to form the larger dotted lines shown linking with that coil. The field would be strongest near the ends of the coil, as is shown by the greater number of lines in those positions, and gradually gets weaker away from those points, as is represented by the greater spacing between the lines.

The number of lines about both *c* and *d*, which lines should be thought of as a measure of the field strength and its direction, will depend on the strength of the electric current. The current, with a given voltage, will depend wholly on the resistance of the circuit. The strength of the field about coil *d* depends on the number of turns of conductor as well as the current strength. Coils made up with an air core are called *solenoids*. When used with an iron core the field is established much more easily and will be much stronger for the same electric current. The form of a coil with an iron core is called an *electromagnet*. Such a device is very frequently used in electrical and radio work because of the ease with which a magnetic field of the desired strength and shape may be established. The field will be removed immediately whenever the electric current is stopped.

INDUCTANCE FIELD

Inductance is the property of a circuit and tends to oppose a change in current in that circuit. Energy is required to establish a magnetic field about a conductor. There is a magnetic stress applied to the material surrounding the conductor, which results in a strained condition that actually stores up the energy. The inductance is the opposing force. The current thus builds up slower than if inductance were not present. After a current is once established and is constant in value the magnetic field remains constant in strength. If the circuit is opened the current tends to die down. The magnetic field now has no force to maintain it, and so collapses almost immediately. The lines of force which expanded from the conductor previously, now contract and finally disappear. However, the energy stored in the magnetic field is nearly all returned to the electric circuit as the field disappears, because of electromotive force established by the lines of force cutting across the conductor. The inductance effect is still responsible, and, by causing the current in the conductor gradually to decrease again, exhibits its property of tending to oppose a change in the current.

INDUCTANCE ON DIRECT CURRENT

An increase or decrease of current in the circuit will increase or decrease, respectively, the strength of the magnetic field. This effect will lag behind the current change and in so doing will tend to prevent the current change. The effect of an inductance coil on a direct current that is just established is to cause the current to increase more gradually than if the coil were not present. The inductance will not affect the steady current value, although the resistance of the conductor will have some effect. The inductance does not take any energy from the circuit after its magnetic field is once established. When the circuit is interrupted the current will decrease and the magnetic field will collapse. The energy stored in the magnetic field will be returned to the circuit in the form of an electric current. If an attempt is made to open the circuit, the energy returned by the inductance may be sufficient to produce an arc across the contact points as they are opened. Then, instead of being returned to the circuit as useful energy, part of the energy of the magnetic field is dissipated as heat in the arc and wasted.

INDUCTANCE ON ALTERNATING CURRENT

On alternating currents the magnetic field constantly reverses periodically with the voltage and current changes. As the voltage increases the current change is opposed by the inductance. Similarly, as the voltage decreases the current change is opposed by the inductance. With special apparatus this effect may be studied as the inductance actually causes the current changes or current wave to lag behind the voltage changes or voltage wave. The relations are such on an alternating-current circuit that the energy stored up in the magnetic field is all returned to the circuit each time the voltage reverses. The inducstance effect of a conductor is greatly increased if it is formed into a coil shape. Another phenomenal increase in the inductance of a coil may be secured by inserting an iron core in the coil. Permalloy, a nickel-steel alloy, as well as compressed pulverized-iron dust are also used as core material in certain electrical and radio coils.

SELF AND MUTUAL INDUCTANCE

The inductance effects that have been described are the result of the flux, or lines of force, upon the conductor that produces them. In a coil, for instance, the lines of force interlink all the turns of wire in that coil. The inductance produced by the action of the electromagnetic field on the coil that produces the field is called the *self-inductance.* Such coils have very extensive use in various phases of radio and electrical work.

The electromagnetic flux from a coil may spread out and interlink a near-by coil as well, such as the part of

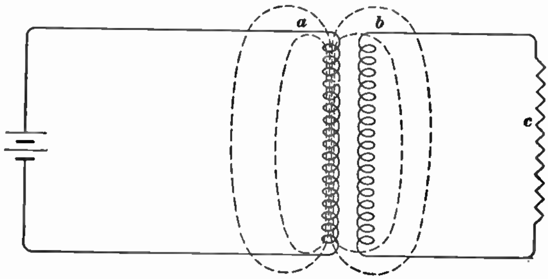


FIG. 9

flux from coil *a*, of Fig. 9, which will link with coil *b*. Some of this flux field will cut the adjacent coil and tend to induce a current in the neighboring coil *b*, which current will become a real transfer of energy and pass through the resistance *c*. The inductance that is due to the flux or effect from another coil is called the *mutual inductance.* Both self-inductance and mutual inductance are alike in principle and produce similar effects.

Transformer action, or the transfer of electric energy from one closed circuit to another is based on the principle of mutual inductance.

UNITS OF INDUCTANCE

Inductance is measured in a unit called the *henry*, and may be expressed in smaller units as the *millihenry* $\left(\frac{1}{1,000}\right.$ henry), which is one one-thousandth of a henry, and the *microhenry* $\left(\frac{1}{1,000,000}\text{ henry}\right)$, which is one one-millionth of a henry. The henry is defined as the inductance of a circuit that induces a voltage of one volt when the current is changed at the rate of one ampere per second.

INDUCTANCE FORMULAS

There are some important fundamental formulas that apply to inductance coils. From these formulas it is possible to see what factors actually influence the inductance of a coil. Such formulas also furnish information for the calculation of the inductance of the coil. Basically, the inductance of a coil is dependent on the amount of flux, the number of turns of the conductor, and the current. Thus, any factor that changes any or all of these factors affects the inductance of a coil.

The inductance of a long coil with an air core may be calculated from its dimensions, which includes the number of turns, by the formula

$$L=\frac{4\pi n^2 A}{10^9 l}$$

in which L = inductance, in henries;

$\pi = 3.1416$;

n = number of turns in the coil;

A = mean area of the coil, in square centimeters;

l = axial length, in centimeters;

The inductance of a long solenoid may also conveniently be expressed as

$$L=\frac{3{,}948 N^2 r^2}{10^{11} l}$$

in which r = radius of the coil, in centimeters, and the other units are as used in the preceding formula.

The following formula may be used where the dimensions r and l are expressed in inches:

$$L=\frac{10{,}028n^2r^2}{10^{11}l}$$

When the length of the coil is not several times the radius of the coil, the following formula may be used:

$$L=\frac{3{,}948n^2r^2}{10^{11}l}K$$

in which the dimensions are in centimeters, with the units as previously given, and K is a value dependent on $\frac{2r}{l}$, which may be obtained from the following table.

TABLE I

VALUES OF K FOR INDUCTANCE FORMULA

$\frac{2r}{l}$	K	$\frac{2r}{l}$	K	$\frac{2r}{l}$	K
.00	1.000	.60	.789	2.0	.526
.05	.979	.65	.775	2.5	.472
.10	.959	.70	.761	3.0	.429
.15	.939	.75	.748	3.5	.394
.20	.920	.80	.735	4.0	.365
.25	.902	.90	.711	4.5	.341
.30	.884	1.00	.688	5.0	.320
.35	.867	1.10	.667	6.0	.285
.40	.850	1.20	.648	7.0	.258
.45	.834	1.40	.612	8.0	.237
.50	.818	1.60	.580	9.0	.219
.55	.803	1.80	.551	10.0	.203

EXAMPLE.—The inductance of a coil of 40 turns 3 inches in diameter and 2 inches long is to be calculated.

SOLUTION.—The inch dimensions can be changed to centimeters by multiplying by the conversion factor 2.54. The radius r is $\frac{1}{2}$ the diameter, or 1.5 inches. The factor $\frac{2r}{l}$ is $\frac{2\times1.5}{2}=1.5$. In the table, K is given for both 1.4 and 1.6 values. The value for 1.5 may be taken as halfway between these two, or as .596.

$$L=\frac{3{,}948\times40^2\times(1.5\times2.54)^2}{10^{11}\times2\times2.54}\times.596$$

$$=.000108 \text{ henry}$$

$$\text{or } L=108 \text{ microhenries.}$$

TYPES OF INDUCTANCE COILS

Inductance coils are made up in many types and forms. In general, inductance coils are air-core coils; that is, they do not have any magnetic material in their fields. Naturally, the prime requisite of an inductance coil is that it shall possess a large amount of inductance. However, it must not introduce other undesirable features, such as high resistance or distributed capacity between the turns of wire. Taps or leads on coils, while very convenient, may be a detriment to the securing of best results.

Inductance coils are often wound on insulating tubing, which acts as a support. This tubing should be rigid, moisture-proof, thin, and good electrically. If it is not good electrically the tubing may introduce losses, which will affect the coil itself. The size of wire is important as affecting the resistance of the coil. The spacing between the turns affects the capacity between those turns, which introduces a capacity effect that must be considered in good design. This spacing is often controlled by the insulation, which should be air, cotton, or silk. Insulating liquids may be used but are not recommended. As the inductance of a single-layer winding is not very great per unit of length such coils must be made awkwardly long to secure the larger inductance values.

Choke coils are simple coils of wire wound on a supporting frame with no magnetic material in the flux field. As such they may be used to block or choke out the passage of high-frequency currents. They do not offer much opposition to the passage of relatively low-frequency currents. An iron core at radio frequencies is not very satisfactory, as its actions are erratic and the iron will not become fully magnetized with each reversal of current.

On relatively low frequencies an iron core is often inserted into the field of the coil. The flux or electromagnetic field will be established through the iron much more easily than through air, and, for the same current strength, the field will be stronger. It takes an appreciable time for this field to be established through the iron core, although actually it is only a very small fraction of a second. The stronger field represents a greater opposition, and a more effective action is secured by the choke coil. Ordinarily, choke coils are used to keep currents of certain frequencies confined to their proper circuits. In the case of a choke-coil amplifier the voltage drop across the coil is made use of in applying a signal change to the succeeding tube.

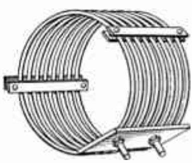


FIG. 10

Coils for the reception of short wave-length, or high-frequency, signals need only a relatively small number of turns of wire. Also, in order to cover a large range of stations, the inherent, or distributed, capacity should be small, which necessitates the spacing of the turns. Fairly heavy wire will give the necessary rigidity to the coil, which may or may not have reinforcing ribs placed lengthwise of the coil. A short-wave coil is illustrated in Fig. 10, and serves as an example of these several features. The coil is equipped with pin-type jacks, which may be used to insert this or other coils readily into the receiving circuit. Sometimes such coils are made with a sort of basket-weave system of winding with thick insulation on the wire. This gives a low distributed capacity and also makes the coil relatively rigid if of large wire. In addition, the turns may be tied with string, where they cross, to secure added rigidity.

Most inductance coils are *fixed*, that is, are not variable. Since it is more convenient to make good variable condensers than variable inductances, tuning of circuits is practically always accomplished with variable condensers. One type of variable inductance, called a *variometer*, has one-half the winding mounted on a rotatable support so its inductive effect may oppose or help that of the other half. Thus a large range of inductance, continuously variable, may be secured. At other times inductance coils are adjustable by means of clip connectors.

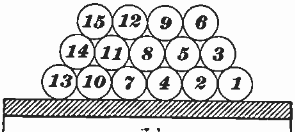


FIG. 11

A *bank winding* is a form of winding in which the turns are banked or piled systematically on top of each other in two, three, or even more layers. A section of a few turns of such a winding is shown in Fig. 11. The numbers inside the circles are the sequential numbers of the winding order; that is, turn 1 is wound first, then turn 2, and turn 3 is then wound on top of, and between, the first two turns. Turns, 4, 5, and 6 are then wound in the order given, then 7, 8, and 9 in their numerical order.

Coils of the *honeycomb* type are multilayer coils formed with a spaced diagonal winding. Adjacent turns do not lie as close to one another as in the preceding types of windings, and hence the distributed capacity is reduced. Such capacity may not be at all objectionable, whereas in other cases it may seriously affect the useful range by limiting the low-wave length tuning. Such a coil is shown in Fig. 12, with its two leads for connection with the circuit. Any liquid binder insulation should be used very sparingly in this or any other type of coil. The honeycomb coils are often mounted on special plugs that serve both as a connection medium and support when plugged into a special receptacle designed for the plugs. A table of inductance values for honeycomb coils is given in another Section.

Spiderweb coils take their name from the general appearance of the winding, which resembles a spider web. As shown by Fig. 13, the coil is wound radially on a wooden spoke form. The turns are well separated in this type of winding and the distributed capacity of such a coil when carefully made will be very satisfactory.

FIG. 12

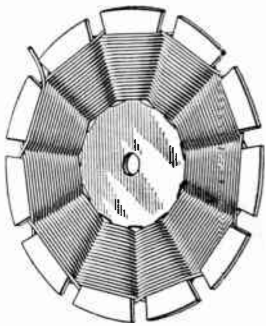


FIG. 13

INDUCTIVE REACTANCE

The inductance of a coil is a property of the coil, and is always a constant value. The opposition of this inductance to the passage of electric currents is called the *inductive reactance.* The inductive reactance of a coil corresponds to a considerable extent with the resistance of a resistance unit or device. The unit of inductive reactance is the ohm. The inductive reactance may be expressed or determined by the formula

$$X_l = 2\pi f L$$

in which X_l = inductive reactance, in ohms;
f = frequency, in cycles per second;
L = inductance, in henries.

When the coil also has an appreciable resistance, as is more usually the case, the total opposition to the passage of an electric current is called the *impedance*. This may be expressed by the formula

$$Z = \sqrt{R^2 + (2\pi f L)^2}$$

in which Z = the impedance, in ohms;
R = the resistance, in ohms; and the other units are as given before.

From the foregoing formulas it may be seen that the higher the frequency the greater will be the reactance of the coil. This is a very important point to remember in dealing with various types of inductance coils. The latter formula also has a term that increases with frequency. If the frequency were zero cycles per second, that is, a direct current, this term would become zero and leave only the resistance term. This is what is found in practice, as then the only opposition offered to a direct current by an inductance coil is that of the resistance, with the exception of the momentary effect noted upon closing or opening the circuit. When considering the effect of inductance coils it is often convenient to divide the resistance and inductance effects into two units and consider that all the inductive effect is localized in one unit and all the resistance effect is concentrated in the other unit.

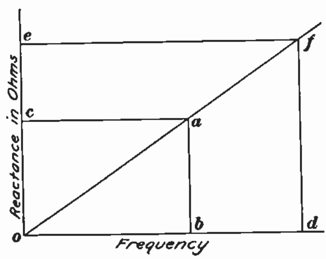


FIG. 14

The manner in which the inductive reactance varies with the frequency may be shown graphically by Fig. 14. The reactance increases directly with the frequency, as was shown by the formula. In the figure the reactance at point *a* for a certain frequency *ob* is represented by the distance *oc*. If the frequency is doubled to point *d* the reactance will also be doubled to the value *oe*, which gives the point *f* on the curve.

OSCILLATORY CIRCUITS

INDUCTIVE AND CAPACITATIVE CIRCUITS

Electric circuits containing an inductance coil and a condenser properly connected have some peculiar phenoena that are of special interest in radio circuits. When the reactive values of these devices are properly related, the circuits, as a whole, possess characteristics different from their properties when other relations obtain. These characteristics are made use of in various ways in the tuning and design of radio circuits. The resistance effect, while not so essential, is a feature of importance and should be considered.

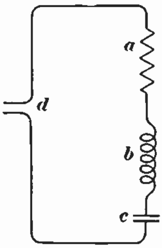


FIG. 15

SERIES RESONANCE

The impedance offered by a circuit to the passage of electric currents includes the opposition of all the devices combined. A circuit made up of three devices in series, as in Fig. 15, with a resistance *a*, an inductance coil *b*, and a condenser *c*, is connected with a source of alternating current at *d*. The total impedance is given by the formula

$$Z=\sqrt{R^2+\left(2\pi fL-\frac{1}{2\pi fC}\right)^2}$$

in which Z = impedance, in ohms;
R = resistance, in ohms;
$\pi = 3.1416$
f = frequency, in cycles per second;
L = inductance, in henries;
C = capacitance, in farads.

Analyzed, this formula is made up of the resistance, the inductive reactance, and the condensive reactance. If the resistance contains any inductance or the coil or condenser possesses any appreciable resistance, these values, if relatively small, may be combined with the main resistance or inductance units for mathematical treatment.

In the preceding formula the inductive reactance term $2\pi fL$ is positive, whereas the capacitative term $\frac{1}{2\pi fC}$ is negative. When these two terms are equal they will counteract each other, leaving only the resistance term. The resistance is then the only factor opposing the current, and the current, when the unit is connected with an alternating-current source, would be theoretically exactly the same as when connected with a direct-current supply source. Actually, if connected with a direct-current circuit the current would cease as soon as the condenser became charged.

When the inductive and capacitative reactances are equal, the current is a maximum, as the total impedance is a minimum. The current is given by the formula

$$I = \frac{E}{Z}$$

in which I = current, in amperes;
E = applied potential, in volts;
Z = impedance, in ohms.

With the impedance a minimum, the current, for any given voltage, will be a maximum. A circuit is said to be in *resonance* when the condition for maximum current is obtained.

The condition of resonance may be shown by curves, as in Fig. 16. Curve *abc* shows the variation of current as the capacity is increased from a low value on through higher values. The largest current at point *b* is secured when the resonance condition is reached at some definite capacity. Its value is determined by the resistance in the circuit. At lower and higher condenser settings the current rapidly decreases to a relatively low value, which is then nearly constant over the remainder of the range of possible condenser settings.

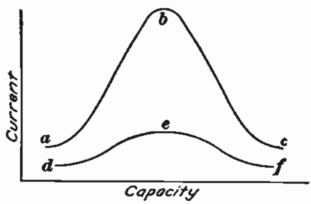


FIG. 16

With a resistance two or three times as large as was used previously the maximum current at resonance is smaller as shown by the curve through points *d*, *e*, and *f*. Points *d* and *f* nearly correspond with similar points on the other resonance curve, but the resonance value peak *e*, while definite, is not so great as was the preceding case at point *b*. These curves emphasize the necessity for keeping the resistance in a circuit low. That is, the lower the resistance, the greater the current or signal strength, and the sharper the tuning.

PARALLEL RESONANCE

A coil with a condenser in parallel will give results far different from those with the coil and condenser connected in series. As there is always some resistance in the conductor forming the coil it will also be considered. While this resistance is actually not a separate unit or device, it will be so considered for convenience in calculations. Such a circuit is represented in Fig. 17 with coil *a* and its resistance *b* shunted by a condenser *c*, all supplied from an alternating-current source connected at *d*.

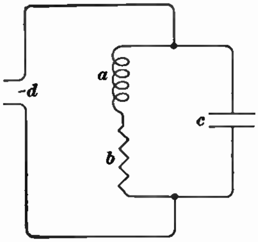


FIG. 17

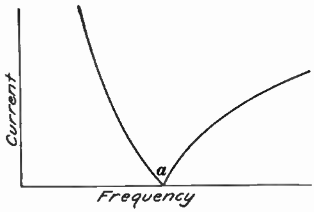


FIG. 18

The current has two paths; namely, through the coil and resistance in series and through the condenser. The total current is expressed by the formula

$$I = E\sqrt{\left(2\pi fC - \frac{2\pi fL}{R^2+(2\pi fL)^2}\right)^2 + \left(\frac{R}{R^2+(2\pi fL^2)}\right)^2}$$

in which I = current, in amperes;
E = potential, in volts;
f = frequency, in cycles per second;
C = capacity, in farads;
L = inductance, in henries.

The condition for minimum current obtains when

$$2\pi fC = \frac{2\pi fL}{R^2+(2\pi fL)^2}$$

This is the value of the properties of the circuit that give the minimum current, which condition is called *parallel resonance.* If, as is often the case, the resistance is negligibly small, the formula is $2\pi fC = \frac{1}{2\pi fL}$ for parallel resonance.

The variation of current with frequency is well shown by the curve in Fig. 18. At low frequencies the current is relatively high, owing to the lessened reactance of the coil. As resonance is approached, at point *a* the current diminishes because of the increased impedance effect. At *a* the current is relatively low and represents only a sufficient amount to supply the losses in the resonant circuit. By the preceding formulas, the resonant current is

$$I_r = \frac{ER}{R^2 + (2\pi f L)^2}$$

in which I_r = the resonant current.

The current increases with still higher frequencies, owing to the increasing total impedance caused chiefly by the condensive reactance.

The main characteristic of a parallel-resonance circuit is the extremely high impedance it can offer to an alternating current. Such a combination is often desirable in radio circuits where it is desired to pass low- or high-frequency currents and to effectively block out currents of a certain frequency.

The three factors, inductance, capacitance, and frequency, are all interrelated and a change in one will alter the resonant frequency. However, for any combination of two factors a value for the third may be found that will give a resonance condition.

INDUCTIVE COUPLING

The transfer of energy from one circuit to another is accomplished by some method of coupling. Ordinarily the electric field from a coil or condenser in one circuit is made to interlink a similar device in the other circuit, and the actual transfer is made by this interlinkage. Such energy transfers are usually between tuned circuits as the transfer is greatest and most efficient under those condi-owing to the larger current at that time.

The field of coil *a* in Fig. 19 is shown as interlinking coil *b* of an adjacent tuned circuit. At the start, with no current in coil *a*, there will be no field around coil *a* and nothing induced in coil *b*. As the current in coil *a* increases the electromagnetic field of coil *a* expands and some of the lines of force cut across the wires of coil *b*. This flux-cutting coil *b* induces an electromotive force therein which sends a current through the remainder of the circuit connected with coil *b*. As the current in coil *a* reverses, the field reverses and induces in coil *b* a potential that is

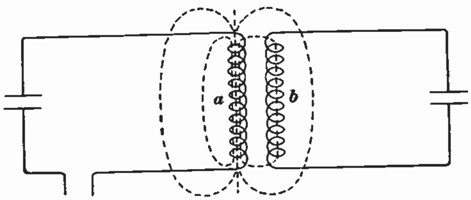


FIG. 19

opposite in direction to that previously obtained. The current in coil *b* and its circuit is also in the opposite direction. The actual direction of the induced voltages and currents is not important, but the actual transfer of energy from one circuit to another is very important. This transfer will continue as long as the current in coil *a* continues to change periodically. If suitably designed and properly placed, this arrangement can transfer a relatively large part of the energy in coil *a* to the circuit of coil *b*. This is called *inductive coupling*, as inductance coils form the active coupling agents. The coils need not necessarily be of the same dimensions. On *transformers* for low-frequency radio work, both coils may be mounted on the same iron core.

DIRECT COUPLING

The coupling between two circuits may also be a *direct coupling* with a common coil or condenser as the intermediate agent. In Fig. 20, coil *a* is the one that affords the coupling between the

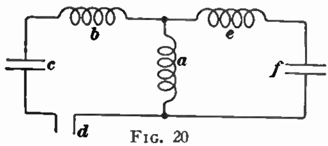


FIG. 20

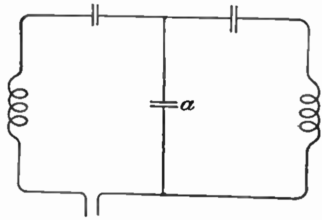


FIG. 21

circuit comprising coil *a*, another coil *b*, and condenser *c*, and the input circuit *d*, over to the circuit comprising coil *a*, another coil *e*, and condenser *f*. In fact, coils *b* and *e* are not essential, as coil *a* and condenser *c* could form one tuned circuit and coil *a* and condenser *f* the other tuned circuit.

The direct coupling may also be by means of a condenser common to both tuned circuits. Such would be as illustrated in Fig. 21 with condenser *a* the direct-coupling device between the two tuned circuits.

CAPACITATIVE COUPLING

The term *capacitative*, or condensive, *coupling* is, strictly speaking, a form of coupling with condensers as the transfer agents through their common active fields. Condenser *a* of Fig. 22 has a strong field, part of which is occupied by condenser *b*. The charging of condenser *a*

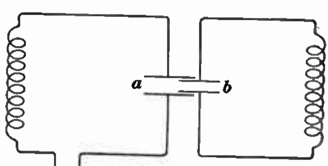


FIG. 22

produces a field that causes a transfer of energy from the circuit connected with condenser *a* to the circuit of condenser *b*.

The energy transfer has been spoken of as occurring between tuned circuits. These methods of coupling may be applied, whether or not the circuits are tuned, but the energy transfer will not be so great with untuned circuits as with circuits resonant to the same frequency.

SOURCES OF ELECTROMOTIVE FORCE

PRIMARY BATTERIES

WET CELLS

An electric cell or battery is a device for transforming chemical energy into electrical energy. There are two general types of primary cells, namely, wet and dry, depending on the nature of applying the electrolyte. In wet cells it is necessary, for continuous service, to renew the electrolyte and the electrode which is consumed by chemical action.

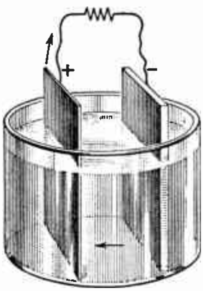


Fig. 1

In general, a primary cell may be made from any two dissimilar metals immersed in an alkaline or acid solution. For example, in Fig. 1 is shown a glass jar, two electrodes, one of zinc on the right and the other of copper immersed in a dilute solution of sulphuric acid. A resistance is shown connected between the two terminals of a cell. If the cell is connected to a voltmeter in place of the resistance, with the copper electrode connected to the plus side of the instrument and the zinc electrode to the minus side, a potential difference of about one volt between the copper and zinc terminals will be indicated on the voltmeter.

If these electrodes are connected to an external load, represented by the resistance in Fig. 1, this difference of potential will establish a current from the positive electrode through the resistance to the negative electrode and from the negative electrode through the solution in the cell to the positive electrode. The changes that take place within the cell when it is delivering current may be briefly summarized as follows: as soon as the cell is connected to the load and current flows through the circuit, the sulphuric acid in the electrolyte attacks the surface of the zinc plate, forming zinc sulphate and hydrogen. The hydrogen immediately collects on the copper plate in the form of bubbles, some of which rise to the surface of the electrolyte and escape into the surrounding air, while others cling to the copper plate. After this process has continued for a short time the copper electrode becomes covered with a film of hydrogen, which, being a non-conductor of electricity, gradually decreases and finally stops the current. A cell in this condition is said to be *polarized*, and therefore will not function properly as a generator of an electromotive force.

Many mechanical and electrical depolarizing schemes have been devised for increasing the active life of a primary cell. The only feasible schemes, however, are of a chemical nature, that is, a chemical is introduced into the cell which reacts strongly with hydrogen and absorbs a portion of it, removing the undesirable polarizing effect.

Other electrodes than those used in the above discussion may be substituted as indicated in Table I, which is arranged so that any single element is negative with respect to all elements between it and the positive end, and positive with respect to all elements between it and the negative end.

All combinations, however, are not commercially feasible, the carbon-zinc combination being the most practical and being commercially used with a sal ammoniac (ammonium chloride) electrolyte in the so-called dry cell.

There are several different types of wet primary cells that are used for supplying current for various purposes. Among these may be mentioned the Daniel, the gravity. The Edison-Lalande, and the Leclanche cells. These cells, however, have little or no application to modern radio receivers because of their space requirements, necessary care, and inability to furnish sufficient power.

TABLE I

ELECTROCHEMICAL SERIES OF ELEMENTS

Negative (−)	Lead
Sodium	Copper
Magnesium	Silver
Aluminum	Platinum
Zinc	Gold
Cadmium	Platinum
Iron	Carbon
Nickel	*Positive* (+)
Tin	

DRY CELLS

Construction.—The primary cell used in many modern radio circuits for *A*, *B*, and *C* battery supply, is the dry cell. Most dry cells are a modification of the Leclanché wet cell except that the electrolyte is carried in the pores of some absorbent material or combined with some gelatinous substance so that the cell may be placed in any position. The negative pole is a zinc cylinder, which replaces the glass jar in the Leclanché type of cell, and the positive pole is a carbon rod held in the center of the cylinder by a sealing compound. The general construction of a typical dry cell is shown in Fig. 2. The zinc container *a* forms the negative terminal, of the cell, with a connector at *j*. The positive terminal is a carbon rod *b*, placed in the center of the can with a connector at *i*. The electrolyte in this case is a solution of sal ammoniac, part of which is absorbed by a pulp-board lining *c*, and the mixture *d* is of powdered carbon and manganese dioxide. The latter is the depolarizing agent. The cell is closed by a water-tight seal *e* that is separated from the lining *c* by a layer of corrugated paper *f*, which is prevented from adhering to the seal by a layer of fine sand *g*. A layer of sawdust *h* separates the corrugated paper from the lining *c*. The purpose of the corrugated paper is to serve as a cushion between the seal and the mixture, thus allowing for any expansion or contraction in the cell. The open-circuit voltage is approximately 1.5.

Dry-Cell A Battery.—Dry cells, in the form described, have a wide variety of uses; chief among them, however, is furnishing the A supply, or filament current, to radio receivers.

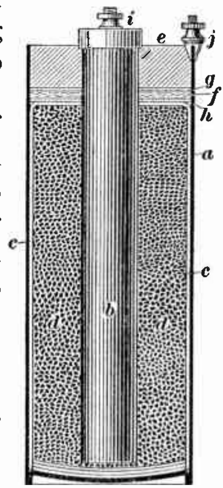


FIG. 2

There are two general types of vacuum tubes designed for operation on dry cells, namely, Radiotron types WD-11 and UX-199. The number of cells to be connected in series, in parallel, or in series parallel, depends on the number of tubes used in the radio set and also on the operation hours of the set.

The WD-11 type of tube has a filament designed to operate on 1.1 volts; therefore, the dry cells for furnishing filament current for this tube should be connected in parallel as in Fig. 3, which gives a terminal voltage of 1.5. A general rule to follow for determining the number of cells to use with this type of tube is one cell for each tube in the radio set.

The UX-199 type of tube has a filament designed to operate on 3 volts; therefore, to supply filament current for this tube, the dry cells must be connected in a series-parallel arrangement as in Fig. 4, which gives a terminal voltage of 4.5. A general rule to follow in using this type of tube is, one set of three dry cells in series for every four tubes, connected in parallel. For example, a radio set having eight UX-199 tubes would require six dry cells connected in series-parallel as in Fig. 4.

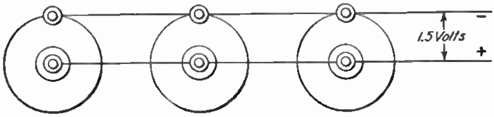


FIG. 3

The UX-201-A type of Radiotron is primarily a storage-battery tube but it may, however, be operated from dry cells connected in a series-parallel arrangement. The filament voltage being 5.0, it becomes necessary to connect four dry cells in series to obtain the proper voltage. A general rule in this case, is one set of four cells in series for each tube in the radio set, connected in parallel. For example, a radio set using four UX-201-A type tubes would require 16 dry cells connected as in Fig. 5.

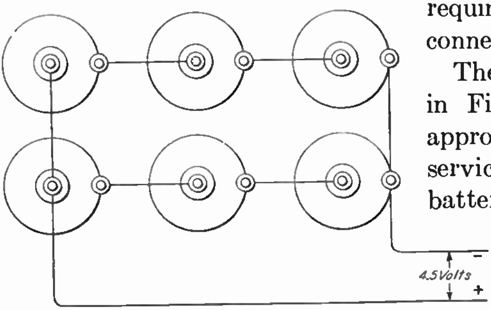


FIG. 4

The curves shown in Fig. 6 give the approximate hours of service of dry-cell *A* batteries when connected in accordance with the rules set forth above.

Dry-Cell B and C Batteries.—For furnishing *B* and *C* voltages to radio sets, the dry cells are made much smaller and are combined into blocks of cells, or batteries, as shown in Fig. 7. A cell of an *A* battery is shown at *A*, a *B* battery at *B*, and a *C* battery at *C*. These *B* and *C* battery blocks are manufactured commercially in various

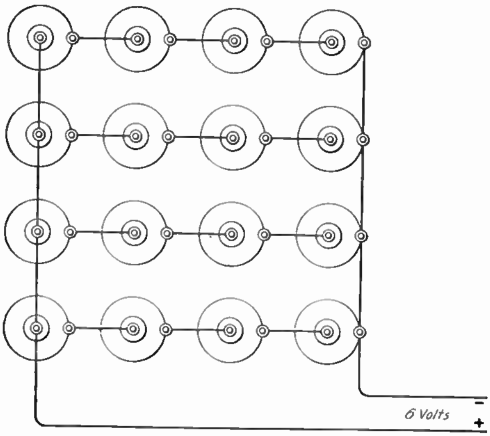

6 Volts
-
+

FIG. 5

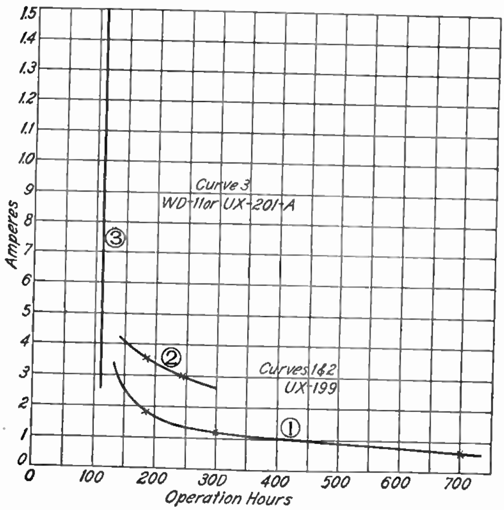

1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
Amperes
0
100
200
300
400
500
600
700
Operation Hours
Curve 3
WD-11 or UX-201-A
Curves 1&2
UX-199
③
②
①

FIG. 6

types and voltage ratings. For *B*-battery supply they are made in blocks of $22\frac{1}{2}$ and 45 volts. For *C*-battery uses they are made in blocks of $4\frac{1}{2}$ and $22\frac{1}{2}$ volts. These blocks are furnished with binding posts in many cases so that various voltages may be obtained for special radio uses. As in the case of dry cells, the life of *B* batteries depends on the operation hours of the radio set, which will be approximately 6 to 9 months under conditions of average use with the proper batteries for any given radio set.

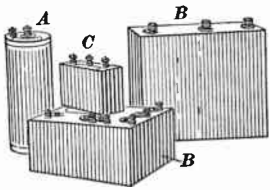


FIG. 7

STORAGE BATTERIES

TYPES

The secondary, or storage, type of cell, unlike the primary type, may be recharged, after being in continuous service, by passing a current through it in a direction opposite to that which it furnished on discharge. There are two general types of storage cells; namely, the lead-sulphuric-acid, or lead, type, and the nickel-iron-alkaline type.

LEAD-SULPHURIC-ACID CELL

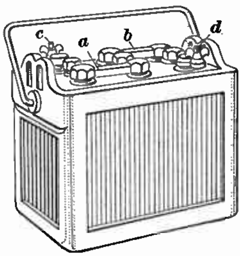
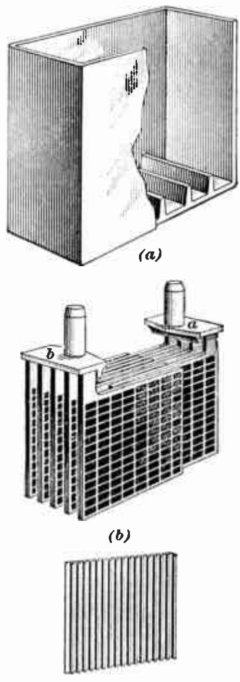


FIG. 8

Construction.—In the lead-sulphuric-acid cell the grids, both positive and negative, are of lead or of lead-antimony alloy. The electrolyte is a solution of sulphuric acid, formed by mixing 1 part of pure concentrated acid with 2.5 parts, by weight (4.5 parts by volume), of distilled water. The specific gravity of the electrolyte—that is, the ratio of the weight of a given volume of electrolyte to that of an equal volume of water—is about 1.2. Two fundamental, or general, types of plates have been developed for use in the lead cell: the *Planté*, or formed, plate, and the *Faure*, or pasted, plate.

The Planté plate, so called after its inventor, Gaston Planté, consists of a sheet or a grid of pure lead, usually ribbed or corrugated, in order to increase the superficial area. By an electrolytic process, the active material is formed on the surface of the plate from the metal composing the plate. This type of plate is rather heavy and costly, but is very durable. The formed-plate cell is commonly used in stationary batteries for heavy service and where durability is of primary importance.



(a) (b) (c)
FIG. 9

The Faure plate, invented at practically the same time by Faure in France and by Brush in the United States, consists of a grid provided with ribs, openings, or pockets, to which is applied the active material in the form of a plate consisting of red lead for the positive plate and of litharge for the negative. After the paste has set, the red lead of the positives is changed to lead peroxide and the litharge of the negatives to pure sponge lead by passing current through them in the proper direction in the forming bath of dilute sulphuric acid. The pasted type of plate is almost exclusively used in portable cells.

An external view of a portable storage battery for radio work is shown in Fig. 8. The battery consists of three cells that are contained in a composition box. The cells are electrically connected by two conductors *a* and *b* that connect the positive terminal of each cell with the negative terminal of the next. The terminals of the battery are shown at *c* and *d*.

The elements of each cell are contained in a composition jar, Fig. 9 (*a*). In one type of cell the supports at the bottom on which the elements rest provide a space for any sediment that may fall from the plates. A detailed view of the plates is shown in Fig. 9 (*b*). The like plates, that is, either the positive or the negative plates, of each cell are

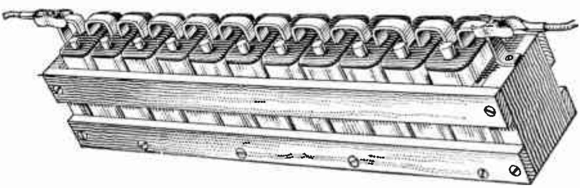


FIG. 10

connected by means of connecting straps *a* and *b*, to which the terminal posts that project through the cover are secured. The outline of the framework of the plates in which the lead paste is pressed can be seen. One of the separators that are placed between the plates in order to prevent short circuits is shown in Fig. 9 (*c*).

When the cell is in working condition, the electrolyte, which consists of sulphuric acid and water, should fill the jar high enough to cover the plates. Provision is made by means of removable plugs in the battery cover for the addition of distilled water as the electrolyte evaporates. The top cover of the battery is sealed in place so as to be acid-tight.

In Fig. 10 is shown a type of storage battery often used as the *B* battery in radio receiving sets. For this purpose a high voltage is desired with a very small current output. The cells are often assembled in units or racks with 11 cells connected in series and the voltage of the battery is 22 volts, approximately.

Normal Voltage.—The normal discharge voltage of a storage battery is usually taken as 2 volts per cell, this being about the average voltage delivered during the normal discharge of a cell, as shown by Fig. 11, which

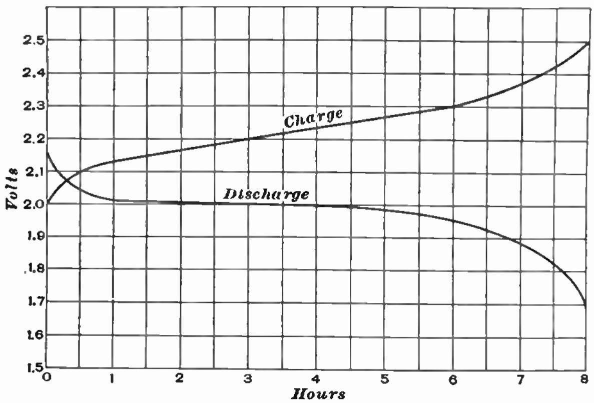


FIG. 11

represents typical charge and discharge curves for a lead-plate cell. For instance, the normal discharge voltage of a three-cell storage battery is 6 volts, although the actual value of the voltage of the battery, when fully charged, is approximately 1 volt higher. Storage batteries are generally designated by their normal voltages, as, for instance, a 6-volt battery, a 12-volt battery, a 16-volt battery, and so on. When the voltage has dropped to about 1.7 per cell, the battery should be recharged, because it retains only a comparatively small amount of electrical energy at this voltage and it drops rapidly during discharge after getting below 1.7. The life of the battery is shortened by discharging below 1.7 volts per cell. The voltage usually remains fairly constant for a discharge at normal rate, but drops off rapidly if the battery is discharged at a more rapid rate. However accurate the voltage readings, they should not be the only factor on which the state of charge or discharge of a cell is based.

Specific Gravity.—The specific gravity of a substance is the quotient obtained by dividing the weight of a given volume of the substance by the weight of the same volume of some other substance used as a standard. Pure water is usually taken as the standard for solids and liquids. It will be noted that the strength, or specific gravity, of the electrolyte decreases during discharge and increases during charge, and furnishes an indication of the state of discharge of the cell. A fully-charged cell should show a specific gravity of the electrolyte of from 1.275 to 1.300. The cell is practically discharged when the specific gravity is as low as 1.150, and recharge should be started as soon as possible. In practice the specific gravity is often used as a whole number. For example, a specific-gravity of 1.275 is often called simply twelve seventy-five.

The *hydrometer* is used for measuring specific gravities of electroytes, and may be obtained with numbered scales ranging from 1.100 to 1.300. The hydrometer sinks into the liquid, and the reading is taken on the scale at the level of the top of the electrolyte.

The ball-type hydrometer contains either two or three small wax balls constructed so that they will float or sink at different values of the specific gravity of the electrolyte. The electrolyte is drawn up into the glass tube holding the balls. The condition of the battery is indicated by the floating or sinking of the individual balls.

Regular Charge.—A regular charge is given to the battery as frequently as may be necessary to restore the energy taken out on discharge. This regular charge can be given at the normal rate throughout; but if it is necessary to hasten the charge, a much higher rate can be used at the beginning, provided the rate is reduced from time to time to prevent violent gassing and to keep the temperature of the cells below 110° F. The regular charge should be continued until the specific gravity of the pilot cell is from 3 to 5 points below the maximum reached on the preceding overcharge. All the cells should then be gassing moderately, but not so freely as at the end of overcharge.

When a battery has been completely discharged, the charge should be started as promptly as possible. Long standing in a discharged condition tends to produce a hard and crystalline form of lead sulphate on the plates that will reduce their capacity temporarily. This sulphate may not cause permanent injury, because it can be decomposed by a long overcharge at low rate.

The most reliable indication of a complete charge in a lead cell is the fact that the voltage and specific gravity have reached a maximum and become stationary for 15 minutes to ½ hour, the charging current being kept constant. These final values of voltage and specific gravity are not always the same, the voltage varying with the temperature, the rate of charge, the type of plates, and the age of the battery; and the specific gravity with the temperature, the height of the electrolyte, and the amount of acid lost by spilling, gassing, or combining with sediment in the bottom of the cell.

Toward the end of the charge the cells will gas very freely, an indication in a healthy cell that the charge is nearing completion. While portable cells in sealed rubber jars are being charged, the soft-rubber stoppers in the covers should be removed and the cover of the battery box or compartment should be left open.

It should always be borne in mind that the gasses, oxygen and hydrogen, given off by a battery toward the end of charge form an explosive mixture. The battery room or compartment should therefore be freely ventilated at such times, and exposed flame should be absolutely kept away.

The electrolyte should be kept above the tops of the plates by filling the cells with chemically pure water from time to time. The local supply of city water is not sufficiently pure, and the use of distilled water is strongly recommended in all cases. Water for filling cells should be stored and handled in wooden, earthenware, or glass vessels; the use of vessels made of iron or other metals should be avoided. Under normal conditions of temperature and ventilation, filling and inspection once a week are sufficient. The acid in the electrolyte does not evaporate, and during normal operation should never be added to the cells except by special instructions from the manufacturer. Electrolyte from one cell should never be mixed with that of another cell.

NICKEL-IRON-ALKALINE CELL

Plates.—The positive plate, Fig. 12 (*a*), of the nickel-iron cell consists of a number of hollow tubes, or pencils, of perforated steel, nickel-plated, supported vertically in a nickel-plated steel grid. The pencils, Fig. 12 (*b*), are made of steel ribbon wound spirally with overlapping riveted seams, and are reinforced at intervals by steel bands. The active material consists of nickel peroxide and flake nickel tamped into the tube in alternate layers. The flake nickel is added to decrease the internal resistance.

The negative plate, Fig. 13, consists of rectangular pockets of perforated nickel-plated steel supported in a nickel-plated steel grid, the pockets being filled with finely divided iron oxide, which is reduced to metallic iron by the initial charge. In Fig. 14 are shown the plates of one cell when assembled.

Separators and Electrolyte.—The plates are separated from each other by vertical strips of hard rubber, square in section, inserted with their vertical edges against the plates, as shown in Fig. 15, which is a view of a cell from above. Sheets of hard rubber are inserted between the outside negative plates and the jar, and hard-rubber bridges *a*, Fig. 14, notched to receive the vertical edges of the plates, serve to separate these edges from the sides of the jar. The plates rest on hard-rubber bridges on the bottom of the jar, as shown in Fig. 14.

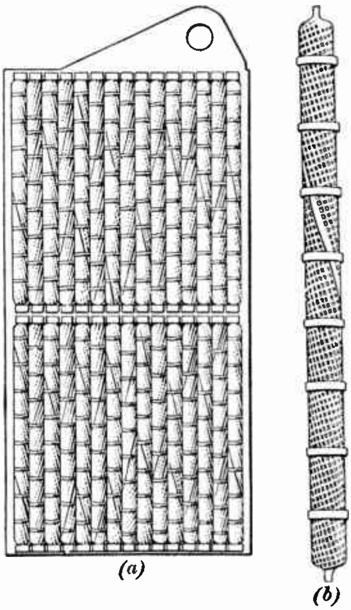

(a) (b)

FIG. 12

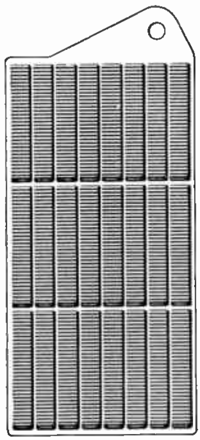


FIG. 13

The electrolyte is a dilute (21 per cent.) solution of potassium hydrate (caustic potash), the specific gravity of which is approximately 1.200. A small amount of lithia (lithium hydroxide) is added.

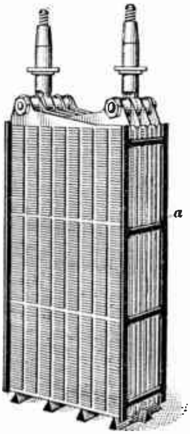


FIG. 14

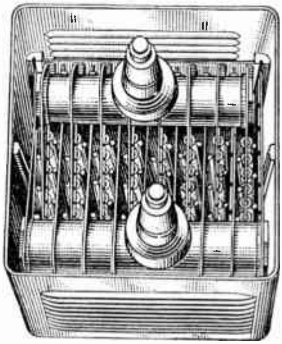


FIG. 15

Container.—The container of the nickel-iron cell is a box made of nickel-plated sheet steel, corrugated to give added stiffness, the cover being welded on after the element is in place. The two terminal posts *a* and *b*, Fig. 16, pass through circular openings provided with rubber bushings. Another opening in the cover, used for filling the cell, is closed by a spring cap containing a valve *c* that allows the gases to escape during charge, but excludes the external air.

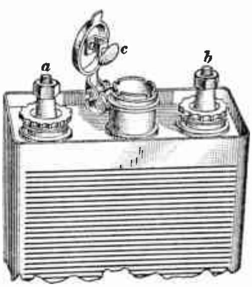


FIG. 16

Voltage.—The open-circuit voltage of the nickel-iron cell is 1.5, and the average discharge voltage 1.2. After a substantial discharge, the open-circuit voltage is restored only very slowly, and never completely until a freshening charge has been given.

In Fig. 17 are curves that show charge and discharge voltages of the nickel-iron cell at normal rate. The discharge curve, as shown, is carried to .9 volt, though the normal-rate discharge is seldom carried below 1 volt in practice. The manufacturers recommend providing a charging voltage of 1.85 per cell.

Efficiency.—The efficiency of the nickel-iron cell is lower than that of the lead cell under similar conditions. Not only is the difference in voltage between charge and discharge proportionately greater in the nickel-iron cell, but the efficiency is low on account of the gassing that

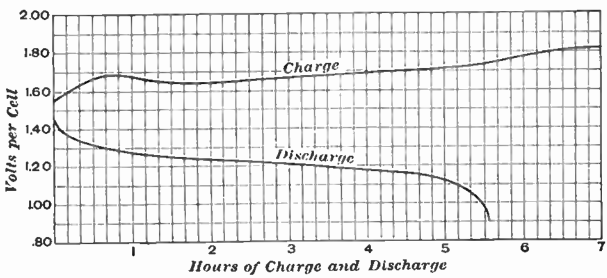


FIG. 17

occurs during the entire charging period. An efficiency of 50 to 60 per cent. in commercial operation is about as high as can be expected, and this figure may be reduced if an attempt is made to utilize the maximum capacity of the battery.

Advantages and Applications.—The principal advantages of the nickel-iron cell are durability, mechanical ruggedness, and ability to withstand neglect and abuse without injury. Life curves published by the manufacturers as a result of laboratory tests show a maximum of 1,100 complete cycles of charge and discharge. The cell is not injured by standing in a discharged condition, nor by excessive overcharge, provided excessive temperature is avoided. At low rates of discharge, the nickel-iron cell is much lighter than the lead cell for the same watt-hour output; but this difference in weight disappears as the rate of discharge increases, on account of the proportionately lower voltage of the nickel-iron cell. The Edison cell is, therefore, best adapted for service at low discharge rates where the cost of charging current is low, where light weight is important, and where indifferent care and attention are given. On the other hand, the nickel-iron cell is not well adapted for high rates of discharge, nor for service in which the cost of charging current is high, nor where a battery must retain its charge for a long period of time without recharging.

Charging.—The state of charge of the nickel-iron cell cannot be determined by the density of the electrolyte, which does not change. Neither is the cell voltage or the amount of gassing a reliable guide. The only practicable method is to measure the output and input in ampere-hours, either by noting the rate in amperes and the time or by means of an ampere-hour meter. The manufacturers recommend a charge of 7 hours at normal rate after a discharge of 5 hours at the same rate, which is equivalent to 40 per cent. overcharge, in ampere-hours. The cell temperature should not be allowed to exceed 120° F.

The method of operation best adapted to the nickel-iron cell is that in which partial, or *boosting*, charges are given in the intervals between partial discharges. Boosting charges are particularly advantageous where the rate of discharge is sufficiently high to produce excessive polarization drop. The boosting charge quickly restores the cell voltage to normal, where otherwise it would remain abnormally low.

Changing Electrolyte.—The electrolyte in nickel-iron cells gradually deteriorates, owing to the absorption of carbonic-acid gas from the air. Deterioration, however, cannot be absolutely prevented, and although this gas does not permanently injure the plates, it reduces the capacity of the cells temporarily. About once in 6 months the electrolyte should be completely renewed.

Water that is to be used for filling the cells must be protected from exposure to the air for any considerable length of time, because water absorbs carbon dioxide (carbonic-acid gas) from the air. The local water supply, or even rainwater, which is very nearly pure, cannot safely be used for filling; distilled water protected from exposure to the air is generally necessary.

Special Precautions.—The containers of nickel-iron cells, being of metal, must be carefully insulated from each other and must be kept clean. The wooden crates in which the cells are supported, as well as the sides and floor of the battery compartment, must be kept clean and dry for the same reason. If the insulation between cells becomes defective from any cause, a small leakage of current will, by electrolytic action, puncture the steel containers.

The nickel-iron cell is gassing more or less at all times, whether charging, discharging, or standing on open circuit. These gases (oxygen and hydrogen) produce an explosive mixture. Care must therefore be taken to guard against bringing an exposed flame or producing an electric spark in the vicinity of the cells, unless the ventilation is very thorough.

CAPACITY OF STORAGE BATTERIES

The *capacity* of a storage battery is usually stated in units called *ampere-hours*. An ampere-hour is a current of one ampere maintained for one hour; hence, the capacity of a battery in ampere-hours is found by multiplying the number of amperes of current delivered by the number of hours during which the current passes. For instance, a storage battery that is capable of discharging 5 amperes of current continuously for a period of 8 hours has a capacity of $5 \times 8 = 40$ ampere-hours; in like manner, one that will deliver a current of 10 amperes for a period of 12 hours has a capacity of 120 ampere-hours, etc. The *rate of discharge* of a battery is often referred to in terms of hours. In the examples just given, the batteries are said to be discharged at the 8- and 12-hour rates, respectively. The ampere-hour capacity varies with the rate of discharge, being less at high rates than at low rates. The term *efficiency* applies to the ratio of energy output to energy input. Under usual conditions, the efficiency of a lead-sulphuric-acid battery that is fully charged and subsequently completely discharged, varies from 70 to 80 per cent. The output of a battery depends on several variable characteristics of its make-up, each of which may cause an appreciable variation in its efficiency. Under favorable operating conditions, where the battery is only partly discharged and soon recharged, the efficiency may be over 90 per cent.

The size of storage battery to use depends largely on the rate of current output required, and the frequency between charges. If a relatively large output is required it is desirable to use a fairly large battery, while if charging facilities are not convenient, one does not like to take the battery to be recharged too often. The 60-ampere-hour battery is one very largely used in radio work where a current of 1 to 3 amperes is required. For some radio work a current of less than .1 ampere is required. Some storage cells of very small capacity have been designed especially for this class of work. They possess small elements made up in miniature sizes, and sell for a much lower price than the large batteries. They may be recharged in the usual manner, and are convenient when used in large radio stations where dry cells would have a short life. They have found a large field of application in research laboratories.

The four general methods of charging storage batteries are from a direct-current line, from an alternating-current line through a mechanical rectifier, from an alternating-current line through a chemical rectifier, and from an alternating-current line through a vacuum-tube rectifier. The last mentioned method is the most common and is described later on.

GENERATORS AND MOTORS

GENERATORS

Principle of Operation.—A generator is a machine that converts mechanical energy into electrical energy. This energy transfer is accomplished by means of an armature carrying upon its surface, conductors that act in conjunction with a magnetic field. The armature, in the case of a direct-current generator, is always the revolving element but this is not true in an alternating-current generator, as the armature in the latter case may be either the revolving or the stationary element.

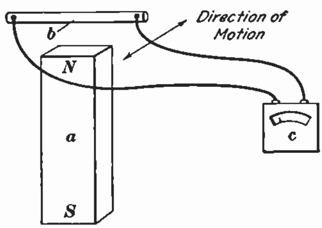


Fig. 18

The underlying theory of generator action may be understood by referring to the following elementary experiment, which covers the principles of electromagnetic induction: In Fig. 18 are shown a permanent magnet *a* and a copper conductor *b*, connected to a voltmeter *c*. If this conductor is moved rapidly across one pole of the magnet, there will be set up, in the conductor, a voltage, which will be indicated on the voltmeter. Now, if the conductor is moved in the opposite direction across the pole of the magnet, it will be seen that the induced voltage, as indicated in the voltmeter, will be in the opposite direction. The amount of voltage that is generated depends on the speed with which the conductor is moved and on the strength of the magnet. The high voltage of a generator is obtained by moving many wires in series very rapidly across the faces of very strong magnets.

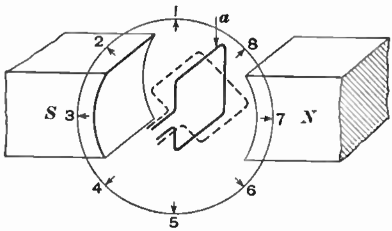


Fig. 19

Alternating-Current Generator.—In Fig. 19 is shown a simple two-pole alternating-current generator, or alternator. The magnetic flux is produced by a magnet having a north pole *N* and a south pole *S*. A single turn of wire *a* is rotated counter-clockwise, by some mechanical means, in the magnetic field produced by the magnet. In rotating this wire one revolution, it will have passed through two alternations, or one cycle. Consider, now, eight successive positions of this wire during one cycle. These eight positions are represented numerically on the diagram.

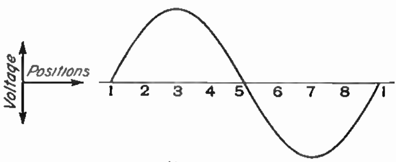


Fig. 20

Position 1. Both sides of this turn or both conductors are moving in a direction parallel to the magnetic lines of force and therefore, no voltage is generated.

Position 2. The conductors are now moving obliquely across the magnetic field and, therefore, an electromotive force is being induced.

Position 3. Here the conductors are moving perpendicularly to the magnetic field and the maximum electromotive force is being generated.

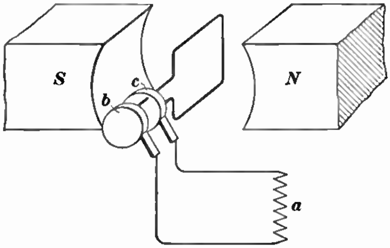


FIG. 21

For the remaining positions of the conductors it will be seen that the electromotive force will gradually decrease and again increase and decrease in the opposite direction. The voltages generated in the various positions of the conductors are indicated in Fig. 20.

The alternating electromotive force varying in the manner shown in Fig. 20 is called a *sine wave* of electromotive force. This electromotive force may be applied

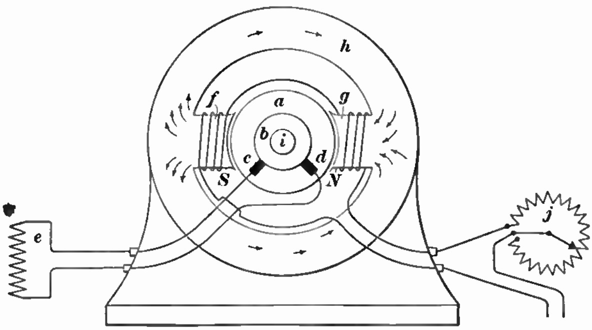


FIG. 22

to an external circuit *a*, as shown in Fig. 21, by connecting the ends of the single-turn coil to the *slip rings b* and *c*. In commercial alternators, this single-turn coil is replaced by a multiturn coil, connected in series, to produce sufficiently high voltages for commercial use.

Revolving-Armature Alternator.—The revolving-armature type of machine is used principally where small output or slow speed is required. In Fig. 22 is shown a

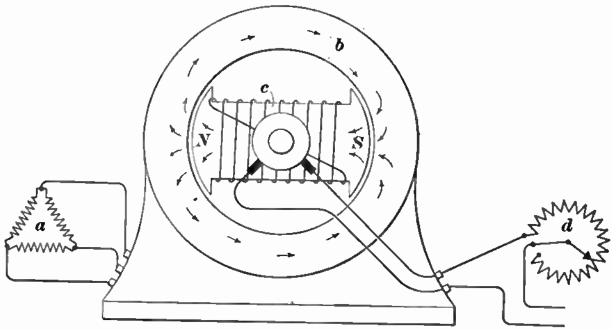


FIG. 23

two-pole revolving armature alternator in which the permanent-magnet field, shown in Fig. 19, is replaced by a separately-excited electromagnetic field. The armature is shown at *a*, Fig. 22, the two slip rings, one behind the other at *b*, the brushes at *c* and *d*, the external circuit at *e*, the two-pole pieces of the magnetic circuit at *f* and *g*, the frame at *h*, and the shaft at *i*. The field coils on the pole pieces are connected through a field rheostat *j* to a direct-current line.

Revolving-Field Alternator.—The revolving-field type of alternator, shown in Fig. 23, is used for large high-voltage machines because the high voltages are more easily insulated and connected to the external circuit *a* when the armature conductors are embedded in slots in the *stator*, or the stationary member, *b*. The *rotor*, or the revolving member, *c* carries the windings of the field coils; these are connected through slip rings and brushes to a direct-current line. The current in the field circuit is regulated by a field rheostat *d*.

Commercial Alternators.—Commercial alternators are built to furnish alternating current at 25, 50, 60, 500 and 100,000 to 200,000 cycles. The 25-cycles machines are primarily intended for power uses; 60-cycle machines are used for both power and lighting loads; 500-cycle and 100,000- to 200,000-cycle alternators are designed for radio transmission. The last mentioned machine is called the Alexanderson alternator, which is of a special construction and is here briefly described.

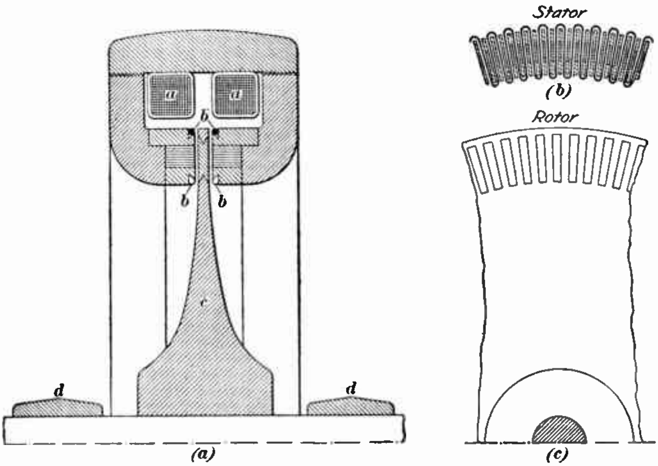


FIG. 24

The *Alexanderson alternator*, so named from its designer, has been successfully operated for the generation of voltages at 100,000 and 200,000 cycles. The field and armature windings are stationary and properly mounted with respect to the magnetic circuit. A rotor of magnetic material with numerous radial slots cut near its outer edge, produces many changes in the flux of the magnetic circuit per revolution, thereby generating in the stationary armature coils a voltage of very high frequency.

The general arrangement of the elementary parts of an Alexanderson alternator is shown in Fig. 24 (*a*), which represents a radial section from the center of the shaft to the outside of the machine. The magnetic circuit is energized by the current in two coils *a*, each extending completely around the inside circumference of the outer frame of the machine. In some machines when the stator frame is in two parts a slightly different arrangement of field coils has been developed. The field coils receive exciting current from an external direct-current source. The armature windings located as shown at *b* are wound, as represented in view (*b*), in zigzag formation in open slots around the whole circumference of the machine. This type of construction is necessary in view of the large number of active conductors (in some cases 600) which must be placed in a rather limited space. The rotor *c*, view (*a*), a portion of which is shown in view (*c*), is made of very high grade steel, carefully machined and balanced. Radial slots are cut near the outer edge of the rotor and filled with some non-magnetic material. This makes the face of the rotor smooth, which, at the high rotative speed, is very essential in preventing excessive windage losses.

The magnetic flux, tending, as always, to follow the path of least opposition, will be tufted or bunched through the spokes of the rotor. The non-magnetic filling of the rotor slots between the spokes will act practically the same as air so far as its influence on the field flux is concerned. As changes in the number of lines of force occur with the passing of the rotor teeth or spokes, the recurring increase and decrease of field flux must necessarily cut the armature conductors and generate voltages in them. The conductors are so spaced that as the flux is increasing near one conductor, it is decreasing near the one next to it, and so on around the armature. Thus the electromotive forces generated by the different conductors can be combined to give the desired value of voltage. As the changes in the values of the magnetic fluxes affecting the armature conductors are made very rapidly, a high-frequency voltage is generated. In some installations the alternator armature windings are connected to a transformer and the voltage for the radio system taken from the high-voltage coils of this device.

The rotor bearings at *d*, Fig. 24 (*a*), are lubricated by oil, supplied by a positive-feed oiling system. It is imperative that oil be kept supplied to the bearings, otherwise they would soon burn out.

The portion of the magnetic circuit near the armature conductors is made up of laminated iron to prevent local currents from being set up by the rapid changes of flux. In larger capacity machines these local currents may cause considerable heating. In some machines of this type, cooling is effected by water circulating through pipes placed near the armature conductors.

These machines are usually driven by high-speed alternating-current or direct-current motors equipped with special apparatus to give them constant speed with fluctuating load. An enclosed gearing is usually employed between the motor and alternator to give a high rotative speed to the alternator rotor. The speed of the rotor is usually at least 2,000 revolutions per minute, and in some cases is as high as 20,000 revolutions per minute. When a rotor with several hundred spokes is used, it is quite possible to generate an alternating voltage of exceedingly high frequency.

Direct-Current Generators.—Direct-current generators are usually designed with the armature the rotating member, because the alternating electromotive force that is generated in the armature must be rectified by commutation. An elementary direct-current generator is shown in Fig. 25.

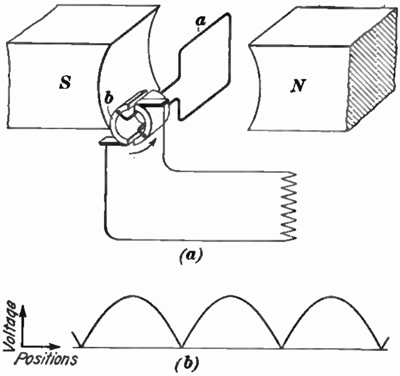


FIG. 25

The principle of generation is exactly the same as in alternating-current generators. The alternating electromotive force generated in the revolving coil *a*, Fig. 25 (*a*), however, is rectified by a commutator *b*, which is a mechanical switch that alternately connects the proper armature conductor to the external circuit, so that the voltage impressed on the external circuit will always be in the same direction. In Fig. 25 (*b*) is a curve showing how the lower half of the alternating-current cycle is rectified by the commutator and placed in the upper half so that a unidirectional voltage is obtained in the external circuit. Direct-current generators are manufactured in three general types that vary in the way their fields are connected.

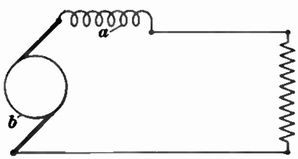


FIG. 26

The *series generator* is indicated schematically in Fig. 26, which shows, as the name implies, the field coil *a* connected in series with the armature *b* and the external circuit. This type of machine is used principally on automobiles for charging storage batteries.

The *shunt generator* has its field coil connected in series with a rheostat across its armature as indicated in Fig. 27

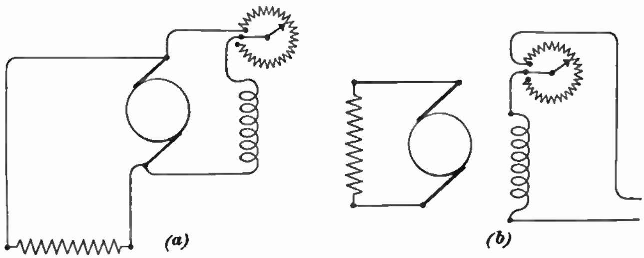


FIG. 27

(*a*). The field rheostat controls the amount of current passing through the field coil, which in turn varies the out-

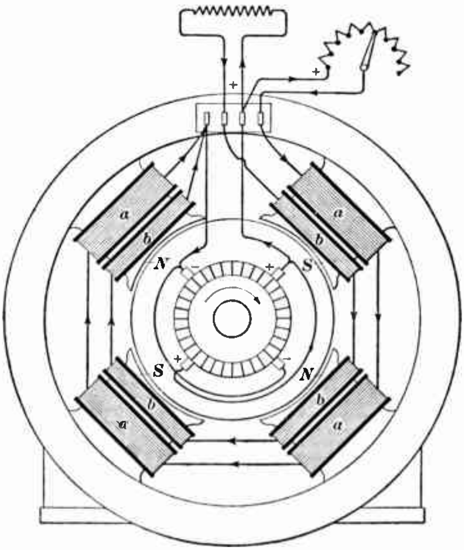


FIG. 28

put of the generator. The field coil may be connected so as to be self-excited or separately excited, depending on the class of service for which the generator is used. These variations are shown in views (*a*) and (*b*). This type of machine is used commercially in power stations.

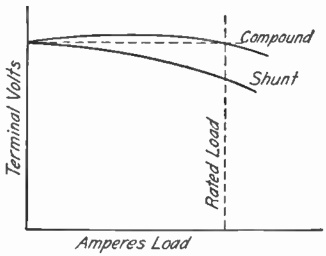


FIG. 29

The *compound generator* is a combination of a series and a shunt machine and combines the desirable qualities of each. The voltage of a shunt generator falls off as load is applied. As a compound generator is provided with shunt coils *a* and series coils *b*, Fig. 28, it overcomes this disadvantage, for, as the load is increased, the increased current in the series field coils *b* increases the field strength, which in turn increases the output voltage. This operation, however, is not a straight-line function; therefore, a compound generator usually has its series field adjusted so that the no-load and full-load voltages will be the same. In Fig. 29 are shown voltage curves comparing a shunt and a compound generator. From these curves the effect of the series coils can be clearly seen.

MOTORS

Alternating-Current Motors.—The principle of action of a polyphase induction motor is here described with reference to Figs. 30 and 31. In Fig. 30 is shown a two-phase induction generator connected to a two-phase induction motor. Phase *A* of the generator is connected to the field windings on two poles *a* on the motor stator. Phase *B* of the generator is shown connected to the field winding on two poles *b* of the motor stator. At the instant shown, phase *A* is generating a maximum voltage and therefore, is delivering current to the motor field coils *a* while phase B is generating no voltage and, therefore, there is no current in the motor field coils b. Thus, a strong magnetic field is established between poles a of the

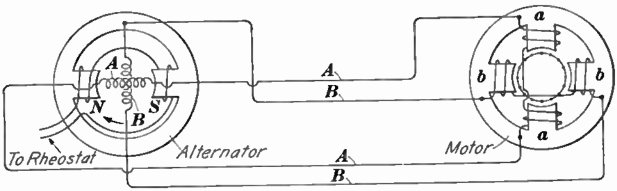


FIG. 30

motor and no magnetic field between poles b. The position of the magnetic field, for this instant, is shown in Fig. 31 (a). When the armature of the generator, Fig. 30, has turned 45° from its present position, the voltage in phase A will decrease, as it is moving out of the generator field, whereas the voltage in phase B will increase, as it is moving into the generator field. The same conditions, therefore, exist

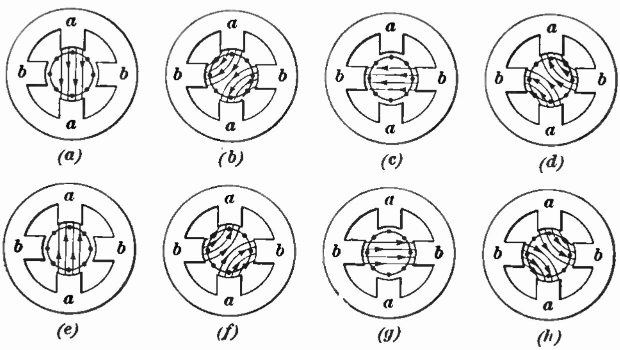


FIG. 31

in the motor; that is, the magnetic field between poles a has decreased and the magnetic field between poles b has increased. The positions of the magnetic fields at this instant are shown in Fig. 31 (b). When the armature of the generator has turned another 45°, the conditions just explained are continued; that is, phase A, Fig. 30, is in the neutral position and, therefore, is generating no voltage while phase B is in a parallel position to the field and is generating maximum voltage. The resultant fields in the motor are further shown for every 45° of motion, in Figs. 31 (*b*) to (*h*). Thus, there is established the principle of an induction motor; that is, a rotating magnetic field has been produced in the stator.

The rotor of an induction motor is made by soldering, welding or casting many bars between two metal rings, thus forming a *squirrel cage,* Fig. 32. This squirrel cage,

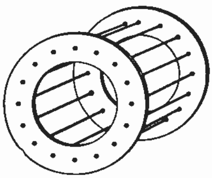


FIG. 32

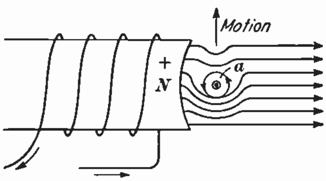


FIG. 33

or rotor, is mounted in the revolving field, and has voltages set up in it by the principle of electromagnetic induction. As the squirrel cage is all connected together electrically, the induced voltages will establish currents in the copper bars. This current in turn sets up a magnetic field around the bars, which field reacts with the revolving magnetic field in the stator, and both produce a rotating, mechanical motion.

The action is more clearly indicated in Fig. 33, where one north pole of the stator is depicted and one conductor a of the squirrel cage. If the current in the conductor is in the direction toward the reader, a magnetic field will be set up around it in a counter-clockwise direction, which reinforces or distorts the original magnetic field from the north pole on the bottom side, and tends to nullify it on the top side. This crowding of magnetic lines of force on one side of the conductor and rarifying them on the other side, will cause the conductor to move upward, which, in turn, causes the squirrel cage to rotate. The commercial forms of alternating-current motors operate on the foregoing principle, but have a large number of poles and many conductors on the squirrel-cage rotor, so the action is frequently repeated.

A three-phase alternator or motor operates on the same general principle, but the currents in the phase windings are 120° out of phase instead of 90° out of phase.

Direct-Current Motors.—The general theory of operation and construction of direct-current motors is identical with that explained under direct-current generators, except that in the case of a generator the armature is revolved and a voltage is produced, whereas in the case of a motor the voltage is supplied and a rotating mechanical motion is produced. The rotation of the armature is caused by the reaction of the magnetic flux of the field and the magnetic flux of the armature conductors. Direct-current motors, like direct-current generators, are divided into three classes, depending on the field connections. They are series, shunt, and compound.

The series motor is used mainly in street car or electric traction service where it operates always under load. It is best adapted to this type of service because of its high starting torque. The shunt and compound motors are used for general power purposes.

CONTROL DEVICES FOR DIRECT-CURRENT MOTORS

Counter Electromotive Force.—When an armature conductor is forced by motor action to move across the flux of the field magnets, an electromotive force is generated in it. This electromotive force is usually called *counter electromotive force*, but it is also known as *motor electromotive force*, *back electromotive force*, and *back voltage*.

An armature has but a very low resistance—a fraction of an ohm in many cases—and if the armature is clamped so that it cannot rotate and the full voltage of the line is then impressed on its terminals, the windings would probably be damaged by the resulting large current.

If the armature is free to rotate, the counter electromotive force established in the active conductors acts in direct opposition to the impressed electromotive force from the power circuit, and thus limits the current. As the speed increases, the counter electromotive force increases and the armature finally reaches such a speed that the opposing action of the counter electromotive force is such that just enough current is taken by the motor to develop the required torque. In the case of a shunt motor, if the load changes, the speed varies slightly and there is automatically established a new value of the counter electromotive force that is suitable for the new value of the current required for the motor load.

The voltage that is actually effective in forcing current through the armature is the difference between the impressed electromotive force and the counter electromotive force. This difference is usually only a few volts, because the ohmic resistance of the armature is so low that only a low effective voltage is required to force the necessary current through the windings.

Purpose of Starting Resistance.—In starting very small motors, the voltage of the line may be impressed directly on the armature terminals, because these armatures have a comparatively high ohmic resistance. In larger motors, the impressed voltage is adjusted to a lower value for starting by the insertion in the armature circuit of an adjustable resistance, called a *starting box*, *starting rheostat*, or *motor* *starter.* As the speed and counter electromotive force of the armature increases, the resistance of the rheostat is gradually cut out of circuit until, finally, the armature is connected directly across the line wires.

With smaller rheostats, the face plates, on which are mounted the arms and contacts by means of which resistance sections are cut into or out of circuit, are placed on the front of the box containing the resistance coils or grids. With larger rheostats, the face plates may be mounted on a switchboard and the resistance sections installed separately.

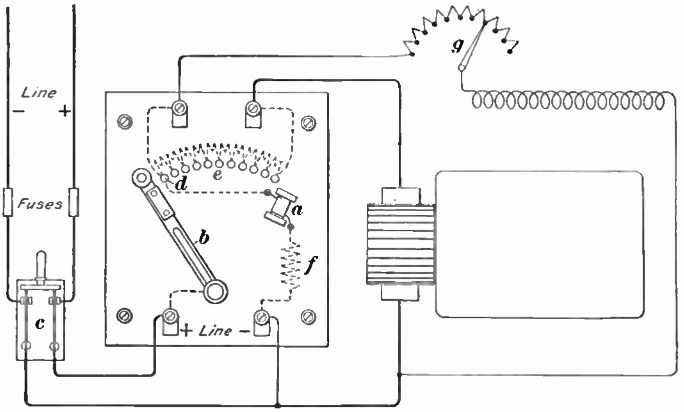


FIG. 34

Starting Box of Simple Type.—In Fig. 34 is shown one type of motor starter connected to a motor and its power circuit. This box has four terminals for connections to external circuits. A protective coil *a* is mounted on the face plate. This coil will hold switch lever *b* when the lever is at its on-position. To start the motor, switch *c* is closed, thus connecting the starter to the line, and the switch lever is moved to the right, making contact with button *d*. The shunt-field circuit of the motor is then energized.

When there is [illegible]
drawn up and the resistance *c* is short-circuited by the bar across contacts *f* and *g*, thereby placing full line voltage on

At the same time the armature circuit is closed through the resistor sections *e*. The current established will

the motor. Simultaneously with the rise of the plunger, the key *h* moves upward, placing resistance *i* in series with coil *d*, which operation decreases the current through this branch circuit. The smaller current through the coil is sufficient to hold the plunger in position, and reduce the likelihood of the coil becoming overheated.

Speed adjustment of the motor is by variation of the field current through changes in the field rheostat *j*. Opening the line switch stops the motor and the plunger drops, owing to gravity, to its proper position for the succeeding start.

Three-Step Automatic Starter.—A complete circuit diagram for a *three-step automatic motor starter* connected to a motor-generator set is shown in Fig. 36. The apparatus mounted in the box *a* is designated as the motor starter, whereas that at *b* is an overload relay serving as auxiliary protective apparatus. When the line switch *c* is closed as shown and the operator's control switch *d* is open, a circuit is completed from the positive line through the shunt-field rheostat *e*, shunt-field winding *f*, and overload coil *g* of the overload relay, to the negative side of the direct-current supply line. The motor field *f* is now energized.

If the machine is to stand idle for some time the main-line switch should be opened, but it is normally left closed. The current in the shunt field is usually small and the power loss is not objectionable when operating intermittently in view of the better starting and stopping characteristics obtained.

To start the motor-generator set, the operator closes the control switch *d*. This operation closes a circuit starting with the positive line, through resistance *h* and coil *i* to the lower contact of the overload relay and its lever *j*, then through control switch *d*, and back to the

The terminals on the box are usually designated by names or letters representing the correct circuit connections for each terminal.

Single-Step Automatic Starter.—The starting device may also be of the *automatic motor-starter* type, in which case the switching is done automatically, each operation cutting out a section of resistance when the motor speed has accelerated to the proper point.

The automatic starter shown in Fig. 35 is of the *single-step* type, as there is only one resistance step to be cut out of the circuit when starting. The single-step starter

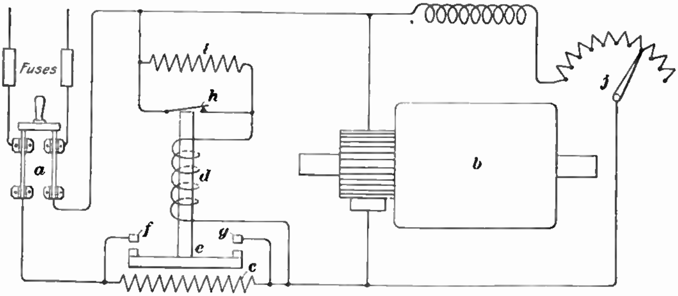


FIG. 35

is satisfactory when used with motors of rather low power output, as they will readily reach full speed, especially when starting without load. Closing the line switch *a* serves to establish a current through the motor armature *b*, which is limited in value by the current-limiting resistance *c*. As the speed of the motor increases, the counter electromotive force of the armature increases. The coil *d* is connected in shunt across the brushes and hence the voltage across the coil is the same as that across the motor. When there is sufficient current in the coil, plunger *e* is drawn up and the resistance *c* is short-circuited by the bar across contacts *f* and *g*, thereby placing full line voltage on the motor. Simultaneously with the rise of the plunger, the key *h* moves upward, placing resistance *i* in series with coil *d*, which operation decreases the current through this branch circuit. The smaller current through the coil is sufficient to hold the plunger in position, and reduce the likelihood of the coil becoming overheated.

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With smaller rheostats, the face plates, on which are mounted the arms and contacts by means of which resistance sections are cut into or out of circuit, are placed on the front of the box containing the resistance coils or grids. With larger rheostats, the face plates may be mounted on a switchboard and the resistance sections installed separately.

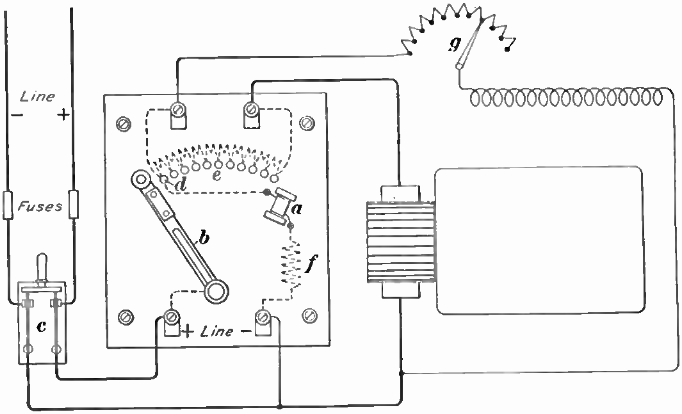

FIG. 34

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At the same time the armature circuit is closed through the resistor sections *e*. The current established will depend on the voltage and on the resistance active in the motor starter and of the rest of the armature circuit. Under normal conditions there will be sufficient current so that the armature will start to rotate and a counter elecmotive force will then be established in the armature conductors. In case of a heavy load on the motor, the lever may move over two or three contact buttons before the motor starts.

Further movement of the lever reduces the active resistance in the starter and the motor armature comes up to normal speed. At the extreme right-hand position of the lever, all of the resistor sections are cut out of the armature circuit and the armature is connected directly across the power circuit. This is the normal running position of the lever.

The holding coil *a* in series with a resistor *f* and the armature-starting resistors to the left of lever *b*, when the lever is at its on-position, is connected across the circuit. The resistors *e* have a very low resistance as compared to the resistance of coil *a* and the resistor *f*. The coil holds the lever in its on-position, but if the power circuit is opened, the magnet *a* releases the lever and a spring carries it back to its off-position. The motor stops and must be started again when the line is in operating condition.

Speed control is accomplished by changing the active resistance of the field rheostat *g*. A change in the current in the field circuit changes the field flux and this affects the speed that is required to generate the proper value of the counter electromotive force for the given load conditions. It is important when connecting up a starting box that all connections be made exactly as specified for proper starting and operation of the motor.

negative line. The current through coil i draws up the plunger k that makes contact with point l, between which point and points m, n, and o are connected the resistance units of the three steps. The rotor will now start, owing to current through the circuit from the positive line to point o, through the resistance units, point l, plunger k and flexible connection p to the positive armature connection, thence from the negative armature connection through coil g, to the negative side of the line. Further movement of the plunger k cuts out the three resistance steps and the motor attains full speed. The rapidity of stepping up of the plunger is controlled by the adjusting point of the resistance h. When the movement of k is completed, the shunt around h is opened automatically, making the holding current through coil i small. The motion of the plunger k is steadied by the action of a piston in a vacuum chamber and this action permits a slow regular advance. After the plunger brings the motor up to full speed on point o, it also makes contact with point q. A circuit is now established through the alternator field winding as follows: the positive line to point o, through plunger k to point q, thence through the alternator-field rheostat r to the inner slip ring, through field windings s and outer slip ring to coil g and negative line.

Speed control of the motor, and consequently of the frequency of the alternator, is accomplished by varying the motor-field rheostat e. The alternator-field rheostat r serves to control the current through the alternator field s and the voltage at the terminals t.

The weight of the plunger inside coils g and u of the overload relay normally keeps the lever of switch j down against the lower contact. The control circuit is then complete and is in its normal operating condition. Should the current through coil g become excessively large, due

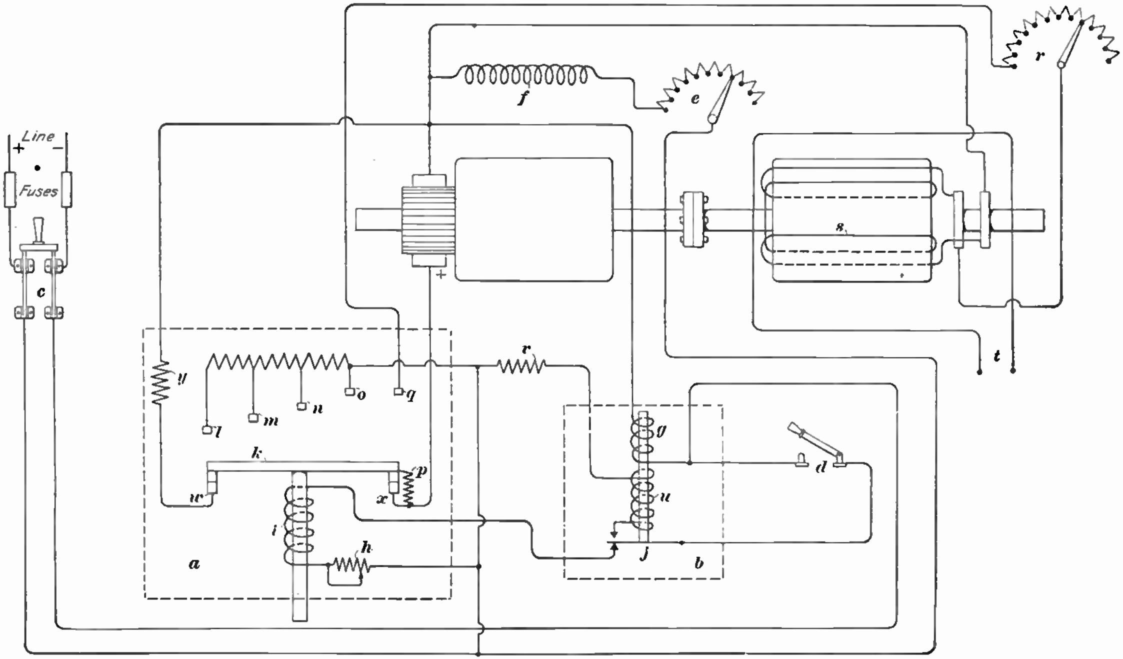

FIG. 36

to overload or other unnatural condition, the iron plunger will be drawn up, by increased electromagnetic action, thus opening the lower switch contact of *j* and closing the upper contact of the same switch. Opening the lower contact of *j* opens the circuit through coil *i*. The plunger *k* then falls and opens the motor armature circuit. The closing of the upper contact of switch *j* energizes coil *u* in the circuit established through the positive line, resistance *v*, coil *u*, upper contact of switch *j*, control switch *d*, and to the negative side of the supply line. This serves to hold the lever *j* on its upper contact until control switch *d* or switch *c* is opened, thus preventing restarting until the trouble can be investigated and corrected.

When the control switch *d* is opened to stop the motor, the coil *i* is deenergized and plunger *k* opens the armature circuit in practically the same way as has just been described. In either case plunger *k* falls across contacts *w* and *x* and makes a low-resistance path between them. A circuit is now closed through the positive armature terminal, contact *x*, plunger *k*, contact *w*, resistance *y*, to the negative armature terminal. As the motor field is excited and the armature will continue to rotate due to inertia, an electromotive force will be generated, sending considerable current through the resistance *y*. This will provide a dragging load on the motor armature and bring it to a quick stop. The three-step starter is particularly desirable in starting large motors, and in giving an acceleration more uniform and steady than would be possible if fewer steps were used.

The current through the control switch *d*, Fig. 36, is only enough to excite the coils *i* and *u* and is so small that an ordinary snap switch or push-button switch can be used. The switch can be located at any convenient point near to or remote from the starter. For example, such a starter can be located near its motor and controlled by means of a small hand-operated switch some distance away. Closing the switch causes the relays to operate and start the motor; opening the switch causes the relays to open and stop the motor.

RECTIFIERS

TYPES OF RECTIFIERS

A rectifier is a device that converts alternating current into pulsating direct current. The following types of rectifiers are commercially used: (1) Hot cathode (high vacuum); (2) Hot cathode (gas arc); (3) Electrolytic; (4) Gas tube; (5) Contact; (6) Mercury arc; (7) Mechanical, (*a*) Synchronous, (*b*) Vibrating.

The action of any rectifier is more easily understood when referred to a mechanical analogy. For all practical purposes, the old-fashioned bellows with its intake valve will serve to illustrate the action of a rectifier. Here an oscillating motion of the handles produces an intermittent or pulsating flow of air through the nozzle. This unidirectional flow is controlled by means of the intake valve. This valve offers little or no resistance to the flow of air into the bellows when the handles are expanded, but when the handles are compressed, the valve closes and offers a high resistance to the outward flow of air through the valve.

This valve action in electrical circuits is accomplished in several ways, which will be described under the individual types listed.

HOT CATHODE (HIGH VACUUM)

Half-Wave Rectifier.—The hot cathode (high vacuum) type of rectifier, better known as a kenotron, consists of a filament and a plate, properly arranged, and enclosed in an evacuated container. The smaller types are somewhat similar in external appearance to a medium-sized electric-lamp bulb. Other types are made in various shapes and sizes. Information on these tubes will be found in another Section.

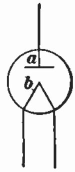

FIG. 37

The internal connections of a kenotron are schematically shown in Fig. 37. The plate *a* is made of molybdenum, nickel, or some suitable alloy and is usually of a cylindrical shape. This plate surrounds the filament *b*, which is usually made of tungsten or a combination of tungsten and thorium, the latter having a better operating efficiency. The size, shape, and spacing of these elements depends on the amount of voltage that will be applied across the plate and filament, and also on the amount of power that the kenotron is intended to furnish. The action that takes place in a kenotron is explained by the electron theory. An electron, by definition, is a minute but highly active particle of negatively charged electricity. Most metals when heated give off electrons. This emission of electrons is improved when certain metals are used or when the metal is placed in a vacuum. The electrons are thrown off at high velocities and in quantities that increase in proportion, up to a certain point, with an increase in temperature of the metal.

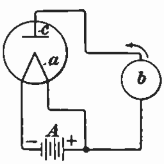

FIG. 38

The electron flow, from the heated filament to the cold plate, in a kenotron, can be best illustrated by a circuit such as is shown in Fig. 38. Here, the filament *a* is heated by a battery, known as the *A* battery. The positive terminal of the battery is also connected through a milliammeter *b* to the plate *c*. As the electron has a negative charge and the plate, in this instance, a positive charge, a large number of the electrons emitted by the filament will be attracted to, and impinge upon, the plate, causing a current between the plate and the filament in the direction indicated by the arrow. This current is opposite to the direction of the electron flow.

If the plate is negative with respect to the filament, that is, the plate return connected to the negative side of the battery, the electrons emitted by the filament will not be attracted by the plate and little or no current indication will be obtained on the milliammeter. If, however, the filament is heated to a greater degree, some stray electrons will collide with the plate by pure accident and produce a slight current as a result. In Fig. 39, *a* represents the tube, *b* the plate, *c* the filament, *d* the milliammeter, *A* the filament heating battery, and *B* the plate battery, which has been added. The plate milliammeter *d* in this case will indicate a larger current than when the *B* battery is omitted, as in Fig. 38.

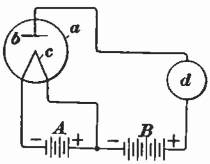

FIG. 39

With the addition of a plate battery, as shown in Fig. 39, many or all of the electrons emitted by the filament will be attracted to the plate because of its higher positive potential with respect to the filament. Now, if the plate battery is reversed so that the negative terminal is connected to the plate, there will be little or no indication of plate current, since the negative charge on the plate tends to repel the electrons emitted by the filament. It should be noted, that electrons are emitted by the heated filament and flow in one direction only, namely, from the filament to the plate, giving the required valve action.

With the conditions of unilateral conduction, as just explained, it follows that if an alternating voltage is applied across the filament and plate, the plate will be positive for one-half cycle and a current will result. During the other half cycle the plate will be negative and there will be no current. In Fig. 40 (*a*) is shown the circuit and in (*b*) the applied voltage curve and the rectified current curve. An alternator *a*, view (*a*), supplies a sine-wave voltage between the filament *b* and the plate *c* of the tube *d*. The filament of the kenotron is heated by the *A* battery. The voltage and current wave shapes are best checked by a very sensitive galvanometer vibrator in an oscillograph represented at *e*. The applied voltage and the resulting direct current are indicated in view (*b*). The negative half of the cycle is entirely cut off, thus producing a pulsating direct current. This is known as a *half-wave rectifier*.

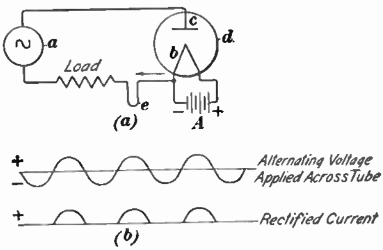

FIG. 40

Full-Wave Rectifier.—If another rectifier of the kenotron type is connected with this tube in such a manner that, during the interval that one tube has a negative potential on its plate, the other has a positive potential, a *full-wave rectifier* is the result. In Fig. 41 (*a*) are shown the connections of the two tubes. The alternator has been replaced by a transformer *a*, the secondary coil of which has a neutral, or mid tap, *b*. The kenotrons are shown at *c* and *d*. Both of

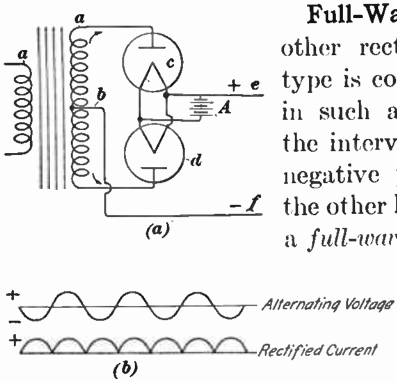

FIG. 41

the filaments are heated by the *A* battery. Suppose that for one alternation the potential on the plate of tube *c* is positive, then there will be a current in this tube. At the same time on the other end of the transformer winding and on the plate of the tube *d*, a negative potential will exist, which means that no current will flow in tube *d*. This action is reversed during the next alternation, and there will be current in tube *d* and no current in tube *c*. Each kenotron plate is positive once during a cycle for full-wave rectification of single-phase alternating current, as shown in view (*b*). Both half waves of the voltage curve serve to supply direct current to the apparatus connected to terminals *e* and *f*. The two halves of the secondary coil of the transformer alternate in supplying current to the rectifier.

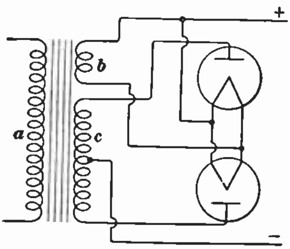

FIG. 42

In Fig. 42 is shown a full-wave rectifier completely operated by alternating current, through a transformer. The alternating line voltage is applied to the primary coil *a*, the filament heating current is obtained from the portion *b* of the secondary coil, and the high voltage for the plates, from the portion *c* of the secondary coil. The resulting wave shape of current is similar to that indicated in Fig. 41 (*b*).

For the rectification of higher voltages, larger transformers, insulated to withstand the high voltages must be employed and the kenotrons constructed accordingly. Kenotrons capable of rectifying voltages up to 100,000 and supplying currents as high as two amperes are in commercial use. Where a great amount of power is required, several kenotrons are connected in parallel.

Kenotron rectifiers may be connected to work on multiphase circuits, producing a fairly smooth and uniform direct current that is easily filtered.

HOT CATHODE (GAS ARC)

Hot cathode (gas arc) rectifiers are commercially known as Tungar or Rectigon rectifiers. The Tungar bulb as shown in Fig. 43 consists of an evacuated glass bulb *a*, a graphite-button plate that forms the anode *b*, a closely wound spiral of fine tungsten wire that forms the filament, or cathode, *c*, and an ordinary Edison lamp base *d*. This base permits convenient connection to the terminals of the filament, while a short projecting wire *e* forms a terminal for the connection of the plate supply, by means of a clip. After the bulb has been evacuated to the highest possible degree, it is filled with an inert gas, such as argon, at low pressure.

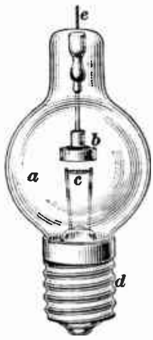

FIG. 43

This type of rectifier has been designed, in some cases, to furnish current up to 25 amperes at voltages not exceeding 25. The reason for the high current at low voltage is explained by considering the action of the tube. During the interval that the anode is positive, the electrons emitted by the incandescent filament *c* are attracted toward the anode, or disk *b*, by the voltage impressed across the tube. In passing from the filament (cathode) *c* to the plate (anode) *b*, the electrons collide with the molecules of the gas, ionizing them. This *ionization by collision* makes the gas conductive in the direction of anode to cathode.

While the plate is negative, on the other half of the cycle, any electrons that are emitted by the filament will be repelled by the charge on the plate, so that ionization does not occur and a high resistance path is established during that half of the cycle.

The tungar rectifier is used chiefly in storage-battery charging appliances, for which it is particularly suited. The same principles of operation apply to the tube, whether it is used as a half-wave rectifier, Fig. 44, or in a full-wave rectifier, Fig. 45.

In the circuit shown in Fig. 44, the tungar bulb is shown at *a*, having a filament *b* and a plate *c* connected, as indicated, to a suitable transformer *d*. When the side *e* of the secondary coil of the transformer winding is positive, the current will be in the direction indicated by the arrows; that is, through the load and bulb, and back through the

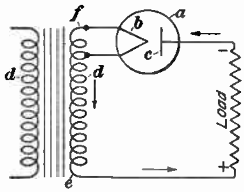

FIG. 44

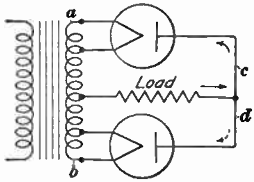

FIG. 45

side *f* of the secondary coil of the transformer. When the alternating-current supply reverses and the side *f* becomes positive, no current flows through the tube.

Full-wave rectification is accomplished by using two half-wave bulbs connected as shown in Fig. 45. When the side *a* of the secondary coil of the transformer is negative, side *b* will be positive, and a current will be established through the load and branch *c*, as indicated by the solid arrow. During this half cycle no current will flow through the branch *d*.

When the alternating-current supply reverses, side *b* becomes negative and a current will be established through the load and branch d, as indicated by the dotted arrow. No current will be in branch c during this half cycle.

The silvery-gray appearance of tungar bulbs is caused by the condensation of the gas purifying agent, magnesium. This is introduced into the bulb to react with any impurities in the argon since the presence of a very small amount of impurity produces a rapid disintegration of the cathode and has a noticeable and harmful effect on the voltage characteristic of the tube.

ELECTROLYTIC RECTIFIERS

If an electrode of aluminum and an electrode of lead are suspended in a suitable electrolyte and a voltage impressed on these two electrodes, a film will form on the surface of the aluminum. This film will offer a high resistance to the current. Thus, if an electrolytic cell consisting of an aluminum anode and a lead cathode immersed in a solution of borax is subjected to an electromotive force, a momentary current will flow but will rapidly decrease and finally reach a low value due to the formation of a coating of aluminum hydroxide on the anode. This operation is dependent on the rate of formation of the oxide film.

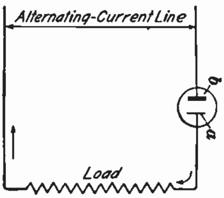

FIG. 46

If the polarity of the impressed electromotive force is reversed so that the aluminum is the cathode and the lead is the anode, the current will be maintained as long as the voltage applied is above a certain minimum. It is seen then, that the cell offers high resistance in one direction and a low resistance in the other. In order to utilize this valve action as a rectifier, a cell is connected as shown in Fig. 46, where the aluminum electrode is shown at a and the lead electrode at b. If a high current is desired, several cells are connected in parallel as shown in Fig. 47, and if full-wave rectification is desired, they should be connected as shown in Fig. 48. The aluminum-lead rectifier is easily made and comparatively cheap. There are several serious disadvantages that limit the use of the aluminum-lead type rectifier.

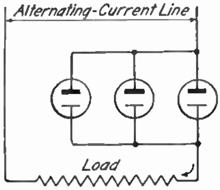

FIG. 47

When first made or if allowed to stand idle, the oxide film is not present, or is impaired by chemical action. To renew the cell it is usually necessary to reform the film by passing a current through it. The maximum voltage applied to a cell is limited by sparking between the electrolyte and the anode through the oxide film.

Another disadvantage of this cell is its high internal resistance. In use, the high resistance of the electrolyte produces a large I^2R, or power, loss which heats the cell and increases the chemical reaction between the electrolyte and the aluminum on the electrode, thereby shortening its life.

A second type of electrolytic cell is found in the tantalum-lead rectifier, employing a solution of sulphuric acid of approximately the same specific gravity as is used in storage batteries. The resistance of the sulphuric-acid solution is low and, therefore, the I^2R loss in this cell is reduced. The corrosive action of the acid solution on tantalum is much less than the similar action existing in the aluminum cell. The formation of the necessary valving oxide film is much more rapid in the tantalum cell and therefore it requires less care.

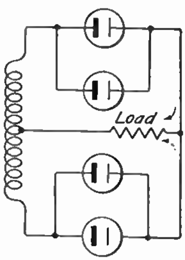

FIG. 48

A commercial tantalum rectifier is made, consisting of an electrode of tantalum and one of lead or lead peroxide immersed in a solution of sulphuric acid. A transformer is furnished to reduce the line voltage to a suitable value. The theory of operation is similar to that of the aluminum-lead rectifier.

GAS-TUBE RECTIFIER

The theory and proof that current easily conducted through a gas at very low pressures gives rise to the existence of a gas-tube rectifier. This type of tube has no filament and operates purely on the principle as stated above. In Fig. 49 (*a*) is illustrated the *point-plane construction* within the tube When the plane *a* is negative an

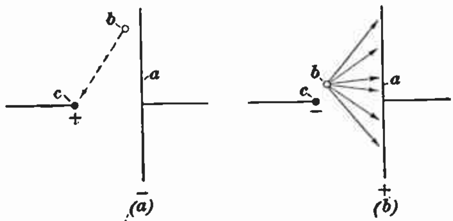

FIG. 49

electron *b*, forced out by applied voltage, is almost immediately attracted to the point *c*. In passing to this point, or anode, it collides with other electrons and ionization occurs. This forms a very low-resistance path and current is established. The polarity of the elements is reversed in view (*b*). When an electron *b* is thrown off from the negative point *c*, it is attracted in a number of directions, and attains a much lower velocity than previously and therefore ionization by collision does not occur. The resistance to a current in this direction (from point to plane) is, therefore, quite high as compared with the reverse direction (from plane to point).

When the tube elements are connected as shown in Fig. 50 to an alternating voltage, this valve action would make the tube perform readily as a rectifier.

The chief advantage of this tube lies in the fact that the power ordinarily required to heat the filament of a kenotron is saved. The regulation of this type of tube is also very much better than a thermionic rectifier, owing chiefly to the absence of a filament.

Argon and neon are some of the gases that are used in this type of tube. It is extremely important that the gas be pure, since the presence of a very small amount of

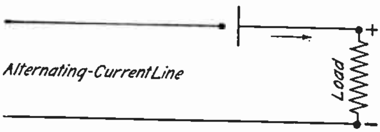

FIG. 50

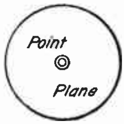

FIG. 51

impurity will impair the desired action. There is a considerable amount of heat generated by this type of tube when working at full capacity and this necessitates the degassing of the metalic elements in manufacture. Some of the tubes now sold commercially, like the Raytheon tube, have a cylindrical plate construction, Fig. 51, with vanes on the stem to increase the radiation and indirectly increase the life of the tube since stem leakage, or electrical leaks between the conductors in the stem, lessens the life of this rectifier. The tubes available are designed for voltages no greater than 500 and currents of less than .5 ampere.

MERCURY-ARC RECTIFIER

The mercury-arc rectifier utilizes the gas-arc principle in that its operation depends on the emission of electrons from a *hot spot* on a pool of mercury within an evacuated container.

Ionization caused by collision of the electrons and the molecules of the mercury vapor creates the required path of the unilateral conductance necessary for valve action. The source of electrons or hot spot on the mercury is caused and maintained by the plate current itself.

In Fig. 52 is shown the general shape of this type of rectifier, with the usual connections. The glass container, of peculiar shape, is shown at *a*, the cathode at *b* with the two carbon anodes, for full-wave operation, sealed in the arms of the tube at *c* and *d*.

In order to start the tube, a voltage is applied across the arms *b* and *e*, which contain separate pools of mercury and which have terminals sealed in the glass for external connections. This voltage is not sufficient to break down the gap between the pools of mercury, but if the tube is tipped slightly so that the two pools come in contact with each other, a current will pass through the mercury path. If the tube is righted again, the breaking of the contact between the separate bodies of mercury will create an arc. This arc is sufficient to ionize enough of the mercury vapor so that as soon as the primary of transformer *f* is closed, the voltage in the secondary winding will set up an arc between cathode *b* and anodes *d* and *c*, alternately.

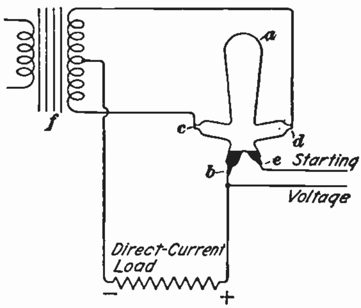

Fig. 52

The starting potential can now be cut off since the plate current of the tube under load will generate sufficient heat on the surface of the mercury pool *b* to maintain the proper emission of electrons.

A small inverse current from the mercury pool to the carbon anodes is always present and may increase to serious proportions with a reduction of vacuum or excess heat. The heat causes the glass to take on a coating of mercury which, if continued, soon creates a low-resistance short-circuiting path.

Small mercury-arc rectifiers are used for charging storage batteries. These have ratings from a minimum of 5 amperes to 30 amperes. The minimum current rating is required to keep the tube alive. Other sizes have been built, rated as high as 50 amperes. When the glass is replaced by a steel casing, the rating can be increased to 300 amperes. Voltage ratings have been obtained up to 6,000.

The regulation of this type of rectifier is very good, since the drop through the bulb does not change with the load. The efficiency of commercial rectifiers ranges from 80 per cent. to 90 per cent.

MECHANICAL RECTIFIERS

Vibrating Type.—The required valve action of a rectifier can be obtained mechanically by the use of a contactor or contactors operating in synchronism with the alternating current to be rectified. The contactor can be arranged to make and break the circuit at proper points on the wave, producing pulsations of current in the same direction. In the theoretical operation, the points are 180° apart, but owing to the inertia of the vibrating element a time lag occurs, which is compensated for by some special electrical or mechanical means so as to cause the contact points to open and close at the proper moments.

Single, or half-wave, rectification can be obtained with an arrangement shown schematically in Fig. 53. The primary coil of a transformer *a* is connected to an alternating current line. The secondary coil, acting through the contactor *b*, vibrates so as to cut off the negative half of the cycle, and allow the positive half of the voltage cycle to be impressed on the load *c*.

Full-wave rectification is obtained by using a circuit arranged as shown in Fig. 54. Here, the secondary coil of the transformer *a* is tapped at the middle point, which is connected through the load to vibrator *b*. The outer ends of the winding are connected to the contacts *c* and *d*. The vibrator *b* makes connection with contact *c* when that

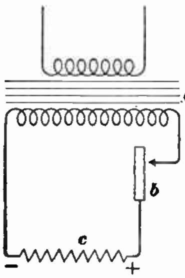

FIG. 53

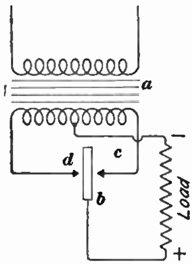

FIG. 54

side of the transformer is positive, and with contact *d* during the other half of the cycle when the other side of the transformer is positive.

The action of the contactor is explained by considering that it consists of a vibrating element, of magnetic material, placed in the field of a permanent magnet. This element is actuated by the superimposed alternating field established by and in synchronism with the voltage to be rectified. The permanent magnetic field polarizes the vibrator element and the alternating field exerts the actuating force. By a mechanical arrangement of springs, the vibrator element is free from both contacts when the rectifier is not in use.

The permanent magnetic field, in the majority of rectifiers, is obtained by the use of a U-shaped permanent magnet. The vibrator element is supported in this field by means of a spring that is clamped at one end. The vibrating system is usually constructed so as to have its natural period of vibration occur at approximately the frequency at which it is intended to work. This is accomplished mechanically and magnetically in commercial rectifiers.

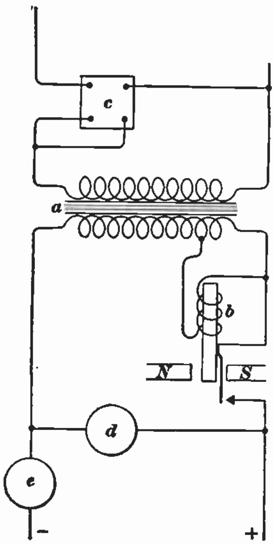

FIG. 55

In Fig. 55 are shown more nearly the actual conditions existing in a commercial half-wave rectifier. The current supply is obtained from the transformer *a*, and a small alternating current is obtained by connecting a few turns of the secondary coil to the vibrator solenoid *b*. The vibrator has, then, an alternating field of its own and is caused to vibrate by the attraction or repulsion of the field set up between the north and south poles of the permanent magnet. The maximum operating efficiency of this type of rectifier is low. Instruments for obtaining this measurement are the wattmeter *c*, the voltmeter *d*, and the ammeter *e*.

Vibrating rectifiers are used chiefly in battery charges for automobile and radio use and in railway work for charging signal batteries. Commercial rectifiers are built capable of delivering current up to 5 amperes at approximately 12 volts. The voltage drop across this type of rectifier is practically negligible. The only objection to the operation of the vibrating rectifier is the necessity of close adjustment of the contacts. Continued sparking, due to poor adjustment, at these points will burn the small silver and carbon contacts, or cause them to stick.

Synchronous Rotary Type.—Rotary rectifiers are driven by synchronous motors. A synchronous motor is one that operates at approximately one speed regardless of the load, within reasonable limits. This speed is said to be in synchronism with the frequency of the operating voltage. In other words, the speed of the motor in r. p. m. (revolutions per minute) is some multiple of the frequency of the applied voltage.

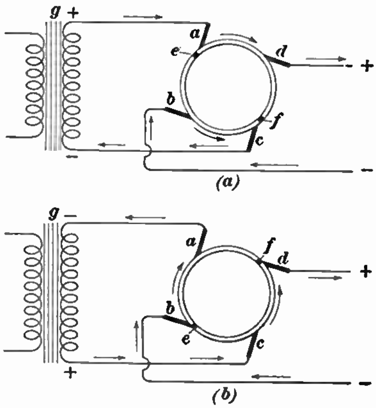

Fig. 56

Attached to the shaft of the motor is a wheel, Fig. 56, of bakelite or some insulating compound with segments of brass or copper imbedded in the rim, and insulated from each other with a gap between their ends. Four copper brushes *a*, *b*, *c*, and *d* are arranged to bear upon brass segments on the periphery of the wheel. The gaps *e* and *f* between the segments are made as small as possible consistent with the prevention of flash over of the high voltage applied across them.

In view (*a*) the transformer *g* has just become positive on the upper end of the winding, making brush *a* positive, and brush *c* negative, since brush *c* is connected to the other end of the transformer winding. The brushes *b* and *d* conduct the rectified current to the load.

Now, assuming the speed of the motor to be 1,800 revolutions per minute, the disk will make 30 revolutions per second or one revolution in $\frac{1}{30}$ of a second. Since the alternation, or period, during which brush *a* is positive lasts for $\frac{1}{120}$ of a second (the supply being 60-cycle), it is seen that the wheel will make $\frac{1}{4}$ of a revolution during this time. This brings the segments in a position with respect to the brushes as shown in view (*b*). But the voltage on the transformer has reversed, making brush *a* negative and brush *c* positive. The direction of the current through the load is still the same as before and the rectification is complete for one cycle. This action is rapidly repeated, alternating current being fed to the two brushes of the wheel and a pulsating direct current taken from the other two.

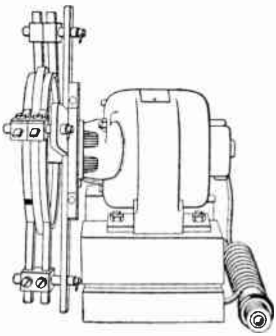

FIG. 57

There are several types and sizes of these rectifiers. The fundamental principle of operation, however, is similar to the explanation given. The synchronous rectifier has found its greatest application in transmitting work, especially the amateur transmitters. Synchronous rectifiers have the particular advantage of being rugged, of having no glass to break and no electrolyte to spill, they are simple and easily operated, and require little or no attention. The chief objection to the use of this type of rectifier is the radio interference that results from sparking as the brushes pass the gaps in the wheel, and the difficulty encountered in filtering the output.

The nature of the load, whether it be reactance or capacitance, affects, in a great measure, the operation of the synchronous rectifier. Since an inductive load will tend to maintain the current when the contact breaks, a destructive lagging arc follows the break. With a capacitance load, there will be a spark from the approaching segment to the brush, since the voltage stored in the condenser from the last impulse is greater than the incoming transformer voltage at the beginning of the alternation.

A commercial type of synchronous rectifier is shown in Fig. 57. These commercial rectifiers have ratings up to 6,000 volts at approximately three-tenths of an ampere.

CONTACT RECTIFIER

The contact rectifier obtains the requisite valve action in a manner similar to the electrolytic rectifier with the exception that no electrolyte is used. The rectifier action takes place between two dry disks of unlike metals, one of which has the unidirectional low-resistance path and the other is conductive in either direction. In practice the first metal disk mentioned consists chiefly of copper specially treated, forming certain copper compounds on one side, which will pass current easily in one direction but offers a high resistance to current in the reverse direction. The other disk is usually made of magnesium, which, like the lead electrode in the electrolytic cell, will conduct current equally well in both directions.

At present, there is no proved and accepted theory explaining how the contact rectifier functions. For that matter, the explanation of the action of the crystal detector and the aluminum-lead cell has yet to be conclusively proved. The engineering world, in general, has discovered and used these particular properties for some time, with but a small interest in a satisfactory explanation of how or why.

The allowable voltage per cell, like the aluminum-lead cell, is low. If a certain maximum voltage is exceeded, the life of the cell decreases rapidly in proportion to the value of the applied voltage. For this reason, the number of cells is increased to an amount sufficient to handle safely the voltages expected in operation.

This type of rectifier has been used in railway work for some time and recently a commercial trickle charger has been offered. In order to obtain high voltages for plate supply, a number of cells in series is required, since the rectified voltage that each cell is capable of delivering is very small.

There is a considerable voltage drop occurring across these cells, due to the internal resistance, which tends to heat the unit. Excessive heat is detrimental to the action of the contact rectifier, although its normal performance is accompanied by a slight rise in temperature.

CHARGING DEVICES

The popularity of radio has led to the design and manufacture of numerous types of small portable storage batteries. The trickle charger has become very popular since, with the reduction in size and ampere-hour rating of the battery, a continuous charge of a small amount is sufficient to keep the battery ready for use.

For general charging purposes of automobile and radio batteries, the types of chargers in the order of their use are (1) Tungar or Rectigon; (2) Electrolytic (Tantalum); (3) Mechanical (Vibrating); (4) Contact.

The first three chargers mentioned have been manufactured in two types, one of which is capable of delivering several amperes for charging and the other is capable of supplying a small current just sufficient to keep the battery fully charged. This last type is known as a trickle charger. The contact rectifier has been manufactured and sold as a unit for trickle-charge purposes.

The general assembly and connections of a charging device are given in Fig. 58. The transformer *a* is simply a means of reducing the line voltage to the required potential

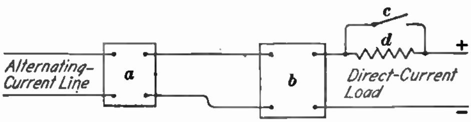

FIG. 58

suitable for the operation of the rectifier *b*, which may be any of the types mentioned. In some cases the full charge and trickle rates are obtained from the same unit by the insertion of a resistance in the battery circuit as shown in Fig. 58. When the switch *c* is closed, the full output of the rectifier is applied to the battery for full charge. If the switch *c* is opened, the resistance *d* is introduced into the circuit, cutting the current down to a very small amount for trickle charge.

One type of Tungar charger is shown in Fig. 59. These chargers are able to charge three cells at a 2-ampere rate, or 48 cells at .25-ampere rate. For charging 3 cells

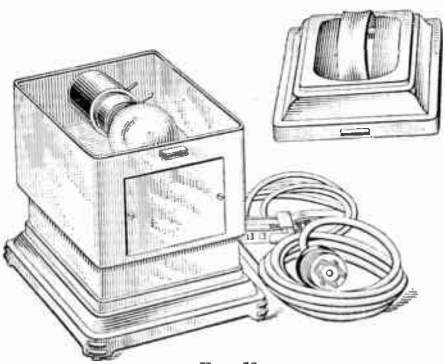

FIG. 59

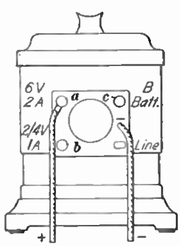

FIG. 60

at 2 amperes or six cells at 1 ampere, connect the positive lead to terminal *a*, Fig. 60. For charging one cell at

1 ampere or two cells at 1 ampere, connect the positive lead to terminal *b*. For charging twelve to forty-eight cells of *B* battery, connect the positive lead to terminal *c* and a 110-volt lamp in the charging lead.

BATTERY ELIMINATORS

A-Battery Eliminators.—The advent of the several types of so-called battery-driven power tubes has increased the drain upon the batteries so that despite the high quality of the standard makes of batteries, it becomes an economic question when the frequent replacement of batteries is considered.

Since the advent of multitube sets, in attractive cabinets designed to take a prominent place in the household furniture, there has been a demand for battery eliminators, and numerous types of *A*-, *B*-, and *C*-battery eliminators in separate or complete units are now available.

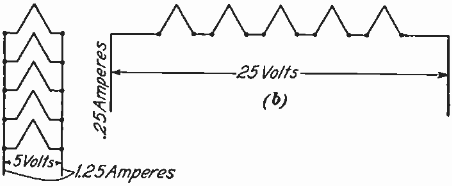

FIG. 61

The elimination of the *A*, or filament-heating, battery has been by far the most difficult problem, since the current is high and the voltage is low. There are several commercial types of alternating-current *A* batteries designed to furnish filament current to multitube sets, using the UX-201A type of tubes, connected in parallel. Rectifiers of the Tungar type are used in many of these outfits because of the low voltage and high current needed for the operation of the filaments connected in parallel.

In Fig. 61 is shown the difference in current requirement when the tubes are connected in parallel, as shown in view (*a*) or in series, as shown in view (*b*). The higher the potential and the lower the current the easier the task of filtering the supply becomes. For this reason, one of the manufacturers has designed an *A* eliminator to operate sets with the filament of the UX-201A tubes connected in series as shown at (*b*). In this case, the total current rectified has been reduced to .25 amperes with a decided reduction in the filter size and cost. It is to be noted that the direct-current power required at the load, instead of being in the neighborhood of 5 volts at 1.25 amperes, is now 25 volts at .25 amperes. Going still further, a satisfactory arrangement for supplying filament current to a radio set using seven tubes is accomplished by using tubes of the UX-199 type, connected in series and shunted by small protective resistances, as shown in Fig. 62. The energy required to operate these filaments is approximately .07 ampere at 25 or 30 volts This last arrangement, then, reduces the filtering problem to such an extent that it is easily accomplished without the use of a costly filter of considerable proportions. The rectifier used in this eliminator is a full-wave connection of two kenotrons, which furnishes current for the *B* and *C* supply for the radio set as well as plate potential for a power amplifier for a complete alternating-current operated loud speaker in combination with the radio set. By using a power unit designed for a heavy duty rectifier, it is possible to obtain all the operating energy from one power unit.

FIG. 62

The perfection of several inexpensive types of storage batteries combined with trickle chargers of the tungar or electrolytic type, has greatly reduced the field of application of alternating-current *A* batteries. The elimination of the *B*, or plate, battery is comparatively easy and economical in contrast with *A*-battery elimination.

B-Battery Eliminators.—Eliminators for the *B* battery are in common use and consist of a rectifier and a filter system. The rectifiers fall within three general classes: (1) Kenotrons; (2) Gas tube; (3) Electrolytic. The action of all of these types of rectifiers has been explained previously.

The earliest types of eliminators used the ordinary three-element tubes of the 201-A type with the grid and plate connected together as kenotrons, but their life was short, since they were not designed to be used as rectifiers delivering plate currents of 20 or 30 milliamperes. Since the recent popularity of *B* eliminators, several types of the rectifiers mentioned have been produced for this class of work. For example, there are several gas-tube rectifiers available at present. A full-wave kenotron in a single bulb has been developed and incorporated in a commercial *B* battery. This tube has two filaments and two plates with the proper connections brought out of the base. A number of electrolytic *B* batteries are now on the market in convenient and quite safe forms considering the presence of a liquid.

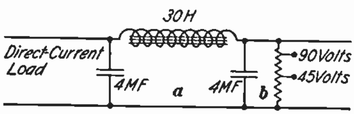

FIG. 63

The voltage output of the rectifiers must be sufficient to overcome the resistance losses in the filter and still furnish sufficient potential and current to supply the tubes of the radio set.

Some *B* eliminators for use on direct-current mains are available and are simple in construction. In Fig. 63 is shown the simple filter *a* consisting of two 4-microfarad condensers and an inductance coil of 30 henries and the tapped potentiometer *b*. Line noises and commutator ripple may vary and the filter system may not always be sufficient.

Filters.—The output of a half-wave rectifier can be filtered, but when the rectification is full-wave, the filtering is much easier, since the frequency of the positive pulsations has been doubled. This follows, since, with an increase in frequency, the tuning of filters becomes much sharper and at radio frequencies, filters can be made to include a very small band, which, however, is not so easily accomplished in the audio-frequency band.

The action of a simple filter can be explained without the usual involved mathematical analysis by referring to Fig. 64. Direct current will not pass through a condenser but an alternating or pulsating current will. In the figure, the output of the rectifier is shown as being made up of a straight arrow representing an average value of direct current having superimposed on it a pulsating current represented by the peculiar-shaped arrow. Now, an iron-core inductance offers considerable resistance to any change of current and therefore the choke coil *a* will offer more resistance to the pulsating current than the condenser *b* and consequently most of the pulsating current, or ripple, takes the shorter path back to the rectifier. The remaining ripple that manages to get past the choke coil tends to pass down through condenser *c*. This type of filter section is known as the π section and if more than one section is used the action as just explained is repeated with a more complete elimination of the ripple from the direct-current supply. These filters are known as multistage filters.

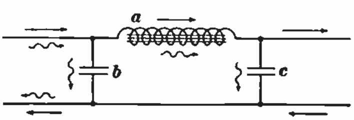

FIG. 64

Filters may be classed in three general groups: (1) Low-pass filters; (2) high-pass filters; (3) band-pass filters.

The names are self-explanatory and indicate their functions. Some of the filter systems used in commercial eliminators with their constants are shown in Fig. 65 (*a*) and (*b*).

Voltage Regulation.—The application of a gas tube containing the point-plane construction with the point mounted in the middle of a cylindrical metal plate, accomplishes two definite purposes.

An eliminator designed to furnish B supply for a six- or eight-tube set would furnish too great a voltage for a two-tube set, since the voltage depends on the load.

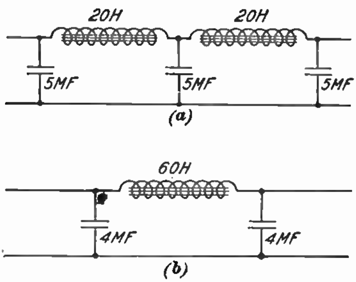

FIG. 65

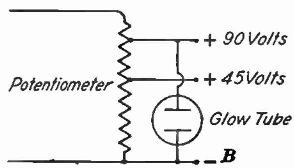

FIG. 66

The regulation of some rectifiers under varying loads is poor, but the glow tube automatically takes care of this fault since, when the eliminator is turned on, the voltage across the potentiometer from $-B$ to $+90$, Fig. 66, rises to 125 volts but when the tube breaks down, that is, the gas ionizes, the drop in voltage across the tube is then 90. The extra current passes through the tube and when the load demands more current the glow tube will automatically supply it, since it is serving as a reservoir of current. The regulation of the tube itself is about 10 volts with a current variation of from .05 to .01 ampere through it.

Another feature of the tube is its equivalent condenser action in by-passing a large percentage of the ripple that gets as far as the potentiometer.

This regulation of voltage could be accomplished by manually operated potentiometers, but with a considerable amount of trouble and uncertainty as to the exact voltage obtained.

Testing.—To prevent the possibility of broken down condensers and short-circuited resistors, the Raytheon Manufacturing Company suggests that these units be tested before assembly. The test may be made with a telephone receiver and dry cell, connected in series, with the two free leads touched to condenser or resistor terminals. A good condenser will give a fairly loud click the first few times the test terminals are applied, after which the click may grow fainter. In the smaller capacities, the click is soon rendered inaudible. Short-circuited condensers will be detected by a loud click each time the test terminals are applied. Short-circuited resistors will provide an excessively loud click which may be as loud as when the test terminals are touched together.

The resistors in the voltage divider, or potentiometer, have a tendency to become fairly warm at full load. If a hot spot should be observed on any of these units it is an indication of an overload or a short circuit in the load connected beyond this resistor. An inspection should be made to determine the cause of this trouble and it should be cleared at once.

Caution.—A battery eliminator, or power unit, is capable of delivering a high voltage with enough power to give a disagreeable shock. Therefore, when working on the power unit or on the receiver to which it is connected, the line current should first be disconnected. It is also good practice to discharge the condensers by shorting the terminals of the power unit after the supply has been shut off. In this way there is no danger of shock.

Operating Hints.—When the power unit supplies only the *B* and *C* voltages to a receiving set, it is advisable to light the filaments of the receiver before turning on the *B* or *C* power. Similarly, the *B* power is turned off before turning off the filaments. It is only when the receiver tube filaments are turned on that the energy from the power unit is safely dissipated. Otherwise, added strain is thrown on the power unit as well as on the receiver tubes, resulting in shortening the life of the equipment and even causing serious breakdown. An automatic relay switch may be used for shutting off the power supply and filament current in a safe manner.

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Vol. II

Radio Tubes and Antennas

RADIO TUBES

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PREFACE

Radio Tubes and Antennas, subjects apparently unrelated, are probably not exceeded in importance by any other individual items in the technical branch of radio communication. Radio tubes are the bases of all modern radio receiving and transmitting sets. Antennas are the connecting links between the radio equipment and the omnipresent conducting medium—the ether. They are the doors by which radio energy may leave or enter a radio station.

The authors have striven to present these subjects in a way that will help both the beginner and the more advanced worker in the radio industry to a better understanding of the principles involved. Progress in the radio industry is inevitable. But progress can come only through appreciation of present practice, through the ability to explain phenomena that have been observed, and, through the knowledge so obtained, to predict with reasonable assurance what results may be expected when new conditions arise.

INTERNATIONAL CORRESPONDENCE SCHOOLS

CONTENTS

RADIO TUBES AND ANTENNAS

RADIO TUBES

INTRODUCTION

The name *radio tubes* is not very scientific and yet it conveys the idea of tubes used in radio communication. Other names, such as *vacuum tubes, electron tubes, triodes, radiotrons, rectrons, valves,* etc., are used, but each of these covers a specific class of tubes. In this Section the theory and application of most of the tubes used in radio communication will be given, including one-element, two-element, and three-element tubes; the operating features of thermionic and gas-containing tubes will also be considered.

ONE-ELEMENT TUBES

Ballast Tubes UV-876 and UV-886.—One-element tubes are used, as a rule, in the power-supply units of radio receiving sets. They act as regulators and stabilizers of voltage or current, and as protectors in certain parts of circuits.

The UV-876 tube, shown in Fig. 1, is a one-element tube designed especially to maintain the supply current constant. The base *a* is exactly like that of an ordinary incandescent lamp. The filament *b* is made of iron wire and so designed in its various dimensions as to give the required voltage drop with the desired current at the critical filament temperature. The filament wire is suspended on mica disks *c*, which also act as separators for the many vertical strands of wire. Hydrogen has is employed in the bulb to provide the necessary voltage range with only a relatively small change in the current.

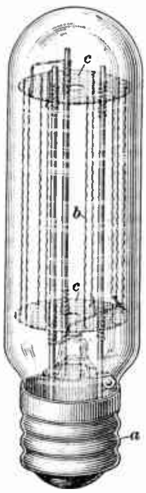

FIG. 1

Principle of Operation.—The peculiar operating characteristics of the UV-876 tube are due to the variations of resistance of the filament wire. The resistance of this wire increases as the temperature is increased. At certain temperatures iron wire changes its resistance by a large amount with a comparatively small change in temperature. One of the marked changes occurs at about 900° C., when the iron becomes dull red. The presence of hydrogen in the bulb prevents the decomposition of the wire at relatively high temperatures. The current rating of this tube is 1.7 amperes.

The main operating characteristics of the UV-876 radio tube are shown by the curve of Fig. 2. The current is plotted against the voltage over a considerable range. The useful operating range, where the regulation is best, is indicated by the portion of the curve lying between points *a* and *b*. A greater range of regulation could be secured in cases where it would be possible to let the current vary between wider limits. Because of the hydrogen gas in the bulb, a crack in the bulb may admit air, which produces an explosive gas mixture; hence the tube should be used only in a metal protective shield.

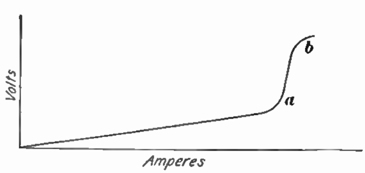

FIG. 2

Connections of UV-876.—The UV-876 ballast tube is connected as shown in schematic form in Fig. 3. The supply line, indicated at *a*, represents the usual electric service line terminating in an extension socket. The UV-876 tube *b* is next, and is connected in the circuit between the supply line and the special radio equipment *c*. The radio outfit, with the UV-876 tube, is designed to operate directly from alternating-current lines of from, say, 105 to 125 volts. When a higher input current is required the UV-886 ballast tube is used. If the line voltage varies from time to time, the regulator tube will maintain the current practically constant, and thereby insure stable operation of the radio equipment or receiver. The average characteristics of these and of the other more common receiving tubes are give in Table I.

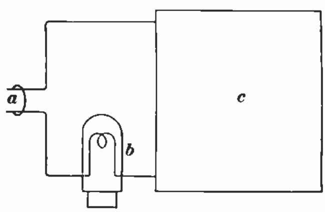

FIG. 3

TWO-ELEMENT TUBES

TYPES OF TWO-ELEMENT TUBES

Two-element tubes have, as the name implies, two active elements, or electrodes, both necessary for the conduction of electricity through the tube. The electrode from which electricity flows through the tube is called the *anode*, while that electrode to which the electricity flows is the *cathode*. All two-element tubes, when operating as they should, will conduct current in only one direction; namely, from the anode to the cathode.

There are two general types of two-element tubes; namely, those in which the operation is based on one heated element and one cold element, and those in which both elements are initially cold. Those with one heated element are called thermionic vacuum tubes; the others may be called non-thermionic tubes. Non-thermionic tubes are sometimes called *gaseous tubes*.

THERMIONIC TWO-ELEMENT TUBES

Theory of Two-Element Thermionic Tubes.—The thermionic two-element tube is dependent in its operation on one heated element that gives off electrons and one element with a positive charge to attract these emitted electrons. The two elements are placed in a bulb partially devoid of air and the connections to the elements are made by means of conductors carried through the stem of the bulb.

The operation of the tube may be best explained with the aid of the diagram of Fig. 4. In this schematic diagram the filament of the tube is shown at *a*, and the plate is at *b*. The filament is heated by current supplied by the filament battery, commonly known as the *A* battery. In series with this battery and the filament of the tube is a rheostat, or variable resistor, *c*, by means of which the filament current, and consequently the filament temperature, may be regulated.

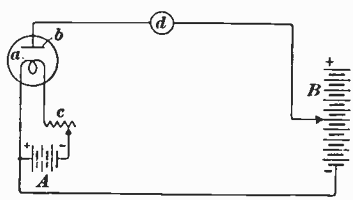

Fig. 4

The plate *b* of the tube is connected to the positive terminal of the plate battery, generally called the *B* battery, and so lettered in the diagram. A milliammeter *d* is connected in the *B*-battery lead, to show the amount of current in the plate circuit. The negative terminal of the *B* battery is connected to one of the filament leads, usually the positive.

The stream of negative electrons from the filament *a* to the positive plate *b* establishes an electron current, which is actually also an electric current and is indicated on the milliammeter *d*. However, the electron current, as produced by the electron stream, is from the filament to the plate, whereas the electric current is considered to be from the point of positive potential to the point with a more negative voltage. Since the electron current is in the plate circuit it is commonly called a *plate current*, in distinction from the current in the filament circuit, which is called the *filament current*.

Characteristics of Two-Element Tubes.—The heated filament *a*, Fig. 4, produces electrons at a rate that depends on the surface area of the filament, the material comprising the surface coating, the material of which the filament is made, and the temperature of the filament. Of these factors the last one is the only one that can be varied in the ordinary tube. The electrons leave the filament, and with no plate voltage, form a cloud around the filament very much as a cloud of water or steam particles is formed. The cloud, being formed of negatively charged electrons, acts to prevent the escape of any further supply of electrons from the filament.

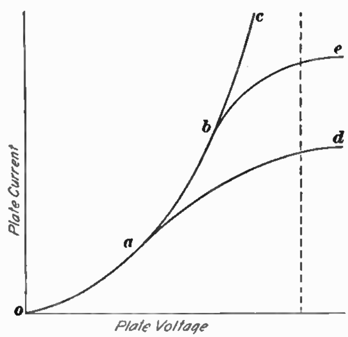

FIG. 5

A positive potential applied to the plate *b* attracts some of the electrons thereto, and produces a plate current. As the plate voltage is increased the plate current rises rapidly, as is indicated by the curve shown between points *o* and *a* in Fig. 5. The available electrons are all attracted to the plate when the plate voltage is raised to some higher value, as, for example, that indicated at the point of intersection of the lower curve and the dotted line. A still further increase in plate voltage will produce only a very slight increase in plate current. This is due to the fact that practically all the available electrons given off by the filament at that temperature are already collected by the plate and a further increase in plate voltage can collect only a few more electrons.

If the filament temperature is raised by a small amount the number of electrons liberated by the filament will be increased. Now as the plate voltage is raised the plate current will vary practically with the plate voltage up to the higher point *b* when the plate-current curve makes a sharp turn and reaches a nearly constant value at the point of intersection of the curve and the dotted line. Beyond this, the rise in plate voltage will cause only a minor increase in the plate current. If the filament temperature is increased to a still higher value, the number of available electrons will be increased so that a still higher plate current, through point *c*, will be secured. That is, as the plate voltage is raised from *o*, the plate current rise will give the curve through points *o*, *a*, *b*, and *c*. Any further increase in filament temperature would not appreciably alter the plate current envelope curve. With a higher applied filament voltage it would be possible to extend the maximum current curve above those shown, although such would probably be above the safe operating conditions for the tube.

When a tube is operated at such filament temperature and fixed plate voltage that an increase in temperature produces no increase in the plate current, the tube is said to show *temperature saturation*. On the other hand, when the temperature remains fixed and the conditions are such that an increase in plate voltage does not increase the plate current, the tube shows *voltage saturation.* Referring to Fig. 5, the curve *d* shows temperature saturation between *o* and *a* and approaches voltage saturation beyond the point *a*. Similarly, the curve *e* shows temperature saturation up to point *b*, and approaches voltage saturation beyond. The saturation values of the filament emission at the various temperatures are indicated by the dotted line.

Half-Wave Rectifier.—The two-element tube is best adapted for rectifier service. This is because of the fact that it will allow current to pass in only one direction, namely, when the plate is positive with reference to the filament. For rectifier service, the two-element tube may be connected as shown in Fig. 6. The primary winding *a* of the transformer connects with an alternating-current supply line. The secondary winding *b*, known as the filament winding, gives a low-voltage output for heating the filament of the rectifier tube. Another winding *c* supplies an alternating potential to the plate of the tube. Current passes in the plate circuit only when the plate is positive, so that the output is a direct pulsating current, having the polarity indicated by the + and − signs in the figure.

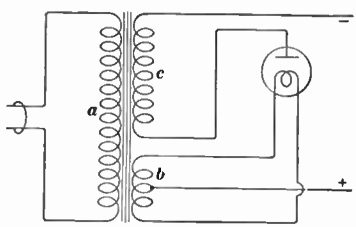

FIG. 6

Full-Wave Rectifier.—Two two-element tubes may be so connected in a circuit as to utilize both sides of the alternating-current supply. Such an arrangement is shown elsewhere. The output from the rectifier is thus virtually doubled and the shape of the output current wave is greatly improved.

Commercial Two-Element Thermionic Tubes.—Among the numerous commercial two-element tubes, radiotrons UX-213, UX-216-B, UX-280, and UX-281 are the best known. Radiotrons UX-216-B and UX-281 are half-wave rectifiers, and radiotrons UX-213 and UX-280 are full-wave rectifiers.

Radiotron UX-216-B is shown in Fig. 7. This tube is rated to operate from a 7.5-volt filament supply with a filament current of 1.25 amperes. The filament is made of thoriated-tungsten wire. The bulb is fairly large and is partly discolored in the process of manufacture. The base is of the large standard UX type with four pins, one of which is not used in the circuit connections. The maximum rated plate voltage is 550 volts (root mean square value), and the rectified output current should not exceed 65 milliamperes.

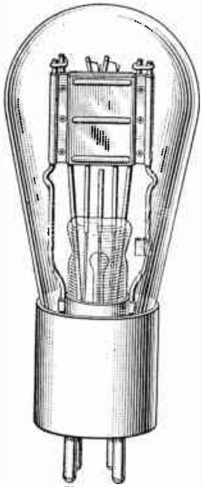
FIG. 7

Radiotron UX-281 is another half-wave rectifier tube of the oxide-coated ribbon filament type. The filament of this tube is very sturdy and gives unusually high emission. The plate has a specially treated surface, which causes rapid dissipation of heat. Its maximum output capacity is 110 milliamperes. Two radiotrons UX-281 may be connected to give full-wave rectification with an output of 220 milliamperes. This tube may be used in circuits designed for radiotron UX-216-B.

Radiotron UX-213, shown in Fig. 8, is a full-wave rectifier. This tube takes the place of two half-wave rectifier tubes. Its output current is 65 milliamperes at a potential of 220 volts a.c. on each of the anodes.

Radiotron UX-280 is an improved full-wave rectifying tube with an oxide-coated ribbon filament. This filament is extremely sturdy, both electrically and mechanically, and gives high emission with low power input. As in the case of radiotron UX-281, the plate of this tube has a specially treated surface, to be noted by its dark appearance, which causes rapid dissipation of heat. The maximum output of radiotron UX-280 is 125 milliamperes. All the rectifier tubes here described are used in the power-supply units of radio receiving sets.

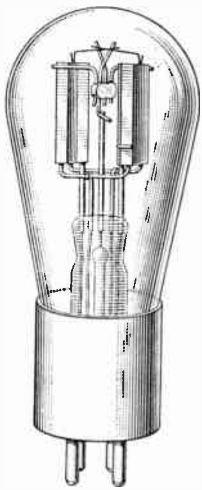

FIG. 8

NON-THERMIONIC TWO-ELEMENT TUBES

Principle of Operation.—A non-thermionic two-element tube operates without a filament. The action is due to the conduction of electricity through a gas at low pressure. The arrangement of the elements is as shown in Fig. 9, views (*a*) and (*b*) indicating side and top views, respectively. The anode *a*, view (*a*), consists of a fine wire carried in an insulating tube. Only the tip of this wire is exposed. The cathode *b* is a metal cylinder surrounding the anode *a*. The element structure is enclosed in a glass vessel in which there is present a gas at very low pressure. The gas must not be very active chemically, and its electrical resistance must not be too high; the characteristics of argon and neon make them suitable for this purpose.

If at a given instant the element *a*, view (*b*), is positive with reference to the element *b*, every free electron liberated by the cathode *b*, like that shown at *c* is attracted forcibly to the element *a*. In so doing it will collide with the atoms of gas with enough violence to remove some more electrons, with the net result that the gas becomes ionized and conduction takes place through the tube. The gas becomes deionized during the interval of zero voltage.

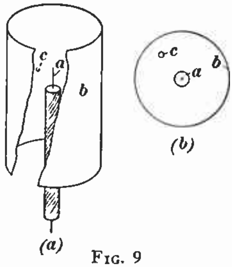

Fig. 9

When the voltage is reversed so that the cylinder *b* is positive, electrons will be liberated only from the anode tip. Because of its relatively small surface, the electron flow and consequent ionization from the anode will be smaller than from the cathode cylinder. For all practical purposes, the tube may be considered as a rectifier, allowing current to pass from the anode *a* to the cathode *b*, but not in the opposite direction. Distinction should here be made between the direction of flow of the electrons and the direction of the current.

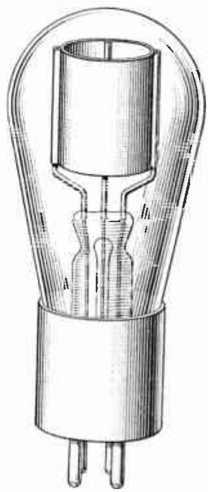
Fig. 10

Commercial Non-Thermionic Two-Element Tubes.—A rather unusual use of gas conduction is exemplified in the voltage regulator tube known as *radiotron* UX-874 and shown in Fig. 10. The tube is equipped with a standard UX base. The anode, or the center electrode, connects with one of the pins in the base, while the cathode, or the cylindrical structure, connects with another pin in the base. The remaining two pins are connected together and may be used for switching purposes in the device in which this tube is used.

Radiotron UX-874 is especially adapted for plate-voltage regulation in radio receiving sets, when such voltage is obtained from a so-called B eliminator. The tube is connected across the 90-volt terminals. When the eliminator is turned on the voltage goes higher (approximately 125 volts d.c.), ionization takes place, and a current is established through the tube. The output voltage will thereafter be maintained at very close to 90 volts.

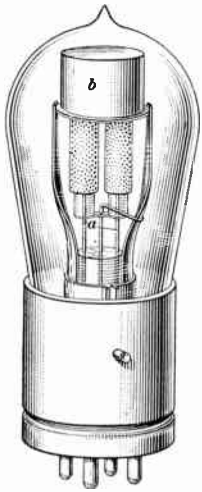

FIG. 11

The rectifying properties of a gas-filled tube are exemplified in the *Raytheon tube*. This is a full-wave rectifier tube, and is shown in Fig. 11. This tube has two anodes, one of which is active during each current reversal, The anodes *a* are introduced within the metal cap *b* through suitable insulating tubes, and only the points of these project within the cathode chamber. Four pins are shown in the base, but only three of these are used for electrical connections.

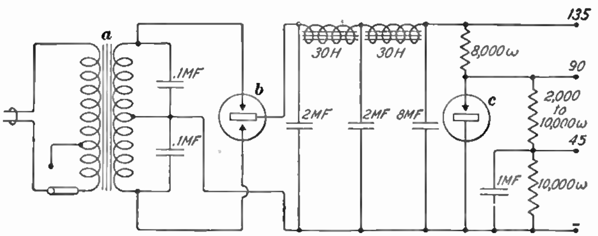

FIG. 12

Several sizes of these tubes are available for various types of rectifier service, varying in output from 125 to 400 milliamperes.

The use of the Raytheon rectifier tube and of radiotron UX-874 is exemplified in the B-eliminator circuit shown in Fig. 12. The energy from some outside source is transformed to the proper voltage value by the transformer *a* and impressed on the Raytheon tube *b*. The rectified energy passes through the filter system, consisting of choke coils and condensers, which results in the elimination of all fluctuations in the rectified current. A series of resistors is connected across the output so as to divide the voltage into values required for the different circuits of a receiving set. Radiotron UX-874 as shown at *c* is connected across the 90-volt terminals so as to keep the voltage constant. The current drain of radiotron UX-874 will vary from 10 to 50 milliamperes in maintaining the potential across its terminals at 90 volts.

THREE-ELEMENT THERMIONIC TUBES

DISTINCTIVE FEATURES

The two-element tube consists essentially of an electron emitting filament and an electron collecting plate. The three-element tube contains a third or control element, commonly known as the *grid*, interposed between the filament and the plate. This type of tube can operate as a rectifier, amplifier of small currents and voltages, detector of small a.-c. voltages, modulator of alternating currents, and generator of electric oscillations. Three-element tubes may be constructed with nearly any reasonable characteristics, and in sizes from the dry-cell operated types to types requiring water cooling of some of the parts.

CONSTRUCTION OF ELEMENTS

Filament.—The construction of the filament determines in most cases the useful life of a tube. Formerly, the filaments of radio tubes were made of tungsten wire, which required a temperature of about 2,400° C. for satisfactory operation. At such high temperature the decomposition of the tungsten was quite rapid, hence it was found necessary to use heavy tungsten wire, and a large current was required to heat it.

It has been found that certain oxides are able to produce a large number of free electrons at moderate temperatures. A filament coated with an oxide, such as that of barium or strontium, will give off more electrons with a smaller expenditure of energy and at much lower temperature than an uncoated filament. In most cases, the filament wire is made of very fine platinum ribbon and coated uniformly with the proper oxides. A filament of this kind requires scarcely a perceptible glow for satisfactory operation. Such filaments are used in many commercial types of tubes.

The electron-emitting characteristics may also be increased by introducing a suitable metal, such as thorium, into the tungsten filament during the process of manufacture. The thorium is diffused through the tungsten and later brought to the surface by normal operation or by special treatment. The filament may then be operated at a temperature well below incandescence with satisfactory emission. The tungsten in the filament operates at a safe temperature and essentially acts only as a combined heater and support agent for the useful thorium. So long as the filament temperature is not excessive, the thorium on the surface is steadily replaced by that from the interior of the filament, and the tube will have a very long useful life. If the electron drain is excessively high the free available electrons will be greatly reduced, and the operation of the tube will be very poor. If the abnormal condition has not been continued for too long a time, special treatment should restore the filament to a good operating condition.

The filament is especially subject to troubles with gas in the tube. The electrons in the plate circuit will decompose any gas atoms in their path and liberate charged ions. Because of the difference in potential between the filament and plate, these positively charged ions will travel rapidly to the filament and strike or bombard it. Such bombardment is very hard on the coated and thoriated types of filaments and in time may ruin the operation of the filament. In a very few cases, a special gas is introduced into the tube to give it special characteristics, such as for detector service.

In order to reduce the gas content, the tube is subjected to a very special pumping or exhaust process during manufacture. Many parts of the tube are heated to assist in the clean-up of gas, both free and that diffused into the glass and metal parts. The heating up of the plate in most cases vaporizes a chemical agent, such as magnesium, which will combine with any gas still left in the tube. This element is commonly called a *getter*. The vaporized getter combines with the atoms of air left in the tube and forms a deposit on the bulb. In the case of magnesium the bulb deposit has a silvery appearance.

The *ageing* of a filament is the process of cleaning its surface of any detrimental effects caused by air or handling while it was exposed to the air, and in putting the tube as a whole into an active operating condition. During manufacture the filament is exposed to the air and its surface will be considerably affected thereby. After the tube is exhausted the filament is operated at special temperatures to put it in good condition. Both the coated and thoriated types of filaments must be given very careful treatments under exacting conditions in order to clear up any traces of gas still in the tube, and in order to produce a filament surface capable of emitting electrons readily.

The reageing of a tube consists primarily in producing an active electron condition on the filament of a tube after emission of electrons has ceased. A tube that has been heavily overloaded for some time may not have any electron emitting substance on the surface of the filament. This condition may affect only the coated and thoriated filaments, as the tungsten filament is made thoroughout of only one material. The characteristics of the coating on the coated filament type of tube are such that the active condition can seldom be restored once it has been seriously damaged. However, such a filament will stand a large amount of mistreatment. The thoriated type of filament tube may often be restored to an active operating condition by reactivation.

Grid.—The control element, known as the grid, is placed between the filament and the plate. The grid is usually made in the general shape of the plate, except that it is somewhat smaller than the plate, and has perforations or openings in its structure. It is often made of wire wound on and secured to suitable heavy support wires. The size of the wire, and the number of turns, and the spacing between the filament and plate are all factors that enter into the degree of control exercised by the grid over the plate current.

Plate.—The earliest types of three-element tubes used a simple small plate or flat pieces of metal to collect the electrons, hence the name *plate.* As most commonly constructed, because of convenience and advantage, the plate generally takes a form which will enclose the grid and filament assembly as much as possible. The plate is generally formed of thin metal securely welded to supports that will hold it in the proper position. In power tubes of the larger sizes the energy that must be dissipated by the plate is so great that water cooling must be employed. In other cases the plate structure is made large enough so that the normal air circulation on the bulb together with the heat radiation will provide sufficient cooling for normal operation.

CHARACTERISTICS OF THREE-ELEMENT TUBES

Action of Grid.—In Fig. 13 is shown a simple schematic circuit of a three-element tube, in which the filament is shown at *a*, the plate at *b*, and the grid, interposed between the filament and the plate, at *c*. As soon as a potential is impressed on the grid, a perceptible change is noticed in the plate current. This impressed potential either aids or neutralizes the space charge that surrounds the filament at all values of plate potential below voltage saturation. A negative potential on the grid will increase the space charge, which is negative, and thereby reduce the plate current. On the other hand, a positive potential on the grid will reduce the space charge effect and increase the plate current. Since the grid is so close to the filament, small changes in grid potential are as effective in changing the plate current as large changes of plate potential.

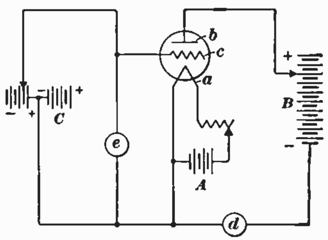

FIG. 13

Characteristic Curves.—With the filament *a*, plate *b*, and grid *c* connected to the *A*, *B*, and *C* batteries, respectively, as shown in Fig. 13, the variations of plate current may be determined by means of the milliammeter *d* for different plate and grid voltages. A voltmeter *e* connected across the *C* battery will show the voltage impressed on the grid of the tube. It is now possible to take a set of characteristic curves like those shown by *A*, *B*, *C*, *D*, *E*, *F*, and *G* in Fig. 14. These curves are typical of the UX-201A general-purpose tube characteristics. The data for curve *E*, which may be taken as an example, would be obtained with the filament set at the rated value of 5 volts, with the plate voltage adjusted to 90 volts, and with the grid bias varied over the desired range, or, in this case, from -10 volts to $+3$ volts. With a 10-volt negative bias the plate current is practically 0 but increases

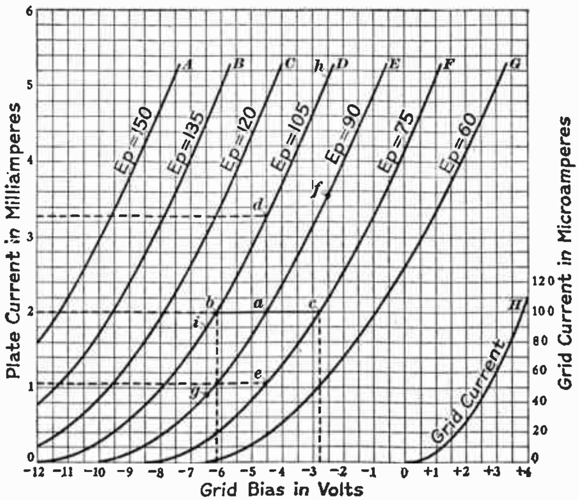

FIG. 14

rapidly as the negative-voltage bias is reduced and becomes positive. The data for the other curves may be secured in a similar manner with the plate voltage set each time to the required value, and with the grid bias varied to cover the desired range of values.

If a milliameter is included in the grid circuit, the grid current may be read with the plate voltage at some moderately high value, say 90 volts, and the grid varied from 0 to $+3$ volts. It will be only slightly higher for lower plate voltages and slightly lower with still higher plate potentials. There is no grid current with negative grid-bias voltages. The grid-current data is of value in a study of the detector characteristics of a tube.

Amplification Factor.—The amplification factor, or constant, of a tube may be readily determined from the data given in a set of plate-current curves. The amplification factor is a measure of the control exercised by the grid over the plate current. This control is usually referred to the plate voltage, and is expressed as a ratio between a relatively small value of plate-voltage change and the grid-voltage change, the plate current being maintained at a constant value.

One method of securing the amplification factor is by means of the curves shown in Fig. 14. At the point where the 90-volt curve crosses the -4.5-volt grid-bias line, The plate current is 2 milliamperes as shown at point *a*. If the 2-milliampere plate-current line is carried to the left it will intersect the 105-volt curve at point *b*, which corresponds with a grid-bias value of -6.2 volts. That is, if the plate voltage is raised to 105 volts the grid bias should be raised to -6.2 volts in order to keep the plate current constant at 2 milliamperes. With the line representing a plate current of 2 milliamperes carried to the right so as to intersect at *c* the 75-volt plate-voltage curve, a grid bias of 2.8 volts will be required. Thus for a constant plate current of 2 milliamperes, the plate-voltage variation of 105 to 75 volts was exactly compensated for by a grid-bias change of from -6.2 volts to -2.8 volts. The amplification factor is expressed as the ratio of these two voltage changes, or

$$\mu=\frac{105-75}{6.2-2.8}=\frac{30}{3.4}=8.8$$

In other words, the grid has 8.8 times as much control over the plate current as does the plate.

Plate Impedance.—The plate impedance of a tube may also be calculated from the plate-current characteristic curves. The plate impedance represents a certain loss of energy that must be taken into consideration. The tube impedance is calculated by dividing the plate-voltage variation over a small range by the resultant plate-current change.

The plate impedance with 90 volts on the plate and with a grid bias of -4.5 volts may be obtained from the plate current shown in Fig. 14. With the grid bias fixed, the plate potential of 105 volts will give a plate current, point *d*, of 3.32 milliamperes. Also, the plate potential of 75 volts will give a plate current, point *e*, of only 1.04 milliamperes. If the grid bias is kept constant at -4.5 volts, a plate potential of 105 volts will give a plate current of 3.32 milliamperes, whereas with 75 volts on the plate the plate current is 1.04 milliamperes. The change in plate current with a known plate-voltage change is a definite measure of the plate impedance. That is, $105-75$ gives 30 volts, whereas $3.32-1.04$ gives 2.28 milliamperes.

The plate impedance is $\frac{30}{.00228}=13{,}000$ ohms, nearly, with the plate at 90 volts and with a grid bias of -4.5 volts. Since the plate impedance of a tube varies considerably with the grid and plate voltages, these values should always be specified. For more accurate work, particularly on the lower sections of the curves, smaller plate-voltage changes would be advisable. These factors may also be obtained on special types of bridges as described elsewhere.

Mutual Conductance.—The mutual conductance of a tube is a very good measure of its value as an amplifier, in that it includes both the amplification factor and the plate impedance. The mutual conductance is defined as the amplification factor divided by the plate impedance. For this case the mutual conductance is given by

$$\frac{\text{amplification factor}}{\text{plate impedance}} = \frac{8.8}{13{,}000} = 677 \text{ micromhos}$$

with the plate at 90 volts and a grid bias of -4.5 volts.

Since the value depends on the plate impedance, which varies with the voltage, the exact plate and grid voltage conditions should be specified.

Importance of Characteristic Curves.—By an examination of the plate-current characteristic curves of a tube it is possible to determine the most suitable grid and plate voltage combination for distortionless amplification. In radio amplifier service the plate voltage generally remains fixed and the proper grid bias is selected to suit the operating requirements. There is some effect on the net voltage applied to the plate by the voltage drop in the transformer or other apparatus in the plate circuit, but the curves as shown may be used to illustrate the point.

With the plate voltage set at 90 volts and the grid bias at -4.5 volts, suppose an alternating-current signal with a two-volt maximum value is applied to the grid. As this signal goes positive with respect to the grid, the effect of the grid bias is reduced a corresponding amount and the plate current rises. The plate-current maximum value, 3.53 milliamperes, will correspond with the plate current at 4.5 -2 volts or with the plate current at -2.5 volts, as indicated at point *f*, Fig. 14. On the alternate half of the signal cycle the grid bias and signal voltages will combine to reduce the plate current. These two voltages will add as $4.5+2$ gives -6.5 volts as an effective grid bias or the plate-current value, .91 milliampere, as shown at *g*. In service the resistance drop in the external plate circuit would have to be considered in order to secure the actual current values.

The changes in plate current from the normal value *a* to values *f* and *g* are not quite equal, namely, 1.53 and 1.09 milliamperes, respectively. This implies that there would be some distortion in an amplifier tube operating under these exact conditions, although it might not show up to an objectionable degree.

If a higher plate voltage is used, such as 105 volts, as shown by curve *D*, the operation as an amplifier will be more satisfactory. The 2-volt signal will cause the plate current to vary by nearly equal amounts from the normal value; namely, from *d* to *h* and from *d* to *i*. In fact, a signal considerably stronger than 2 volts could be applied without introducing an appreciable amount of distortion so long as equal grid-voltage changes produce equal plate-current changes.

Suppose a 4.5-volt signal is applied to the 90-volt curve with the normal grid bias of −4.5 volts. On the positive signal swing the grid bias will be exactly neutralized and the plate current will rise to the corresponding value. On the negative swing the effective grid bias will be raised to −9 volts, which reduces the plate current to nearly 0. Operation of a tube under these conditions would produce a considerable amount of distortion, as equal grid-voltage changes would not produce equal plate-current changes. If the signal voltage is increased still further the effective grid voltage will, on some pulses, go positive and cause a grid current, and on the other end of the swing the grid voltage will go so far negative as to cut off the plate current entirely. Under these two conditions the distortion becomes very objectionable.

LOW AMPLIFICATION FACTOR TUBES

The signal applied to the last audio-amplifier tube is usually quite strong and the output must be fed into a loud speaker. The relatively large grid signal applied to the tube in this position means that for distortionless amplification the grid bias shall be relatively high. The tube characteristics are such that when the grid bias is high the amplification factor is rather low. However, in this service the low amplification factor is not enough of a disadvantage to outweigh the advantages of such a tube.

The last audio-stage tube should be able to operate well into a loud speaker. In order to give a large plate-current change and to deliver as much as possible of the power into the loud speaker, the plate impedance of the output tube must be relatively low. This property of low plate impedance works out very well, as it naturally accompanies the low amplification factor of a tube of such characteristics. The low plate impedance means that with a fairly high plate voltage the plate current will be large and the output energy will be large. Since the internal plate impedance is low the amount of energy used up in the plate circuit of the tube itself is relatively low. The output tube then should have a low amplification factor, and low plate impedance, and should operate with a high grid bias and plate voltage.

HIGH AMPLIFICATION FACTOR TUBES

For some types of service the voltage amplification of a tube, as it is called, is the main property desired. That is, with a certain input voltage or strength of signal, it may be that a relatively high output voltage will be the most important characteristic. Since such a tube will ordinarily be required to amplify a relatively weak signal the normal grid bias need not be high.

Since a high-amplification type of tube will, in general, be required to deliver only a small amount of actual power, the plate current need not be large. Owing to the inherent properties of a tube with a high amplification factor, the internal plate impedance will be rather high. In order to secure the necessary voltage output it may be necessary to use rather high values of plate voltage. However, in most cases the plate-current drain is quite low so that the plate energy is not excessively high. Because of the high impedance of the plate circuit of the tube it is necessary to employ properly designed coupling or output-circuit apparatus if the gain provided by the high-amplification tube is to be utilized to the fullest extent. For this reason, such tubes have not been used on an extensive scale, except for certain applications requiring tubes of their peculiar characteristics.

THREE-ELEMENT TUBE AMPLIFIERS

Classification of Amplifiers.—Amplifier circuits may for convenience be divided into two general classes, namely, radio-frequency amplifiers and audio-frequency amplifiers. When two or more tubes are required, in cascade, amplifier circuits, either radio frequency or audio frequency, may be further classified according to the form of coupling, or connection, between successive tubes. The coupling device may be a resistance, a retardation, or choke coil, or a transformer, with other necessary units.

Resistance-Coupled Amplifier.—The coupling units in a resistance-coupled amplifier are, obviously, resistors. Such a coupling is shown in Fig. 15 between the tubes *a* and *b* at *c*. An alternating-input voltage to the tube *a* produces variations of current in the plate circuit of this tube. The voltage drop across the resistance *c*, which may be of the order of 50,000 or 100,000 ohms, is applied to the input circuit of tube *b* through the condenser *d*. The function of the condenser *d* is to prevent the constant *B*-battery voltage from being applied directly to the grid of tube *b*. A grid leak *e* serves to fix the steady potential on the grid at some desired negative value. The negative voltage may be obtained from the negative terminal of the *A* battery, as shown, or a *C* battery may be inserted in the grid-leak lead. The blocking condenser *d* must be large enough so that no appreciable drop or loss of signal shall occur between the resistance *c* and the grid of the tube *b*. The grid leak *e* must have a resistance considerably higher

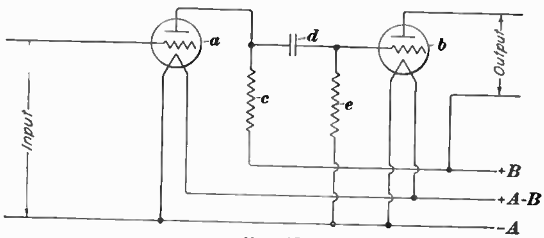

FIG. 15

than the coupling resistance *c* so as not to reduce the amplification. At high radio frequencies and even at high audio frequencies the grid-filament reactance is considerably reduced and becomes a shunt of a rather low value on the coupling resistance *c*, so that even though the grid leak has a high resistance, nevertheless the tube capacity reduces the amount of amplification. For this reason, resistance coupling is advantageous only in circuits of audio-frequency amplifiers and in low-frequency radio amplifiers.

The alternating-current component in the plate circuit of a resistance-coupled amplifier tube may be expressed as follows:

$$I_p = \frac{\mu E_g}{R_p + R} \qquad (1)$$

in which I_p = plate current, in amperes;
μ = amplification factor of tube;
E_g = grid potential, in volts;
R_p = plate resistance, in ohms;
R = coupling resistance, in ohms.

The voltage that is impressed on the next tube, for example, tube b, Fig. 15, is

$$E'_g = I_p R = \frac{\mu E_g R}{R_p + R} \qquad (2)$$

in which E'_g = voltage handed to the following tube.

The amplification of such an amplifier may be expressed as a ratio of the voltage impressed between the grid and filament of tube b to the corresponding voltage on the tube a, or

$$A = \frac{E_g'}{E_g} = \frac{\mu R}{R_p + R} \qquad (3)$$

in which A = voltage amplification.

EXAMPLE.—If in Fig. 15 the tube has a voltage amplification factor of 8 and a plate resistance of 12,000 ohms, what amplification will be obtained with a coupling resistance of 100,000 ohms?

SOLUTION.— $A = \frac{\mu R}{R_p + R} = \frac{8 \times 100,000}{12,000 + 100,000} = 7.1$

It will be seen that as the resistance value of the coupling is increased, the amplification per stage approaches the amplification factor of the tube, and at a certain value of coupling resistance $A = \mu$.

The capacity of the blocking condenser d, Fig. 15, must be within certain definite limits. For most purposes a capacity of .1 to 1 microfarad will be found satisfactory. The coupling resistance, as has already been mentioned, may have a resistance of 50,000 to 100,000 ohms. The grid leak in a multistage amplifier should be about 1 megohm in the first stage, $\frac{1}{2}$ megohm in the second stage, and $\frac{1}{4}$ megohm in the third stage. A negative potential should be kept on each grid sufficient to keep the grid from becoming positive at any time.

Inductance-Coil Coupling.—An inductance-coil coupling is shown in Fig. 16 between the tubes *a* and *b* at *c*. A blocking condenser *d* and grid leak *e* are used the same as in a resistance-coupled amplifier. Since the direct-current resistance of the coil is not as high as that of the resistance coupling, it is possible to use lower plate potentials with this type of amplifier. The impedance of the plate circuit may be calculated by the formula

$$Z=\sqrt{R_p^2+X_l^2} \qquad (1)$$

in which Z = impedance, in ohms;
R_p = plate resistance of tube, in ohms;
X_l = inductive reactance of the coupling unit, in ohms.

The plate current is obtained as follows:

$$I_p=\frac{\mu E_g}{\sqrt{R_p^2+X_l^2}} \qquad (2)$$

The voltage that is handed to the next tube is

$$E_g=I_pX_l=\frac{\mu E_g X_l}{\sqrt{R_p^2+X_l^2}} \qquad (3)$$

The voltage amplification per stage is

$$A=\frac{E_g'}{E_g}=\frac{\mu X_l}{\sqrt{R_p^2+X_l^2}}=\frac{\mu}{\sqrt{l+\left(\frac{R_p}{X_l}\right)^2}} \qquad (4)$$

EXAMPLE.—If the tube *a*, Fig. 16, has an amplification factor of 8 and a plate resistance of 12,000 ohms, what amplification will be obtained with a coupling reactance of 100,000 ohms?

SOLUTION.—Using formula 4 gives

$$A = \frac{8}{\sqrt{1+\left(\frac{12{,}000}{100{,}000}\right)^2}} = \frac{8}{\sqrt{1+.12^2}} = \frac{8}{1.0144} = 7.9$$

The value of the inductance coil must be so chosen as to have an LC value outside the range of frequencies for which the amplifier is to be used, otherwise greater amplification will be obtained on the resonant frequency than on other frequencies with resultant distortion. Tuned circuits may be used for coupling purposes, especially in the radio-frequency stages; such would not be practical in an audio-frequency amplifier.

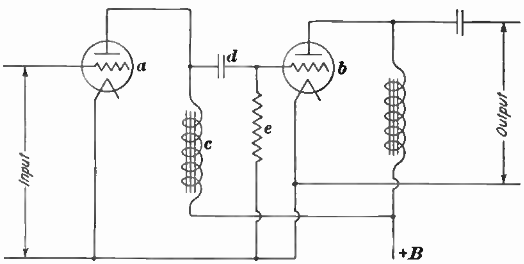

FIG. 16

In place of the resistance grid leak *e*, Fig. 16, it is sometimes more desirable to use a high inductance together with a negative grid bias. Better operation is thus obtained in many audio-frequency amplifiers. The coupling inductance coil and the leak inductance coil are sometimes wound on the same core system.

Transformer-Coupled Amplifier.—A schematic diagram of a transformer-coupled amplifier is shown in Fig. 17. The two tubes *a* and *b* have their output and input, respectively, coupled by means of the transformer *c*. This form of coupling is used in both radio-frequency and audio-frequency amplifiers.

In audio-frequency amplifiers the transformer is of the iron-core type. The primary winding may be considered the same as the inductance coil in the amplifier of Fig. 16. The secondary winding of the transformer *c*, Fig. 17, may have a greater number of turns than the primary, giving, therefore, a voltage amplification in addition to the amplification obtained with the tube.

In radio-frequency amplifiers the coupling transformers are either of the tuned or untuned type. A tuned coupling requires a change in adjustment for every change in wavelength or frequency. An untuned transformer is so designed as to give satisfactory amplification over a band of frequencies or wavelengths.

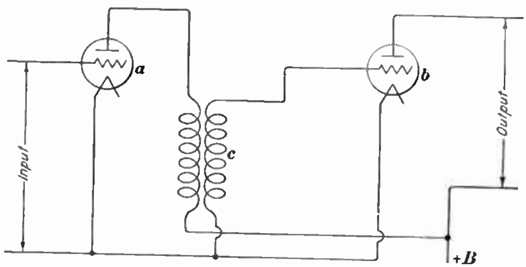

FIG. 17

THREE-ELEMENT TUBE DETECTORS

Detection Without Grid Condenser.—The object of detection is to separate different frequencies; for example, the audio frequency from a combination of radio and audio frequency, as received from a broadcasting station. There are two general ways of accomplishing this; namely, by utilizing the curved portion of the plate characteristic curve, and by the drooping grid-voltage curve. The first method is exemplified in detector circuits that have no grid condenser, whereas the second, in circuits that have a grid condenser.

In Fig. 18 is shown schematically a circuit utilizing the curved portion of the plate-current characteristic curve for

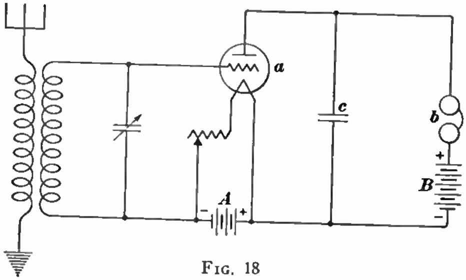

FIG. 18

detection. A negative bias is placed on the grid of the tube *a* through the connection to the negative terminal of the *A* battery. This locates the zero grid-voltage line, Fig. 19, at or near the lower bend of the plate-current curve. A series of impulses as shown at *a* impressed on the grid of the tube will result in the plate-current variations shown at *b*. The change in plate current caused by the positive grid voltage is much greater than that produced by the negative grid-voltage change. The average plate current will therefore be that indicated by the dotted line, and this represents the signal impulse impressed on the telephone receivers *b*, Fig. 18. The condenser *c* provides a low-resistance path for the high-frequency component of the plate current.

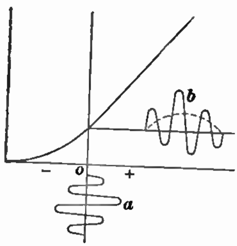

FIG. 19

Detection With Grid Condenser.—A detector circuit with a grid condenser *a* is shown in Fig. 20. High-frequency voltages impressed on the grid of the tube as shown by the full-line curve at *a*, Fig. 21, cause a gradual accumulation of electrons on the grid of the tube so that successive alternations gradually become more negative in value and the grid voltage takes the shape of the dotted curve shown

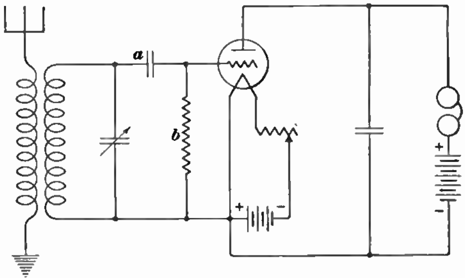

FIG. 20

at *a*. The plate current *b* has a diminishing characteristic, and the average plate current shown by the dotted line at *b* brings out the audio-frequency signal. The grid leak *b*, Fig. 20, provides a path for the accumulated electrons to the filament.

THREE-ELEMENT TUBE OSCILLATOR

Principle of Operation.—Essentially an oscillator consists of one main tuned circuit with a method for maintaining oscillations therein. The oscillations, usually at radio frequency, are maintained by energy supplied by the plate circuit of the tube, and by the plate-circuit voltage supply. Enough of the output energy must be returned to the grid circuit to energize it for the succeeding cycle, and thus to make the oscillations continuous. The distribution of the inductive and capacitative parts of the circuit determines the charac-

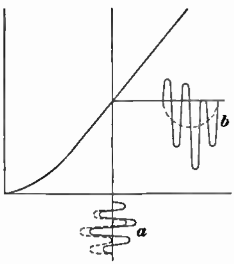

FIG. 21

teristics of operation, and together with the method of grid feed-back determines the style or type of the oscillator circuit, of which there are several in commercial service.

The tuned circuit is necessary so that the proper circuit conditions for continuous oscillations may be fulfilled. In addition the energy will be available as useful energy at the wavelength or frequency determined by the inductance and capacity of the tuned circuit. Oftentimes this tuned circuit forms a part of the plate or grid circuit, whereas in other instances the tuned circuit is coupled with the tube circuits by inductance coils or condensers. The feed-back of energy into the grid circuit may be by inductive or capacitative means, with a method provided whereby the amount of energy feed-back may be controlled. In some instances the grid and plate circuits are both tuned to the desired frequency with the feed-back between the tube elements acting to sustain the oscillations.

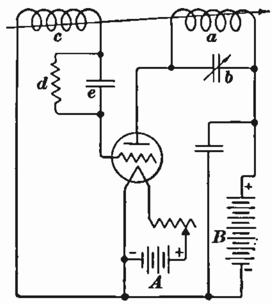

FIG. 22

Oscillator Connections.—One type of tube oscillator is shown in the circuit of Fig. 22. The plate coil *a* and the variable condenser *b* form the main oscillating circuit. The coil *c* is coupled with coil *a* to feed energy into the grid circuit. The grid bias is secured by the grid leak *d*. A grid condenser *e* is necessary to provide an easy path for the grid voltages to reach the grid element and to insulate the grid from the filament.

The tube is placed in operation by applying the proper plate and filament voltages and varying the coupling between coils *a* and *c*. A milliammeter in the plate or grid circuits or a radio-frequency ammeter connected in the circuit adjacent to condenser *b* may be used to indicate when the tube is oscillating. The grid-leak resistance *d* should be varied until the correct value is obtained. The coupling between coils *a* and *c* should also be adjusted so that the tube operates with minimum heating of the plate. Filament and plate voltmeters are very useful in order to secure the rated operating voltages with certainty.

MODULATOR SERVICE

Present-day tubes find a very extensive field of service as modulators, especially in radio broadcasting. The modulator tube acts, to all intents and purposes, like a special sort of amplifier connected with an oscillator circuit. It is possible to connect the tube which actually does the transmitting as an oscillator, and to impress the desired signal on the radio-frequency wave by supplying it to the grid circuit. This process is called grid modulation, as the modulating signal is applied to the grid of the oscillator tube. This system of modulation is not suitable for broadcasting service and is seldom employed, owing to the distortion and output limitations.

A system of constant plate-current modulation, known as the Heising method of modulation, has proved so effective and practicable that it is almost exclusively employed in radio broadcasting service. The modulator and oscillator tubes are connected with a common plate supply through a choke coil, which is also common to both sets of tubes. Any plate-current change of the modulator tube is impressed or modulated onto the plate current of the oscillator and consequently its radio-frequency output current. The scheme may be seen by reference to Fig. 23, which illustrates the essentials of a complete transmitter.

The desired voice or music is picked up by the microphone *a*, operated by the local battery *b*. The current pulsations are sent through the transformer *c* and as many audio-frequency amplifier stages as necessary before it is impressed on the grid of the modulator tube or tubes at *d*. The oscillator tube or tubes *e* are also connected with the same *B* or plate supply, in this case a generator. The common plate supply includes an iron-core choke coil *f*, whose duty it is to keep the total plate current taken by the modulator and oscillator tubes at a constant value. For

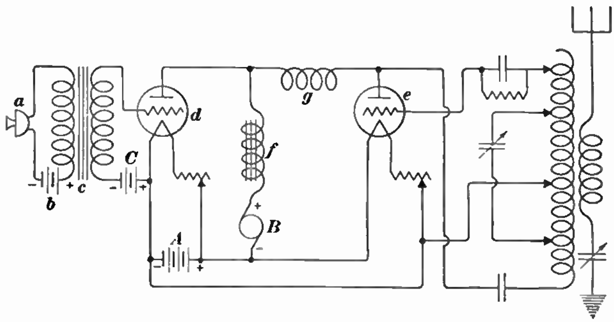

FIG. 23

example, suppose tube *e* with its attendant circuit is oscillating at radio frequency. At the instant at which the signal increases the plate current of the modulator tube, the plate current available for the oscillator tube is decreased by a corresponding amount, and consequently the radio-frequency oscillating current is reduced. At the instant the plate current of the modulator is a minimum, that of the oscillator is a maximum with the radio-frequency current increased above its normal steady value. The air-core choke coil *g* serves only to prevent the radio-frequency current from going back into the modulator stage. The oscillator circuit shown in connection with tube *e* is given merely as an example; any type of standard oscillator circuit may be employed.

The modulator and oscillator tubes are commonly of the same types, with two or three times as many modulators necessary in order to give good modulation without distortion. The modulator tubes must operate with a grid bias and over a relatively straight part of their characteristic curve in order not to introduce any distortion. Also, it is necessary to keep the average modulation signal down to a relatively low value so that the maximum signal pulses or high peak voltages will not vary outside the safe limits.

COMMERCIAL THREE-ELEMENT TUBES

TUBES IN RECEIVING SYSTEMS

Characteristics of Commercial Receiving Tubes.—Tubes have been developed for different uses in receiving systems. There are the so-called dry-cell tubes whose filament current is so small that ordinary dry cells may be economically used for this purpose. Larger tubes require storage cells for satisfactory filament operation. The plate and grid construction differs in different types of tubes, which gives different grid-voltage plate-current characteristics. All these peculiarities of receiving tubes have been tabulated for the more commonly used tubes and are given in Table I. A brief description of some of the better known tubes will be given herewith.

WD-11 and WX-12 Tubes.—The WD-11 was one of the earliest tubes to be marketed in large quantities and was the pioneer in the dry-cell operated field to become extensively employed. In order that it would not be used in higher voltage sockets a distinctive base and base-pins arrangement was devised. A large-sized pin in the base forms the plate connection. The grid pin is opposite the plate pin, and the other two pins form the filament connection. This tube is also mounted in a UX type of base and is then given the UX-12 name. These tubes are

TABLE I

AVERAGE CHARACTERISTICS OF RECEIVING RADIOTRONS

General					Detection				Amplification						
Model	Use	"A" Supply	Filament Terminal Voltage	Filament Current (Amperes)	Detector Grid Return Lead To	Grid Leak (Megohms)	Detector "B" Battery Voltage	Detector Plate Current (Milliamperes)	Amplifier "B" Battery Voltage	Amplifier "C" Battery Voltage	Amplifier Plate Current (Milliamperes)	A.C. Plate Resistance (Ohms)	Mutual Conductance (Micromhos)	Voltage Amplification Factor	Maximum Undistorted Output (Milliwatts)
WD-11	Detector or Amplifier	Dry Cell 1½V. Storage 2V.	1.1	.25	+F	3 to 5	22½ to 45	1.5	90 135	4½ 10½	2.5 3.5	15,500 15,000	425 440	6.6 6.6	7 35
WX-12	Detector or Amplifier	Dry Cell 1½V. Storage 2V.	1.1	.25	+F	3 to 5	22½ to 45	1.5	90 135	4½ 10½	2.5 3.5	15,500 15,000	425 440	6.6 6.6	7 35
UX-112-A A	↓ Detector or Amplifier	Storage 6V.	5.0	.25	+F	3 to 5	45	1.5	90 135	4½ 9	5.5 7	5,300 5,000	1,500 1,600	8 8	30 120
UV-199	Detector or Amplifier	Dry Cell 4½V. Storage 4V.	3.0 3.3	.060 .063	+F	2 to 9	45	1	90	4½	2.5	15,500	425	6.6	7
UX-199	Detector or Amplifier	Dry Cell 4½V. Storage 4V.	3.0 3.3	.060 .063	+F	2 to 9	45	1	90	4½	2.5	15,500	425	6.6	7
UX-200-A	Detector	Storage 6V.	5.0	.25	−F	2 to 3	45	1.5	Following UX-200-A Characteristics apply only for Detector Connection			30,000	666	20	——
UX-201A	Detector or Amplifier	Storage 6V.	5.0	.25	+F	2 to 9	45	1.5	90 135	4½ 9	2.5 3	11,000 10,000	725 800	8 8	15 55
UX-222	↓ Radio Frequency Amplifier	Dry Cell 4½V. Storage 4-6V.	3.3	.132	——	——	——	——	135	1½ ✱	1.5	850,000	350	300 M	——
UX-222	↑ Audio Frequency Amplifier	Dry Cell 4½V. Storage 4-6V.	3.3	.132	——	——	——	——	180 ∮	1½ □	.3	150,000	400	60	——
UX-226	Amplifier A-C Filament Type	Transformer 1.5V.	1.5	1.05	——	——	——	——	90 135 180	6 9 13½	3.5 6 7.5	9,400 7,400 7,000	875 1,100 1,170	8.2 8.2 8.2	20 70 160
UY-227	Detector A.-C. Heater Type	Transformer 2.5V.	2.5 H	1.75	C	2-9 ¼-1	45 90	2 7	Following UY-227 Characteristics apply only for Detector Connection			10,000 8,000	800 1,000	8 8	——
UX-240	Detector or Amplifier	Storage 6V.	5.0	.25	+F	2 to 5	135 180	.3 .4	135 ∮ 180 ∮	1½ 3	.2 .2	150,000 150,000	200 200	30 30	——
UX-112-A A	↑ Power Amplifier	Storage 6V. Transformer 5V	5.0	.25	——	——	——	——	135 157½	9 10½	7 9.5	5,000 4,700	1,600 1,700	8 8	120 195
UX-120	Power Amplifier	Dry Cell 4½V. Storage 4V.	3.0 3.3	.125 .132	——	——	——	——	135	22½	6.5	6,300	525	3.3	110
UX-171-A A	Power Amplifier L. S. C.	Storage 6V. Transformer 5V.	5.0	.25	——	——	——	——	90 135 180	16½ 27 40½	10 16 20	2,500 2,200 2,000	1,200 1,360 1,500	3.0 3.0 3.0	130 330 700
UX-210	Power Amplifier L. S. C.	Transformer 7.5V.	7.5	1.25	——	——	——	——	250 300 350 400 425	18 22½ 27 31½ 35	10 13 16 18 18	6,000 5,600 5,150 5,000 5,000	1,330 1,450 1,550 1,600 1,600	8 8 8 8 8	340 600 925 1,325 1,540
UX-250	Power Amplifier L. S. C.	Transformer 7.5V.	7.5	1.25	——	——	——	——	250 300 350 400 450	45 54 63 70 84	28 35 45 55 55	2,100 2,000 1,900 1,800 1,800	1,800 1,900 2,000 2,100 2,100	3.8 3.8 3.8 3.8 3.8	900 1,500 2,350 3,250 4,650

Model	Use	Purpose		
UX-213	Full-Wave Rectifier	Rectification in Eliminators particularly Designed for this Radiotron	Filament Terminal Voltage....... 5 Volts Filament Current............... 2 Amperes } R M S A.C. Plate Voltage..............220 Volts (Max. per plate)	Max. D.C. Output Current (both plates)...................................... 65 Milliamperes D.C. Output Voltage at max. current as applied to filter of typical rectifier circuit...170 Volts
UX-216-B	Half-Wave Rectifier	Rectification in Eliminators particularly Designed for this Radiotron	Filament Terminal Voltage....... 7.5 Volts Filament Current...............1.25 Amperes } R M S A.C. Plate Voltage..............550 Volts (Maximum)	Max. D.C. Output Current.. 65 Milliamperes D.C. Output Voltage at max. current as applied to filter of typical rectifier circuit.. 470 Volts
UX-280	Full-Wave Rectifier	Rectification in Eliminators Designed for this Radiotron or Rectron UX-213	Filament Terminal Voltage...... 5 Volts Filament Current............... 2 Amperes } R M S A.C. Plate Voltage...............300 Volts (Max. per plate)	Max. D.C.Output Current (both plates).......................................125 Milliamperes D.C. Output Voltage at max. current as applied to filter of typical rectifier circuit...260 Volts
UX-281	Half-Wave Rectifier	Rectification in Eliminators Designed for this Radiotron or Radiotron UX-216-B	Filament Terminal Voltage.......7.5 Volts Filament Current..............1.25 Amperes } R M S A.C. Plate Voltage.............750 Volts (Maximum)	Recommended Maximum A.C. Plate Voltage...650.........750 Volts D.C. Output Current...65.........110 Milliamperes D.C. Output Voltage as applied to filter of typical rectifier circuit...620.........620 Volts
UX-874	Voltage Regulator	Constant Voltage Device	Designed to keep output voltage of B eliminators constant when different values of "B" current are supplied	Operating Voltage............ 90 Volts D.C. Starting Voltage............. 125 Volts D.C. Operating Current............10.50 Milliamperes
UV-876	Current Regulator (Ballast Tube)	Constant Current Device	Designed to insure constant input to power operated radio receivers despite fluctuations in line voltage	Operating Current............ 1.7 Amperes Mean Voltage Drop.......... 50 Volts Permissible Variation.........±10 Volts
UV-886	Current Regulator (Ballast Tube)	Constant Current Device	Designed to insure constant input to power operated radio receivers despite fluctuations in line voltage	Operating Current............ 2.05 Amperes Mean Voltage Drop.......... 50 Volts Permissible Variation.........±10 Volts

↑ (↓) Note other use of this Radiotron above (below)
✱ Inner Grid-1½Volts; Outer Grid+45 Volts, .15 Milliamperes
□ Outer Grid-1½Volts; Inner Grid+22½Volts, 6 Milliamperes
∮ Applied through plate coupling resistance of 250,000 Ohms

NOTE: All grid voltages are given with respect to cathode or negative filament terminal

Max. Values not to be exceeded

A.....Except for half ampere filament, UX-112 and UX-171 characteristics are identical respectively to UX-112-A and UX-171-A.
C.....Cathode
H.....Heater Voltage
LSC...Loud Speaker Coupling, consisting of either Choke Coil and By-Pass Condenser or Output Transformer of 1: 1 or step down ratio, recommended wherever plate current (D.C) exceeds 10 Milliamperes.
M.....With a screen-grid tube, on account of circuit limitations, the actual voltage amplification obtainable does not bear as high a relation to the voltage amplification factor as in the case of three element tubes.

labeled C-11 and CX-12 by another manufacturer. An external view of the complete WD-11 tube is shown in Fig. 24. If this tube is operated from a storage bettery, extreme care should be exercised to see that the rated filament voltage is not exceeded. It should be connected with only one cell and a rheostat used to reduce the filament voltage to the proper value not in excess of its rating. The bulb is usually very much discolored by a silvery coating deposited on the inside during the process of manufacture. The electrical characteristics are given in Table I.

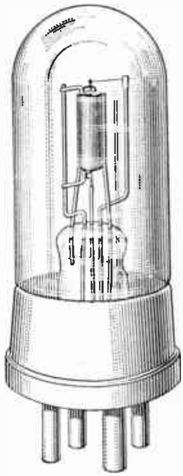
FIG. 24

UX-201-A.—The UX-201-A radiotron is a name given to a very good type of general-purpose tube. The type number CX-301-A and many other similar symbols have been applied to tubes of the same general characteristics. This tube is designed to take a filament current of .25 ampere, at a filament potential of 5 volts and with other requirements as in Table I.

The UX-201-A tube, as the type number implies, is equipped with the new large standard UX-push-type base. This base will fit into any of the UX type sockets. The mount assembly of this tube is shown in Fig. 25. The plate which has a flat oval shape surrounds the grid of smaller dimensions. The filament forms an inverted **V** with a spring support wire at the top. All the support wires are securely held in the flattened glass section of the press. The lead wires at the bottom connect with the proper pins in the base of the tube.

During the process of manufacture the getter produces a heavy silvery coating on the inside of the bulb. The filament, which is made of thoriated tungsten, operates normally at a moderately low temperature. With the heavy bulb coating it is often impossible to observe the brightness of the filament, hence it is especially important that a voltmeter be used as a guide in setting the filament voltage. Under most conditions it should be possible to reduce the filament voltage considerably without impairing reception, and with a saving in filament energy and a possible improvement in tube life. The thoriated filament fails more often from a loss of emission than from burn-out or breakage of the filament wire.

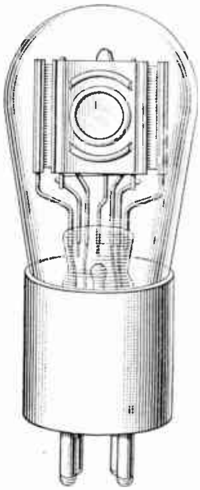
FIG. 25

The plate current versus grid voltage characteristics of the UX-201-A tube make it a very good general-purpose amplifier tube in both radio- and audio-frequency circuits. It may also be used as a detector and as an oscillator.

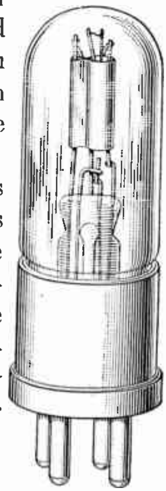
FIG. 26

UX-199 and UV-199. The UX- and UV-199 tubes are alike electrically, but the UX tube has the new small standard UX base, whereas the other has the older special small UV type of base. This tube is marked with various other type numbers and names, usually with the 99 forming part of the distinguishing type number. The mount of the UX-199 tube, as shown in Fig. 26, comprises cylindrical plate and grid structures, with a straight filament along their axes. A glass-bead crowfoot construction at the top holds the three elements together rigidly. The whole assembly is, in turn, supported by the glass press, which also includes the exhaust stem. Three 1½-volt dry cells connected in series will give the necessary voltage and current for not exceeding 3 tubes. Additional 3-cell sets of batteries may be connected in parallel for each additional set of three tubes, or less. The filament circuit should include a suitable rheostat capable of operating the tubes at from 3.0 to 3.3 volts, with even lower values sufficing for most conditions of operation. The very small dimensions of the thoriated filament may be illustrated by the diameter, which is only about .0006 inch. It is very important that the tube should not be mishandled and that the rated operating voltages should not be exceeded. The end of useful life will generally occur from loss of thorium emission rather than from burn-out of the filament. If the overload has existed for only a short time the filament may be seasoned by reactivation.

UX-112 and 112-A Power Amplifiers.—The UX-112 radiotron is capable of handling more power than many of the other types. Its appearance and external dimensions closely resemble those of the other storage-battery tubes. This tube is especially designed and recommended for amplifier service. In radio frequency amplifier service a grid bias of 4½ volts and a plate potential of 90 volts should give excellent results. Small *C* batteries in each grid-return lead will permit of grid bias without excessive coupling effects.

A plate potential of 45 volts with the grid return to the negative filament terminal will give very good results where it is not practicable to use a *C* battery. This tube will give excellent results as an audio-frequency amplifier at 135 and −9 volts. Radiotron UX-112 has a thoriated-tungsten filament requiring .5 ampere at 5 volts. Radiotron UX-112-A has a coated filament requiring .25 ampere at 5 volts. In all other respects the two types are identical.

UX-171 and 171-A Power Output Tubes.—The UX-171 radiotron is designed to operate as a power amplifier in the last audio stage. The best operating grid and plate voltages, which are also the highest that are recommended, require a 40.5-volt negative grid bias and 180 volts on the plate. The plate current of 20 milliamperes should preferably be supplied by a suitable type of *B*-battery eliminator. The plate impedance will be about 2,000 ohms, which is a rather low value. The amplification factor is relatively low or about 3 for a wide range of grid and plate voltages. Owing to the rather large plate current a 1 to 1 transformer or choke-coil coupling should be used to keep the plate current from burning out the loud-speaker windings or affecting the magnets. With 135 volts on the plate the grid bias should be -27 volts. The plate current will be somewhat lower, but very good operation should be secured. The tube will operate satisfactorily also with 90 volts on the plate and with a grid bias of $-16\frac{1}{2}$ volts. However, with these lower grid-bias values the tube cannot handle such a large signal without introducing some distortion. This tube is not adapted to detector service. Radiotron UX-171 compares with UX-171-A just like UX-112 compares with UX-112-A.

UX-120 Radiotron.—The UX-120 radiotron is a dry-cell operated type of tube designed to operate only as the last audio-stage amplifier in conjunction with UX-199 tubes. The 3-volt filament requires .125 ampere, hence it may be operated from a dry-cell battery with reasonable life. Its filament temperature is not critical and the filament may be operated directly in parallel with other 3-volt tubes. Its size is essentially the same as that of the UX-199 radiotron and the UX-120 has the new small standard UX base. The filament is of thoriated tungsten and it should give a long useful life if not misused in any way.

The grid bias should be −22.5 volts with a plate potential of 135 volts. Since there is no current taken from the *C* battery, it may be one of the small dry-cell types. The high grid bias of −22.5 volts means that the operation of the tube will be practically free from distortion with an input signal not in excess of 22.5 volts for the maximum or peak values. If this value is exceeded, the grid goes positive during part of the time and the resultant grid current will produce distortion. This tube should not be employed as a dectector, nor at lower plate voltages unless the grid bias is made large enough to keep the plate current down. Higher plate voltages are not recommended.

High-Amplification Tube.—The high-amplification factor tube, such as the MU-20, is another special type of receiver tube. This one, as the name implies, has a relatively high-amplification factor, say around 20 or even 25. The filament of the MU-20 tube is rated at 6 volts and may be operated directly from a 6-volt storage battery with a current consumption of .25 ampere. The bulb is tubular, and the molded base is of the old standard UV-navy type.

The MU-20 tube gets its name from the fact that its amplification factor, or *mu* as it is often called, is about 20. With 135 volts on the plate and a grid bias of −3 volts the plate current will be just over one milliampere and the plate impedance close to 40,000 ohms. With 90 volts on the plate and with no grid bias the plate current will be about 1.5 milliamperes and the plate impedance approximately 35,000 ohms. With the higher plate voltages used in practice, there will be a considerable voltage drop in the plate coupling resistance so that the voltage actually applied to the plate will be considerably reduced. Also, a grid leak is commonly used in the coupling stage, which automatically tends to hold the plate current to a reasonable value. Even then this tube may be operated to advantage with a small negative grid bias. This tube is suitable for operation only in the intermediate audio stages of resistance-coupled amplifiers.

Radiotron UX-240, another high *mu* detector and voltage amplifier, is designed for use in resistance- or impedance-coupled circuits. Having a voltage amplification factor (*mu*) of 30, radiotron UX-240 is especially useful in resistance-coupled circuits. The use of these circuits has been limited because the general-purpose tube required so much *B* battery. Radiotron UX-240, however, consumes less than one-tenth the plate current of the average general-purpose tube. The filament current consumption and voltage are identical to radiotron UX-201-A. The UX-240 may be used in the popular types of resistance-coupled amplifier circuits without change in plate coupling resistances. Best performance is obtained, however, when the values recommended in the instruction sheet accompanying this tube are employed.

Alternating-Current Operated Tubes.—At least one type of tube has been marketed designed for operation of the cathode element directly from the alternating-current supply line. This tube has a rather heavy filament mounted inside on an insulator. An oxide-coated metal sleeve outside the insulator receives heat from the alternating-current heated filament. The sleeve acts as a cathode and is connected with a filament terminal in the base. The heater filament leads are brought out of the bulb at the top and connect with a special type of base. The filament supply circuit for all of the tubes is thus kept away from the grid and plate-circuit wiring. The alternating-current energy is received directly from a transformer designed to supply energy at the rated tube voltage. The transformer should be placed far enough away from the set so that it will not give detrimental coupling effects.

The electrical characteristics of the alternating-current type of tube are somewhat better than those of the UX-201-A type. However, it is possible to substitute the alternating-current tubes in most types of sets without rewiring and without much adjustment, although auxiliary filament leads of heavy flexible wire are usually required. The filament leads on the set should be connected together to be sure that the grid return to the filament circuit is closed. It takes nearly a minute for the cathode to heat up after the filament is turned on, so a little time will elapse before signals will be heard. The manufacturer's recommendations regarding the grounding of the circuit should be strictly followed.

Radiotron UX-226 is an amplifier tube, the filament of which is operated from alternating current. It can be used for radio or transformer-coupled audio-frequency amplification. It is not, however, ordinarily, suited for detection, nor is it equal to a power tube in the last audio stage. This tube contains a plate, a grid, and a heavy filament of the oxide-coated type designed to operate at a relatively low voltage. The values of filament voltage and current have been so chosen as to minimize the a.c. hum. The tube is equipped with the large standard UX base.

Radiotron UY-227 is a detector tube containing a heater element which permits operation from alternating current. It is especially recommended for sets using radiotron UX-226 in the radio and first audio stages of amplification. This tube contains four elements, namely, a plate, a grid, a heater, and an oxide-coated cathode electrically insulated from but heated by the heater element.

Connections are made to these elements through a special five-prong base. Grid-leak detection is recommended for the average receiver. A plate voltage of 45, with a 5- to 9-megohm grid leak and a .00025-microfarad grid condenser usually gives greatest sensitivity. More stable operation is insured, however, with a 2- to 5-megohm grid leak. Grid-bias detection, though not usually as sensitive as grid-leak detection, gives extremely fine quality of reproduction if high-grade transformers of high input impedance are used.

Kellogg Types 401 and 403 A.-C. Tubes.—Kellogg a.-c. tubes are of the so-called heater type. The cathode or

TABLE II

AVERAGE CHARACTERISTICS TYPE 401—GENERAL PURPOSE DETECTOR, RADIO AND AUDIO AMPLIFIER TUBE

Heater voltage—3.0 volts. Heater current—1.0 amp.							
Plate voltage	45*	90		135		180	
Negative grid bias	0	4.5	6.0	7.5	9.0	10.5	12.0
Plate current (milliamperes)	3.8	3.7	2.5	5.3	3.9	7.2	5.8
Plate impedance (ohms)	9,060	10,750	13,300	9,520	11,700	9,330	10,500
Amplification factor	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Mutual conductance (Micromhos)	1,100	930	750	1,050	850	1,070	952
Power output† (milliwatts)		20	25	65	75	135	165

*For use as detector only using grid leak and condenser detection.

†The values given for output represent undistorted output or output of negligible distortion. These values are for optimum load resistance or a load resistance of approximately twice the tube impedance.

electron-emitting element of the Kellogg a.-c. tube corresponds to the filament of the ordinary d.-c. tube except that instead of being heated by direct application of current, the cathode is heated by an internal heating element which uses alternating current direct from the house lighting circuit. Since the heater element of the Kellogg a.-c. tube takes only 3 volts, it is necessary to use a small step-down transformer on the line between the 110-volt light socket and the tube.

Alternating current to heat the tube is fed through the top instead of through the base, thus segregating it entirely from the rest of the tube circuits. The cathode proper has only one lead, which is connected to the negative filament terminal at the base of the tube. Kellogg a.-c. tubes have standard UX bases, thus permitting standard tube sockets to be used.

TABLE III

AVERAGE CHARACTERISTICS TYPE 403—POWER AMPLIFIER FOR LAST AUDIO STAGE

Heater voltage—3.0 volts. Heater current—1.5 amps.

Plate voltage	135	180
Negative grid bias	27	40
Plate current (milliamperes)	15	20
Plate impedance (ohms)	2,500	2,500
Amplification factor	3.0	3.0
Mutual conductance (micromhos)	1,200	1,200
Power output* (milliwatts)	360	660

*The values given for output represent undistorted output or output of negligible distortion. These values are for optimum load resistance or a load resistance of approximately twice the tube impedance.

The Kellogg a.-c. tube cannot be successfully used in so-called d.-c. sets unless the circuit has been carefully rewired and it will not operate in some circuits at all. The average characteristics of these tubes are given in Tables II and III.

Four-Element Tube.—A good example of a four-element radio tube is radiotron UX-222. This is a screen-grid tube particularly designed for radio-frequency amplification. The experimentally inclined set builder will find that by using this tube with the proper shielding, neutralizing or stabilizing devices are unnecessary. The introduction of the shielding screen grid between the usual, or control, grid and plate not only decreases plate to grid feed-back capacity, but also increases the mutual conductance of the tube. This tube may also be used in a totally different role as an audio-frequency amplifier in resistance-coupled circuits. Higher overall amplification at audio frequencies is possible with this tube without greater plate resistance than that of three-element high-mu tubes. The tube has a standard four-prong UX base with an additional terminal on top of the glass bulb. The filament operates at 3.3 volts and .132 ampere, but with a series resistor of 15 ohms it can be connected in parallel with 5-volt filaments.

UX-200-A Detector Tube.—The UX-200-A is a good typical gas-content detector tube designed only for detector service. The filament voltage of 5 volts with a .25 ampere filament makes it feasible to operate this detector in parallel with other 5-volt tubes. In order to secure some adjustment, which is, however, not critical, a separate filament rheostat of 10 ohms is recommended. The bulb and completed tube are similar to the other 5-volt tubes in dimensions, although the UX-200-A is often not completely silvered inside the bulb. The internal construction is about the same except that a special caesium getter is liberated in the tube during manufacture, which gives the tube its special sensitiveness.

The plate voltage of the UX-200-A tube is not critical, and should be not over 45 volts. The grid condenser should have a capacity of .00025 microfarad, whereas the grid-leak resistance should be very close to 2 megohms. The grid return may connect with either the positive or negative filament terminal with a preference for the latter.

Somewhat improved characteristics are secured by the high-amplification factor of the tube. It also has a fairly high plate impedance, and is suitable for either resistance or transformer coupling. The plate-current drain is quite moderate under the recommended operating conditions. The extreme sensitiveness of this tube is not effective on strong signals, but is apparent in the reception of relatively weak signals.

Super Power Amplifier Tubes.—Radiotrons UX-210 and UX-250 may be termed as super power amplifier tubes. The filament is designed primarily for operation at 7.5 volts directly from a transformer. It may, however, be operated from an 8-volt storage battery. The plate voltages may be supplied from B batteries that are capable of furnishing sufficient current, although the tubes are primarily for use with rectified alternating current. These tubes are capable of handling far greater volume without distortion than any of the other tubes, and their output is ample to supply any loudspeaker to its limit of volume.

Radiotron UX-250 adapts itself for use with loudspeakers to be used in large auditoriums. For the same filament current and plate voltage radiotron UX-250 has more than twice the undistorted power output of the UX-210. Because of its low plate impedance it must be used with an output transformer or choke coil and coupling condenser.

TUBES IN TRANSMITTING SYSTEMS

UX-210.—Radiotron UX-210, in addition to being a good power tube in radio reception, can also be used in low-power transmitters. The tube is so designed that the plate will stand a continuous dissipation of 7.5 watts. In appearance it resembles the UX-201-A radiotron. The bulb is larger than is commonly the case with the tubes equipped with the new large standard push-type UX base. The characteristics of this tube as well as those of other tubes may be seen at a glance in Table IV.

The UX-210 tube has a thoriated filament that takes 1.25 amperes at 7.5 volts. The plate is specially mounted so as to permit of safe operation on voltages as high as 500 volts. This tube may be used as an oscillator for radio-communication transmitting sets of small power, with plate voltages not in excess of 500 volts. The circuit adjustments should be so made that the plate dissipation of the tube does not exceed 7.5 watts. The plate voltage should not be raised to increase the power output, but more tubes should be connected in parallel if best life is to be secured. This tube makes a very good power amplifier with 425 volts on the plate and with a grid bias of −35 volts. The plate current will be about 22 milliamperes, and the plate impedance about 5,000 ohms. The amplification factor of this tube is a little greater than 7.5. The tube may also be operated at lower plate and grid voltages with very good results. With 6 volts on the filament, or directly from a storage battery, the plate potential of 135 volts is recommended with a grid bias of −9 volts. Under these conditions the plate current will be about 4.5 milliamperes and the plate impedance approximately 8,000 ohms. Although the amplification constant will still be 7.5, the power output from the tube will be very seriously reduced.

UX-216-B Rectifier Tube.—The UX-216-B rectifier tube is almost identical in construction with the UX-210 tube except that the UX-216-B tube has no grid element. It is rated to operate with a maximum alternating-current effective voltage, as read by an alternating-current voltmeter, of 550 volts. The maximum output current is 65 milliamperes. This type of tube may be used in a half-

TABLE IV

POWER RATINGS OF CERTAIN STANDARD TUBES

Model	Use	Filament Voltage	Filament Current Amperes	Plate Voltage	Plate Current Milliamperes	Power Output
UX-210.....	Amplifier Oscillator	7.5	1.25	500	25	7.5 watts
UX-216-B...	Rectifier	7.5	1.25	550 A.C.	60 D.C.	25 watts
UV-203-A...	Amplifier Oscillator	10	3.25	1,000	125	50 watts
UX-852.....	Amplifier Oscillator	10	3.25	2,000	75 (osc.)	75 watts
UV-204-A...	Amplifier Oscillator	11	3.85	2,000	200	250 watts
UV-851.....	Amplifier Oscillator	11	15.5	2,000	875 (osc.)	750 watts
UV-206.....	Amplifier Oscillator	11	14.75	10,000	135	1 K.W.
UV-218.....	Rectifier	11	14.75	15,000 A.C.		2.5 K.W.
UV-207.....	Amplifier Oscillator	21	51	10,000 to 15,000	1,400 to 1,800	10 to 20 K.W
UV-219.....	Rectifier	22	24.5	15,000 A.C.		12.5 K.W.

or full-wave rectifier for plate supply for the UX-210 tube or for the smaller receiving tubes.

50-Watt Tubes.—Tubes rated at 50 watts plate dissipation are made with both tungsten and thoriated filaments. The filaments of these tubes are designed for 10 volts, with a current of 6.5 amperes for those with tungsten filaments, and about 3.25 amperes for the tubes with thoriated filaments. In some other cases the filament is of the oxide-coated type. With this voltage rating the filament may be conveniently operated from a 12-volt storage battery with a rheostat for proper voltage control. A tube of this general class is illustrated in Fig. 27. The overall length of the tube and base is about $10\frac{1}{4}$ inches, whereas the maximum diameter should not exceed $2\frac{5}{16}$ inches. The base is of a large special bayonet-mounting type.

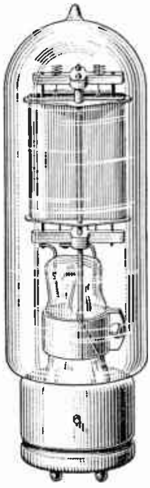

FIG. 27

As shown, the bulb is only partially discolored so as to permit of as free heat radiation from the plate as possible. The plate is separately mounted away from the grid and filament leads so that the tube can stand the high voltages for which it is designed. The design of the plate element is such that it will present a large radiating surface, and also so that it will be able to hold its shape when heated. The plate dissipation of 50 watts should not be exceeded for continuous operation, although a larger amount of energy may be handled for a short time. The plate should show only a slight reddish color under normal operating conditions.

The thoriated filament tubes, which are the most widely used, are made in two general types, namely, the UV-203-A and the UV-211. The filament voltage and current is the same for both types. The UV-203-A has an amplification factor of 25. With 1,000 volts on the plate and a zero grid bias the plate current is about .125 ampere, and the plate impedance approximately 5,000 ohms. The amplification factor of the UV-211 tube is lower and averages close to 11. The plate impedance, with 1,000 volts on the plate and a grid bias of −50 volts, is about 2,700 ohms, while the plate current is close to .085 ampere. At 1,000 volts on the plate in amplifier service the UV-203-A should be operated with a grid bias of 40 volts and the UV-211 with a grid bias of about 100 volts in order to hold the plate dissipation to a safe figure. In oscillator service the bias may be provided by the voltage drop in the grid leak.

Rectifier tubes are made in these same general styles of construction, except that the grid element is omitted. For very high voltage service the plate lead is taken out of the top of the bulb.

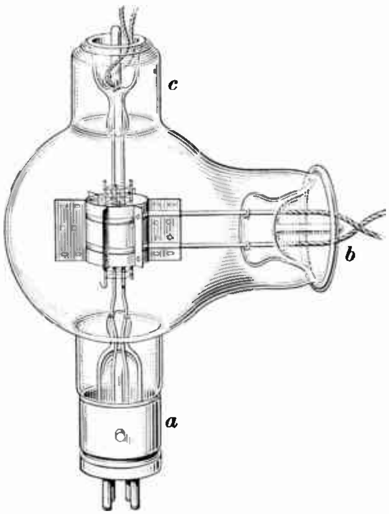

FIG. 28

75-Watt Tube for Short-Wave Work.—In Fig. 28 is shown a 75-watt tube known as UX-852. This tube was developed to satisfy the insistent demand of amateurs for a type of tube that could be used satisfactorily in short-wave work. The elements of this tube are of rugged construction and so well spaced that the internal capacity is much smaller than in most transmitting tubes. The filament terminals are in the base *a*. Connection to the plate is made by means of the conductors extending from the side of the tube at *b*. The grid connections are made at *c*. Two leads extend from the plate and two from the grid to the external circuit. The two leads from each element should be twisted together.

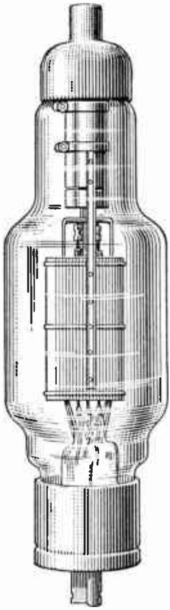

FIG. 29

The filament current is 3.25 amperes with an e.m.f. of 10 volts. The normal plate potential is 2,000 volts with a plate current of 75 milliamperes (oscillatory). The tube has a safe power dissipation of 100 watts, and the rated power output is 75 watts. The amplification constant of this tube is 12.

250-Watt Power Tube.—The 250-watt power tube is designed and rated to operate with a continuous plate dissipation of 250 watts. A special type of construction is necessary to accommodate the rather large plate, and to give a construction which will safely withstand the attendant high voltages that are necessary in normal operation. These tubes are sometimes made with tungsten filaments rated to take about 15 amperes at 11 volts. The special thoriated filament tube, often called the UV-204-A, has a filament current consumption of 3.85 amperes at 11 volts. If the filament is operated from an alternating-current supply, the grid-return connection should be made with a mid-tap on the secondary winding of the transformer. If operated from a direct-current supply, the grid return should connect with the negative-filament terminal.

As shown by Fig. 29, the bulb is nearly all clear to better allow the heat to be radiated. For this reason, a free circulation of air should be possible around the tube. The base, or filament end, has two large round pins for the filament connections with the special socket for this tube. The grid connects with a wide blade mounted midway between the two filament pins. The plate is entirely supported from the opposite end and connects with a metal cap on the end of the tube. With this type of construction, very high voltages may be applied to the plate with no danger of base trouble. A $\frac{3}{32}$-inch spark gap between the grid and one of the filament pins should form part of the mounting so that excessively high voltages which may be produced between these elements may discharge safely outside the tube.

The tube should be operated either vertically, with the cathode up, preferably, or horizontally with the plate element on edge. The supports should be cushioned so that no sudden jars will be transmitted to the tube. The maximum overall length is about 14½ inches, and the bulb diameter should not exceed 4¼ inches. In oscillator service an efficiency, or ratio of output to input, of over 50 per cent. should be possible with proper circuit adjustments. In any event the plate dissipation should not exceed 250 watts continuously if best life is to be secured. The oscillator circuit should not require a plate current of more than .2 ampere under any conditions with the plate at 2,000 volts direct current.

The amplification constant of this tube is close to 25. With 2,000 volts on the plate and with a grid bias of −25 volts the plate current will be about .175 ampere and the plate impedance close to 6,000 ohms. In any radio or audio-frequency amplifier service the plate dissipation should never exceed the rated value of 250 watts. In general, this corresponds with a slight reddish color on the plate, but this observed temperature should never be relied upon in place of an instrument reading.

Rectifier tubes with plate elements about the size of the 250-watt tube plate are made with many various rated outputs. The energy used up inside the tube must, as elsewhere, be dissipated by the plate, and the tube rating should correspond with the safe operating value. However, it is possible to operate such tubes so that the safe output in the load circuit may be several times the tube dissipation. Such tubes are variously rated at the maximum safe plate dissipation value in watts with the maximum plate voltage and according to the maximum output current and voltage. Such tubes are customarily supplied with tungsten filaments that are operated directly from the supply line with a transformer to give the correct voltage.

20-K.W. Power Tube.—The 20-K.W. tube, one make of which is often called the UV-207, is able to deliver 20 kilowatts of power to the load circuit continuously. In order to handle this large amount of power, a tube with air cooling would have to be so large as to be entirely impracticable. It is necessary to make the plate element a part of the external tube body so that it may be water-cooled. This requires a seal between the glass and metal parts of the glass bulb and the metal plate element, which will maintain a very high degree of vacuum inside the tube. This is commonly accomplished by melting the glass to form a permanent seal with a knife-edge fin of copper made on the plate proper.

One typical water-cooled power tube is illustrated in Fig. 30, in its operating position, namely, with the plate down. This element is often made of copper, with a method provided whereby the water-jacket may be attached securely. The plate-circuit connection may conveniently be made with the water-jacket. The grid element, as in other cases, is inside the plate structure. The grid is supported by glass tubing on the filament end over which the grid collar is clamped. The grid-lead connection is taken out of one side of the bulb so as to remove it as much as possible from the proximity of the filament and plate elements. The filament leads are made of heavy flexible copper conductors.

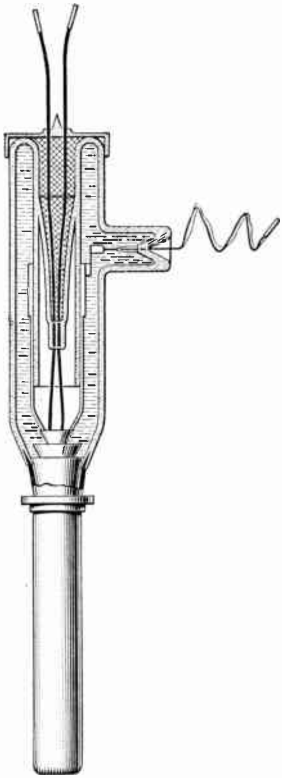
FIG. 30

The tube is mounted by supporting the water-jacket, hence no base is necessary. A cap may be provided to keep the filament leads from shorting with each other. The filament and grid leads should be connected so that no strain is placed on any part of the tube, and especially on the glass-to-metal seal. A steady flow of about 2 gallons of water per minute must be maintained through the water-jacket at all times when the tube is operated. It is advisable to connect an interlock system between the water and electrical system so that the tube cannot be started if there is no water flow or so that it will be immediately disconnected in case the water pressure fails for any reason. If it does not cause too much deposit on the plate, the local water supply will serve the purpose. Otherwise a special water circulating system will prove advantageous.

The 20-K.W. tube may be operated as an oscillator in any of the usual oscillator types of circuits. The circuit should be adjusted carefully so that the tube may operate in as efficient a manner as possible. With a plate dissipation of 10,000 watts it should be possible to secure the full rated output of 20 K. W., or 20,000 watts, with some allowance for circuit losses. With the rated plate potential of 15,000 volts the oscillating plate current should not exceed 2 amperes. The grid circuit and grid leak should be so adjusted as to keep the grid current as low as is consistent with good operation.

The tube may also be used as an amplifier with the plate dissipation held to a safe value for continuous operation. The amplification factor is close to 20. The plate impedance is close to 3,000 ohms with 15,000 volts on the plate and with a grid bias of 550 volts, whereas the plate current, with these voltages, will be close to .650 ampere. The tube should always be operated with a bias sufficient to limit the plate dissipation to the rated safe value.

Operation as either an amplifier or oscillator at extremely low wavelengths or high frequencies is hard on the tube and the safe output will have to be considerably reduced if good life is to be secured. The filament should always be operated at the rated voltage or current as recommended by the manufacturer. A voltmeter connected directly across the filament terminals will be of value in securing the best operating conditions.

Water-cooled tubes of this same general type are also used in rectifier service where the output current is quite large. They look much like the three-element tubes, except, of course, that the grid element is omitted. The rectifier tubes are made in a wide range of ratings for various types of service at high and low applied plate voltages. Such tubes will operate in the usual rectifier systems, with the extra precautions regarding the features of the water-cooling system.

ANTENNAS

PRINCIPLES OF TRANSMISSION

Magnetic and Electric Fields.—The function of an antenna is to radiate or collect the high-frequency energy used for radio communication. The simple antenna may be considered as a doublet, as shown in Fig. 1. Here a source of high-frequency energy, such as an alternator *a*, is connected to a vertical wire *b* extended upwards, and a similar wire *c* extended downwards. The two wires *b* and *c* have capacity between them and may be considered as the plates of a condenser with an air dielectric.

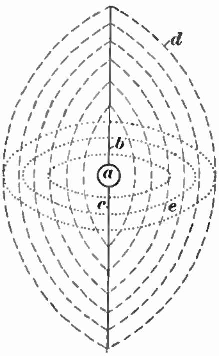

FIG. 1

Suppose the alternator *a* is just starting on a positive cycle and charges the wire *b* positive and the wire *c* negative. An electric strain is set up in the space about the antenna, which may be represented by imaginary electrostatic lines of force *d* extending from one wire to the other. These lines of force immediately start to move away from the antenna with the velocity of light. In the meantime, the alternator voltage advances to the peak of its positive cycle, at which time the electrostatic lines of force reach a maximum value. These lines of force represent stored energy, just as a stretched spring represents stored energy. As soon as the alternator voltage starts to decrease, the electrostatic lines of force begin to collapse back onto the antenna, giving up their energy, which reappears in the form of a magnetic field set up by the current in the antenna. This electromagnetic field may be represented by imaginary lines of force *e* at right angles to the electrostatic lines of force.

Before all of the electrostatic field has had time to return to the antenna, the alternator starts on its negative cycle, charging the wire *b* negative, and the wire *c* positive, thereby setting up a field that is opposite to what it was before, making it impossible for the remaining portion of the returning electrostatic field to give up its energy to the antenna. This portion of the electrostatic field never returns to the antenna, but travels away from the antenna with the velocity of light as a free wave. This action takes place on every half cycle of the alternator, and continues as long as the alternator voltage is applied to the antenna.

Radiation and Induction Fields.—It follows, then, that the field about the antenna can be considered as having two portions, one portion that builds up and collapses on the antenna itself, and a second portion that becomes detached from the antenna, never to return. The first portion is called the *induction field*, and the second portion is called the *radiation field*. It is the radiation field that is useful in radio communication.

It can be shown, mathematically, that the induction field and the radiation field have very definite proportions at any given distance from the antenna. The induction field falls off as the square of the distance from the antenna, whereas the radiation field falls off directly as the first power of the distance. At a distance of one wavelength from the antenna, the induction field is small compared with the radiation field, and its effect may be considered as negligible.

Aside from absorption of energy by the earth, the total energy in the radiated wave remains constant. Hence, as the wave advances, the energy becomes spread out over a greater area, and the energy at any point decreases directly as the distance increases. The decrease in amplitude of the radiated wave is analogous to the decrease in amplitude of a water wave produced by throwing a stone into a smooth mill pond. The water wave has a large amplitude at first, but the amplitude becomes smaller and smaller as the wave expands in ever-widening circles, because the original energy of the impact of the stone spreads out over a large area.

The traveling radiation field has two components, the electrostatic field and the electromagnetic field, the energy in these two fields being equal. The form of these two fields will be considered later in connection with an antenna with an earth connection in place of the lower half of the doublet.

Frequency and Wavelength.—There is a definite relation between the frequency of the alternator or other transmitter and the wavelength. While the transmitter passes through one complete cycle, the radiated wave travels a distance of one wavelength. Since the radiated wave travels with the velocity of light, it will travel 186,000 miles, approximately, or 300,000,000 meters in one second. When the frequency of the transmitter is known, the distance the wave will travel during one cycle, or the wavelength, may be calculated by the following equation:

$$\lambda = \frac{V}{f} = \frac{300,000,000}{f} \text{ meters.}$$

in which λ = wavelength, in meters;

V = velocity of electromagnetic waves;

f = frequency, in cycles.

This equation may be used for calculating the frequency from the wavelength, and vice versa. For example, 1,000,000 cycles per second would correspond to a wavelength of 300 meters; 100,000 cycles would correspond with a wavelength of 3,000 meters, etc.

When the radiated wave reaches the receiving antenna, it induces in the antenna a voltage having the same frequency as the transmitter. This induced voltage causes a current in the antenna, and this current will be a maximum if the antenna is tuned to resonance for that particular frequency. Some of the energy is transferred to the receiving set, where it is detected and amplified and operates the telephones, loud speaker, or other device attached to the output of the receiver.

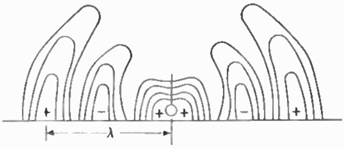

FIG. 2

Antenna and Ground. The simple doublet of Fig. 1 is rarely used except at extremely high frequencies or short wavelengths, where the wires of the doublet are only a few meters long. On long wavelengths, a doublet suitable for radiating considerable amounts of power would be very high, and it would be very expensive to provide towers high enough to support it.

To overcome this difficulty, the lower half of the doublet is usually omitted, and an earth connection is substituted. The capacity effect then exists between the antenna and the earth. The distribution of the electrostatic lines of force from a grounded antenna is as shown in Fig. 2. This figure also shows the probable shape of the electrostatic field after the lines of force have become detached from the antenna and are traveling as free waves. At the instant shown, the antenna is assumed to be charged at a maximum positive voltage. The distance from the antenna to the center of the positive traveling wave, shown as λ, is one wavelength, since this positive traveling wave was radiated by the preceding positive cycle of the transmitter. The electromagnetic lines of force are not shown, but they are traveling parallel to the surface of the earth in ever-widening circles, with the antenna as a center, analogous to water waves traveling from the center of disturbance when a stone is dropped into still water.

TYPES OF ANTENNAS

INVERTED L ANTENNA

The amount of power that can be put into an antenna is often limited by the voltage built up on the antenna, particularly at the longer wavelengths. In order to keep this voltage down to the limits of practical insulation, it is often necessary to increase the capacity of the antenna by adding a flat-top, or horizontal, portion. The addition of a flat-top portion also has the important effect of increasing the effective height, so that, for towers of a given height, the antenna becomes more effective both as a radiator and as a receiving antenna. This will be discussed later in this Section.

There are many types of antennas, but nearly all of them are simply modifications of the idea of combining a flat-top portion with a vertical portion, or *lead-in*, as the vertical portion is usually called.

Perhaps the most common form of antenna is the *inverted* L type shown in Fig. 3. The horizontal or flat-top portion is shown at *a*, whereas the lead-in, or vertical portion, is shown at *b*. The antenna is tuned by inductance *c*.

If the flat-top portion is long compared with the vertical height, the inverted L antenna is somewhat directional, with maximum transmission and reception in the direction opposite the free end, that is, from the left in Fig. 3. This directive effect is not clearly understood, but in ordinary antennas it is relatively small, and it may be neglected entirely if the horizontal length *a* is not much greater than the vertical height *b*. In some cases, the horizontal length is over ten times the vertical height, and, in such cases, appreciable directive effect is noted, as, for example, in the case of the Marconi bent antenna, which is a form of the inverted **L** antenna, with a very long horizontal portion.

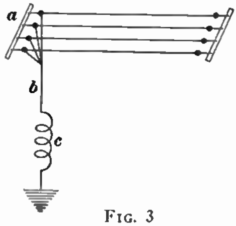

FIG. 3

T-TYPE ANTENNA

The **T**-type antenna is similar to the inverted **L** type, except that the lead-in is brought down from the center, rather than from one end. The **T**-type antenna is practically non-directional. It is used frequently on ships, where the radio room is in the center of the ship.

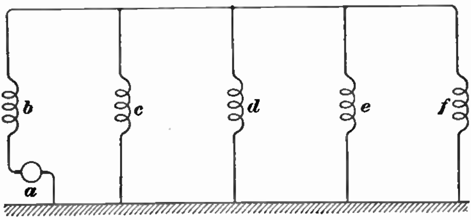

FIG. 4

MULTIPLE-TUNED ANTENNA

The Alexanderson multiple-tuned antenna is a special arrangement making it possible to use a very long horizontal portion efficiently. It is equivalent to operating several antennas in parallel. In Fig. 4, down leads are shown coming down from several points in the antenna to suitable tuning coils connected to earth. The alternator *a* feeds energy at only one down lead, such as at *b*. Each section *b*, *c*, *d*, *e*, and *f* is tuned separately in such a manner that all of the currents in the vertical portions are in phase, so that the total antenna current is the sum of the currents in all of the down leads. A typical antenna of this type is 1.25 miles long and 400 feet high, operating at wavelengths from 11,000 to 20,000 meters, for transoceanic telegraph service. The multiple-tuned antenna is rarely used as a receiving antenna, but is one of the most important types of transmitting antennas.

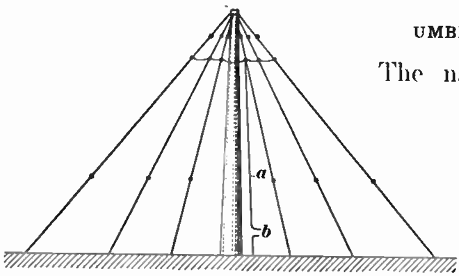

FIG. 5

UMBRELLA ANTENNA

The name of the umbrella-type antenna is quite descriptive of its construction, as it consists of a high center support, Fig. 5, with wires extending radially from it like the ribs of an umbrella. The antenna wires are insulated from the earth and from the central mast, and are connected together at the top and to the lead-in *a*. The receiving or transmitting system is connected at *b*. The antenna wires also act as guys to support the pole.

If the lower ends of the wires come too close to the ground, the field will be confined in the space between the lead-in and the wires, and there will be very little radiation. The wires should not make an angle of less than 50 or 60 degrees with the mast, and the lower ends should be insulated at some distance from the ground, so that the lower ends of the wires are half the mast height or more from the ground.

The umbrella type antenna is frequently used for portable stations and is also sometimes used in long-wave transmitting stations, where twenty or more wires are spaced equally about the mast, with the lower ends supported on shorter masts, in some cases. It has the advantage of being non-directional and gives a considerable amount of capacity and effective height with a single high mast, which is a considerable factor, as high masts are very expensive.

CONDENSER ANTENNA

For measuring work, or in cases where it is desirable to calculate the effective height of the antenna, a condenser-type antenna is sometimes used. This usually consists of two large metal plates or screens, with relatively small vertical separation. If the separation is small compared with the dimensions of the plates, the effective height is very nearly equal to the separation between the plates. Furthermore, since the antenna is practically an efficient air condenser, the dielectric losses are very low and considerable energy can be radiated, in spite of the low effective height.

GROUND ANTENNA

There are other types of antennas more particularly adapted to reception than to transmission. Many types of ground antennas come under this classification. Owing to losses in the earth, waves arriving from a distance are tilted forward slightly, and therefore have a small horizontal component of energy, which will induce voltages in a horizontal conductor, practically independent of the vertical distance of the horizontal conductor above ground.

If the horizontal length is over a quarter of a wavelength, this type of antenna becomes considerably directive; that is, it receives better from stations toward which it points than from stations that are off to one side.

Insulated wires lying on the ground, buried in the ground, or laid in shoal water, have been used by different investigators, notably Commander A. H. Taylor and Mr. Rogers. The voltage induced in these wires by the horizontal component of the wave is practically independent of the distance the wire is suspended above ground, as was previously mentioned, but, if the wire is suspended at some distance above ground, it will have vertical antenna effects superimposed upon the horizontal antenna effects. The magnitude of the horizontal component depends on the wavelength and the conductivity of the ground, whereas the vertical antenna effect is dependent only on the height of the wire above ground. The horizontal component varies from practically zero over deep-sea water to perhaps 10 per cent. of the vertical component over dry sand. Hence, to operate only on the horizontal component of the wave, a ground antenna should be one hundred or more times longer than its vertical height. The length of insulated ground wire that can be used is limited by the low velocity of the currents in the wire, which is on the order of half of the velocity of light or less. For this reason, it is usually best to use bare wires supported a short distance above the ground, as this increases the velocity and makes it possible to use a longer wire. On the other hand, where space is a consideration, it is probable that a buried ground wire will give greater directivity for the same length than a bare wire suspended above the earth.

WAVE ANTENNA

The *wave antenna* is a special form of directive horizontal antenna, which operates on the horizontal component of the wave, similar to a ground wire. It derives its name from the fact that it is usually about one wavelength long, this length having been found best from practical considerations. In its simple form, the wave antenna is simply a long wire suspended a few feet above the ground on poles.

A wave traveling from the right reaches end *a*, Fig. 6, first, and, owing to the wave tilt, a voltage is induced in the wire at *a*. As the wave travels along the wire from *a* to *b*, the voltage induced at *a* travels along in the wire at

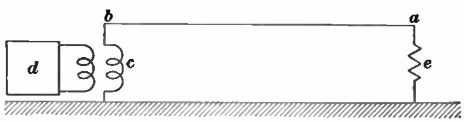

FIG. 6

practically the same velocity as the wave in space, that is, the velocity of light. In like manner, the voltage induced at any intermmediate point in the wire travels along the wire at the same speed as the wave. The result is that all of the voltages induced in the wire by the traveling wave, arrive at the end *b* in phase, and, passing through the coil *c*, produce a strong signal at the terminals of the receiver *d*. This effect is analogous to producing a water wave in a long narrow trough by swinging a shovel into the water at regular intervals of time. If the shovel is dipped into the water in synchronism with the movements of the water wave in the trough, the wave builds up to a very large amplitude at the far end of the trough.

A wave traveling from *b* to *a* builds up to a large amplitude at *a*. If the end *a* were directly grounded or left open, the energy would be reflected back to the receiver at *d*, and the antenna would be bidirectional; that is, it would receive from both directions *ab* and *ba*. By placing a resistance *e* between the antenna and ground at *a*, the energy traveling in the direction *ba* is absorbed, making

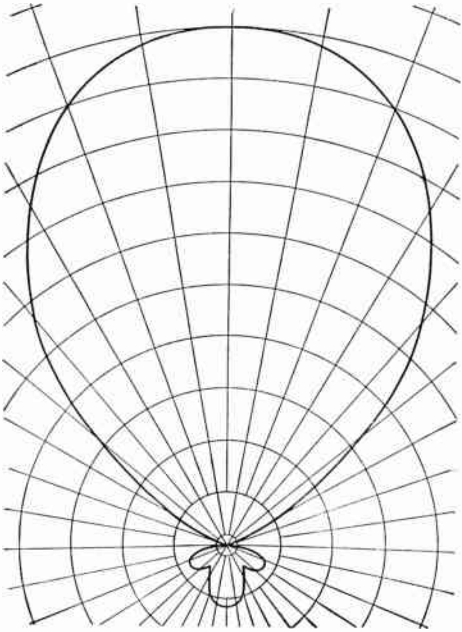

FIG. 7

the antenna unidirectional; that is, it receives only from the direction *ab*. The resistance *e* must be made equal to the *natural*, or *surge*, *impedance* of the wire with respect to the earth. This resistance is somewhat analogous to placing a shoaling sand surface at the end of the trough to absorb the water wave instead of allowing it to dash against a solid wall, which would reflect the wave back down the trough and setting up a flow in the reverse direction.

The unidirectional receiving properties of a horizontal wire one wavelength long, and properly damped at one end, are shown in Fig. 7. This polar diagram shows the strength of signal that would be received if a transmitting station at a considerable distance were moved around the receiving antenna in a complete circle, always keeping the same distance from the receiving antenna.

Owing to losses in the wire, the reception from the direction opposite to the direction of maximum reception is not quite zero, but it is relatively small, as shown.

The wave antenna is particularly useful for receiving from long-wave fixed stations, where the major portion of the static and interference originates from directions other than the direction of the desired signals. It is used extensively for transoceanic reception, and for long-distance reception from ships.

LOOP ANTENNA

The loop antenna is another form of directive antenna that is used mainly for receiving. It consists of one or more closed turns of wire, usually wound in the form of a square, as shown in Fig. 8. It may be tuned by a condenser *a* and loading coils *b* and *c*, although it is not always necessary to use loading, as the loop inductance alone is sufficient if enough turns are used. The receiver is coupled to coil *b* by means of coil *d*.

An arriving electromagnetic wave coming from the right of Fig. 8 induces a voltage in side *e* of the loop in all wires. An instant later, the same part of the wave reaches side *f*, where it induces an equal voltage in the wires of side *f*. These two voltages are exactly equal and are opposed, but there is a slight difference in phase owing to the time it took the wave to travel from *e* to *f*. Because of this slight difference in phase, there is a small resultant voltage left which causes a current in the loop. This phase difference is given by the equation

$$\phi = \frac{2\pi D}{\lambda}$$

in which π = phase difference, in radians;

$\pi = 3.1416$;

D = distance between sides of loop, expressed in meters;

λ = wavelength, in meters.

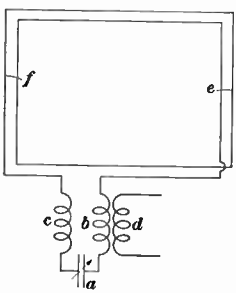

FIG. 8

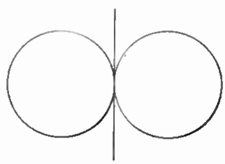
FIG. 9

If the signal arrives from a direction exactly at right angles to the plane of the loop, the wave reaches both sides of the loop at exactly the same instant, so there is no phase difference between the sides of the loop, and the voltages from the two sides exactly oppose, resulting in no signal. A further consideration of this subject would show that for other directions, there would be a signal of varying intensity, depending on the angle the signal makes with the plane of the loop, and that this variation is a simple cosine law. If the cosine is plotted on polar coordinate paper, it results in the *figure 8* diagram shown in Fig. 9, which is, therefore, the directive diagram of the simple loop.

If the loop is made so it can be rotated on its vertical axis, it can be used to indicate the direction from which a signal is arriving. When the loop is turned until the signal is a maximum, the plane of the loop is pointing toward the transmitting station. On the other hand, if the loop is swung around until the signal disappears, the signal is coming from a transmitting station located at right angles to the plane of the loop. The zero on a properly adjusted loop can be set much closer than the maximum, because it is comparatively easy to tell where the signal disappears, but very difficult to judge slight changes in intensity near the maximum. For this reason radio bearings are almost always taken on the minimum or zero line of the loop.

A bearing taken on the loop alone, indicates the true line of direction, but does not indicate the absolute direction, or *sense* of direction. For example, if the loop gives zero signal when its plane is East and West, it is known that the transmitting station is either directly North or directly South, but it is not possible to tell which direction is correct.

LOOP-VERTICAL ANTENNA

In order to get the *sense* of direction, it is necessary to make the loop unidirectional; that is, receptive from one direction, but non-receptive from a direction 180 degrees opposite.

This may readily be accomplished by combining the loop with a vertical antenna, as shown in Fig. 10. For the sake of simplicity, only one turn is shown on the loop, but several turns could be used. The loop is shown as *ab*, and the vertical antenna is shown as *cd*, with coil *e* in series with the vertical antenna. The coupling between coils *e* and *f* is adjusted until the voltage received from the vertical antenna is equal to the voltage received from the loop.

Assume an oncoming signal wave *g*; this wave will progressively induce a voltage in *a*, *cd*, and *b*. All of the voltages will be in the same direction, as indicated by the small arrows. It has already been explained how the voltages in *a* and *b* do not quite neutralize, because of the phase difference between sides *a* and *b*, the voltage in side *a* being slightly in advance of the voltage in side *b*. Now suppose the loop is turned 180 degrees on its vertical center line as an axis, so that side *b* is nearest the signal. Now the voltage in side *b* will be slightly in advance of the voltage in side *a*, whereas, before the loop was turned 180 degrees, the voltage in side *b* was lagging. The result is that the voltage in the loop is exactly reversed when the loop is reversed by turning it 180 degrees on its axis. On the other hand, the direction of the voltage in the vertical antenna remained the same as before.

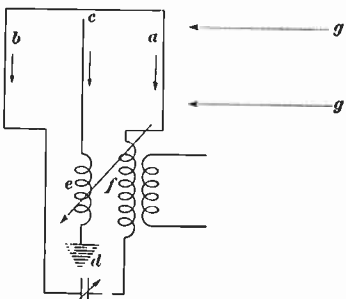

FIG. 10

Of course, the voltages are always changing as the wave advances, but the relative phase relations between the sides of the loop and the vertical antenna always remain the same.

If the vertical-antenna phase and intensity are properly adjusted, the loop voltage and vertical-antenna voltage will exactly balance for one position of the loop, and will add in phase if the loop is turned around 180 degrees, as this reverses the direction of the loop voltage without changing the direction of the vertical antenna voltage, as already explained. The resultant reception diagram is a *cardioid*, or heart-shaped, curve, as shown in Fig. 11 at *a*.

If the vertical-antenna voltage is not as strong as the loop voltage, the loop effect predominates, resulting in the unsymmetrical curve *b*. If the vertical-antenna voltage is too strong, the vertical-antenna effect predominates, resulting in the distorted curve shown at *c*. Any

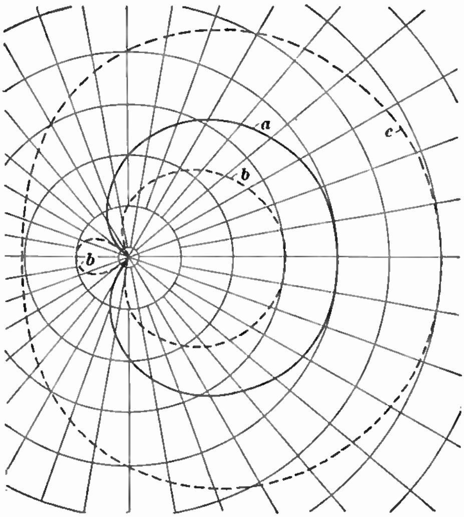

FIG. 11

of these diagrams may be rotated by turning the loop, or they may be reversed 180 degrees by reversing either the loop or vertical-antenna connections.

DIRECTION FINDING

It has already been explained how the line of direction could be determined with a simple loop by swinging it until the signal disappeared, at which point the plane of the loop is perpendicular to the line of direction of the signal, and that the absolute sense of direction was not evident from the loop bearing alone.

The point is further illustrated in Fig. 12. Suppose the transmitter is at *a* and the loop is shown as *bc*. The signal is zero when the loop is at right angles to the line of direction *ad*, but the transmitter might be at either *a* or *d*. To determine which position is correct, the loop is swung around 90 degrees so that the signal is received at its maximum intensity. Then the vertical antenna is switched on, as shown in Fig. 10, resulting in one of the reception diagrams of Fig. 11. If the transmitting station is at *a*, Fig. 13, the vertical-antenna and loop voltages may add, producing a stronger signal than the loop alone, as shown by the full-line curve, where *bc* is the position of the loop. If the transmitting station had been at *d*, the loop voltage would have opposed, resulting in no signal, or a much weaker signal when the vertical antenna was switched on. If the loop had been turned around 180 degrees, switching on the vertical antenna would have weakened the signal at *a* and strengthened a signal at *d*, now indicated by the dotted curve. Hence, when a radio compass is installed, it is necessary to check the relative direction of the loop and vertical-antenna voltages, and to mark the *sense* scale plainly, so that there can be no doubt about the proper sense of direction. Once this scale has been properly set, the loop connections should not be changed.

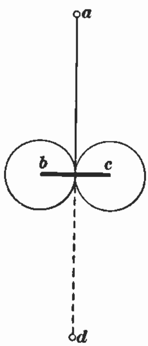

FIG. 12

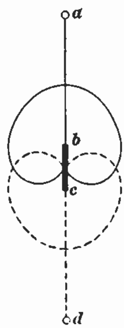

FIG. 13

The radio compass is a great aid to the navigation of ships and aircraft, and it is possible for them to navigate in heavy fog, or other weather of low visibility, by frequently taking radio bearings. There are two general methods for taking these radio bearings, namely:

(*a*) The ship may be equipped with a radio compass for taking bearings on fixed stations of known location.

(*b*) The ship may not be equipped with a radio compass installation, but has a radio transmitter. The ship sends certain identification signals, and two or more fixed land stations take radio bearings for the ship.

In Fig. 14, the ship is at *a*. Suppose the ship is equipped with a radio compass, and suppose that at points *b*, *c*, and *d* there are three land stations transmitting certain identification letters. The radio operator or navigating officer takes bearings on each of these stations, noting how many degrees East or West of North the loop bearing is by comparing with the ship's compass. The positions of the transmitting stations are marked on the chart, and the observer lays off the radio bearings on the chart. The intersection of these bearings gives the ship's position at *a*.

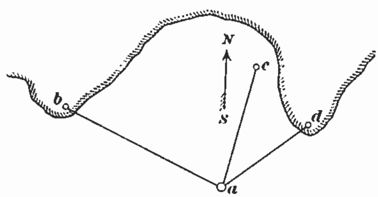

FIG. 14

If the ship has no radio compass, she calls the master compass station, located, say, at *b* and asks for bearings. Station *b* asks the ship to send certain identification letters, and notifies stations *c* and *d* by telephone or telegraph, to take bearings on this ship. In this case, stations *c* and *d* do not transmit, but are equipped with radio-compass installations for taking bearings. As soon as stations *c* and *d* have taken their bearings, they transmit them to station *b* by wire. The operator at *b* then transmits all three bearings to the ship, where they are plotted on the chart, giving the position of the ship at *a* as in Fig. 14.

By either method, two bearings would be sufficient to locate the position of the ship, but a third bearing is sometimes taken as a check. It is desirable that, for accurate results, stations *b*, *c*, and *d* should be considerably separated, so that there is a large angle between the bearings. Then, if a slight error is made in one of the bearings, it would not change the location determined for the ship appreciably.

Both methods are used extensively. The United States government maintains both transmitting and receiving radio-compass stations at important points along the coast. The transmitting compass stations are of relatively low power, to minimize interference, and consist mostly of automatic-spark transmitters working on a wavelength of about 1,000 meters. It has been found that the shorter wavelengths give the most accurate bearings, and also that spark, or damped-wave, transmitters give more accurate and consistent bearings than continuous-wave transmitters.

Of course, it is very simple for the ship to call the land compass station to get her bearings, but in the vicinity of a busy port, in bad weather there are so many ships requesting bearings that it is sometimes impossible for a ship to get bearings without considerable delay. The tendency, now, is for ships to have their own radio-compass installation, so they can take their bearings as frequently as they desire.

SOURCES OF ERROR IN RADIO COMPASS

If the signal on which a bearing is being taken is weak, static and interference may cause the signal to disappear at some distance at either side of the minimum. If the interference is steady, it is possible to determine the disappearing point on each side of the minimum, thereby locating the true minimum as half way between these disappearing

The directive property of the loop is useful for eliminating strong station interference and induction, where the source of the interference comes from a signal point more or less at right angles to the direction of the desired signal. The loop will also eliminate some static under certain conditions, but it is not nearly so effective on static as on induction and interference, because, as a rule, the static that affects broadcast waves comes from practically all directions.

For measuring signal strength, the loop is very useful, as it is easy to calculate its effective height from its physical dimensions.

ANTENNA PROPERTIES

FUNDAMENTAL WAVELENGTH

The fundamental wavelength of an antenna is the wavelength at which the antenna oscillates with no loading at the base. This wavelength is sometimes called the *quarter-wave oscillation*, because the current and voltage assume a distribution in the antenna similar to one quarter of a sine wave.

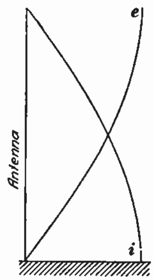

FIG. 15

In Fig. 15 is shown the distribution of the current and voltage in a simple vertical antenna at the fundamental wavelength, that is, without loading at the base. Curve *e* shows the voltage distribution, the voltage being zero at the base, or earth connection, and a maximum at the upper end. Curve *i* shows the current distribution, the current being a maximum at the earth connection, and zero at the upper end.

Since the voltage and current distribution covers one quarter of a sine wave, it would appear that the fundamental wavelength should be four times the total length of the antenna. This would be true if the velocity of the current in the wire were the same as the velocity of the wave in space, that is, equal to the velocity of light. For a simple vertical wire, the current velocity is only slightly less than the velocity of light, so the fundamental wavelength is 4 to 4.2 times the vertical height of the antenna.

If the antenna has a horizontal portion, the horizontal portion must be added to the length of the lead-in to calculate the fundamental wavelength. If there is more than one wire in the flat top or lead-in, the velocity of the current is lowered a certain amount, depending on the number of wires and their spacing. To calculate the fundamental wavelength of an antenna roughly, measure the total length of the antenna from the instruments to the far end of the antenna, including the lead-in and the flat-top portion. Express this length in meters, (1 meter = 3.28 ft.) and multiply by 4 to 4.2 for a single-wire antenna, by 4.3 to 5 for an antenna with more than one wire, but with a narrow flat top, and multiply by 5 to 6 for an antenna with a wide flat top.

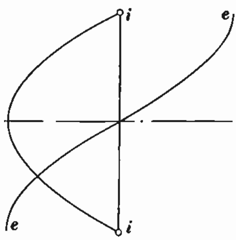

FIG. 16

The fundamental wavelength for a doublet is the same as for the simple vertical antenna half as long as the doublet. The reason for this is that the lower half of the doublet takes the place of the earth connection, leaving the current in the upper half of the doublet distributed the same as it was in the simple vertical antenna. The distribution of the voltage and current in the doublet is shown in Fig. 16. At the center of the doublet the voltage is zero, whereas the current is a maximum. At the ends the current is zero, whereas the voltage is a maximum. The voltage distribution, as shown by curve *e*, is at opposite potential at the two ends of the doublet, as will be remembered from the fundamental theory of the doublet.

HIGHER HARMONICS

Both the grounded antenna and the doublet will resonate at other frequencies higher than the fundamental. For example, in Fig. 17, the distribution of the current and voltage is shown for a grounded antenna oscillating at the three-quarter wave oscillation. The current is zero at a point one-third of the distance up from the base and again at the top. The voltage is zero at the base, and again zero at a point two-thirds of the distance up from the base.

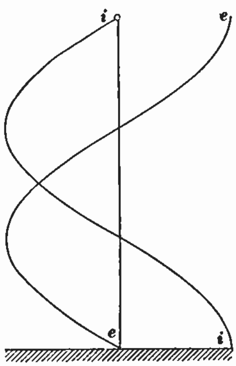

FIG. 17

If it is kept in mind that the current must always be zero at the open end of the antenna, and that the voltage is a maximum where the current is zero, it is a simple matter to draw out the distribution of current and voltage for any mode of oscillation.

If the length of the simple grounded antenna is given in meters and if the velocity of the current in the antenna is assumed to be equal to the velocity of light, it can be shown that the antenna will resonate without loading at any *odd* quarter wave, that is, at $\frac{4L}{1}, \frac{4L}{3}, \frac{4L}{5}, \frac{4L}{7}$, etc., meters, in which L is the length of the antenna in meters. It can be shown that the doublet will resonate without loading at any *even* quarter wave, that is, at $\frac{4L}{2}, \frac{4L}{4}, \frac{4L}{6}, \frac{4L}{8}$, etc., meters, in which L is the total length of the doublet in meters. The even quarter-wave oscillations are more often called half-wave oscillations, since they are multiples of the half-wave.

These higher harmonics are not so well known as the fundamental, or quarter-wave, oscillation, as it has usually been the practice to use only the quarter-wave oscillation. However, the higher harmonics are now frequently used for transmission at very short wavelengths. The doublet is also sometimes used for short-wave transmission, frequently with the doublet in a horizontal position, which is totally contrary to all long-wave theory and practice.

LOADING THE ANTENNA

The antenna may be used at wavelengths longer than the fundamental by inserting a loading inductance at the base. The voltage and current distribution is changed by the loading, and is somewhat as shown in Fig. 18. Since the capacity of the loading coil *a* to ground is small, the current is practically uniform in the whole coil, but assumes a more or less sine-wave distribution in the antenna, as shown by curve *i*. On the other hand, owing to the inductive impedance of the coil *a*, there is a linear building up of voltage in the coil, so that the top of the coil is at high voltage with respect to earth. In the antenna itself, the voltage increases still further, following more or less the sine-wave law, as shown by curve *e*.

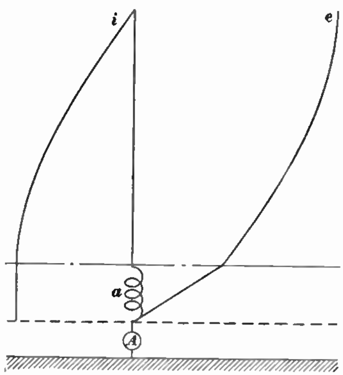

FIG. 18

The antenna can be operated at a wavelength lower than the quarter-wave fundamental by placing a condenser in series with the lead-in, in place of the loading inductance. Of course, it is necessary to keep some inductance at the

TABLE I

AVERAGE CHARACTERISTICS OF RECEIVING RADIOTRONS

General					Detection				Amplification						
Model	Use	"A" Supply	Filament Terminal Voltage	Filament Current (Amperes)	Detector Grid Return Lead To	Grid Leak (Meg-ohms)	Detector "B" Battery Voltage	Detector Plate Current (Milliamperes)	Amplifier "B" Battery Voltage	Amplifier "C" Battery Voltage	Amplifier Plate Current (Milliamperes)	A.C. Plate Resistance (Ohms)	Mutual Conductance (Micromhos)	Voltage Amplification Factor	Maximum Undistorted Output (Milliwatts)
WD-11	Detector or Amplifier	Dry Cell 1½V. Storage 2V.	1.1	.25	+F	3 to 5	22½ to 45	1.5	90 135	4½ 10½	2.5 3.5	15,500 15,000	425 440	6.6 6.6	7 35
WX-12	Detector or Amplifier	Dry Cell 1½V. Storage 2V.	1.1	.25	+F	3 to 5	22½ to 45	1.5	90 135	4½ 10½	2.5 3.5	15,500 15,000	425 440	6.6 6.6	7 35
UX-112-A A	↓ Detector or Amplifier	Storage 6V.	5.0	.25	+F	3 to 5	45	1.5	90 135	4½ 9	5.5 7	5,300 5,000	1,500 1,600	8 8	30 120
UV-199	Detector or Amplifier	Dry Cell 4½V. Storage 4V.	3.0 3.3	.060 .063	+F	2 to 9	45	1	90	4½	2.5	15,500	425	6.6	7
UX-199	Detector or Amplifier	Dry Cell 4½V. Storage 4V.	3.0 3.3	.060 .063	+F	2 to 9	45	1	90	4½	2.5	15,500	425	6.6	7
UX-200-A	Detector	Storage 6V.	5.0	.25	−F	2 to 3	45	1.5	Following UX-200-A Characteristics apply only for Detector Connection			30,000	666	20	——
UX-201A	Detector or Amplifier	Storage 6V.	5.0	.25	+F	2 to 9	45	1.5	90 135	4½ 9	2.5 3	11,000 10,000	725 800	8 8	15 55
UX-222	↓ Radio Frequency Amplifier	Dry Cell 4½V. Storage 4-6V.	3.3	.132	——	——	——	——	135	1½ #	1.5	850,000	350	300 M	——
UX-222	↑ Audio Frequency Amplifier	Dry Cell 4½V. Storage 4-6V.	3.3	.132	——	——	——	——	180 ‡	1½ □	.3	150,000	400	60	——
UX-226	Amplifier A-C Filament Type	Transformer 1.5V.	1.5	1.05	——	——	——	——	90 135 180	6 9 13½	3.5 6 7.5	9,400 7,400 7,000	875 1,100 1,170	8.2 8.2 8.2	20 70 160
UY-227	Detector A.-C. Heater Type	Transformer 2.5V.	2.5 H	1.75	C	2-9 ¼-1	45 90	2 7	Following UY-227 Characteristics apply only for Detector Connection			10,000 8,000	800 1,000	8 8	——
UX-240	Detector or Amplifier	Storage 6V.	5.0	.25	+F	2 to 5	135 180	.3 .4	135 ‡ 180 ‡	1½ 3	.2 .2	150,000 150,000	200 200	30 30	——
UX-112-A A	↑ Power Amplifier	Storage 6V. Transformer 5V	5.0	.25	——	——	——	——	135 157½	9 10½	7 9.5	5,000 4,700	1,600 1,700	8 8	120 195
UX-120	Power Amplifier	Dry Cell 4½V. Storage 4V.	3.0 3.3	.125 .132	——	——	——	——	135	22½	6.5	6,300	525	3.3	110
UX-171-A A	Power Amplifier L. S. C.	Storage 6V. Transformer 5V.	5.0	.25	——	——	——	——	90 135 180	16½ 27 40½	10 16 20	2,500 2,200 2,000	1,200 1,360 1,500	3.0 3.0 3.0	130 330 700
UX-210	Power Amplifier L. S. C.	Transformer 7.5V.	7.5	1.25	——	——	——	——	250 300 350 400 425	18 22½ 27 31½ 35	10 13 16 18 18	6,000 5,600 5,150 5,000 5,000	1,330 1,450 1,550 1,600 1,600	8 8 8 8 8	340 600 925 1,325 1,540
UX-250	Power Amplifier L. S. C.	Transformer 7.5V.	7.5	1.25	——	——	——	——	250 300 350 400 450	45 54 63 70 84	28 35 45 55 55	2,100 2,000 1,900 1,800 1,800	1,800 1,900 2,000 2,100 2,100	3.8 3.8 3.8 3.8 3.8	900 1,500 2,350 3,250 4,650

Model	Use	Purpose		
UX-213	Full-Wave Rectifier	Rectification in Eliminators particularly Designed for this Radiotron	Filament Terminal Voltage....... 5 Volts Filament Current.............. 2 Amperes A.C. Plate Voltage..............220 Volts (Max. per plate) R M S	Max. D.C. Output Current (both plates).................. 65 Milliamperes D.C. Output Voltage at max. current as applied to filter of typical rectifier circuit ....170 Volts
UX-216-B	Half-Wave Rectifier	Rectification in Eliminators particularly Designed for this Radiotron	Filament Terminal Voltage....... 7.5 Volts Filament Current...............1.25 Amperes A.C. Plate Voltage..............550 Volts (Maximum) R M S	Max. D.C. Output Current.................. 65 Milliamperes D.C. Output Voltage at max. current as applied to filter of typical rectifier circuit.................. 470 Volts
UX-280	Full-Wave Rectifier	Rectification in Eliminators Designed for this Radiotron or Rectron UX-213	Filament Terminal Voltage....... 5 Volts Filament Current.............. 2 Amperes A.C. Plate Voltage................300 Volts (Max. per plate) R M S	Max. D.C.Output Current (both plates)..................125 Milliamperes D.C. Output Voltage at max. current as applied to filter of typical rectifier circuit..................260 Volts
UX-281	Half-Wave Rectifier	Rectification in Eliminators Designed for this Radiotron or Radiotron UX-216-B	Filament Terminal Voltage.......7.5 Volts Filament Current...............1.25 Amperes A.C. Plate Voltage.............750 Volts (Maximum) R M S	Recommended / Maximum A.C. Plate Voltage..................650.........750 Volts D.C. Output Current.................. 65.........110 Milliamperes D.C. Output Voltage as applied to filter of typical rectifier circuit...620.........620 Volts
UX-874	Voltage Regulator	Constant Voltage Device	Designed to keep output voltage of B eliminators constant when different values of "B" current are supplied	Operating Voltage............ 90 Volts D.C. Starting Voltage.............. 125 Volts D.C. Operating Current............10.50 Milliamperes
UV-876	Current Regulator (Ballast Tube)	Constant Current Device	Designed to insure constant input to power operated radio receivers despite fluctuations in line voltage	Operating Current............ 1.7 Amperes Mean Voltage Drop........... 50 Volts Permissible Variation......... ±10 Volts
UV-886	Current Regulator (Ballast Tube)	Constant Current Device	Designed to insure constant input to power operated radio receivers despite fluctuations in line voltage	Operating Current............ 2.05 Amperes Mean Voltage Drop........... 50 Volts Permissible Variation......... ±10 Volts

↑ (↓) Note other use of this Radiotron above (below)
Inner Grid-1½ Volts; Outer Grid +45 Volts, .15 Milliamperes
□ Outer Grid-1½ Volts; Inner Grid +22½ Volts, 6 Milliamperes
‡ Applied through plate coupling resistance of 250,000 Ohms

NOTE: All grid voltages are given with respect to cathode or negative filament terminal

Max. Values not to be exceeded

A.....Except for half ampere filament, UX-112 and UX-171 characteristics are identical respectively to UX-112-A and UX-171-A.
C.....Cathode
H.....Heater Voltage
LSC...Loud Speaker Coupling, consisting of either Choke Coil and By-Pass Condenser or Output Transformer of 1:1 or step down ratio, recommended wherever plate current (D.C) exceeds 10 Milliamperes.
M.....With a screen-grid tube, on account of circuit limitations, the actual voltage amplification obtainable does not bear as high a relation to the voltage amplification factor as in the case of three element tubes.

labeled C-11 and CX-12 by another manufacturer. An external view of the complete WD-11 tube is shown in Fig. 24. If this tube is operated from a storage bettery, extreme care should be exercised to see that the rated filament voltage is not exceeded. It should be connected with only one cell and a rheostat used to reduce the filament voltage to the proper value not in excess of its rating. The bulb is usually very much discolored by a silvery coating deposited on the inside during the process of manufacture. The electrical characteristics are given in Table I.

UX-201-A.—The UX-201-A radiotron is a name given to a very good type of general-purpose tube. The type number CX-301-A and many other similar symbols have been applied to tubes of the same general characteristics. This tube is designed to take a filament current of .25 ampere, at a filament potential of 5 volts and with other requirements as in Table I.

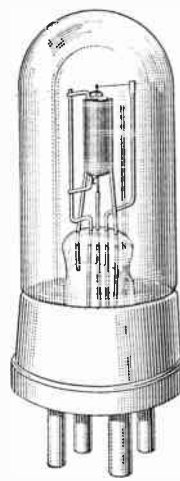

FIG. 24

The UX-201-A tube, as the type number implies, is equipped with the new large standard UX-push-type base. This base will fit into any of the UX type sockets. The mount assembly of this tube is shown in Fig. 25. The plate which has a flat oval shape surrounds the grid of smaller dimensions. The filament forms an inverted **V** with a spring support wire at the top. All the support wires are securely held in the flattened glass section of the press. The lead wires at the bottom connect with the proper pins in the base of the tube.

During the process of manufacture the getter produces a heavy silvery coating on the inside of the bulb. The filament, which is made of thoriated tungsten, operates normally at a moderately low temperature. With the heavy bulb coating it is often impossible to observe the brightness of the filament, hence it is especially important that a voltmeter be used as a guide in setting the filament voltage. Under most conditions it should be possible to reduce the filament voltage considerably without impairing reception, and with a saving in filament energy and a possible improvement in tube life. The thoriated filament fails more often from a loss of emission than from burn-out or breakage of the filament wire.

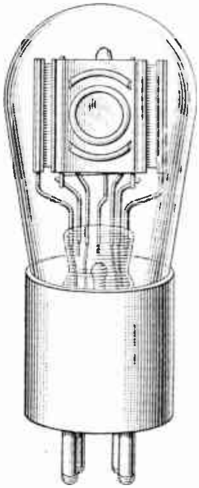

Fig. 25

The plate current versus grid voltage characteristics of the UX-201-A tube make it a very good general-purpose amplifier tube in both radio- and audio-frequency circuits. It may also be used as a detector and as an oscillator.

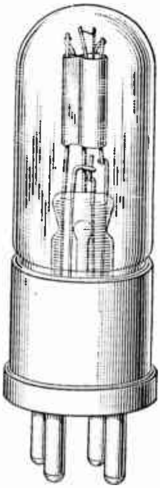

Fig. 26

UX-199 and UV-199. The UX- and UV-199 tubes are alike electrically, but the UX tube has the new small standard UX base, whereas the other has the older special small UV type of base. This tube is marked with various other type numbers and names, usually with the 99 forming part of the distinguishing type number. The mount of the UX-199 tube, as shown in Fig. 26, comprises cylindrical plate and grid structures, with a straight filament along their axes. A glass-bead crowfoot construction at the top holds the three elements together rigidly. The whole assembly is, in turn, supported by the glass press, which also includes the exhaust stem. Three $1\frac{1}{2}$-volt dry cells connected in series will give the necessary voltage and current for not exceeding 3 tubes. Additional 3-cell sets of batteries may be connected in parallel for each additional set of three tubes, or less. The filament circuit should include a suitable rheostat capable of operating the tubes at from 3.0 to 3.3 volts, with even lower values sufficing for most conditions of operation. The very small dimensions of the thoriated filament may be illustrated by the diameter, which is only about .0006 inch. It is very important that the tube should not be mishandled and that the rated operating voltages should not be exceeded. The end of useful life will generally occur from loss of thorium emission rather than from burn-out of the filament. If the overload has existed for only a short time the filament may be seasoned by reactivation.

UX-112 and 112-A Power Amplifiers.—The UX-112 radiotron is capable of handling more power than many of the other types. Its appearance and external dimensions closely resemble those of the other storage-battery tubes. This tube is especially designed and recommended for amplifier service. In radio frequency amplifier service a grid bias of $4\frac{1}{2}$ volts and a plate potential of 90 volts should give excellent results. Small *C* batteries in each grid-return lead will permit of grid bias without excessive coupling effects.

A plate potential of 45 volts with the grid return to the negative filament terminal will give very good results where it is not practicable to use a *C* battery. This tube will give excellent results as an audio-frequency amplifier at 135 and −9 volts. Radiotron UX-112 has a thoriated-tungsten filament requiring .5 ampere at 5 volts. Radiotron UX-112-A has a coated filament requiring .25 ampere at 5 volts. In all other respects the two types are identical.

UX-171 and 171-A Power Output Tubes.—The UX-171 radiotron is designed to operate as a power amplifier in the last audio stage. The best operating grid and plate voltages, which are also the highest that are recommended, require a 40.5-volt negative grid bias and 180 volts on the plate. The plate current of 20 milliamperes should preferably be supplied by a suitable type of *B*-battery eliminator. The plate impedance will be about 2,000 ohms, which is a rather low value. The amplification factor is relatively low or about 3 for a wide range of grid and plate voltages. Owing to the rather large plate current a 1 to 1 transformer or choke-coil coupling should be used to keep the plate current from burning out the loud-speaker windings or affecting the magnets. With 135 volts on the plate the grid bias should be -27 volts. The plate current will be somewhat lower, but very good operation should be secured. The tube will operate satisfactorily also with 90 volts on the plate and with a grid bias of $-16\frac{1}{2}$ volts. However, with these lower grid-bias values the tube cannot handle such a large signal without introducing some distortion. This tube is not adapted to detector service. Radiotron UX-171 compares with UX-171-A just like UX-112 compares with UX-112-A.

UX-120 Radiotron.—The UX-120 radiotron is a dry-cell operated type of tube designed to operate only as the last audio-stage amplifier in conjunction with UX-199 tubes. The 3-volt filament requires .125 ampere, hence it may be operated from a dry-cell battery with reasonable life. Its filament temperature is not critical and the filament may be operated directly in parallel with other 3-volt tubes. Its size is essentially the same as that of the UX-199 radiotron and the UX-120 has the new small standard UX base. The filament is of thoriated tungsten and it should give a long useful life if not misused in any way.

The grid bias should be −22.5 volts with a plate potential of 135 volts. Since there is no current taken from the *C* battery, it may be one of the small dry-cell types. The high grid bias of −22.5 volts means that the operation of the tube will be practically free from distortion with an input signal not in excess of 22.5 volts for the maximum or peak values. If this value is exceeded, the grid goes positive during part of the time and the resultant grid current will produce distortion. This tube should not be employed as a dectector, nor at lower plate voltages unless the grid bias is made large enough to keep the plate current down. Higher plate voltages are not recommended.

High-Amplification Tube.—The high-amplification factor tube, such as the MU-20, is another special type of receiver tube. This one, as the name implies, has a relatively high-amplification factor, say around 20 or even 25. The filament of the MU-20 tube is rated at 6 volts and may be operated directly from a 6-volt storage battery with a current consumption of .25 ampere. The bulb is tubular, and the molded base is of the old standard UV-navy type.

The MU-20 tube gets its name from the fact that its amplification factor, or *mu* as it is often called, is about 20. With 135 volts on the plate and a grid bias of −3 volts the plate current will be just over one milliampere and the plate impedance close to 40,000 ohms. With 90 volts on the plate and with no grid bias the plate current will be about 1.5 milliamperes and the plate impedance approximately 35,000 ohms. With the higher plate voltages used in practice, there will be a considerable voltage drop in the plate coupling resistance so that the voltage actually applied to the plate will be considerably reduced. Also, a grid leak is commonly used in the coupling stage, which automatically tends to hold the plate current to a reasonable value. Even then this tube may be operated to advantage with a small negative grid bias. This tube is suitable for operation only in the intermediate audio stages of resistance-coupled amplifiers.

Radiotron UX-240, another high *mu* detector and voltage amplifier, is designed for use in resistance- or impedance-coupled circuits. Having a voltage amplification factor (*mu*) of 30, radiotron UX-240 is especially useful in resistance-coupled circuits. The use of these circuits has been limited because the general-purpose tube required so much *B* battery. Radiotron UX-240, however, consumes less than one-tenth the plate current of the average general-purpose tube. The filament current consumption and voltage are identical to radiotron UX-201-A. The UX-240 may be used in the popular types of resistance-coupled amplifier circuits without change in plate coupling resistances. Best performance is obtained, however, when the values recommended in the instruction sheet accompanying this tube are employed.

Alternating-Current Operated Tubes.—At least one type of tube has been marketed designed for operation of the cathode element directly from the alternating-current supply line. This tube has a rather heavy filament mounted inside on an insulator. An oxide-coated metal sleeve outside the insulator receives heat from the alternating-current heated filament. The sleeve acts as a cathode and is connected with a filament terminal in the base. The heater filament leads are brought out of the bulb at the top and connect with a special type of base. The filament supply circuit for all of the tubes is thus kept away from the grid and plate-circuit wiring. The alternating-current energy is received directly from a transformer designed to supply energy at the rated tube voltage. The transformer should be placed far enough away from the set so that it will not give detrimental coupling effects.

The electrical characteristics of the alternating-current type of tube are somewhat better than those of the UX-201-A type. However, it is possible to substitute the alternating-current tubes in most types of sets without rewiring and without much adjustment, although auxiliary filament leads of heavy flexible wire are usually required. The filament leads on the set should be connected together to be sure that the grid return to the filament circuit is closed. It takes nearly a minute for the cathode to heat up after the filament is turned on, so a little time will elapse before signals will be heard. The manufacturer's recommendations regarding the grounding of the circuit should be strictly followed.

Radiotron UX-226 is an amplifier tube, the filament of which is operated from alternating current. It can be used for radio or transformer-coupled audio-frequency amplification. It is not, however, ordinarily, suited for detection, nor is it equal to a power tube in the last audio stage. This tube contains a plate, a grid, and a heavy filament of the oxide-coated type designed to operate at a relatively low voltage. The values of filament voltage and current have been so chosen as to minimize the a.c. hum. The tube is equipped with the large standard UX base.

Radiotron UY-227 is a detector tube containing a heater element which permits operation from alternating current. It is especially recommended for sets using radiotron UX-226 in the radio and first audio stages of amplification. This tube contains four elements, namely, a plate, a grid, a heater, and an oxide-coated cathode electrically insulated from but heated by the heater element.

Connections are made to these elements through a special five-prong base. Grid-leak detection is recommended for the average receiver. A plate voltage of 45, with a 5- to 9-megohm grid leak and a .00025-microfarad grid condenser usually gives greatest sensitivity. More stable operation is insured, however, with a 2- to 5-megohm grid leak. Grid-bias detection, though not usually as sensitive as grid-leak detection, gives extremely fine quality of reproduction if high-grade transformers of high input impedance are used.

Kellogg Types 401 and 403 A.-C. Tubes.—Kellogg a.-c. tubes are of the so-called heater type. The cathode or

TABLE II

AVERAGE CHARACTERISTICS TYPE 401—GENERAL PURPOSE DETECTOR, RADIO AND AUDIO AMPLIFIER TUBE

Heater voltage—3.0 volts. Heater current—1.0 amp.

Plate voltage	45*	90		135		180	
Negative grid bias	0	4.5	6.0	7.5	9.0	10.5	12.0
Plate current (milliamperes)	3.8	3.7	2.5	5.3	3.9	7.2	5.8
Plate impedance (ohms)	9,060	10,750	13,300	9,520	11,700	9,330	10,500
Amplification factor	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Mutual conductance (Micromhos)	1,100	930	750	1,050	850	1,070	952
Power output† (milliwatts		20	25	65	75	135	165

*For use as detector only using grid leak and condenser detection.

†The values given for output represent undistorted output or output of negligible distortion. These values are for optimum load resistance or a load resistance of approximately twice the tube impedance.

electron-emitting element of the Kellogg a.-c. tube corresponds to the filament of the ordinary d.-c. tube except that instead of being heated by direct application of current, the cathode is heated by an internal heating element which uses alternating current direct from the house lighting circuit. Since the heater element of the Kellogg a.-c. tube takes only 3 volts, it is necessary to use a small step-down transformer on the line between the 110-volt light socket and the tube.

Alternating current to heat the tube is fed through the top instead of through the base, thus segregating it entirely from the rest of the tube circuits. The cathode proper has only one lead, which is connected to the negative filament terminal at the base of the tube. Kellogg a.-c. tubes have standard UX bases, thus permitting standard tube sockets to be used.

TABLE III

AVERAGE CHARACTERISTICS TYPE 403—POWER AMPLIFIER FOR LAST AUDIO STAGE

Heater voltage—3.0 volts. Heater current—1.5 amps.		
Plate voltage	135	180
Negative grid bias	27	40
Plate current (milliamperes)	15	20
Plate impedance (ohms)	2,500	2,500
Amplification factor	3.0	3.0
Mutual conductance (micromhos)	1,200	1,200
Power output* (milliwatts)	360	660

*The values given for output represent undistorted output or output of negligible distortion. These values are for optimum load resistance or a load resistance of approximately twice the tube impedance.

The Kellogg a.-c. tube cannot be successfully used in so-called d.-c. sets unless the circuit has been carefully rewired and it will not operate in some circuits at all. The average characteristics of these tubes are given in Tables II and III.

Four-Element Tube.—A good example of a four-element radio tube is radiotron UX-222. This is a screen-grid tube particularly designed for radio-frequency amplification. The experimentally inclined set builder will find that by using this tube with the proper shielding, neutralizing or stabilizing devices are unnecessary. The introduction of the shielding screen grid between the usual, or control, grid and plate not only decreases plate to grid feed-back capacity, but also increases the mutual conductance of the tube. This tube may also be used in a totally different role as an audio-frequency amplifier in resistance-coupled circuits. Higher overall amplification at audio frequencies is possible with this tube without greater plate resistance than that of three-element high-mu tubes. The tube has a standard four-prong UX base with an additional terminal on top of the glass bulb. The filament operates at 3.3 volts and .132 ampere, but with a series resistor of 15 ohms it can be connected in parallel with 5-volt filaments.

UX-200-A Detector Tube.—The UX-200-A is a good typical gas-content detector tube designed only for detector service. The filament voltage of 5 volts with a .25 ampere filament makes it feasible to operate this detector in parallel with other 5-volt tubes. In order to secure some adjustment, which is, however, not critical, a separate filament rheostat of 10 ohms is recommended. The bulb and completed tube are similar to the other 5-volt tubes in dimensions, although the UX-200-A is often not completely silvered inside the bulb. The internal construction is about the same except that a special caesium getter is liberated in the tube during manufacture, which gives the tube its special sensitiveness.

The plate voltage of the UX-200-A tube is not critical, and should be not over 45 volts. The grid condenser should have a capacity of .00025 microfarad, whereas the grid-leak resistance should be very close to 2 megohms. The grid return may connect with either the positive or negative filament terminal with a preference for the latter.

Somewhat improved characteristics are secured by the high-amplification factor of the tube. It also has a fairly high plate impedance, and is suitable for either resistance or transformer coupling. The plate-current drain is quite moderate under the recommended operating conditions. The extreme sensitiveness of this tube is not effective on strong signals, but is apparent in the reception of relatively weak signals.

Super Power Amplifier Tubes.—Radiotrons UX-210 and UX-250 may be termed as super power amplifier tubes. The filament is designed primarily for operation at 7.5 volts directly from a transformer. It may, however, be operated from an 8-volt storage battery. The plate voltages may be supplied from B batteries that are capable of furnishing sufficient current, although the tubes are primarily for use with rectified alternating current. These tubes are capable of handling far greater volume without distortion than any of the other tubes, and their output is ample to supply any loudspeaker to its limit of volume.

Radiotron UX-250 adapts itself for use with loudspeakers to be used in large auditoriums. For the same filament current and plate voltage radiotron UX-250 has more than twice the undistorted power output of the UX-210. Because of its low plate impedance it must be used with an output transformer or choke coil and coupling condenser.

TUBES IN TRANSMITTING SYSTEMS

UX-210.—Radiotron UX-210, in addition to being a good power tube in radio reception, can also be used in low-power transmitters. The tube is so designed that the plate will stand a continuous dissipation of 7.5 watts. In appearance it resembles the UX-201-A radiotron. The bulb is larger than is commonly the case with the tubes equipped with the new large standard push-type UX base. The characteristics of this tube as well as those of other tubes may be seen at a glance in Table IV.

The UX-210 tube has a thoriated filament that takes 1.25 amperes at 7.5 volts. The plate is specially mounted so as to permit of safe operation on voltages as high as 500 volts. This tube may be used as an oscillator for radio-communication transmitting sets of small power, with plate voltages not in excess of 500 volts. The circuit adjustments should be so made that the plate dissipation of the tube does not exceed 7.5 watts. The plate voltage should not be raised to increase the power output, but more tubes should be connected in parallel if best life is to be secured. This tube makes a very good power amplifier with 425 volts on the plate and with a grid bias of −35 volts. The plate current will be about 22 milliamperes, and the plate impedance about 5,000 ohms. The amplification factor of this tube is a little greater than 7.5. The tube may also be operated at lower plate and grid voltages with very good results. With 6 volts on the filament, or directly from a storage battery, the plate potential of 135 volts is recommended with a grid bias of −9 volts. Under these conditions the plate current will be about 4.5 milliamperes and the plate impedance approximately 8,000 ohms. Although the amplification constant will still be 7.5, the power output from the tube will be very seriously reduced.

UX-216-B Rectifier Tube.—The UX-216-B rectifier tube is almost identical in construction with the UX-210 tube except that the UX-216-B tube has no grid element. It is rated to operate with a maximum alternating-current effective voltage, as read by an alternating-current voltmeter, of 550 volts. The maximum output current is 65 milliamperes. This type of tube may be used in a half-

TABLE IV

POWER RATINGS OF CERTAIN STANDARD TUBES

Model	Use	Filament Voltage	Filament Current Amperes	Plate Voltage	Plate Current Milliamperes	Power Output
UX-210.....	Amplifier Oscillator	7.5	1.25	500	25	7.5 watts
UX-216-B...	Rectifier	7.5	1.25	550 A.C.	60 D.C.	25 watts
UV-203-A...	Amplifier Oscillator	10	3.25	1,000	125	50 watts
UX-852.....	Amplifier Oscillator	10	3.25	2,000	75 (osc.)	75 watts
UV-204-A...	Amplifier Oscillator	11	3.85	2,000	200	250 watts
UV-851.....	Amplifier Oscillator	11	15.5	2,000	875 (osc.)	750 watts
UV-206.....	Amplifier Oscillator	11	14.75	10,000	135	1 K.W.
UV-218.....	Rectifier	11	14.75	15,000 A.C.		2.5 K.W.
UV-207.....	Amplifier Oscillator	21	51	10,000 to 15,000	1,400 to 1,800	10 to 20 K.W
UV-219.....	Rectifier	22	24.5	15,000 A.C.		12.5 K.W.

or full-wave rectifier for plate supply for the UX-210 tube or for the smaller receiving tubes.

50-Watt Tubes.—Tubes rated at 50 watts plate dissipation are made with both tungsten and thoriated filaments. The filaments of these tubes are designed for 10 volts, with a current of 6.5 amperes for those with tungsten filaments, and about 3.25 amperes for the tubes with thoriated filaments. In some other cases the filament is of the oxide-coated type. With this voltage rating the filament may be conveniently operated from a 12-volt storage battery with a rheostat for proper voltage control. A tube of this general class is illustrated in Fig. 27. The overall length of the tube and base is about $10\frac{1}{4}$ inches, whereas the maximum diameter should not exceed $2\frac{5}{16}$ inches. The base is of a large special bayonet-mounting type.

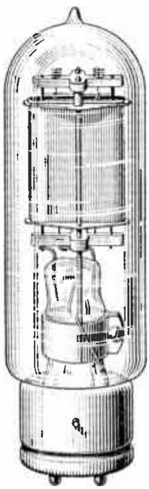

FIG. 27

As shown, the bulb is only partially discolored so as to permit of as free heat radiation from the plate as possible. The plate is separately mounted away from the grid and filament leads so that the tube can stand the high voltages for which it is designed. The design of the plate element is such that it will present a large radiating surface, and also so that it will be able to hold its shape when heated. The plate dissipation of 50 watts should not be exceeded for continuous operation, although a larger amount of energy may be handled for a short time. The plate should show only a slight reddish color under normal operating conditions.

The thoriated filament tubes, which are the most widely used, are made in two general types, namely, the UV-203-A and the UV-211. The filament voltage and current is the same for both types. The UV-203-A has an amplification factor of 25. With 1,000 volts on the plate and a zero grid bias the plate current is about .125 ampere, and the plate impedance approximately 5,000 ohms. The amplification factor of the UV-211 tube is lower and averages close to 11. The plate impedance, with 1,000 volts on the plate and a grid bias of −50 volts, is about 2,700 ohms, while the plate current is close to .085 ampere. At 1,000 volts on the plate in amplifier service the UV-203-A should be operated with a grid bias of 40 volts and the UV-211 with a grid bias of about 100 volts in order to hold the plate dissipation to a safe figure. In oscillator service the bias may be provided by the voltage drop in the grid leak.

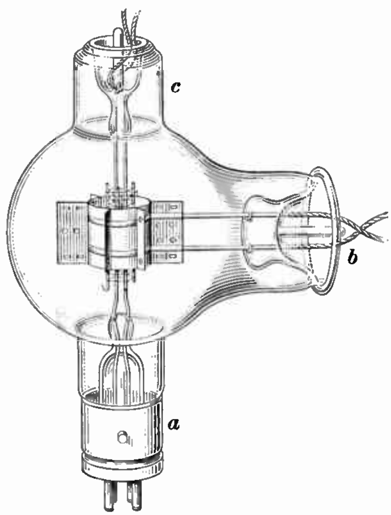

FIG. 28

Rectifier tubes are made in these same general styles of construction, except that the grid element is omitted. For very high voltage service the plate lead is taken out of the top of the bulb.

75-Watt Tube for Short-Wave Work.—In Fig. 28 is shown a 75-watt tube known as UX-852. This tube was developed to satisfy the insistent demand of amateurs for a type of tube that could be used satisfactorily in short-wave work. The elements of this tube are of rugged construction and so well spaced that the internal capacity is much smaller than in most transmitting tubes. The filament terminals are in the base *a*. Connection to the plate is made by means of the conductors extending from the side of the tube at *b*. The grid connections are made at *c*. Two leads extend from the plate and two from the grid to the external circuit. The two leads from each element should be twisted together.

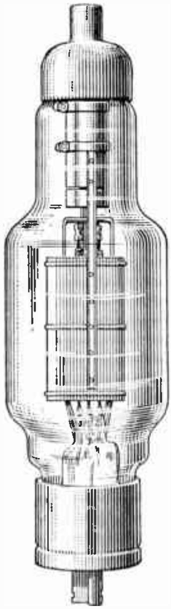

FIG. 29

The filament current is 3.25 amperes with an e.m.f. of 10 volts. The normal plate potential is 2,000 volts with a plate current of 75 milliamperes (oscillatory). The tube has a safe power dissipation of 100 watts, and the rated power output is 75 watts. The amplification constant of this tube is 12.

250-Watt Power Tube.—The 250-watt power tube is designed and rated to operate with a continuous plate dissipation of 250 watts. A special type of construction is necessary to accommodate the rather large plate, and to give a construction which will safely withstand the attendant high voltages that are necessary in normal operation. These tubes are sometimes made with tungsten filaments rated to take about 15 amperes at 11 volts. The special thoriated filament tube, often called the UV-204-A, has a filament current consumption of 3.85 amperes at 11 volts. If the filament is operated from an alternating-current supply, the grid-return connection should be made with a mid-tap on the secondary winding of the transformer. If operated from a direct-current supply, the grid return should connect with the negative-filament terminal.

As shown by Fig. 29, the bulb is nearly all clear to better allow the heat to be radiated. For this reason, a free circulation of air should be possible around the tube. The base, or filament end, has two large round pins for the filament connections with the special socket for this tube. The grid connects with a wide blade mounted midway between the two filament pins. The plate is entirely supported from the opposite end and connects with a metal cap on the end of the tube. With this type of construction, very high voltages may be applied to the plate with no danger of base trouble. A $\frac{3}{32}$-inch spark gap between the grid and one of the filament pins should form part of the mounting so that excessively high voltages which may be produced between these elements may discharge safely outside the tube.

The tube should be operated either vertically, with the cathode up, preferably, or horizontally with the plate element on edge. The supports should be cushioned so that no sudden jars will be transmitted to the tube. The maximum overall length is about $14\frac{1}{2}$ inches, and the bulb diameter should not exceed $4\frac{1}{4}$ inches. In oscillator service an efficiency, or ratio of output to input, of over 50 per cent. should be possible with proper circuit adjustments. In any event the plate dissipation should not exceed 250 watts continuously if best life is to be secured. The oscillator circuit should not require a plate current of more than .2 ampere under any conditions with the plate at 2,000 volts direct current.

The amplification constant of this tube is close to 25. With 2,000 volts on the plate and with a grid bias of -25 volts the plate current will be about .175 ampere and the plate impedance close to 6,000 ohms. In any radio or audio-frequency amplifier service the plate dissipation should never exceed the rated value of 250 watts. In general, this corresponds with a slight reddish color on the plate, but this observed temperature should never be relied upon in place of an instrument reading.

Rectifier tubes with plate elements about the size of the 250-watt tube plate are made with many various rated outputs. The energy used up inside the tube must, as elsewhere, be dissipated by the plate, and the tube rating should correspond with the safe operating value. However, it is possible to operate such tubes so that the safe output in the load circuit may be several times the tube dissipation. Such tubes are variously rated at the maximum safe plate dissipation value in watts with the maximum plate voltage and according to the maximum output current and voltage. Such tubes are customarily supplied with tungsten filaments that are operated directly from the supply line with a transformer to give the correct voltage.

20-K.W. Power Tube.—The 20-K.W. tube, one make of which is often called the UV-207, is able to deliver 20 kilowatts of power to the load circuit continuously. In order to handle this large amount of power, a tube with air cooling would have to be so large as to be entirely impracticable. It is necessary to make the plate element a part of the external tube body so that it may be water-cooled. This requires a seal between the glass and metal parts of the glass bulb and the metal plate element, which will maintain a very high degree of vacuum inside the tube. This is commonly accomplished by melting the glass to form a permanent seal with a knife-edge fin of copper made on the plate proper.

One typical water-cooled power tube is illustrated in Fig. 30, in its operating position, namely, with the plate down. This element is often made of copper, with a method provided whereby the water-jacket may be attached securely. The plate-circuit connection may conveniently be made with the water-jacket. The grid element, as in other cases, is inside the plate structure. The grid is supported by glass tubing on the filament end over which the grid collar is clamped. The grid-lead connection is taken out of one side of the bulb so as to remove it as much as possible from the proximity of the filament and plate elements. The filament leads are made of heavy flexible copper conductors.

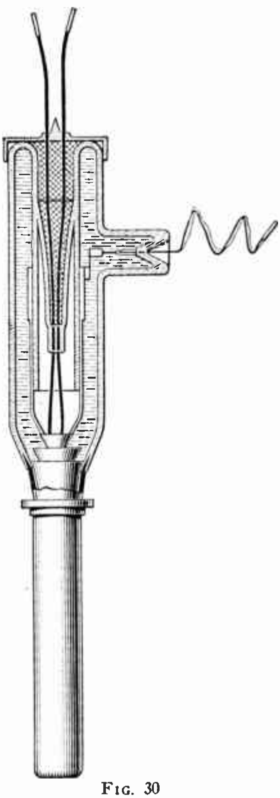
FIG. 30

The tube is mounted by supporting the water-jacket, hence no base is necessary. A cap may be provided to keep the filament leads from shorting with each other. The filament and grid leads should be connected so that no strain is placed on any part of the tube, and especially on the glass-to-metal seal. A steady flow of about 2 gallons of water per minute must be maintained through the water-jacket at all times when the tube is operated. It is advisable to connect an interlock system between the water and electrical system so that the tube cannot be started if there is no water flow or so that it will be immediately disconnected in case the water pressure fails for any reason. If it does not cause too much deposit on the plate, the local water supply will serve the purpose. Otherwise a special water circulating system will prove advantageous.

The 20-K.W. tube may be operated as an oscillator in any of the usual oscillator types of circuits. The circuit should be adjusted carefully so that the tube may operate in as efficient a manner as possible. With a plate dissipation of 10,000 watts it should be possible to secure the full rated output of 20 K. W., or 20,000 watts, with some allowance for circuit losses. With the rated plate potential of 15,000 volts the oscillating plate current should not exceed 2 amperes. The grid circuit and grid leak should be so adjusted as to keep the grid current as low as is consistent with good operation.

The tube may also be used as an amplifier with the plate dissipation held to a safe value for continuous operation. The amplification factor is close to 20. The plate impedance is close to 3,000 ohms with 15,000 volts on the plate and with a grid bias of 550 volts, whereas the plate current, with these voltages, will be close to .650 ampere. The tube should always be operated with a bias sufficient to limit the plate dissipation to the rated safe value.

Operation as either an amplifier or oscillator at extremely low wavelengths or high frequencies is hard on the tube and the safe output will have to be considerably reduced if good life is to be secured. The filament should always be operated at the rated voltage or current as recommended by the manufacturer. A voltmeter connected directly across the filament terminals will be of value in securing the best operating conditions.

Water-cooled tubes of this same general type are also used in rectifier service where the output current is quite large. They look much like the three-element tubes, except, of course, that the grid element is omitted. The rectifier tubes are made in a wide range of ratings for various types of service at high and low applied plate voltages. Such tubes will operate in the usual rectifier systems, with the extra precautions regarding the features of the water-cooling system.

ANTENNAS

PRINCIPLES OF TRANSMISSION

Magnetic and Electric Fields.—The function of an antenna is to radiate or collect the high-frequency energy used for radio communication. The simple antenna may be considered as a doublet, as shown in Fig. 1. Here a source of high-frequency energy, such as an alternator *a*, is connected to a vertical wire *b* extended upwards, and a similar wire *c* extended downwards. The two wires *b* and *c* have capacity between them and may be considered as the plates of a condenser with an air dielectric.

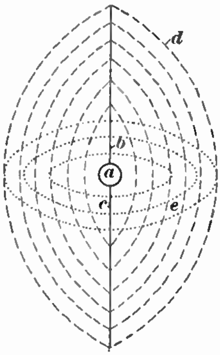

Fig. 1

Suppose the alternator *a* is just starting on a positive cycle and charges the wire *b* positive and the wire *c* negative. An electric strain is set up in the space about the antenna, which may be represented by imaginary electrostatic lines of force *d* extending from one wire to the other. These lines of force immediately start to move away from the antenna with the velocity of light. In the meantime, the alternator voltage advances to the peak of its positive cycle, at which time the electrostatic lines of force reach a maximum value. These lines of force represent stored energy, just as a stretched spring represents stored energy. As soon as the alternator voltage starts to decrease, the electrostatic lines of force begin to collapse back onto the antenna, giving up their energy, which reappears in the form of a magnetic field set up by the current in the antenna. This electromagnetic field may be represented by imaginary lines of force *e* at right angles to the electrostatic lines of force.

Before all of the electrostatic field has had time to return to the antenna, the alternator starts on its negative cycle, charging the wire *b* negative, and the wire *c* positive, thereby setting up a field that is opposite to what it was before, making it impossible for the remaining portion of the returning electrostatic field to give up its energy to the antenna. This portion of the electrostatic field never returns to the antenna, but travels away from the antenna with the velocity of light as a free wave. This action takes place on every half cycle of the alternator, and continues as long as the alternator voltage is applied to the antenna.

Radiation and Induction Fields.—It follows, then, that the field about the antenna can be considered as having two portions, one portion that builds up and collapses on the antenna itself, and a second portion that becomes detached from the antenna, never to return. The first portion is called the *induction field*, and the second portion is called the *radiation field*. It is the radiation field that is useful in radio communication.

It can be shown, mathematically, that the induction field and the radiation field have very definite proportions at any given distance from the antenna. The induction field falls off as the square of the distance from the antenna, whereas the radiation field falls off directly as the first power of the distance. At a distance of one wavelength from the antenna, the induction field is small compared with the radiation field, and its effect may be considered as negligible.

Aside from absorption of energy by the earth, the total energy in the radiated wave remains constant. Hence, as the wave advances, the energy becomes spread out over a greater area, and the energy at any point decreases directly as the distance increases. The decrease in amplitude of the radiated wave is analogous to the decrease in amplitude of a water wave produced by throwing a stone into a smooth mill pond. The water wave has a large amplitude at first, but the amplitude becomes smaller and smaller as the wave expands in ever-widening circles, because the original energy of the impact of the stone spreads out over a large area.

The traveling radiation field has two components, the electrostatic field and the electromagnetic field, the energy in these two fields being equal. The form of these two fields will be considered later in connection with an antenna with an earth connection in place of the lower half of the doublet.

Frequency and Wavelength.—There is a definite relation between the frequency of the alternator or other transmitter and the wavelength. While the transmitter passes through one complete cycle, the radiated wave travels a distance of one wavelength. Since the radiated wave travels with the velocity of light, it will travel 186,000 miles, approximately, or 300,000,000 meters in one second. When the frequency of the transmitter is known, the distance the wave will travel during one cycle, or the wavelength, may be calculated by the following equation:

$$\lambda = \frac{V}{f} = \frac{300,000,000}{f} \text{ meters.}$$

in which λ = wavelength, in meters;

V = velocity of electromagnetic waves;

f = frequency, in cycles.

This equation may be used for calculating the frequency from the wavelength, and vice versa. For example, 1,000,000 cycles per second would correspond to a wavelength of 300 meters; 100,000 cycles would correspond with a wavelength of 3,000 meters, etc.

When the radiated wave reaches the receiving antenna, it induces in the antenna a voltage having the same frequency as the transmitter. This induced voltage causes a current in the antenna, and this current will be a maximum if the antenna is tuned to resonance for that particular frequency. Some of the energy is transferred to the receiving set, where it is detected and amplified and operates the telephones, loud speaker, or other device attached to the output of the receiver.

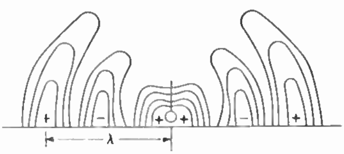

FIG. 2

Antenna and Ground. The simple doublet of Fig. 1 is rarely used except at extremely high frequencies or short wavelengths, where the wires of the doublet are only a few meters long. On long wavelengths, a doublet suitable for radiating considerable amounts of power would be very high, and it would be very expensive to provide towers high enough to support it.

To overcome this difficulty, the lower half of the doublet is usually omitted, and an earth connection is substituted. The capacity effect then exists between the antenna and the earth. The distribution of the electrostatic lines of force from a grounded antenna is as shown in Fig. 2. This figure also shows the probable shape of the electrostatic field after the lines of force have become detached from the antenna and are traveling as free waves. At the instant shown, the antenna is assumed to be charged at a maximum positive voltage. The distance from the antenna to the center of the positive traveling wave, shown as λ, is one wavelength, since this positive traveling wave was radiated by the preceding positive cycle of the transmitter. The electromagnetic lines of force are not shown, but they are traveling parallel to the surface of the earth in ever-widening circles, with the antenna as a center, analogous to water waves traveling from the center of disturbance when a stone is dropped into still water.

TYPES OF ANTENNAS

INVERTED L ANTENNA

The amount of power that can be put into an antenna is often limited by the voltage built up on the antenna, particularly at the longer wavelengths. In order to keep this voltage down to the limits of practical insulation, it is often necessary to increase the capacity of the antenna by adding a flat-top, or horizontal, portion. The addition of a flat-top portion also has the important effect of increasing the effective height, so that, for towers of a given height, the antenna becomes more effective both as a radiator *and* as a receiving antenna. This will be discussed later in this Section.

There are many types of antennas, but nearly all of them are simply modifications of the idea of combining a flat-top portion with a vertical portion, or *lead-in*, as the vertical portion is usually called.

Perhaps the most common form of antenna is the *inverted* L type shown in Fig. 3. The horizontal or flat-top portion is shown at *a*, whereas the lead-in, or vertical portion, is shown at *b*. The antenna is tuned by inductance *c*.

If the flat-top portion is long compared with the vertical height, the inverted L antenna is somewhat directional, with maximum transmission and reception in the direction opposite the free end, that is, from the left in Fig. 3. This directive effect is not clearly understood, but in ordinary antennas it is relatively small, and it may be neglected entirely if the horizontal length *a* is not much greater than the vertical height *b*. In some cases, the horizontal length is over ten times the vertical height, and, in such cases, appreciable directive effect is noted, as, for example, in the case of the Marconi bent antenna, which is a form of the inverted **L** antenna, with a very long horizontal portion.

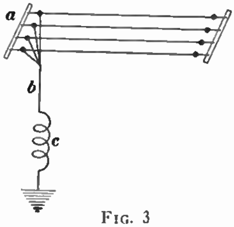

FIG. 3

T-TYPE ANTENNA

The **T**-type antenna is similar to the inverted **L** type, except that the lead-in is brought down from the center, rather than from one end. The **T**-type antenna is practically non-directional. It is used frequently on ships, where the radio room is in the center of the ship.

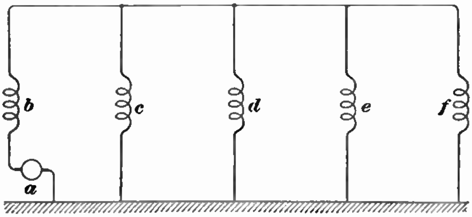

FIG. 4

MULTIPLE-TUNED ANTENNA

The Alexanderson multiple-tuned antenna is a special arrangement making it possible to use a very long horizontal portion efficiently. It is equivalent to operating several antennas in parallel. In Fig. 4, down leads are shown coming down from several points in the antenna to suitable tuning coils connected to earth. The alternator *a* feeds energy at only one down lead, such as at *b*. Each section *b*, *c*, *d*, *e*, and *f* is tuned separately in such a manner that all of the currents in the vertical portions are in phase, so that the total antenna current is the sum of the currents in all of the down leads. A typical antenna of this type is 1.25 miles long and 400 feet high, operating at wavelengths from 11,000 to 20,000 meters, for transoceanic telegraph service. The multiple-tuned antenna is rarely used as a receiving antenna, but is one of the most important types of transmitting antennas.

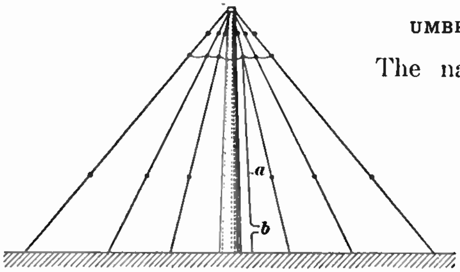

FIG. 5

UMBRELLA ANTENNA

The name of the umbrella-type antenna is quite descriptive of its construction, as it consists of a high center support, Fig. 5, with wires extending radially from it like the ribs of an umbrella. The antenna wires are insulated from the earth and from the central mast, and are connected together at the top and to the lead-in *a*. The receiving or transmitting system is connected at *b*. The antenna wires also act as guys to support the pole.

If the lower ends of the wires come too close to the ground, the field will be confined in the space between the lead-in and the wires, and there will be very little radiation. The wires should not make an angle of less than 50 or 60 degrees with the mast, and the lower ends should be insulated at some distance from the ground, so that the lower ends of the wires are half the mast height or more from the ground.

The umbrella type antenna is frequently used for portable stations and is also sometimes used in long-wave transmitting stations, where twenty or more wires are spaced equally about the mast, with the lower ends supported on shorter masts, in some cases. It has the advantage of being non-directional and gives a considerable amount of capacity and effective height with a single high mast, which is a considerable factor, as high masts are very expensive.

CONDENSER ANTENNA

For measuring work, or in cases where it is desirable to calculate the effective height of the antenna, a condenser-type antenna is sometimes used. This usually consists of two large metal plates or screens, with relatively small vertical separation. If the separation is small compared with the dimensions of the plates, the effective height is very nearly equal to the separation between the plates. Furthermore, since the antenna is practically an efficient air condenser, the dielectric losses are very low and considerable energy can be radiated, in spite of the low effective height.

GROUND ANTENNA

There are other types of antennas more particularly adapted to reception than to transmission. Many types of ground antennas come under this classification. Owing to losses in the earth, waves arriving from a distance are tilted forward slightly, and therefore have a small horizontal component of energy, which will induce voltages in a horizontal conductor, practically independent of the vertical distance of the horizontal conductor above ground.

If the horizontal length is over a quarter of a wavelength, this type of antenna becomes considerably directive; that is, it receives better from stations toward which it points than from stations that are off to one side.

Insulated wires lying on the ground, buried in the ground, or laid in shoal water, have been used by different investigators, notably Commander A. H. Taylor and Mr. Rogers. The voltage induced in these wires by the horizontal component of the wave is practically independent of the distance the wire is suspended above ground, as was previously mentioned, but, if the wire is suspended at some distance above ground, it will have vertical antenna effects superimposed upon the horizontal antenna effects. The magnitude of the horizontal component depends on the wavelength and the conductivity of the ground, whereas the vertical antenna effect is dependent only on the height of the wire above ground. The horizontal component varies from practically zero over deep-sea water to perhaps 10 per cent. of the vertical component over dry sand. Hence, to operate only on the horizontal component of the wave, a ground antenna should be one hundred or more times longer than its vertical height. The length of insulated ground wire that can be used is limited by the low velocity of the currents in the wire, which is on the order of half of the velocity of light or less. For this reason, it is usually best to use bare wires supported a short distance above the ground, as this increases the velocity and makes it possible to use a longer wire. On the other hand, where space is a consideration, it is probable that a buried ground wire will give greater directivity for the same length than a bare wire suspended above the earth.

WAVE ANTENNA

The *wave antenna* is a special form of directive horizontal antenna, which operates on the horizontal component of the wave, similar to a ground wire. It derives its name from the fact that it is usually about one wavelength long, this length having been found best from practical considerations. In its simple form, the wave antenna is simply a long wire suspended a few feet above the ground on poles.

A wave traveling from the right reaches end *a*, Fig. 6, first, and, owing to the wave tilt, a voltage is induced in the wire at *a*. As the wave travels along the wire from *a* to *b*, the voltage induced at *a* travels along in the wire at

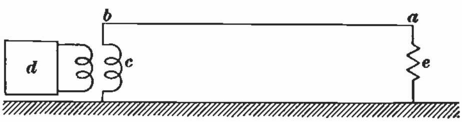

FIG. 6

practically the same velocity as the wave in space, that is, the velocity of light. In like manner, the voltage induced at any intermmediate point in the wire travels along the wire at the same speed as the wave. The result is that all of the voltages induced in the wire by the traveling wave, arrive at the end *b* in phase, and, passing through the coil *c*, produce a strong signal at the terminals of the receiver *d*. This effect is analogous to producing a water wave in a long narrow trough by swinging a shovel into the water at regular intervals of time. If the shovel is dipped into the water in synchronism with the movements of the water wave in the trough, the wave builds up to a very large amplitude at the far end of the trough.

A wave traveling from *b* to *a* builds up to a large amplitude at *a*. If the end *a* were directly grounded or left open, the energy would be reflected back to the receiver at *d*, and the antenna would be bidirectional; that is, it would receive from both directions *ab* and *ba*. By placing a resistance *e* between the antenna and ground at *a*, the energy traveling in the direction *ba* is absorbed, making

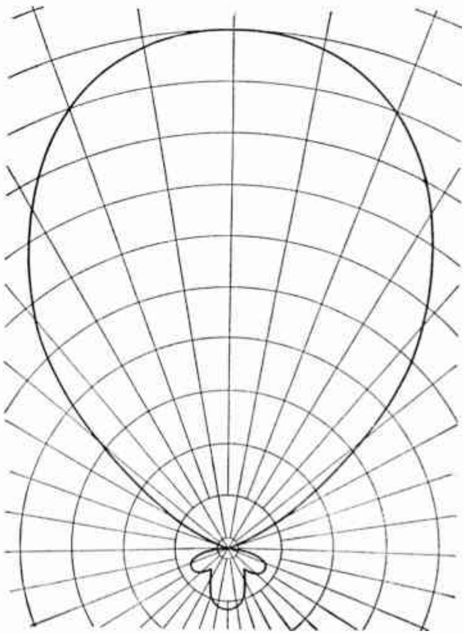

FIG. 7

the antenna unidirectional; that is, it receives only from the direction *ab*. The resistance *e* must be made equal to the *natural*, or *surge, impedance* of the wire with respect to the earth. This resistance is somewhat analogous to placing a shoaling sand surface at the end of the trough to absorb the water wave instead of allowing it to dash against a solid wall, which would reflect the wave back down the trough and setting up a flow in the reverse direction.

The unidirectional receiving properties of a horizontal wire one wavelength long, and properly damped at one end, are shown in Fig. 7. This polar diagram shows the strength of signal that would be received if a transmitting station at a considerable distance were moved around the receiving antenna in a complete circle, always keeping the same distance from the receiving antenna.

Owing to losses in the wire, the reception from the direction opposite to the direction of maximum reception is not quite zero, but it is relatively small, as shown.

The wave antenna is particularly useful for receiving from long-wave fixed stations, where the major portion of the static and interference originates from directions other than the direction of the desired signals. It is used extensively for transoceanic reception, and for long-distance reception from ships.

LOOP ANTENNA

The loop antenna is another form of directive antenna that is used mainly for receiving. It consists of one or more closed turns of wire, usually wound in the form of a square, as shown in Fig. 8. It may be tuned by a condenser *a* and loading coils *b* and *c*, although it is not always necessary to use loading, as the loop inductance alone is sufficient if enough turns are used. The receiver is coupled to coil *b* by means of coil *d*.

An arriving electromagnetic wave coming from the right of Fig. 8 induces a voltage in side *e* of the loop in all wires. An instant later, the same part of the wave reaches side *f*, where it induces an equal voltage in the wires of side *f*. These two voltages are exactly equal and are opposed, but there is a slight difference in phase owing to the time it took the wave to travel from e to f. Because of this slight difference in phase, there is a small resultant voltage left which causes a current in the loop. This phase difference is given by the equation

$$\phi = \frac{2\pi D}{\lambda}$$

in which π = phase difference, in radians;

$\pi = 3.1416$;

D = distance between sides of loop, expressed in meters;

λ = wavelength, in meters.

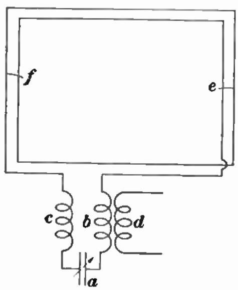

FIG. 8

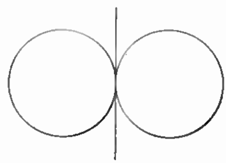

FIG. 9

If the signal arrives from a direction exactly at right angles to the plane of the loop, the wave reaches both sides of the loop at exactly the same instant, so there is no phase difference between the sides of the loop, and the voltages from the two sides exactly oppose, resulting in no signal. A further consideration of this subject would show that for other directions, there would be a signal of varying intensity, depending on the angle the signal makes with the plane of the loop, and that this variation is a simple cosine law. If the cosine is plotted on polar coordinate paper, it results in the *figure 8* diagram shown in Fig. 9, which is, therefore, the directive diagram of the simple loop.

If the loop is made so it can be rotated on its vertical axis, it can be used to indicate the direction from which a signal is arriving. When the loop is turned until the signal is a maximum, the plane of the loop is pointing toward the transmitting station. On the other hand, if the loop is swung around until the signal disappears, the signal is coming from a transmitting station located at right angles to the plane of the loop. The zero on a properly adjusted loop can be set much closer than the maximum, because it is comparatively easy to tell where the signal disappears, but very difficult to judge slight changes in intensity near the maximum. For this reason radio bearings are almost always taken on the minimum or zero line of the loop.

A bearing taken on the loop alone, indicates the true line of direction, but does not indicate the absolute direction, or *sense* of direction. For example, if the loop gives zero signal when its plane is East and West, it is known that the transmitting station is either directly North or directly South, but it is not possible to tell which direction is correct.

LOOP-VERTICAL ANTENNA

In order to get the *sense* of direction, it is necessary to make the loop unidirectional; that is, receptive from one direction, but non-receptive from a direction 180 degrees opposite.

This may readily be accomplished by combining the loop with a vertical antenna, as shown in Fig. 10. For the sake of simplicity, only one turn is shown on the loop, but several turns could be used. The loop is shown as *ab*, and the vertical antenna is shown as *cd*, with coil *e* in series with the vertical antenna. The coupling between coils *e* and *f* is adjusted until the voltage received from the vertical antenna is equal to the voltage received from the loop.

Assume an oncoming signal wave *g*; this wave will progressively induce a voltage in *a*, *cd*, and *b*. All of the voltages will be in the same direction, as indicated by the small arrows. It has already been explained how the voltages in *a* and *b* do not quite neutralize, because of the phase difference between sides *a* and *b*, the voltage in side *a* being slightly in advance of the voltage in side *b*. Now suppose the loop is turned 180 degrees on its vertical center line as an axis, so that side *b* is nearest the signal. Now the voltage in side *b* will be slightly in advance of the voltage in side *a*, whereas, before the loop was turned 180 degrees, the voltage in side *b* was lagging. The result is that the voltage in the loop is exactly reversed when the loop is reversed by turning it 180 degrees on its axis. On the other hand, the direction of the voltage in the vertical antenna remained the same as before. Of course, the voltages are always changing as the wave advances, but the relative phase relations between the sides of the loop and the vertical antenna always remain the same.

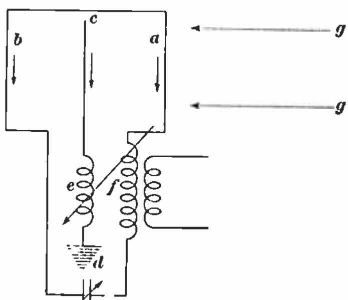

FIG. 10

If the vertical-antenna phase and intensity are properly adjusted, the loop voltage and vertical-antenna voltage will exactly balance for one position of the loop, and will add in phase if the loop is turned around 180 degrees, as this reverses the direction of the loop voltage without changing the direction of the vertical antenna voltage, as already explained. The resultant reception diagram is a *cardioid*, or heart-shaped, curve, as shown in Fig. 11 at *a*.

If the vertical-antenna voltage is not as strong as the loop voltage, the loop effect predominates, resulting in the unsymmetrical curve *b*. If the vertical-antenna voltage is too strong, the vertical-antenna effect predominates, resulting in the distorted curve shown at *c*. Any

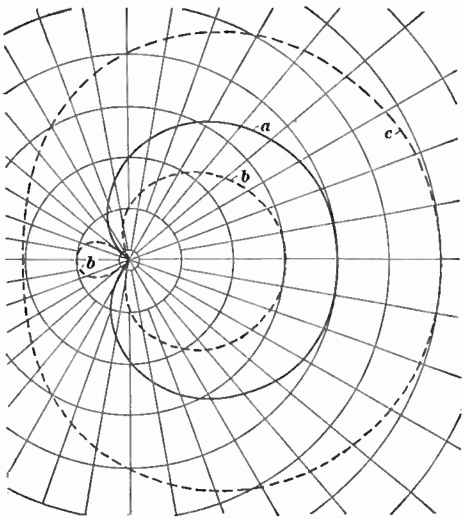

FIG. 11

of these diagrams may be rotated by turning the loop, or they may be reversed 180 degrees by reversing either the loop or vertical-antenna connections.

DIRECTION FINDING

It has already been explained how the line of direction could be determined with a simple loop by swinging it until the signal disappeared, at which point the plane of the loop is perpendicular to the line of direction of the signal, and that the absolute sense of direction was not evident from the loop bearing alone.

The point is further illustrated in Fig. 12. Suppose the transmitter is at *a* and the loop is shown as *bc*. The signal is zero when the loop is at right angles to the line of direction *ad*, but the transmitter might be at either *a* or *d*. To determine which position is correct, the loop is swung around 90 degrees so that the signal is received at its maximum intensity. Then the vertical antenna is switched on, as shown in Fig. 10, resulting in one of the reception diagrams of Fig. 11. If the transmitting station is at *a*, Fig. 13, the vertical-antenna and loop voltages may add, producing a stronger signal than the loop alone, as shown by the full-line curve, where *bc* is the position of the loop. If the transmitting station had been at *d*, the loop voltage would have opposed, resulting in no signal, or a much weaker signal when the vertical antenna was switched on. If the loop had been turned around 180 degrees, switching on the vertical antenna would have weakened the signal at *a* and strengthened a signal at *d*, now indicated by the dotted curve. Hence, when a radio compass is installed, it is necessary to check the relative direction of the loop and vertical-antenna voltages, and to mark the *sense* scale plainly, so that there can be no doubt about the proper sense of direction. Once this scale has been properly set, the loop connections should not be changed.

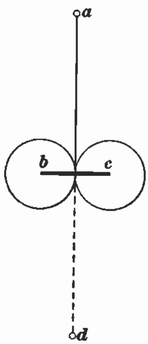

FIG. 12

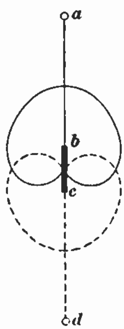

FIG. 13

The radio compass is a great aid to the navigation of ships and aircraft, and it is possible for them to navigate in heavy fog, or other weather of low visibility, by frequently taking radio bearings. There are two general methods for taking these radio bearings, namely:

(*a*) The ship may be equipped with a radio compass for taking bearings on fixed stations of known location.

(*b*) The ship may not be equipped with a radio compass installation, but has a radio transmitter. The ship sends certain identification signals, and two or more fixed land stations take radio bearings for the ship.

In Fig. 14, the ship is at *a*. Suppose the ship is equipped with a radio compass, and suppose that at points *b*, *c*, and *d* there are three land stations transmitting certain identification letters. The radio operator or navigating officer takes bearings on each of these stations, noting how many degrees East or West of North the loop bearing is by comparing with the ship's compass. The positions of the transmitting stations are marked on the chart, and the observer lays off the radio bearings on the chart. The intersection of these bearings gives the ship's position at *a*.

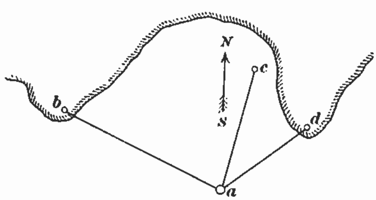

FIG. 14

If the ship has no radio compass, she calls the master compass station, located, say, at *b* and asks for bearings. Station *b* asks the ship to send certain identification letters, and notifies stations *c* and *d* by telephone or telegraph, to take bearings on this ship. In this case, stations *c* and *d* do not transmit, but are equipped with radio-compass installations for taking bearings. As soon as stations *c* and *d* have taken their bearings, they transmit them to station *b* by wire. The operator at *b* then transmits all three bearings to the ship, where they are plotted on the chart, giving the position of the ship at *a* as in Fig. 14.

By either method, two bearings would be sufficient to locate the position of the ship, but a third bearing is sometimes taken as a check. It is desirable that, for accurate results, stations *b*, *c*, and *d* should be considerably separated, so that there is a large angle between the bearings. Then, if a slight error is made in one of the bearings, it would not change the location determined for the ship appreciably.

Both methods are used extensively. The United States government maintains both transmitting and receiving radio-compass stations at important points along the coast. The transmitting compass stations are of relatively low power, to minimize interference, and consist mostly of automatic-spark transmitters working on a wavelength of about 1,000 meters. It has been found that the shorter wavelengths give the most accurate bearings, and also that spark, or damped-wave, transmitters give more accurate and consistent bearings than continuous-wave transmitters.

Of course, it is very simple for the ship to call the land compass station to get her bearings, but in the vicinity of a busy port, in bad weather there are so many ships requesting bearings that it is sometimes impossible for a ship to get bearings without considerable delay. The tendency, now, is for ships to have their own radio-compass installation, so they can take their bearings as frequently as they desire.

SOURCES OF ERROR IN RADIO COMPASS

If the signal on which a bearing is being taken is weak, static and interference may cause the signal to disappear at some distance at either side of the minimum. If the interference is steady, it is possible to determine the disappearing point on each side of the minimum, thereby locating the true minimum as half way between these disappearing points. If the interference is intermittent, it may be very difficult to take an accurate bearing. It is obvious that bearings taken at a relatively short distance, where the signal is strong, would be the most accurate.

One of the common sources of error in a radio compass is due to the vertical-antenna effect. That is, if the loop is not symmetrical with respect to earth, the loop itself may act as a vertical antenna, and if the two sides of the loop are not electrically balanced, more vertical-antenna current may pass to earth through one side of the loop than through the other side, producing a bad or displaced minimum. For example, in Fig. 10, the loading coil *f* is shown in only one side of the loop. To make the loop symmetrical to earth, a loading coil, similar to coil *f*, should be placed in series with the other side of the loop, as in Fig. 8. When this unbalanced effect is present, it either makes a very bad minimum, or else it produces a distorted figure 8 diagram similar to that shown at *b*, Fig. 11, in which case the two minimums will not come 180 degrees apart, thereby warning the operator that the bearing is not accurate. This effect is not present to an appreciable extent in a properly installed radio compass.

Another source of possible error is due to radiation from metal objects near the loop, particularly mast stays, other antennas, etc. In some cases, these sources of error are eliminated by breaking up the radiating system with insulators, and, in other cases, where the effect is symmetrical about the keel of the ship, the errors are corrected by the compass calibration, which is relatively simple in such cases.

Sometimes the apparent bearing of the transmitter will change. This frequently happens when the signal has to skirt along a coast line, or over shoal water, for a considerable distance. Owing to the good transmission over the sea and the poor transmission over the land, the signal tends to come over the sea route, turning the bearing toward the sea route. In some cases, errors as high as 15 to 20 degrees have been noted from this effect. This error is reduced to practically zero by placing the compass stations on points of land or small islands to keep the transmission all over sea.

At sunrise or sunset and during the night, bearings are sometimes erratic, owing to a phenomenon known as *night effect*. This is supposed to be a distortion of the wave front, caused by the signal arriving over two routes: (1) the regular normal path along the surface of the earth, and (2) a path that exists only at night, assumed to be a conducting medium high above the earth, known as the *heaviside layer*. If the *sky wave* arrives at a high angle, a residual voltage will be left when the loop is at right angles to the normal direction of the transmitter, resulting in a bad minimum. This effect is not noticed at short distances and can be recognized by an experienced observer by the indistinct, *mushy* sort of minimum that it produces.

Under normal conditions, a properly operating radio compass will give bearings within about 1.5 to 2 degrees on the average. Individual bearings may vary considerably more than this, but if several bearings are taken, the average should come within the limits mentioned above.

OTHER USES FOR LOOP ANTENNA

The loop antenna is used frequently on broadcast receivers, where it is undesirable to put up an outside antenna. Owing to the low effective height of the loop the receiver must be very sensitive to deliver loudspeaker output, but the required sensitivity is readily attained in modern receivers having several stages of radio-frequency amplification.

The directive property of the loop is useful for eliminating strong station interference and induction, where the source of the interference comes from a signal point more or less at right angles to the direction of the desired signal. The loop will also eliminate some static under certain conditions, but it is not nearly so effective on static as on induction and interference, because, as a rule, the static that affects broadcast waves comes from practically all directions.

For measuring signal strength, the loop is very useful, as it is easy to calculate its effective height from its physical dimensions.

ANTENNA PROPERTIES

FUNDAMENTAL WAVELENGTH

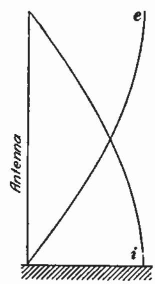

FIG. 15

The fundamental wavelength of an antenna is the wavelength at which the antenna oscillates with no loading at the base. This wavelength is sometimes called the *quarter-wave oscillation*, because the current and voltage assume a distribution in the antenna similar to one quarter of a sine wave.

In Fig. 15 is shown the distribution of the current and voltage in a simple vertical antenna at the fundamental wavelength, that is, without loading at the base. Curve *e* shows the voltage distribution, the voltage being zero at the base, or earth connection, and a maximum at the upper end. Curve *i* shows the current distribution, the current being a maximum at the earth connection, and zero at the upper end.

Since the voltage and current distribution covers one quarter of a sine wave, it would appear that the fundamental wavelength should be four times the total length of the antenna. This would be true if the velocity of the current in the wire were the same as the velocity of the wave in space, that is, equal to the velocity of light. For a simple vertical wire, the current velocity is only slightly less than the velocity of light, so the fundamental wavelength is 4 to 4.2 times the vertical height of the antenna.

If the antenna has a horizontal portion, the horizontal portion must be added to the length of the lead-in to calculate the fundamental wavelength. If there is more than one wire in the flat top or lead-in, the velocity of the current is lowered a certain amount, depending on the number of wires and their spacing. To calculate the fundamental wavelength of an antenna roughly, measure the total length of the antenna from the instruments to the far end of the antenna, including the lead-in and the flat-top portion. Express this length in meters, (1 meter = 3.28 ft.) and multiply by 4 to 4.2 for a single-wire antenna, by 4.3 to 5 for an antenna with more than one wire, but with a narrow flat top, and multiply by 5 to 6 for an antenna with a wide flat top.

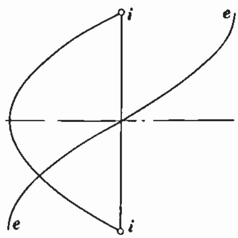

FIG. 16

The fundamental wavelength for a doublet is the same as for the simple vertical antenna half as long as the doublet. The reason for this is that the lower half of the doublet takes the place of the earth connection, leaving the current in the upper half of the doublet distributed the same as it was in the simple vertical antenna. The distribution of the voltage and current in the doublet is shown in Fig. 16. At the center of the doublet the voltage is zero, whereas the current is a maximum. At the ends the current is zero, whereas the voltage is a maximum. The voltage distribution, as shown by curve *e*, is at opposite potential at the two ends of the doublet, as will be remembered from the fundamental theory of the doublet.

HIGHER HARMONICS

Both the grounded antenna and the doublet will resonate at other frequencies higher than the fundamental. For example, in Fig. 17, the distribution of the current and voltage is shown for a grounded antenna oscillating at the three-quarter wave oscillation. The current is zero at a point one-third of the distance up from the base and again at the top. The voltage is zero at the base, and again zero at a point two-thirds of the distance up from the base.

If it is kept in mind that the current must always be zero at the open end of the antenna, and that the voltage is a maximum where the current is zero, it is a simple matter to draw out the distribution of current and voltage for any mode of oscillation.

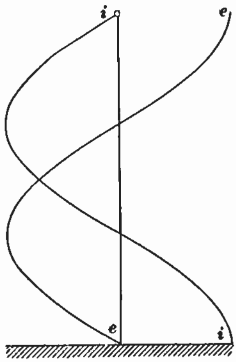

FIG. 17

If the length of the simple grounded antenna is given in meters and if the velocity of the current in the antenna is assumed to be equal to the velocity of light, it can be shown that the antenna will resonate without loading at any *odd* quarter wave, that is, at $\frac{4L}{1}, \frac{4L}{3}, \frac{4L}{5}, \frac{4L}{7}$, etc., meters, in which L is the length of the antenna in meters. It can be shown that the doublet will resonate without loading at any *even* quarter wave, that is, at $\frac{4L}{2}, \frac{4L}{4}, \frac{4L}{6}, \frac{4L}{8}$, etc., meters, in which L is the total length of the doublet in meters. The even quarter-wave oscillations are more often called half-wave oscillations, since they are multiples of the half-wave.

These higher harmonics are not so well known as the fundamental, or quarter-wave, oscillation, as it has usually been the practice to use only the quarter-wave oscillation. However, the higher harmonics are now frequently used for transmission at very short wavelengths. The doublet is also sometimes used for short-wave transmission, frequently with the doublet in a horizontal position, which is totally contrary to all long-wave theory and practice.

LOADING THE ANTENNA

The antenna may be used at wavelengths longer than the fundamental by inserting a loading inductance at the base. The voltage and current distribution is changed by the loading, and is somewhat as shown in Fig. 18. Since the capacity of the loading coil *a* to ground is small, the current is practically uniform in the whole coil, but assumes a more or less sine-wave distribution in the antenna, as shown by curve *i*. On the other hand, owing to the inductive impedance of the coil *a*, there is a linear building up of voltage in the coil, so that the top of the coil is at high voltage with respect to earth. In the antenna itself, the voltage increases still further, following more or less the sine-wave law, as shown by curve *e*.

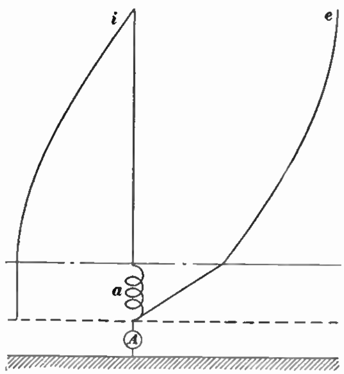

FIG. 18

The antenna can be operated at a wavelength lower than the quarter-wave fundamental by placing a condenser in series with the lead-in, in place of the loading inductance. Of course, it is necessary to keep some inductance at the base of the antenna for coupling to the transmitter, but this may be relatively small.

The antenna has distributed inductance and distributed capacity. If the antenna consists of more than one wire, the capacity is increased, but the inductance is decreased. If the wires are very close together, the decrease in inductance is proportional to the increase in capacity, so their product remains nearly constant, and the velocity of the current in the wires does not change much. This is the reason why the fundamental wavelength does not change much when more wires are added, provided the flat-top portion is narrow. If the wires are considerably separated, the capacity is increased in greater ratio than the decrease in inductance, which lowers the velocity and increases the fundamental wavelength.

When the inductance and capacity are concentrated, as, for example, in a closed oscillating circuit, the resonant frequency is given by the formula:

$$f = \tfrac{1}{2}\pi\sqrt{LC} \qquad (1)$$

in which L = inductance in henries;
C = capacity in farads.

In the case of the loaded antenna, the resonant frequency may be calculated approximately, by assuming that the antenna capacity C_a is concentrated, and using for the total inductance the inductance of the loading coil plus one-third of the distributed antenna inductance L_a, thus:

$$f = \tfrac{1}{2}\pi\sqrt{\left(L+\frac{L_a}{3}\right)C_a} \qquad (2)$$

This formula reduces to

$$\lambda = 1885\sqrt{\left(L+\frac{L_a}{3}\right)C_a} \qquad (3)$$

in which λ = wavelength, in meters;
L = inductance of loading coil, in microhenries;
L_a = inductance of antenna, in microhenries;
C_a = capacity of antenna, in microfarads.

The antenna capacity C_a may be measured at low frequency. Ordinarily, it will vary from .0003 microfarad for a small receiving antenna, up to .01 microfarad for a large long-wave transmitting antenna.

EFFECTIVE HEIGHT OF ANTENNA

The effective height of an antenna may be defined as the height of an equivalent ideal antenna, having a uniform current in the vertical portion equal to the maximum current existing at any point in the actual antenna. In ordinary practice, this maximum current is usually at the base of the antenna, if the antenna is operated at a wavelength longer than the fundamental wavelength.

The effective height of an antenna would be the same as the total vertical height if the current in the vertical portion were uniform at a value equal to the current at the base, and there were no radiation from the horizontal portion. However, the current is never uniform in the vertical portion, so it is necessary to determine the distribution of the current and then calculate the average current, which will be less than the maximum current at the base of the antenna or other point of maximum current. For example, in Fig. 15, the average current would be the average of a sine wave with a maximum amplitude of I_b, where I_b is the current at the base of the antenna. Thus,

$$I \text{ average} = \left(\frac{2}{\pi}\right) I_b = .637\ I_b \qquad (1)$$

The effectiveness of the antenna as a radiator on a given wavelength is determined by the product of the effective height and antenna current, or HI, which product is known as the *meter-amperes.*

Hence, for the simple vertical antenna, the value of meter-amperes is

$$HI = .637 \times I_b \times H \qquad (2)$$

in which H = total height, in meters.

In actual installations, however, it is customary to read the maximum current on an ammeter at the base of the antenna, and instead of using the product of the average current multiplied by the total height, it is much more convenient to refer to the maximum current I_b multiplied by the *effective height.* Obviously, the product of the maximum current and effective

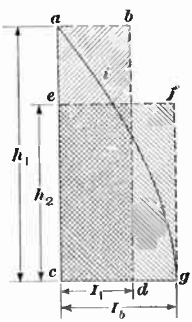

FIG. 19

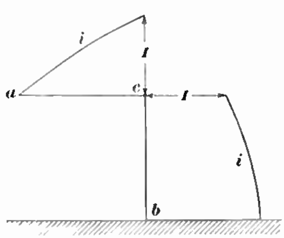

FIG. 20

height should be numerically equal to the product of the average current and maximum height. This equivalence is illustrated graphically in Fig. 19, for the case of the simple vertical antenna. The actual current distribution is shown by curve i. The current at the base of the antenna is I_b. The meter-amperes may be considered as $h_1 \times I_1$ or $h_2 \times I_b$, where $h_2 = .637h_1$, and $I_1 = .637\ I_b$. Then, $h_1 I_1 = h_2 I_b$, where h_2 is the effective height. In other words, the area of the rectangle *abdc* is equal to the area of the rectangle *efgc.*

If the antenna has a horizontal or flat-top portion, the current distribution is changed, as illustrated in Fig. 20. In effect, the current distribution is somewhat the same as it would be if a vertical antenna of length *ab*, were bent over at point *c*. It is modified somewhat by the increased capacity between the horizontal portion and the earth, which is greater than it would have been if the antenna had not been bent over at point *c*. The important feature to note in this figure is the fact that the average current in the vertical portion has been increased by adding the flat-top portion. In other words, the addition of the flat-top portion has increased the effective height.

The accurate calculation of the effective height of a complicated antenna structure is very difficult, as it is dependent on many factors, such as the presence of the towers, guy wires, and other conducting objects in the field of the antenna. It is also dependent to some extent on the amount of loading at the base of the antenna, the conductivity of the earth, whether or not a counterpoise is used, etc.

If the antenna has a large flat-top portion that is approximately horizontal, the effective height may be calculated from the height to the center of capacity of the actual antenna. To do this, the capacity C_1 of the flat-top portion to earth, is calculated by any reliable capacity formula. Then, after the antenna is installed, the actual antenna capacity is measured. The measured capacity is always greater than the calculated capacity, owing to the capacity added by the towers, down-leads, etc., which were disregarded in the calculation. If the measured capacity is called C_2, on the assumption that the center of capacity was lowered by the presence of the towers and down-lead, the final center of capacity of the actual antenna is located at a height h_2, thus:

$$\frac{h_2}{h_1}=\frac{C_1}{C_2} \qquad (3)$$

and

$$h_2=\frac{h_1C_1}{C_2} \qquad (4)$$

Here, h_1 is the actual height of the flat-top portion, and h_2 is the height to the center of capacity, or the effective height.

In cases where the flat-top portion is considerably longer than the vertical length of the down-lead, calculation by the above method gives an effective height on the order of 70 per cent. of the actual height of the flat-top portion, and, in actual installations, the effective height determined by measurement of the field strength at a distance, has been found to agree very well with the effective height calculated by the center of capacity method.

ANTENNA RESISTANCE

If an antenna is replaced by an efficient air-dielectric condenser, having a capacity equal to the antenna capacity, and the circuit thus formed is tuned to resonance by the antenna loading coil, it will be found that the current in this circuit is much larger than the current that was ob-obtained at the base of the antenna with the same power input, when the antenna itself was used in place of the condenser. Now, if a non-inductive resistance is added to the condenser circuit, the current can be brought down to the same value it had with the actual antenna for the same power input. If the condenser is an efficient air-dielectric condenser with negligible losses, the added resistance will consume energy at the same rate as the antenna, and the total effective resistance of the actual antenna is equivalent to the resistance added to the condenser circuit. The power consumed in either case is the same and is equal to I^2R, in which I is the current, and R is the resistance. Hence, we may define the antenna resistance as an effective resistance that is numerically equal to the quotient of the average power in the entire antenna circuit divided by the square of the effective current at the point of maximum current.

The total antenna resistance is composed of two portions; the radiation resistance, which represents power radiated, and the loss resistance, which represents power lost in the antenna.

The efficiency of the antenna is given by the following equation:

$$\text{Antenna efficiency} = \frac{\text{Power radiated}}{\text{Total power}} = \frac{I^2_b R_n}{I^2_b R_t} = \frac{R_r}{R_t}$$

in which I_b = antenna current at the base of the antenna, in amperes;

R_r = radiation resistance, in ohms;

R = total antenna resistance, in ohms.

RADIATION RESISTANCE

The exact calculation of the radiation resistance is very complicated, as it is dependent on the calculation of the effective height, which is very difficult to calculate accurately for complicated antenna structures, as has already been mentioned. In addition to this, the radiation from the flat top should be taken into account.*

For wavelengths above the fundamental, with antennas of known effective height, or simple antennas for which it is possible to calculate the effective height, the radiation resistance may be calculated approximately by the following simple formula

*"Electric Oscillations and Electric Waves" by Dr. George Pierce, published by McGraw Hill. (2) "On the Radiation Resistance of a Simple Vertical Antenna at Wavelengths Below the Fundamental" by Stuart Ballantine, Proc. Inst. of Radio Eng. Dec. 1924.

$$R_r = 160\pi^2\left(\frac{H}{\lambda}\right)^2 = 1580\left(\frac{H}{\lambda}\right)^2$$

in which R_r = radiation resistance, in ohms;
H = effective height of antenna, in meters;
λ = wavelength, in meters.

ANTENNA LOSSES

The losses in an antenna include ground resistance, radio-frequency resistance of conductors in the antenna circuit, equivalent resistance due to corona, eddy currents, insulator leakage, dielectric loss, etc. Ordinarily, the largest losses are the dielectric and ground losses.

The dielectric losses are due to the fact that the antenna is an imperfect condenser, and has objects in its field which have high dielectric absorption. If the antenna has a large flat-top portion, the capacity current spreads out for a considerable distance beyond the antenna, and if the lines of force encounter poor dielectrics, like trees, buildings, poorly conducting earth surface such as sand, etc., considerable energy is absorbed.

The dielectric losses can be greatly reduced by keeping the field of the antenna free from buildings, trees, bushes, etc., and by installing a net work of wires, called a *counterpoise*, underneath the antenna, to reduce the losses at the surface of the ground.

If the antenna is erected over sea water or highly conducting ground, the ground losses are usually small, but if the antenna is erected over dry sand, or other poorly conducting ground, the ground currents must travel a considerable distance through poorly conducting material to complete the circuit back to the transmitter. The ground can therefore introduce large conduction losses, as well as large dielectric losses, particularly at long wavelengths, where the dielectric losses are high. The use of a counterpoise greatly reduces the ground-conduction losses as well as the dielectric losses, as it provides a highly conducting path for the current to follow directly back to the transmitter. Instead of using a counterpoise suspended a few feet above the ground, a system of ground wires, similar to the counterpoise may be burried a few inches in the ground. The buried ground wires, in many cases, are practically as effective as the counterpoise system, although it is probably true that the dielectric losses would ordinarily be somewhat lower with the counterpoise than with the buried wires.

The losses in the antenna conductors are usually small compared with the dielectric and ground losses, but may be reduced by using larger conductors. However, the size of the conductors is usually determined by mechanical considerations, as a conductor that is strong enough mechanically, generally has sufficient conductivity to carry its share of the antenna current without much loss.

Other losses, such as eddy currents in the towers, corona or brush discharge, leakage over insulators, etc., are ordinarily small in a properly designed antenna.

DISTRIBUTION OF ANTENNA RESISTANCE

The distribution of the resistances in an antenna is shown in Fig. 21. Curve *a* shows the radiation resistance, which is an inverse function of the square of the wavelength. Curve *b* shows the dielectric, leakage, and corona loss resistance, which increases with increase in wavelength. Curve *c* shows the loss resistance due to eddy currents, and conduction loss in the antenna and ground conductors. This loss resistance decreases slightly with increase in wavelength, owing to decrease in skin effect, etc. Curve *d* is the sum of curves *b* and *c* and shows the total loss resistance. Curve *e* is the total resistance, including the useful radiation resistance, and is the curve that would be determined by an experimental determination of the antenna resistance.

Owing to the fact that some of the losses increase with wavelength, whereas other losses decrease with wavelengths, there is sometimes a point *f* on curve *d* where there

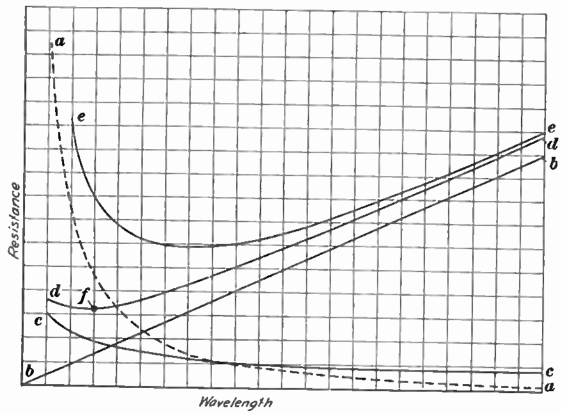

FIG. 21

is a broad minimum in the loss curve, and it is at, or near, this point that the antenna should be most efficient.

Sometimes, when the total resistance of the antenna is determined experimentally, the curve is not smooth, but has one or more decided peaks. These peaks are usually caused by something in the field of the antenna which absorbs energy at that particular wavelength, as, for example, resonance in a guy wire, a mast, nearby antenna tin roof, or other mass of metal.

RADIO TRANSMISSION AS FUNCTION OF ANTENNA CONSTANTS

It has already been mentioned that, for a given wavelength, the effectiveness of a transmitter could be expressed in terms of *meter-amperes,* or the product of the effective height of the antenna by the antenna amperes. The effectiveness of a transmitter may be measured in terms of signal strength produced at a distance. It is customary to express this signal strength in terms of volts per meter of vertical height; that is, measured along the direction of an imaginary electrostatic line of force, as pictured in Fig. 2 of this Section.

In actual practice, it is possible to make use of signals having a field strength as low as a few millionths of a volt per meter, so it is more convenient to express field strength in terms of microvolts per meter (1 volt =1,000,000 microvolts).

The strength of the field radiated from an antenna can be calculated for any point on a theoretical basis, in so far as the effect of the spreading of the wave in all directions is concerned. However, it has been found that, in addition to the spreading effect, there is an absorption effect, caused by absorption of the wave as it travels along the surface of the earth. The absorption varies greatly with the character of the earth over which the wave passes. For sea water, the absorption is comparatively low, whereas, for dry sand, the absorption is very large. The absorption varies so greatly for different earth conditions that it is almost impossible to calculate the field strength for a signal received over land, without having considerable experimental data covering that particular route or a similar route.

For an over-sea route, in daylight the strength of the signal is directly proportional to the antenna current and is the sum of curves *b* and *c* and shows the total loss resistance. Curve *e* is the total resistance, including the useful radiation resistance, and is the curve that would be determined by an experimental determination of the antenna resistance.

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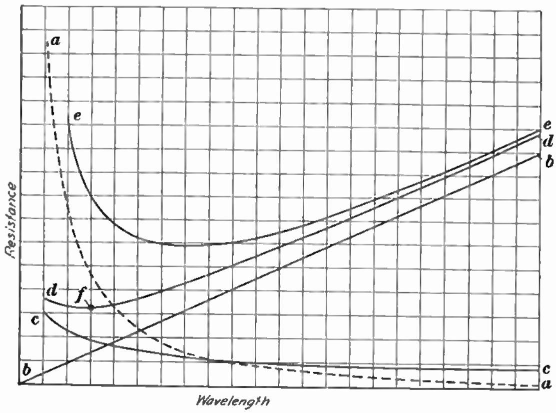

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For an over-sea route, in daylight the strength of the signal is directly proportional to the antenna current and effective height at the transmitter, and is inversely proportional to the wavelength and the distance.

There is a decrease of the signal strength due to absorption, which differs for over-sea transmission in daylight and overland transmission. Overland transmission may cause the signal to drop down to only a small fraction of the value of over-sea transmission. On the other hand, at night, on certain wavelengths, notably in the broadcast band, the waves appear to travel along the Heaviside layer, and do not suffer appreciable absorption. This is sufficient to account for the very long "freak" night range, so often noted on broadcast wavelengths, as, during the absence of heavy static, 50 to 100 microvolts per meter is sufficient to give fairly satisfactory broadcast reception, and a 5 kilowatt broadcasting station would produce a signal of that strength at a distance of 3,000 to 4,000 miles, if there were no absorption.

On the very short wavelengths, below 100 meters, very little quantitative data is available, but it seems that a complete change in transmission mechanism takes place, such that normal absorption does not take place, as on the longer waves. On wavelengths below 40 meters. it has been found feasible to communicate over distances of thousands of miles, even in daylight. On these waves, however, there is a *skip effect.* At a short distance from the transmitter, the signal becomes very weak, or even may disappear entirely, but at some greater distance the signal can be heard again. As a rule, the shorter the wave, the greater the skip distance, and the greater the daylight range. Because of this skip effect, the very short waves are not adapted to short-distance communication, but may prove very useful for long-distance communication.

MEASUREMENT OF FIELD STRENGTH AND ANTENNA EFFECTIVE HEIGHT

As was previously mentioned, one of the important advantages of the loop antenna was its use as a standard of effective height, which may be easily and accurately calculated from its dimensions. The effective height of a loop may be calculated as follows:

$$H = \frac{2\pi NA}{\lambda} \qquad (1)$$

in which H = effective height of the loop, in meters;
$\pi = 3.1416$;
N = number of turns;
A = area of loop, in square meters, or length $\times$ height;
λ = received wavelength, in meters.

The voltage induced in the loop by a signal toward which the loop is turned for maximum reception is

$$V = HE \qquad (2)$$

in which V = total microvolts induced in loop;
H = effective height of loop, in meters;
E = field strength of signal, in microvolts per meter.

If some means were available for measuring this induced voltage, it would be a simple matter to calculate the field strength of the signal. On very strong signals, this voltage may be determined directly by measuring the current induced in the loop by means of a sensitive miliammeter, also measuring the effective resistance of the loop and meter, and then calculating the total induced voltage by Ohm's law (current, in amperes times resistance, in ohms, equals e.m.f. in volts.)

On weaker signals, the induced voltage can be measured by a comparison method, as has been described several times in techanical papers given before the Institute of Radio Engineers.*

ANTENNA INSTALLATIONS

TRANSMITTING ANTENNAS

The higher the antenna is located above the earth connection, the greater will be its radiation and reception abilities. Transmitting antennas, in particular, must be installed with the view of obtaining considerable effective height with low losses. The design of receiving antennas is not so important, as the effect of the losses can readily be made up by increased selectivity and sensitivity in the receiver.

Except at very short wavelengths, it is customary to use a flat-top portion in the transmitting antenna. In the first place, because of the great cost of high towers, it is more economical to use lower towers, making up for the difference by lowering the losses and raising the effective height by using a flat top, thus making the most effective use of the towers. In the second place, the increased capacity due to the flat-top section makes it possible to put more current into the antenna without exceeding the maximum safe voltage of the antenna insulation.

The flat-top portion is usually supported by two or more towers. For small antennas, these towers may be made of wood, but it is more common practice to use steel towers, as very strong supports are required to keep the antenna wires stretched up tight. If the wires are not kept taut, there will be considerable sag, which reduces the

*Proc. of Institute of Radio Engineers, Vol 11, No. 2, "Radio Transmission Measurements" by Bown, Englund, and Friis. Vol. 11, No. 6, "Radio Transmission Measurements on Long Wavelengths" by Beverage and Peterson. Vol. 14, No. 3, "Portable Receiving Sets for Measuring Field Strengths at Broadcast Frequencies" by Axel G. Jensen.

effective height and also causes the antenna constants to change in a high wind, as the antenna wires sway. The towers must be strong enough to stand the strain when the wires are loaded with sleet in high winds.

The antenna conductors must have considerable tensile strength, and yet must not be too heavy. Steel wire would be strong enough, but it has high losses due to skin effect. Copper-clad steel is frequently used with good results, particularly on long wavelengths, but stranded phosphor-bronze or silicon bronze are the most commonly used materials, as they have good high-frequency conductivity with great tensile strength. Hard-drawn copper is often used for short spans.

In order to increase the capacity of the flat-top portion, it is customary to use several wires. These wires may be supported by a horizontal cross-arm or bridge on top of the tower, or they may be supported by a wooden or metal spreader. The wires are usually separated 3 to 10 feet, as moderate separation is practically as effective as more wires with small separation and is much easier to maintain.

On shipboard, or in places where the flat top is difficult to maintain, *cage antennas* are often used. These consist usually of four wires equally spaced on metal rings 3 to 12 inches in diameter. These rings are placed at frequent intervals, so the antenna looks like a long squirrel cage or *sausage*. The cage antenna is very rugged and easy to maintain, but it has perhaps 20 per cent. to 30 per cent. less capacity than the same number of wires would have when spread out by a spreader.

If the antenna is operated at high voltage, say at 100,000 volts or more, corona or brush discharge is likely to appear at sharp points, particularly at the far end of the antenna. This is caused by the excessive voltage gradient near the surface of the wire, which breaks down the air, or ionizes it. The corona results in considerable loss, if the voltage is raised above the point where the corona starts. The break-down voltage will be raised if the area of the surface is increased, such as, by using a larger conductor, by attaching corona shields, or otherwise increasing the surface of the conductor at the break-down points.

It has already been pointed out that a counterpoise, or network of wires supported just above the ground and directly beneath the antenna, is very effective in reducing the dielectric and ground losses. On the longer wavelengths, this is very important, as the readiation resistance is often only a small fraction of an ohm with the highest towers it is economical to use, and in some cases, only 1 per cent. or 2 per cent. of the total antenna energy would be radiated, if the dielectric and ground losses were not reduced, as Fig. 21 shows. On short wavelengths, where the antenna is operated at the fundamental or below, the radiation resistance is so high that the dielectric and ground losses are small in comparison, and no counterpoise is necessary.

As the electrostatic lines of force spread out considerably beyond the antenna, it is a good rule to extend the counterpoise beyond the antenna, and off to the sides, for a distance comparable with the height of the antenna. The counterpoise should not be supported too high above the ground, as it takes the place of the ground and will tend to lower the effective height of the antenna if placed too high. Usually the counterpoise is supported 8 to 10 feet from the ground, just high enough to be out of reach. The counterpoise wires may be joined together at the transmitter end, and should be connected to the transmitter in place of the ground connection.

In cases where it is not desirable to erect a counterpoise, a system of wires similar to the counterpoise may be buried a few inches in the earth. If the antenna is erected over highly conducting earth, like a salt marsh, it may be sufficient to bury a few copper plates near the transmitter for an earth connection, but, as a rule, the buried-wire ground system directly underneath the antenna is better.

Small antennas may be insulated with glass or high-grade composition insulators; but for very high voltages, long, glazed porcelain insulators are frequently used. In some cases the wires are individually insulated from the cross-arm or spreader, and in other cases the wires are attached directly to the spreader, and the spreader is insulated from the tower by a single large strain insulator.

The lead-in should go as directly as possible from the transmitter to the antenna, and should not run too close to the tower or the walls of the building, because of eddy currents in metal objects and dielectric losses in other material, such as, wood, brick, and concrete.

It has already been mentioned that the field of the antenna should be free from trees, buildings, and wire lines. Antennas erected on the tops of high buildings are sometimes ineffective at certain wavelengths, presumably because of counter radiation from the building itself, and absorbing and reflection effects in nearby buildings.

In case the towers are guyed, the guy wires should be broken up with insulators at frequent intervals to prevent loss of energy due to circulating currents through the guys and the mast.

RECEIVING ANTENNAS

The remarks made about transmitting antennas used to apply with equal force to receiving antennas back in the days of the crystal or other non-amplifying detectors. With the advent of the vacuum tube and amplification, it is possible to obtain very good results with receiving antennas that would be very inefficient as transmitting antennas. It is true that, with many types of receivers, the antenna would tune sharper and would give more signal strength if used with a counterpoise, and all precautions were taken to reduce losses, but it is seldom done, as most receivers will go down to the static level with a very inefficient antenna. However, some of the points mentioned for transmitting antennas are well worth keeping in mind for receiving antennas, such as, keeping the lead-in away from the building as much as possible, making the antenna as high as possible above the receiver, running the ground lead direct to a good ground, erecting the antenna over a clear space free from buildings, wires, and trees, insulating the antenna well to prevent leakage, etc.

A single wire is practically as good as several spaced wires as far as reception is concerned, as the loss in effective height would be so small as to be hardly noticeable on the receiver. The total length of antenna to use depends on the wavelength, and, to some extent, on the type of receiver, but, as a rule, the longer the wire, the stronger the received signal will be. On the other hand, as the length of the wire is increased, the selectivity decreases and directive effects may become noticeable. In any case, the fundamental wavelength of the antenna should be lower than the shortest wavelength that it is desired to receive, except, possibly, for waves below 100 meters. For example, consider an antenna for broadcast reception. The shortest wavelength to be received is about 200 meters, say. The fundamental wavelength should be below 200 meters, so the greatest length of wire that should be used is $200 \div .2 = 47.5$ meters, or 156 feet; so any length from 30 feet to 150 feet might be used, depending on whether selectivity or increased signal strength is desired. The average of the two extremes, or 90 feet, would be a good compromise. It should be remembered that this length includes the length of the horizontal part as well as the length of the lead-in.

A water pipe is usually a good ground connection for receiving. The ground lead from the receiver should be as short as possible and should be securely connected to the pipe by soldering or by using a good ground clamp, the pipe being thoroughly cleaned before the clamp is attached. If the water-pipe system is extensive enough, it might serve as a counterpoise in cases where it makes poor contact with the earth, but, as a rule, it is desirable to have the pipe make good contact with the earth.

It is essential to protect the receiving set from possible damage by lightning, either by putting in a heavy single-pole double-throw switch, or by using an approved vacuum or other type of lightning arrester, or both, according to the local fire underwriters' rules. If both are used, the lightning arrester will protect the receiver while it is in use. When the receiver is not in use, the antenna switch should be thrown down to disconnect the antenna from the receiver, and connect it directly to ground. This may be accomplished by connecting the antenna to the blade of the switch, the receiver to the top contact, and the ground to the bottom contact. The grounding switch should preferably be placed outside of the window, with the ground wire running as directly as possible to a ground rod, buried plate, or outside water pipe. The ground wire should have somewhat greater current-carrying capacity than the antenna lead-in, but, in any case, it should not be smaller than No. 14 B. & S. copper wire. This is to make sure that the antenna lead will burn off before the ground lead burns off, in case of a direct stroke of lightning or accidental contact with power wires.

If necessary to cross other wires with the antenna, the crossing should be made as near to right angles as possible to minimize inductive interference. It is not advisable to erect an antenna across a high-voltage power line or trolley line, as it would obviously be very dangerous if the antenna should break and come in contact with the high-voltage wires.

Sometimes the house-lighting circuit can be used as a receiving antenna with good results, particularly if the feeders from the outside transformer come in for some distance on the poles. Generally, one side of the lighting circuit is grounded, so better results may be had with one side of the lighting circuit than the other. A small, well-insulated condenser should always be placed between the lighting circuit and the receiver, as, otherwise, the lighting circuit may be short-circuited through the receiver.

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Vol. III

Radio Transmitters and Carrier Currents

RADIO TRANSMITTERS

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PREFACE

Somewhat less than one hundred years ago the only system of electric communication was the Morse telegraph. Though extremely crude, compared with present standards, this system survived, at least in principle, to the present time. Gradually followed the invention and subsequent development of the telephone, and later that of the radio telegraph and radio telephone.

The present volume is concerned with the development of radio-telegraph and radio-telephone transmitters and that branch of line communication in which radio-frequency currents are used as carriers of the message; hence the title, Radio Transmitters and Carrier Currents. The authors have endeavored to present the principles of these subjects in the light of modern practice. The result is a happy combination of theory and practice.

International Correspondence Schools

CONTENTS

RADIO TRANSMITTERS AND CARRIER CURRENTS

RADIO TRANSMITTERS

EARLY RADIO DEVELOPMENTS

The electromagnetic wave is the basis of all radio communication. Its scientific conception originated with James Clerk-Maxwell in 1865. Professor Dolbear, an American, was the first one to transmit radio signals. In 1882 he succeeded in transmitting radio signals a distance of a half mile. Professor Dolbear patented his apparatus, and although the theory of his experiments was not understood, it is quite safe to assume that his transmitting equipment was of the spark type.

In 1885, Mr. H. R. Hertz developed apparatus for producing and detecting electromagnetic waves, but this apparatus was not beyond the development stage at this time. Guglielmo Marconi was assigned British patent No. 7,777, in 1900, for the first commercial wireless, or radio, transmitter and receiver. Marconi's transmitter was of the spark type and his receiver employed a coherer as a detector.

The first time that radio signals were transmitted to any appreciable distance was in 1899 when Marconi succeeded in transmitting signals across the English Channel. Radio signals were first sent across the Atlantic Ocean in 1901, when Marconi succeeded in sending the letter *S* from Poldhu, England, to St. Johns, Newfoundland. He used a spark type of transmitter at Poldhu, and a coherer for a detector at St. Johns.

SPARK TRANSMITTERS

USES OF SPARK TRANSMITTERS

The spark type of radio-telegraph transmitter was the first to be used commercially and, despite the increasing use of continuous-wave transmitters, a large number of marine transmitters and many of those used at land stations are of the spark type; so they are, as yet, by no means obsolete. In instances where the continuous-wave type of transmitter is used, even on the larger ships that are equipped with the most modern types of tube transmitters, there is usually an auxiliary spark set ever ready for use.

FUNDAMENTAL CIRCUITS OF SPARK TRANSMITTER

Power Circuit.—In Fig. 1 is shown a schematic wiring diagram of the fundamental circuits involved in the spark method of radio-telegraph transmission. Alternating current at a potential of approximately 140 volts is applied from the alternator *a* to the primary winding of a step-up transformer *b*, through a telegraph key *c*. In this case it may be assumed that the frequency of the applied voltage is 500 cycles, although some of the other standard frequencies that may be used, are 60, 120, 240, 480, 500, and 600 cycles per second.

Closed Oscillatory Circuit.—The potential at the secondary terminals of the step-up transformer *b*, Fig. 1, may be of the order of 12,000 volts (in the case of a 2-kw. type of transmitter). At this point will be considered what is happening at any particular instant. The voltage across the secondary terminals is assumed to be rising toward its maximum positive value. The condenser *d* charges to a point which is determined by the setting or spacing of the electrodes in the spark gap *e*. When the potential across the condenser *d* reaches the break-down value of potential for the spark gap, several things take place.

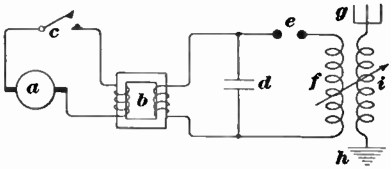


Fig. 1

Just before the spark gap breaks down, the energy is stored in the dielectric between the plates of the condenser *d*. When the gap *e* breaks down, a current passes from the positive plate of the condenser *d* through the spark gap *e* and through the inductance coil *f* to the negative side of the condenser. In Fig. 2 (*a*) are shown the conditions that exist just before the condenser discharges into the circuit, through the spark gap. The section of curve under the circuit diagram, view (*a*), shows the different values of potential that exist on the plates of the condenser *d* from the time when the conditions are as shown in the diagram in view (*a*), until the time the conditions are as shown in the diagram in view (*b*). Thus the voltage on the upper plate of

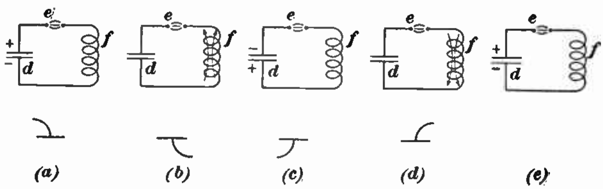


Fig. 2

the condenser *d*, view (*a*), goes from its maximum positive value to zero, and the energy is now stored in the form of an electromagnetic field around the inductance coil *f*, view (*b*).

When the current from the positive plate of the condenser *d*, becomes zero, the field around the inductance coil *f* collapses and current passes around the circuit in the opposite direction; thus the voltage of the upper plate of the condenser *d* reaches its maximum negative value. The energy is now stored in the electrostatic field between the plates of the condenser and this charge not only has the opposite polarity to that of the initial charge, but the quantity of electricity in this case is less than that of the initial charge, owing to the fact that some of the energy has been expended in the resistance of the circuit and the production of heat, light, and sound.

The curve below the diagram at (*b*) shows what happens to the voltage on the upper plate of the condenser *d* between the time when the conditions are as shown in the diagram at (*b*) and the time when they are as shown at (*c*), where the energy is stored in the dielectric between the plates of the condenser. The condenser now discharges through the circuit in a direction opposite to that shown in view (*a*) and the energy is again stored in the magnetic field around the inductance coil *f* as shown in view (*d*). The curve in view (*c*) shows that the voltage on the upper plate of the condenser *d* goes from its maximum negative value, which it had when conditions were as shown in view (*c*), to zero, which latter condition is represented at (*d*).

When the current through the circuit becomes zero the field around the coil *f* again collapses and current passes in the opposite direction to that shown in view (*b*). This completes the cycle of events involved in one oscillation, and the upper plate of the condenser is once more charged positively. The curve in view (*d*) shows what happens between conditions as represented in views (*d*) and (*e*).

Although the condenser is once more charged so that is has the same polarity as the initial charge, view (*a*), the quantity of electricity is considerably less than in the case of the initial charge, as there is a loss of energy every time the current passes through the circuit in either direction. Thus the amplitude of the voltage and current curves decreases to zero after a number of oscillations.

These oscillations are of radio frequency and the frequency is determined by the values of capacity and inductance in the circuit. If the constants of the oscillatory circuit were such as to produce a 600-meter wave, the frequency of the oscillatory current would be 500,000 cycles per second, and, since the frequency of the voltage which gives the condenser its initial charge is 500 cycles, it can be readily seen that the radio frequency is 1,000 times the frequency of the supply voltage.

Open Oscillatory Circuit.—The radio-frequency energy in the closed circuit *def*, Fig. 1, is induced into the open oscillatory circuit by means of the inductive coupling between the two. The open oscillatory circuit consists of the antenna *g*, ground *h*, and the coupling coil *i*.

There are three methods of coupling the closed oscillatory circuit to the open oscillatory circuit; namely, inductive, conductive, and capacitive coupling. In order to comply with the legal requirements, it is usual to employ inductive coupling.

In the case of inductive coupling, the closed- and open-circuit inductors, *f* and *i*, respectively, are placed in inductive relation to each other, and oscillations generated in the closed circuit are transferred to the open circuit. It is necessary that the two circuits be tuned to resonance to obtain a maximum transfer of energy.

If the coupling coils *f* and *i* between the two circuits are placed very close together, the oscillations in the antenna circuit will have a fast rate of decay, owing to the transfer of part of the energy from the antenna circuit back into the closed circuit. This is undesirable, since it means that the transmitted energy is not being confined to a narrow band of wavelengths. Hence, loose coupling between the closed and open oscillatory circuits is conducive to the confining of the transmitted energy on a narrow band of wavelengths.

DAMPING AND DECREMENT

In considering the spark type of radio-telegraph transmitter, it is well to have a clear understanding of the difference between damped and undamped, or continuous, waves. An undamped, or continuous, wave train is shown in Fig. 3 (*a*), where the amplitude of each succeeding oscillation remains unchanged. This type of wave is characteristic of the arc and the tube transmitter. The abbreviation for continuous wave is cw.

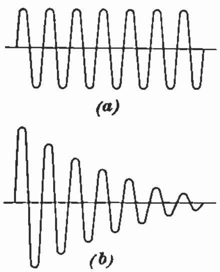


FIG. 3

A damped wave train is shown in view (*b*), where each oscillation has a smaller amplitude than the preceding one, the end of the wave train being reached when the amplitude becomes zero. This type of wave train is characteristic of the spark type of transmitter. The amplitude is the highest value of voltage or current reached during one alternation.

Logarithmic decrement is a term which is indicative of the decay, or the damping, of the oscillations in a damped wave train. The logarithmic decrement is the Napierian logarithm of the ratio of one oscillation to that of the next oscillation, in the same direction, in a train of decreasing oscillations. This is a constant ratio. By international law, the limit fixed for the value of the logarithmic decrement is .2. Thus, to be with the law, all spark transmitters must emit a wave that has a decrement of .2 or under.

The lower the decrement, the less the damping, the longer it takes a wave train to die out and the more it approaches the form of a continuous wave, and the sharper it tunes at the receiver. One of the inherent characteristics of a continuous wave transmitter is that the signals tune sharply, owing to the fact that the signal energy is confined to one frequency, and not to a band of frequencies, as is the case with a spark transmitter having a high value of decrement.

High decrement means broad tuning and low decrement means sharp tuning. Modern ship transmitters of the spark type have a decrement value lying between .05 and .1.

A wave that has a decrement of .2 or under means that the wave in question will have a slow rate of decay; hence, the oscillations in the antenna circuit should have a slow rate of decay in a spark transmitter in order to produce sharp tuning at the receiver. This is accomplished by obtaining a high degree of damping in the closed oscillatory circuit; for, when the converse is true, and the oscillations in the closed oscillatory circuit are not rapidly damped out, there is an opportunity for some of the energy in the open oscillatory, or antenna, circuit to get back into the closed oscillatory circuit by virtue of the fact that, as long as oscillations continue in the closed circuit, there are sparks jumping across the ionized atmosphere between the spark-gap electrodes, thereby providing a closed circuit.

This loss of energy from the antenna circuit increases the decay of the oscillations in that circuit, hence it increases the damping and subsequently the decrement. Now, if the oscillations in the closed circuit are highly damped, the cessation of the functioning of the spark gap causes it to effect an open circuit in the series combination of coil, condenser, and gap, which forms the closed oscillatory circuit. This effect aids in suppressing a transfer of energy from the antenna circuit back into the closed circuit and prevents the rapid decay of the oscillations in the antenna circuit.

ANALYSIS OF CURRENTS IN SPARK TRANSMITTER

In Fig. 4 is given a graphical analysis of what takes place in the different circuits in the spark transmitter.

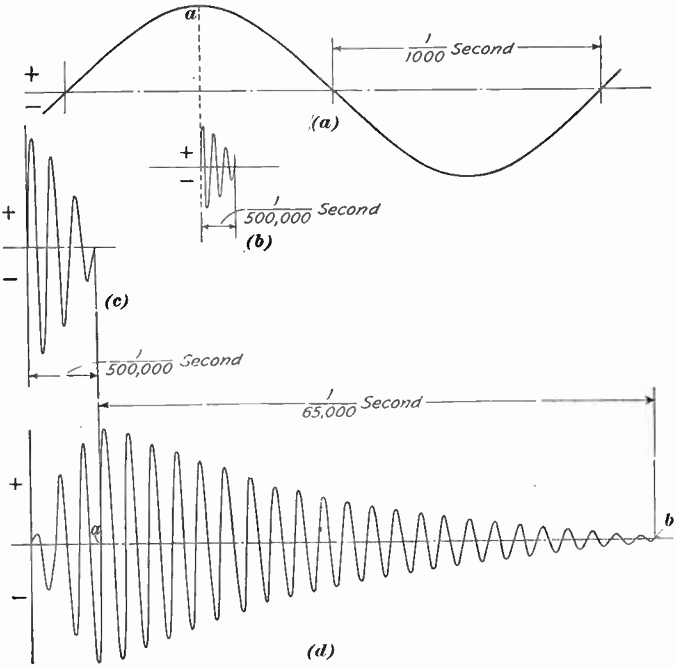


FIG. 4

The analysis will be confined to the tranformation of a 500-cycle supply into radio-frequency current in both the closed and the open oscillatory circuits.

The curve, Fig. 4 (*a*), shows one cycle of the 500-cycle supply voltage. When the voltage across the condenser *d*, Fig. 1, in the closed oscillatory circuit, and consequently across the gap *e*, reaches a point *a*, Fig. 4 (*a*), near is maximum value, the gap breaks down and a series of radio-frequency oscillations take place in the closed circuit, which are quickly damped out, as shown in view (*b*). The curves in views (*b*) and (*c*) are drawn to different scales, but both represent the current in the closed circuit.

Because of the radio-frequency oscillations in the closed circuit, oscillations of similar frequency are established in the antenna circuit and, because of the rapid quenching that takes place in the closed circuit, the oscillations in the open circuit are free to continue as shown in view (*d*) without any reaction on the closed circuit with subsequent loss in energy. Thus, rapid quenching in the closed circuit means low decrement in the open circuit, which latter is the opposite of rapid quenching. Oscillations continue in the antenna circuit during the interval *ab*, long after the closed circuit has ceased to function.

SPARK GAPS

Purpose and Classification of Spark Gaps.—In spark transmission the efficiency of the gap employed, enters largely into the tuning and the carrying qualities of the transmitted signals. The function of the spark gap is to break down when the condenser has been permitted to charge to a potential determined by the gap separation and permit the condenser charge to surge back and forth until it is entirely dissipated. The gap should also aid in the rapid damping out of oscillations in the closed circuit.

Three types of gaps are employed in spark transmission; the fixed, the rotary, and the quenched types. The inherent characteristics that the gap must possess, are a high break-down voltage value while the condenser in the closed oscillatory circuit is charging, and a low resistance during discharge. A fixed type of spark gap is shown in Fig. 5. It is the least efficient of all, owing to the fact that it does not damp out the oscillations in the closed circuit fast enough.

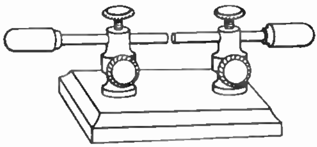


Fig. 5

Rotary Gaps.—The rapid damping characteristic is possessed to a greater extent by both the rotary and the quenched types. There are two types of rotary gaps, the synchronous and the non-synchronous types. A synchronous rotary gap is shown in Fig. 6, with a portion of

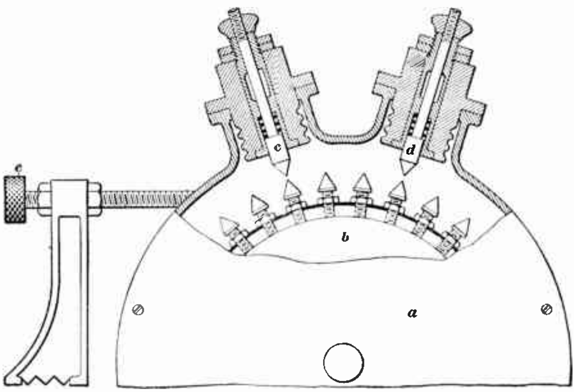


Fig. 6

the casing *a* removed. This gap consists of a disk *b* having electrodes mounted around its periphery. The number of electrodes is such that there is a spark discharge for each half cycle of the generator frequency. This disk is mounted directly on the main shaft of the motor generator, and, as the name implies, rotates in synchronism with the motor-generator shaft.

There are two stationary electrodes *c* and *d* on the frame of the synchronous gap and these two are the terminals of the gap. These two stationary electrodes are so spaced, relative to the spacing of the electrodes on the rotary disk, that at any instant in which there is a rotary electrode directly beneath one of the stationary electrodes, there is another rotary electrode directly beneath the second stationary electrode. The circuit through the gap is traced from one of the stationary electrodes, through the air gap to the rotary electrode, through the metallic disk upon which the rotary electrodes are mounted, and out through the air gap between another of the rotary electrodes and the second stationary electrode.

The electrodes are usually wedge-shaped and are so adjusted that there is about $\frac{1}{64}$-inch air gap between the rotary and the stationary pieces. An adjusting screw *e* is provided for shifting the two stationary electrodes, the same distance being maintained between them, so that they are opposite a pair of rotary electrodes at the instant there is maximum voltage across the secondary terminals of the step-up power transformer.

The advantages of this type of gap are: quick damping, or rapid quenching, of the closed-circuit oscillations, preventing return of the antenna current; cooling of the electrodes due to the wind resistance; regular intervals of sparking, giving a pure musical note and greater carrying qualities with a higher degree of ability to penetrate static.

The synchronous type of gap is generally used in cases where the frequency of the supply generator is of the order of 500 cycles. In this case there would be a spark discharge, or a wave train, for every voltage peak in the alternating-current supply and this would mean that there would be 1,000 spark discharges per second. This would also be the wave-train frequency and it would be the frequency of the rectified signal at the receiver. Thus, in conjunction with a supply generator having a frequency of the order of 500 cycles, the synchronous gap is used and a high-pitched, musical note is produced in the ear phones at the receiving station.

The non-sychronous type of rotary gap is similar to the synchronous type with the exception that the former has a sufficient number of electrodes to produce a greater or a lesser number of spark discharges than there are voltage peaks in the alternating-current supply. In other words, when this type of gap is used, a discharge can take place before or after the a.-c. supply voltage has reached its maximum value.

This type of gap is generally used where it is desired to produce a high musical note at the receiving station, where the supply generator at the transmitting station has a frequency of the order of 60 cycles per second. Thus it is possible to produce a 500 cycle note where the frequency of the supply generator is only 60 cycles. This note, however, is not as pure as in the case of a synchronous gap, which would be operating in conjunction with a supply generator having a frequency of the order of 240 cycles. But, although the note from the non-synchronous type of gap is not as pure as that from the synchronous type, it is musical and easily read. The frequency produced in the case of the non-synchronous type of gap is given by the equation

$$\text{frequency} = \frac{\text{revolutions per minute of disk} \times \text{number of studs}}{60}$$

Quenched Gap.—The most efficient of all types of spark-discharge apparatus is the quenched gap, one type of which is shown in Fig. 7. It is made up of a number of individual gaps *a*, view (*a*). Each gap consists of two disks and an insulating washer. These disks are of the form shown in view (*b*). The outer material of the gap is of brass and the sparking surface is usually of silver.

The complete gap is compressed by means of clamps, and this makes each individual gap air-tight. The outer surface is arranged in the form of a cooling fin and an air blast is used to lower the temperature of the gap. The sparking distance between individual gaps is usually .01 inch and this permits a voltage of 1,000 for each individual

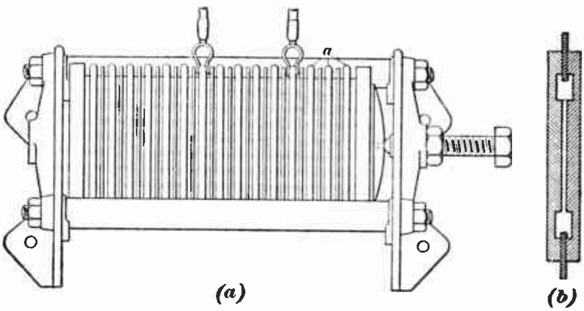


FIG. 7

gap. By using the proper number of gaps in series, any voltage, or variation in power, may be taken care of.

A different number of gaps may be cut in the circuit by means of clips, which allow for quick adjustment. Because of the rapid quenching characteristic of the quenched gap, the oscillations in the closed oscillatory circuit are rapidly damped out. This allows the antenna circuit to swing into its own natural period of vibration without reaction on the closed circuit, and without loss of energy from this last cause (reaction on the closed circuit), which means a slow decaying of the oscillations in the open circuit, a low decrement, and sharp tuning at the receiver.

The quenched gap, then, permits the antenna to oscillate at its own frequency and damping. This gap is noiseless in operation, which is quite an asset after one has heard one of the synchronous gaps in operation. Another important point about the quenched gap is that it permits the use of transformers having low-voltage secondaries.

Owing to its rapid quenching qualities this gap may be used with much closer coupling between the closed and open oscillatory circuits, which tends toward higher antenna currents, at the same time allowing a pure wave to be emitted. This type of gap has no moving parts.

COMMERCIAL TYPES OF SPARK TRANSMITTERS

Purpose of Different Types.—There have been four different types of spark transmitters designed for marine use. Certain classes of vessels require a greater transmitting range than others and have therefore been equipped with higher-powered transmitters. Spark transmitters are usually of one of the following: ½ kw.; 1 kw.; 2 kw.; and 5 kw.

For the smaller vessels, including yachts and small cargo vessels, and for auxiliary purposes, the ½-kw. transmitters are employed. They have an average range of 150 miles in daylight and upwards of 1,000 miles at night.

The 1-kw. equipment is used on small coastal steamers and the larger cago vessels. It has a range of approximately 200 miles in daylight and upwards of 1,200 miles at night.

The 2-kw. transmitter is practically standard equipment for the larger coastal steamers and largest cargo vessels as well as on a great number of transatlantic passenger vessels. Since this type of transmitter is the most common in marine use, it will be described in detail.

The 5-kw. types of transmitters are to be found on the largest transoceanic liners and first line men-of-war.

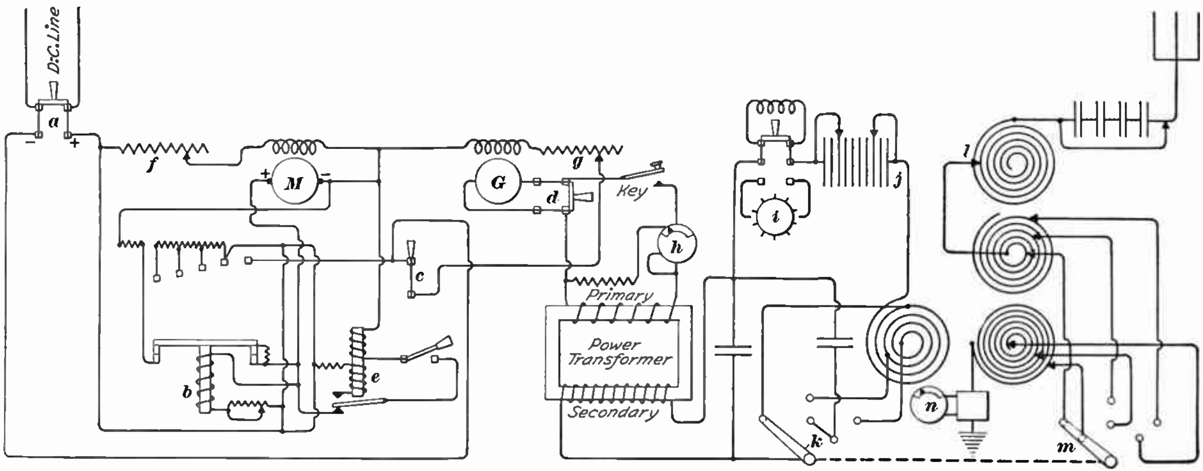

D.C. Line
a
f
M
G
g
d
Key
c
h
Primary
Power Transformer
Secondary
b
e
i
j
k
l
m
n

Fig. 8

Standard 2-Kw. Spark Transmitter.—Spark equipment of the 2-kw. type has followed the original design of the American Marconi Company (now the Radio Corporation of America). Transmitters of this type have been made by the United States Navy and several other manufacturers. In Fig. 8 is shown a wiring diagram of this apparatus.

Direct-current power is taken from the ships mains at a potential of the order of 120 volts. This input is controlled by the main d.-c. switch *a*. From here it is supplied to the motor-generator set through the automatic starter *b*. The switch *c* is in the field circuit of the generator *G*, and the switch *d* in the output circuit of this 500-cycle generator. The overload relay is shown at *e*. The current in the field of the motor *M* may be varied by means of the rheostat *f*; the result is a variation of speed with a resultant variation in the frequency of the current in the generator circuit. The generator voltage may be varied by means of the rheostat *g*. The power circuit also includes the wattmeter *h* and the transmitting key.

From the secondary of the power transformer, Fig. 8, the high-voltage low-frequency alternating current is changed into a high-frequency current in the closed oscillating circuit. Either the rotary gap *i* or the quenched gap *j* may be switched in the circuit. When the rotary gap is used, the clips on the quenched gap are fastened to the same disk, thus short-circuiting the quenched gap. A small inductance coil is in series with the quenched gap to compensate for the inductance of the leads to the rotary-spark gap.

This transmitting set is so arranged that the wavelength may be instantly changed from 300 to 600 or 800 meters by means of the wave-change switch *k*. The switch *k* controls two other switches, which, when the switch *k* is moved, cut in the proper amount of inductance and capacity into the closed and open oscillating circuits. Fine adjustments of inductance in the antenna circuit may be made with a variometer *l*. The coupling between the open and closed circuits may be varied by means of the lever *m*. The antenna circuit also includes an ammeter *n* for reading the current in the antenna circuit.

In adjusting a transmitter of this type, it is necessary to tune the closed circuit by means of a wavemeter and then to couple the open circuit to it. The open, or antenna, circuit is then brought into resonance, which is manifested by maximum reading of the current-indicating device in the antenna circuit.

The radio-frequency current in the antenna circuit, when a transmitter of this type is used, varies with the wavelength, for any particular antenna. In the case of the average ship's antenna, between 14 and 18 amperes may be expected on 600 meters when the quenched gap is used. At 450 meters, the current should be between 9 and 14 amperes. When working on the 300-meter wavelength, the value of the antenna current will be greater if the natural period of the antenna system is low enough to permit operation on this wavelength without the insertion of a series condenser. If the short-wave condenser is not connected in the antenna circuit, one may expect between 8 and 9 amperes, but if the fundamental of the antenna is so high that the series condenser has to be cut in the circuit for tuning down to 300 meters, the antenna current will probably be between 3 and 5 amperes.

TIMED-SPARK TRANSMITTER

ADVANTAGES OF CW. TRANSMISSION

In the early days of radio-telegraph communication, it was quickly learned that continuous-wave signals provided a more reliable means of communication than damped waves. The Marconi Wireless Telegraph Company engineers devised a system whereby continuous waves were emitted from a spark transmission system, where waves of equal amplitude were formed by the proper phasing of a plurality of spark oscillations.

It is well to stop for a moment and summarize the outstanding advantages that make cw. telegraph transmission more desirable than spark.

First of all, the transmission range by the continuous-wave method, for a given power, is much greater than by the spark method. This is due to the fact that in cw. transmission, all the energy is concentrated into, and radiated at, one frequency, whereas in spark transmission, the radiated energy is spread out over a band of frequencies.

If follows, then, that the inverse of the above is true; namely, for a given range, less power is required to transmit by the continuous-wave method than by the spark method; or, in other words, the efficiency of transmission, in the case of cw., is an improvement over spark.

Greater selectivity is experienced in tuning cw. than in tuning spark signals at the receiving station. In the case of cw., the signal note may be adjusted at the receiving station to suit the operator, by simply changing the frequency of the beat note, which is manifested in the detector output circuit, in the course of cw. reception, and which is caused by the beating of the incoming radio-frequency signals with the radio-frequency energy that is generated at the receiving station and that has a frequency a few hundred cycles above or below the frequency of the incoming signals. In the case of spark signals the signal note is more or less a fixed quantity; that is, it is under the control of the transmitting operator. But it is the receiving operator that really should control the note frequency.

It is also true that a given antenna will have a greater possible energy radiation on continuous waves than on damped waves. This is considered from a standpoint of antenna insulation; hence, the optimum possible voltage whereat the antenna insulation breaks down is the limiting factor and it is a fact that, for a given power in the antenna, the amplitude of the cw. oscillations need not be so great as the amplitude of the damped-wave oscillations. A quantitative analysis of this point follows:

In the case of cw. transmission, energy is radiated in a continuous stream, when a signal is being sent out, or 100 per cent. of the time.

In the case of spark transmission, with a 500-cycle supply generator and a quenched spark gap, for example, the number of oscillations per spark is equal to the constant 4.605 plus the decrement of the emitted wave, divided by the decrement. If the decrement is .1, the

$$\text{Number of oscillations per spark} = \frac{4.605 + .1}{.1} = 47.05$$

In this case, there are 1,000 sparks per second, so the number of complete oscillations per second is equal to $1{,}000 \times 47.05$ which is 47,050. In order to determine the length of time involved in the completion of these 47,050 oscillations, the rate of speed at which they oscillate; that is, the frequency, must be known. This is a function of the wavelength and, when sending on 300 meters, the frequency will be

$$\frac{300{,}000{,}000}{300} = 1{,}000{,}000 \text{ cycles per second}$$

Thus, the 47,050 oscillations take place at the rate of 1,000,000 per second, which means that the time interval for the completion of each one is $\frac{1}{1,000,000}$ of a second and the time involved in the completion of the total number is equal to $47,050 \times \frac{1}{1,000,000}$, which equals $\frac{47}{1,000}$ or .047 of a second. From this it is found that during one second of time, in the case of spark transmission, there is energy being radiated 4.7 per çent of the time. When this value is compared with that for cw. transmission, where energy is being radiated 100 per cent. of the time, it will be apparent that the amplitude of the oscillations in the case of spark transmission will have to be much greater to obtain a given amount of energy radiated per second than in the case of cw., for, in the former, energy is being radiated only a small fraction of the time.

Thus there is an optimum amplitude of oscillations above which the antenna insulation will break down. If this optimum amplitude is effected in the course of cw. transmission, the energy radiated per second will be much greater than in the case of spark transmission where the same optimum amplitude is effected.

The following is a list of devices by means of which continuous radio-frequency energy can be generated: the timed spark, the Alexanderson alternator, the Poulsen arc, frequency multipliers, and the vacuum tube. All these systems will be considered in detail.

THEORY OF TIMED-SPARK TRANSMISSION

In outlining the characteristics of spark wave trains it was shown that no two oscillations were similar, but decayed at a given rate, in a certain time, so determined by the decrement of the circuit. These oscillations and their resulting ether waves are in groups separated by definite time intervals. The function of the timed-spark discharge transmitter is to fill up these invervals of time with other groups of oscillations, which are set up by other discharge circuits. The idea is similar to using a six-cylinder engine in place of a single-cylinder one. In Fig. 9 is shown the general idea of the method. The lines *a*, *b*, *c*, and *d* show groups of discharges set up in four different circuits, so arranged that the discharges of the different circuits follow each other in a regular sequence. It is then obvious that if these discharges are made to act

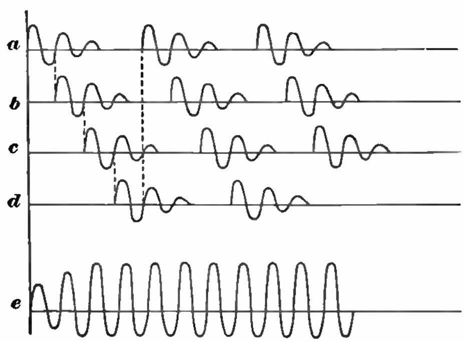


FIG. 9

inductively on a collecting circuit, the resulting oscillations in this circuit will have undamped characteristics as shown by the wave form at *e*. The adjustment so that the discharges do not overlap each other in phase is somewhat critical to maintain. Two of the foreign high-powered transatlantic stations are now using this method for undamped-wave telegraph communication with good results.

A schematic diagram of a timed-spark transmitter is shown in Fig. 10. The rotary gaps *a*, *b*, *c*, and *d* are fixed to the same shaft in such a manner that a discharge takes place across each gap at a different interval. A rotary and a quenched spark gap are included in each circuit. When the high-voltage direct current is impressed across the electrodes a discharge takes place, which starts an oscillating current, say in the circuit of the gap *a*. By induction the energy is transferred to the antenna circuit. The discharges across the second, third, and fourth gaps follow in close succession, and thus maintain the current in the antenna circuit at constant amplitude.

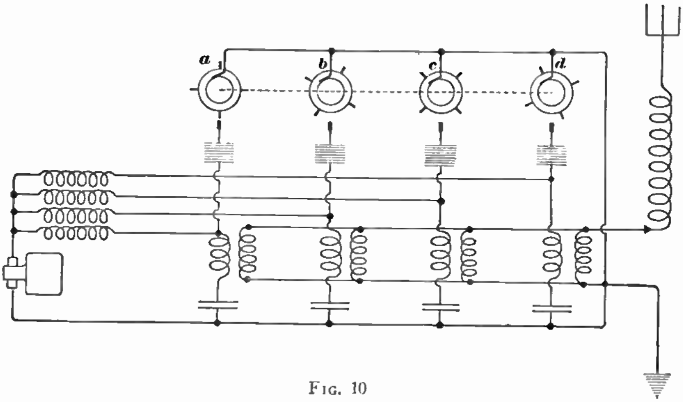


FIG. 10

A slight overlap of oscillations is permitted in order to produce higher transmission efficiencies, but this also introduces a certain degree of decrement in the emitted signal, which does not allow for as fine tuning as in other types of cw. transmitting equipment.

This type of transmitter is noted for is extreme ruggedness but must be carefully adjusted. Although there are other types of timed-spark transmitters, it may be said that they are only modifications of the circuit arrangement described in the foregoing paragraphs. One improvement has been the adaption of an auxiliary timing disk to insure the proper phase relation between the allied circuits.

Apparatus of this type is to be found in some of the English and Norwegian stations. The one American installation has already been replaced by the high-frequency alternator.

ALEXANDERSON SYSTEM

The Alexanderson high-frequency alternator, as installed at the majority of the high-power telegraph stations in the United States, is capable of delivering 200 kilowatts of radio-frequency energy at 25,000 cycles or less. It consists essentially of a two-phase motor driving a high-speed generator through a step-up gearing. This generator contains a steel-disk rotor that has a large number of slots on its periphery filled with non-magnetic material (bronze). These slots cause magnetic fluctuations when the disk rotates, and alternating currents are induced in the armature coils, which are stationary and wound in slots adjacent to the disk. There are 64 armature coils and these are coupled to a large common secondary, which is connected to the antenna and ground system. The magnetic circuit is energized by the current in the stationary field coils.

One of the armature coils is led to an independent circuit, and the current from it is rectified by a small vacuum-tube rectifier and is then used for operating the speed regulator. The actual regulation is accomplished through a reactance coil, which in turn changes the value of the voltage supply to the driving motor. This method of regulation is very accurate and sensitive. Any wavelength desired, within the design limit of the machine, can be obtained by changing the speed of the machine, which is accomplished by the turning of one control handle.

A schematic diagram of the Alexanderson alternator connected to an antenna system is shown in Fig. 11. The armature coils of the alternator *a* are each connected to separate windings in the primary *b* of the oscillation transformer. The secondary winding *c* is connected directly in the antenna circuit.

The antenna *d* is of the multiple-tuned type, where a number of down leads are employed, each connected to an independent outdoor tuning coil *e* and common ground system. The antenna efficiency is thereby greatly increased, and a greater antenna current is obtained with the same power input than would be otherwise possible.

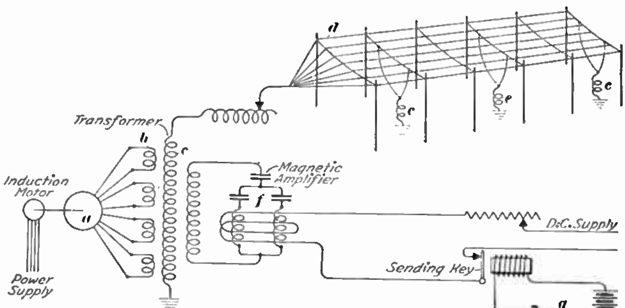


FIG. 11

The alternator equipment is fully protected, and has automatic alarms and controls which shut down the machine in case of failure of proper supply of oil and water to the various cooling systems.

Keying is effected through a magnetic amplifier *f*, an apparatus operated by small values of direct current, which in turn has the effect of throwing the alternator in or out of resonance with the antenna system. A telegraph key *g*, controlling through a relay the direct-current supply to this magnetic amplifier, is used for telegraphic signaling.

ARC TRANSMITTERS

USE OF ARC TRANSMITTERS

The arc transmitter was the first to be used for transmitting undamped waves. Prior to the development and use of the tube transmitter, the arc transmitter was the only system capable of producing sustained oscillations in the antenna for the purpose of transmitting by radio telephony. While its use for radio-telephony has diminished, the arc has been adopted for both high-power transoceanic and low-power ship stations.

The advantages of the arc are the same as those for tube transmitters, plus simplicity and ruggedness. Owing to the difficulty of modulating an arc transmitter, its use is confined mostly to telegraphic transmission. The equipment to be described consists of a 2-kw. shipboard installation.

One of the outstanding inherent characteristics of the cw. transmitter is selectivity. By confining all of the radiated wave on one definite frequency, the efficiency of the transmitting range is greatly increased, and, at the same time, more stations can work within a given frequency band without interference.

THEORY OF OSCILLATING ARC

In Fig. 12 is shown a schematic diagram of the fundamental arc transmitting circuit. The arc gap is supplied with high voltage from a d.-c. generator *a*, through a controlling resistance *b* and radio-frequency choke coils *c*. The arc electrodes consist of a copper anode *d* and a carbon cathode *e*. The oscillatory circuit consists of the inductance coil *f* and the condenser *g*, shunted across the arc.

The antenna is inductively coupled to the closed oscillatory circuit by means of the coupling and tuning coil *h*. There is a radio-frequency ammeter *i* in series with the antenna circuit.

The arc is struck, or started, by moving the cathode *e* until it touches the anode *d*, the resistance *b* preventing a short circuit on the supply generator. Upon separating the electrodes an arc is struck, or formed, and it will be found upon measuring the voltage across the gap that there is a difference in potential, because of the drop caused by the current through the resistance of the arc itself. This state of inequality in potentials causes a cur-

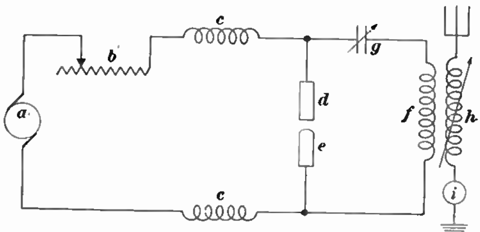


FIG. 12

rent in the oscillatory circuit, which charges the condenser *g*.

In charging the condenser *g*, the current in the arc is decreased and the potential existing across the arc is increased because of the increase in the resistance of the arc with the decreased in current. This rise in potential causes a still greater charge to be placed on the plates of the condenser.

When the condenser reaches full charge, it discharges across the arc, thereby decreasing the arc voltage. This aids in completing the discharge of the condenser, and owing to the resistance of the oscillatory circuit, the discharge continues in the opposite direction, setting up an alternating current in this circuit, the frequency of which is determined by the capacity of the condenser *g*, the inductance of the coil *f*, and the resistance of the oscillatory circuit. The maximum amount of energy is radiated from the antenna circuit when the latter is tuned to the frequency of the oscillations established in the closed oscillatory circuit.

FEDERAL 2-KILOWATT ARC TRANSMITTER

Circuit Diagram and Operation of Set.—Radio transmitters are designed and constructed with a view to their ultimate power output. In the case of arc sets, the power output is usually reflected in the construction of the arc chamber and its auxiliary apparatus. The same principle of operation, however, holds true for both the low- and high-power arc transmitters. To explain the construction and operation of a commercial arc transmitter, the Federal 2-kw. set will be used.

The operation of an arc transmitter is dependent on the formation of an arc between two electrodes. In the transmitter represented in Fig. 13, the energy required by the arc is supplied by the d.-c. generator *a*. The current passes from the positive terminal of the generator, through the electromagnet *b*, copper electrode *c*, carbon electrode *d*, to the negative terminal of the generator. The antenna or radiating circuit includes the antenna *e*, series condenser *f*, loading inductor *g*, variometer *h*, front contact and armature of the key relay *i*, ammeter, resistance *j*, electrodes *c* and *d*, and ground. When the transmitting key *k* is closed, the relay *i* draws up its armature and completes the antenna circuit. As soon as the antenna circuit is completed, undamped oscillations are set up in the antenna circuit and continue as long as the transmitting key *k* is closed.

When the key *k* is opened the generation of oscillations is not stopped, but rather shifted to the back-shunt, or dummy-antenna, circuit. This circuit resembles the antenna circuit in that it possesses capacity represented by the condenser *l*, inductance represented by the coil *m*, and resistance represented by the resistor *n*. By operat-

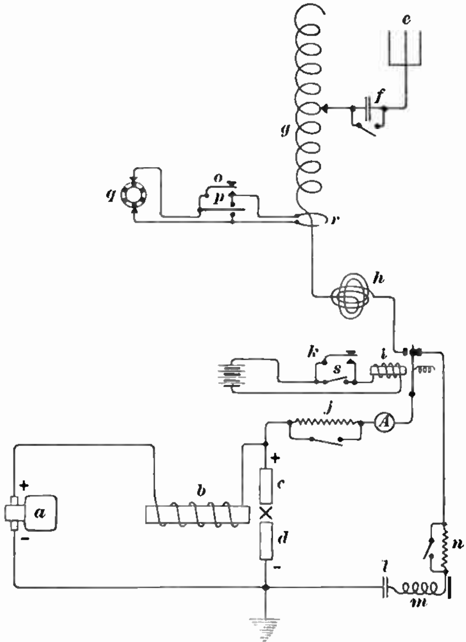


FIG. 13

ing the key *k* the generation of oscillations is shifted alternately from the antenna to the dummy-antenna circuit as required for transmitting a message. The arc is, therefore, always active when the set is in operation.

The method of signaling with the key *k*, just described, is known as the back-shunt method. The energy in the antenna circuit may also be modified by means of the auxiliary key *o*. This key is provided with a single-pole double-throw switch *p*, which, when in contact with its upper stop, short-circuits the key *o*; when in contact with the lower stop, it short-circuits the chopper *q*; when the switch *p* is in its intermediate position, in contact with neither stop, the key *o*, the chopper *q*, and the single turn *r* coupled to coil *g*, are all connected in series.

To transmit signals with the key *o*, the antenna circuit must be closed through the front contact of the relay *i*. This may be done either by closing the short-circuiting switch *s* of the key *k* and holding the armature of relay *i* magnetically against its front stop, or by placing an insulating wedge between the armature and its back stop and thus holding it in contact with the front stop.

In order to transmit continuous waves the switch *p* is brought in contact with the lower stop. This short-circuits the chopper *q*, and places the loop *r* in series with the key *o* only. If under this condition the key *o* is closed the inductance of coil *g* will be changed and the transmitted wave will be on a different wavelength. The antenna inductor *g* must then be so arranged that it transmits on the proper wave-length when the key *o* is closed.

For interrupted continuous-wave (icw.) transmission the switch *p* is in its intermediate position. The inductance of the antenna coil *g* is then modified not only by the operation of key *o*, but also by the chopper *q*. Each dot and dash will be sent out as a series of audio-frequency pulsations.

The chopper *q* may also be used in connection with the key *k*. The switch *p* is brought in contact with its upper stop so as to short-circuit the key *o*. The dots and dashes formed by the key *k* will then be modulated, or broken up, by the action of the chopper *q*.

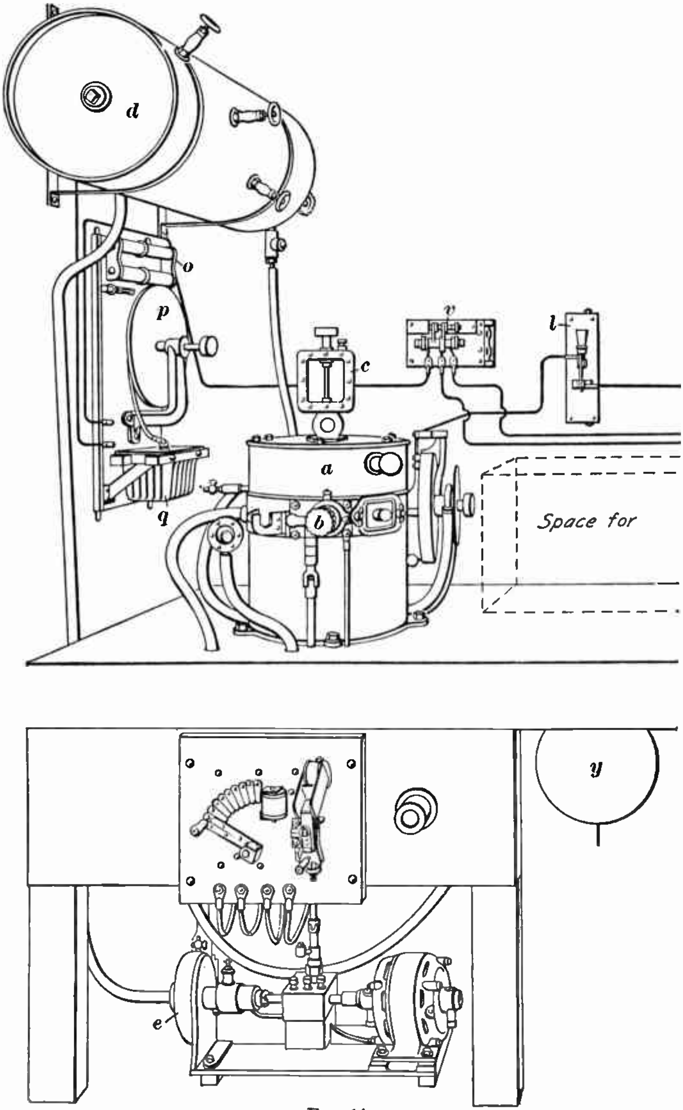


FIG. 14

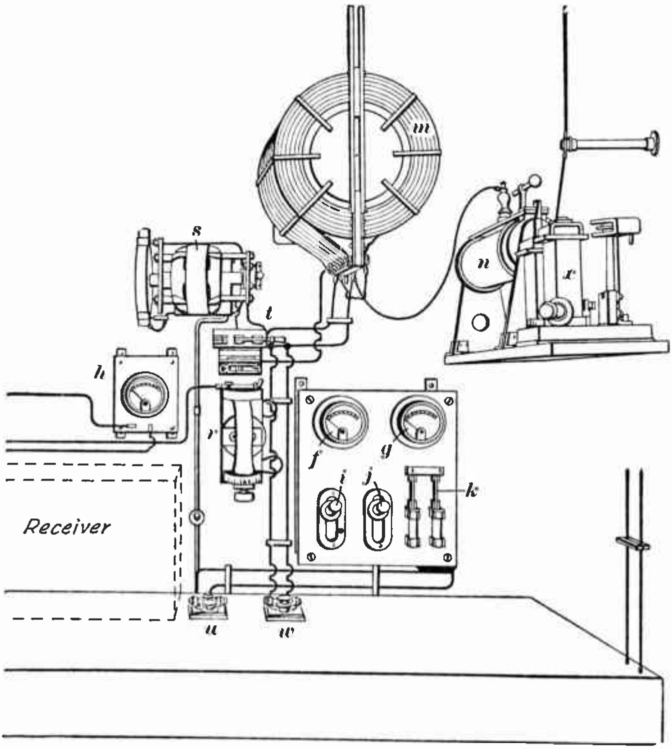


FIG. 14 (*Continued*)

The resistances *j* and *n* are provided with short-circuiting switches, which are closed when greater power is required. The antenna condenser *f* is also provided with a short-circuiting switch, which is closed when transmission takes place on the longer wavelengths. Wavelength adjustments are made on the antenna coil *g*, and the final or vernier adjustment is made with the variometer *h*. The ammeter in the antenna circuit shows the value of current in that circuit. Other measuring instruments are provided, but these are not shown in the illustration.

Assembly of 2-Kw. Arc Set.—The various units of the Federal Telegraph Company's 2-kw. arc transmitter are shown mounted and interconnected in Fig. 14. The arc converter *a* consists of a chamber in which may be found the anode and the cathode. The carbon holder *b* is latched into position and is so arranged as to engage a key in the slot of a member that rotates slowly while the set is used for transmitting purposes, thus insuring an even consumption of the carbon electrode. The electromagnets are located near the top and bottom of the container. Above the container is the alcohol or hydrocarbon feed-cup *c*, which is so arranged that the proper number of drops of liquid is permitted to enter the arc chamber. The introduction of the alcohol assists in dispersing the ions of the arc. The enclosing chamber of the converter is so constructed as to provide ample water cooling surface for efficient operation. The cooling-water tank *d* is connected through suitable piping with the centrifugal pump *e*, the latter forcing the water through the cooling compartment of the arc chamber.

The control panel contains a d.-c. ammeter *f*, and a d.-c. voltmeter *g* for determining the current and voltage respectively, in the d.-c. generating circuit; a radio-, frequency ammeter *h* for determining the value of the current in the oscillating circuit; the arc main-line switch *i*; starting-resistance switch *j*; and the set supply switch *k*. On the left of the control panel is shown a resistor *l*, which is sometimes connected in the antenna circuit when low-power tranmission is desired. The resistor can be short-circuted by the switch. The motor-generator controls are shown in the lower left-hand corner of the figure. The antenna circuit includes the inductance coil *m* and the series condenser *n*; the dummy-antenna, or back-shunt, circuit shown at the extreme left of the figure, is made up of the fixed resistor *o*, the variable resistance *p*, and the condenser *q*. The antenna circuit also includes the variometer *r*, which is used by the operator to make slight changes in the wavelength. The chopper *s* may be switched into the antenna circuit by means of the switch *t* when icw. transmission is desired. The operation of the Morse key *u* operates the back-shunt relay key *v*, which, when the key is closed, completes an oscillating circuit through the antenna. When the key *u* is open, the relay key completes the oscillating circuit through the back-shunt devices. The auxiliary hand key is shown at *w*.

The switch *x* may be placed in any one of three positions. In one position it connects the transmitting equipment with the antenna; in its second position it connects the receiving equipment, not shown, with the antenna; and in its third position it grounds the antenna. The arc pressure regulator *y* controls the density of the gas in the arc chamber. The dotted rectangle represents the space reserved for the receiver.

FREQUENCY MULTIPLIERS

TYPES OF FREQUENCY MULTIPLIERS

Frequency changers, or multipliers, may be static (constructed like an ordinary power transformer) or they may employ a moving element (constructed quite similar to an ordinary motor, with a rotor and a stator).

Many different forms of the static type of frequency changer have been tried out and they are all fundamentally the same, differing mainly in the manner of their connections and the number of frequency transformations attained. They all depend, for their operation, on the asymmetrical variation of flux with magnetizing force, in saturated iron cores. This action will be considered a little more in detail.

STATIC FREQUENCY MULTIPLIERS

In Fig. 15 is shown the schematic circuit arrangement of a static frequency multiplier and in Fig. 16 a graphic analysis of the actions that take place. There are two identical transformers *a* and *b*, Fig. 15, The primary windings a_1 and b_1 are connected in series and the input voltage is applied across this series circuit.

The two secondary windings a_2 and b_2 are connected in series, but, instead of connecting them the same as the primaries are connected, the connections to the secondaries are reversed. The output of the two secondary windings is applied to a tuned circuit consisting of a condenser *c* and an inductance coil *d*, which effect tuning to that frequency which is double the frequency of the voltage applied to the primary windings.

There is a tertiary winding a_3 on the transformer *a*, and there is a tertiary winding b_3 on the second transformer *b*. These two windings are connected in series with a direct-current source of supply *e* and a choke coil *f*, the function of the latter being to prevent the passage of alternating current in the tertiary circuit.

Sufficient direct current is passed through the two tertiary windings to bring the two transformer fluxes to just the point where saturation occurs, right at the knee of the hysteresis curve. The connections to the two tertiary windings have been such that the flux produced in the core of transformer *a* by current through the tertiary circuit, is in a clockwise direction, whereas the flux produced in the core of transformer *b*, due to the same current, passes around the core in a counter-clockwise direction.

Now considering both Figs. 15 and 16 there is a supply of voltage *E* of a given frequency. If the primary circuit is considered to be all inductance, then the current and flux will lag 90° behind the applied voltage E.

The particular instant shown in Fig. 15, is now considered. The current through the primary windings a_1 and b_1 is in the direction indicated by the arrow, causing a flux to be set up in the cores of each of the two transformers which passes in a clockwise direction. This is called the

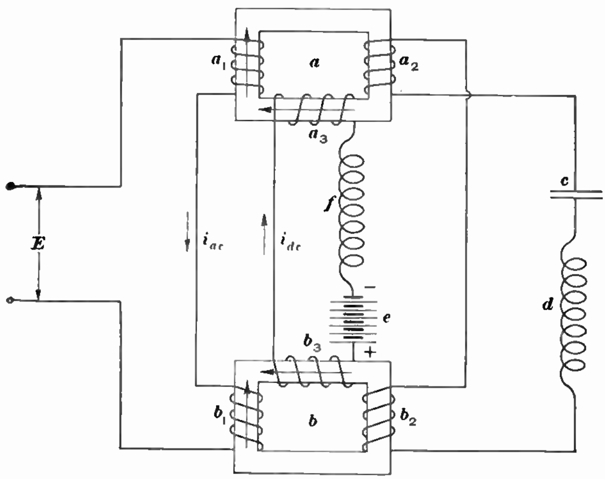


FIG. 15

positive half of the current cycle. During this alternation, or one-half cycle, the flux of transformer a will change very little because the magnetomotive force of the primary winding assists the magnetomotive force of the direct-current winding, whereas the flux of transformer b will undergo a large change because the magnetomotive force of the primary winding is in opposition to the magnetomotive force of the direct-current. The reason why the flux of transformer a changes very little even though the magnetomotive force of the primary windings assists the magnetomotive force of the direct-current winding, is that the current through the direct-current winding has produced sufficient flux to bring the transformer flux to the point of saturation and any further increase in the magnetomotive force, no matter how great, can only produce a small change in resultant flux. However, in the case of transformer b, at the instant taken into consideration, the magnetomotive force of the primary winding is in opposition to that of the direct-current winding and there is a large change in resultant flux because, in this case, the total flux is decreasing, away from the point of saturation.

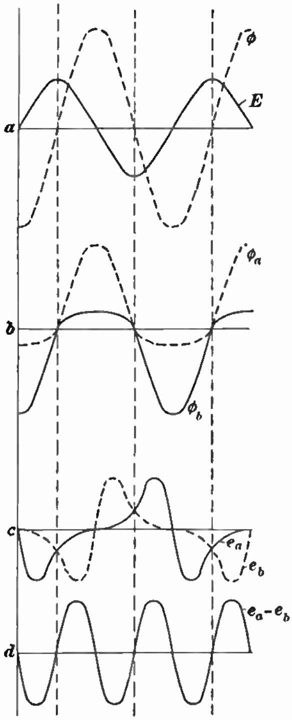


FIG. 16

During the next alternation, or half cycle, conditions are reversed and the flux of transformer a undergoes a large change while the flux of transformer b changes but little, for the reasons mentioned in the preceding paragraph. Curves a, Fig. 16, show graphically the applied voltage E and the flux ϕ due to the current forced through the primary windings of the two transformers. Curves b show the resultant fluxes in the cores of transformers a and b, Fig. 15. The flux curve ϕ_a is that of transformer a; the flux curve ϕ_b is that of transformer b.

Since these two fluxes exist in separate cores, they do not combine to form a double-frequency flux, and with the secondary windings connected in the normal series arrangement, not as shown in Fig. 15, the two voltage waves e_a and e_b as shown at *c*, Fig. 16, exist in the output circuit.

If the connections to one of the secondary windings are now reversed so that they are as shown in Fig. 15, the voltage curve will be as shown at *d*, Fig. 16, having twice the frequency of the input voltage, which frequency is obtained graphically by subtracting c_b from c_a

VACUUM-TUBE TELEGRAPH TRANSMITTERS

VACUUM TUBE AS GENERATOR OF RADIO-FREQUENCY ENERGY

The operation of the vacuum tube as a generator of radio-frequency oscillations can be explained with the use of Figs. 17 and 18. In Fig. 17 is shown a source of radio-frequency energy *a*, which is applied to the grid of the vacuum tube *b* through the medium of the inductive coupling between the two coils *c* and *d*. By virtue of the inherent characteristic of the vacuum tube to produce amplified variation, in its plate circuit, of the variations in current and voltage applied to its grid, the radio-frequency oscillations originating at *a* are manifested in amplified form in the output circuit of the tube *b*.

It may be necessary to apply 1 watt to the grid of the tube *a* (grid excitation) to get 10 watts output. If 1 watt is put into an electrical device and 10 watts taken out, the additional energy must be coming from some other source, and in this case it is supplied by the *B* battery.

Since all that is necessary for the excitation of the grid of the tube in this case is 1 watt, and since 10 watts are available in the output circuit, there is no reason why the source at *a* could not be removed and 1 watt fed back from the energy available in the plate circuit for exciting the grid of the tube a sufficient amount to maintain oscillations. This is done in Fig. 18.

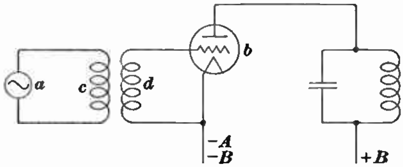


FIG. 17

When the power is applied to a circuit of this type, there are surges of current established which take the form of feeble oscillations, having a frequency determined by the capacity *a* and the inductance *b* in the plate circuit, which in this case is tuned. Some of this energy is fed back into the grid circuit by means of the coils *c* and *d* and is manifested again in the plate circuit in a magnified form, owing

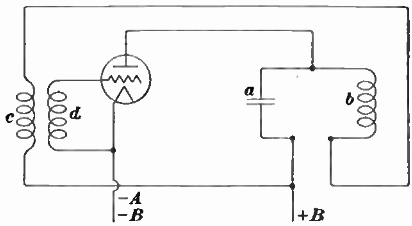


FIG. 18

to the amplification characteristics of the tube. If the coupling between the plate and grid circuits is sufficient, the oscillations will be maintained.

DIFFERENT TYPES OF VACUUM-TUBE TRANSMITTING CIRCUITS

Meissner Circuit.—The different types of fundamental vacuum-tube oscillating circuits are shown in Figs. 19 to 25, inclusive. In Fig. 19 is shown the schematic wiring diagram of the *Meissner circuit* where the grid excitation is obtained by means of inductive coupling between the grid coil L_g and the plate coil L_p.

The amount of grid excitation obtained is a function of the number of turns in the grid coil L_g relative to the number of turns in the plate coil L_p, and the numerical value of this ratio of $L_g \div L_p$ becomes smaller the larger the size of the tube used, whether it be 5 watt, 50 watt, 250 watt, or larger. For instance, when a 5-watt tube was used in a circuit of this type tuned to a wavelength of

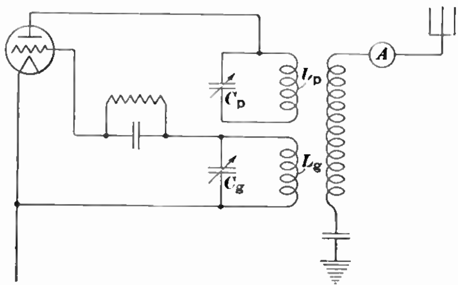


FIG. 19

300 meters, the number of turns necessary in the plate coil L_p was 30 and the number in the grid coil, for efficient operation, was 20. The ratio of grid turns to plate turns, then, was $\frac{20}{30}$, or 2 to 3. When a 50-watt tube was used in the same circuit, the ratio was $\frac{15}{30}$, or 1 to 2. When a 250-watt tube was used, the ratio became $\frac{10}{30}$, or 1 to 3. Thus, the larger the size of the tube, the fewer the number of turns necessary for proper grid excitation.

Both the plate coil and the grid coil are inductively coupled to the antenna circuit. The tuning condensers C_p and C_g may be shunted across the plate and grid coils, respectively, for tuning, but they are not necessary in all cases. The current indicating device is shown in the antenna circuit.

Tickler-Coil Circuit With Inductive Grid Coupling.—In Fig. 20 is shown a schematic diagram of a tickler-coil circuit with inductive grid coupling. In this circuit the plate of the oscillator tube is directly coupled to the antenna, and grid excitation is obtained by means of the grid coil L_g, which is inductively coupled to the antenna

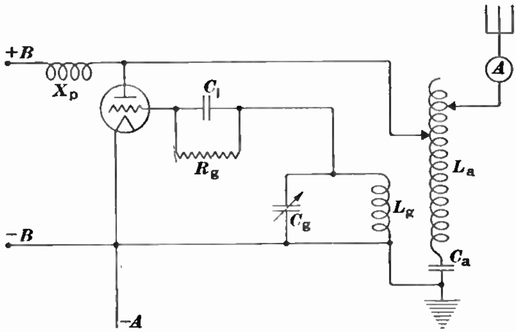


FIG. 20

coil L_a. The condenser C_g may be shunted across the grid coil for tuning or it may be left out of the circuit. The series condenser C_a is for tuning down to wavelengths shorter than the natural period of the antenna system. The direct current in the grid circuit through the resistance R_g produces the proper operating bias voltage on the grid of the tube. The condenser C_1 by-passes radio-frequency currents around the bias resistance. The coil X_p is a radio-frequency choke, which prevents radio-frequency from getting back into the plate supply circuit.

Tickler-Coil Circuit With Inductive Plate Coupling.—A schematic wiring diagram of a tickler-coil circuit with inductive plate coupling is shown in Fig. 21. This type of circuit is used to a great extent in commercial 1-kw. ship transmitters. In this circuit the oscillating energy in the plate circuit of the tube is transferred to the antenna system through the medium of the inductive coupling between the plate coil L_p and the antenna coil L_a. The plate coil may be tuned with the condenser C_p or this condenser may be omitted.

The excitation for the grid of the tube is obtained by tapping the grid directly on to the antenna coil through a capacity C_1. The amount of grid excitation obtainable is a function of the value of the condenser C_1 and the number of turns included in that part of the antenna coil below the point where the grid is tapped off. The condenser C_1 also blocks the direct current in the grid circuit from getting into the antenna coil, so it takes the path through the grid choke X_g and the biasing resistance R_g. The choke coil keeps radio-frequency current out of the bias circuit, thus preventing unnecessary losses, and the bias resistance

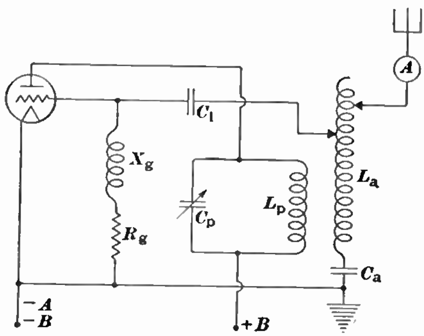


FIG. 21

functions to produce the proper operating bias on the grid of the tube.

Hartley Circuit.—A schematic wiring diagram of a Hartley oscillating circuit is shown in Fig. 22. In this circuit the plate is tapped on one end of a coil L_a and the grid on the other end, and the grounded filament is brought to the proper point between the plate and grid taps. The antenna may be directly coupled to this type of circuit, as shown in the figure.

That part of the coil L_a that is between the points *a* and *b* may be considered the plate coil and that part of the coil that is between the points *b* and *c* may be considered the grid coil. The amount of grid excitation is determined by the ratio of grid to plate turns. In the case of the coil L_a having 40 turns of 4-inch diameter, a 5-watt tube being used, the ground may be brought to such a point *b* on the coil that there would be 17 grid turns and 23 plate

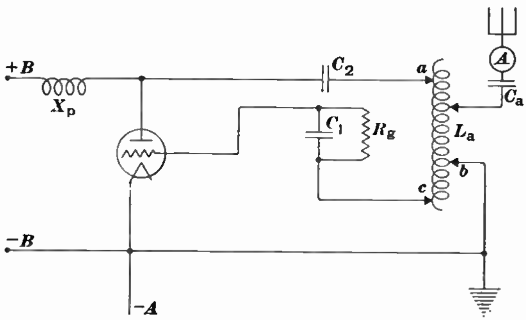


FIG. 22

turns; whereas, in the case of a 1-kw. tube in the same circuit, only 6 grid turns would be needed to 34 plate turns. This will give an idea of the relative number of turns necessary for grid excitation with different powered tubes. The resistance R_g is the biasing resistance in this circuit, the condenser C_1, the grid by-pass condenser, and the coil X_p the radio-frequency choke in the plate circuit.

Colpitts Circuit.—A schematic wiring diagram of a Colpitts oscillating circuit is shown in Fig. 23 (*a*). This circuit is somewhat similar to the Hartley circuit inasmuch as the plate is connected to one end of a coil, the grid to the other end, but the grounded filament is brought to the mid-point between two condensers that are connected in series across the inductance L in the oscillatory circuit. The grid excitation in this circuit depends on the relative values of C_g and C_p, since it is the voltage drop across C_g that is applied to the grid of the tube through condenser C_1.

The oscillatory circuit is shown in view (*a*). In view (*b*) is shown one way of applying this circuit to an antenna

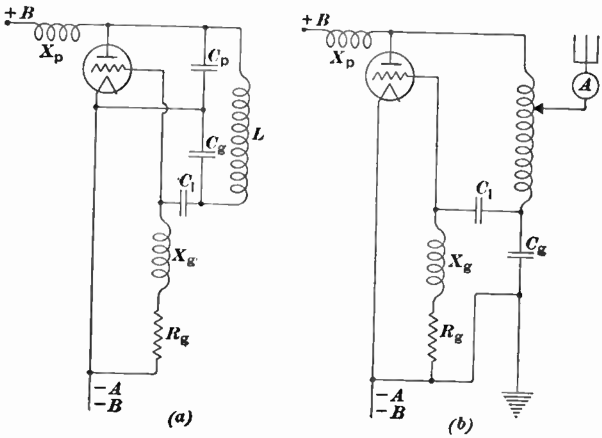


FIG. 23

system. The capacity that appeared in the oscillatory circuit in view (*a*) as C_p is replaced by the capacity of the antenna, view (*b*).

Reverse Feed-Back Circuit.—The connections of the Armstrong tuned-plate, or reverse feed-back, circuit are shown in Fig. 24. In this circuit, as the name implies, the plate circuit is tuned, but there is no inductive coupling between the plate and the grid coils, excitation being supplied to the grid by means of capacity coupling between these two electrodes. In some cases there is sufficient capacity within the tube itself to furnish adequate coupling, hence the proper amount of grid excitation. Where

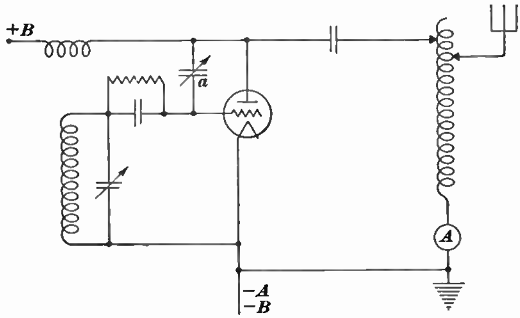


FIG. 24

this internal capacity is not sufficient, an external capacity is connected between the plate and the grid terminals as shown at *a*.

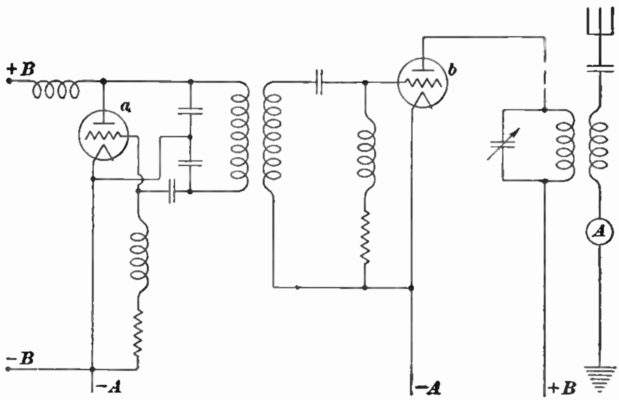


FIG. 25

Master-Oscillator Circuit.—The master-oscillator type of circuit is shown schematically in Fig. 25. In this type of circuit, one tube *a* is used for generating the desired radio-frequency output and the energy thus obtained is used to excite the grid of another tube *b*, which is termed the amplifier tube. The amplifier tube *b* in turn can feed into the antenna system, or, if there are several power tubes in the transmitting assembly, they can all be used in successive stages of amplification. The master oscillator determines the frequency of the emitted wave, and owing to the fact that the master oscillator is not directly coupled to the antenna system, this arrangement is free from frequency changes, in the course of transmission, caused by a swinging antenna, etc.

COMBINATION SPARK AND TUBE TRANSMITTERS

As cw. transmitters began coming into more general use is was apparent that for economic reasons a combination of the existing spark equipment with the addition of the vacuum-tube circuits necessary for transmission by this latter method would mean the saving of a considerable sum. Both the commercial and military radio authorities immediately began the adoption of the tube as an auxiliary to the standard spark equipment.

The schematic diagram of a spark-tube transmitter, Fig. 26, shows the application of two vacuum tubes and their auxiliary circuits to a spark set. This is one method of effecting a means for transmission on both spark and modulated cw., at a minimum of installation costs. Two-250-watt power tubes are used in a self-rectifying circuit and because of this fact, the wave emitted has a 1,000-cycle ripple in it (since there is a 500-cycle a.-c. supply), which means 1,000-cycle modulation. In all spark-tube transmitters the plan has been to use a.-c. on the plates of the transmitting tubes, keeping smoothing at a minimum possible value and thus effecting a well modulated transmitted wave.

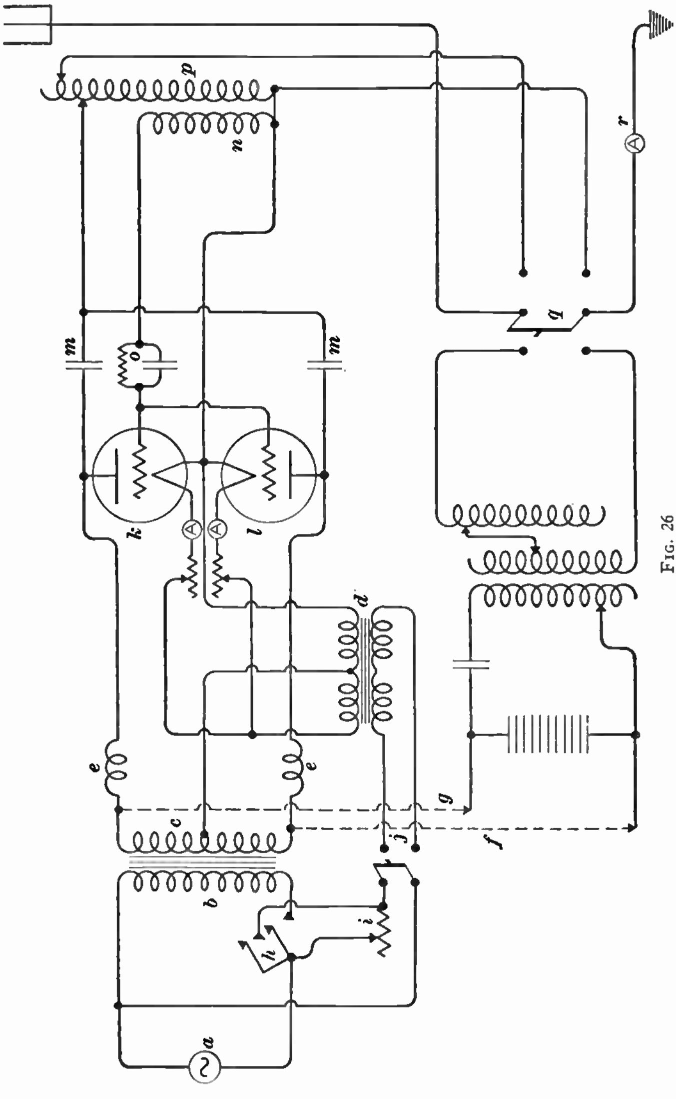


FIG. 26

It is to be remembered that there is big step between the tuning in of spark signals and the tuning in of cw. signals at the receiving station. The former tune the broadest and the latter tune the sharpest. Thus, in order to educate operators away from spark transmission and reception, it was necessary to do it gradually. After working with spark, where the tuning is broad, most operators have considerable difficulty in trying to tune for cw. transmitters, and that is one reason why the self-rectifying type of tube transmitters were the first to be used in conjunction with spark transmitting equipment.

A 500-cycle, a.-c. generator *a*, Fig. 26, which is a part of a motor-generator set, is connected to the primary winding of the step-up transformer *b*. A mid-tap is brought out from the secondary winding *c* of the step-up transformer and this lead is connected to the mid-tap on the secondary winding of the filament transformer *d*. Choke coils are placed at *e* to prevent radio-frequency currents from getting back into the secondary winding of the power transformer. Flexible leads *f* and *g* are brought to the oscillatory circuit of the spark transmitter, when it is desired to transmit by this latter method.

Power for heating the filaments of the transmitting tubes is brought from the 140-volt, 500-cycle generator *a*, to the primary winding of the filament transformer *d*. A special double-contact transmitting key *h* cuts out the resistance *i* in the primary circuit of the filament transformer at the same time the circuit isclosed through the primary winding of the high-voltage transformer.

When it is desired to transmit with the tube set, the motor-generator set is started and the switch *j* is closed, which effects the heating of the filaments of the power tubes through the medium of the filament transformer *d*. The resistance *i* in the primary circuit of the filament transformer is so adjusted that the filaments of the tubes burn at normal temperature when the transmitting key *h* is open. Thus, there is then only the light load due to the filaments of the two transmitting tubes applied to the supply generator. With this light load the terminal voltage of the a.-c. generator is high, but following the application of full load, through the closing of the transmitting key *h*, the terminal voltage of the supply generator drops, and the resistance in the primary circuit of the filament transformer has to be correspondingly decreased to compensate for the drop in the value of the supply voltage. Thus, one set of contacts of the transmitting key *h* shorts out part of the resistance *i* and the temperature of the tubes remains unchanged with the key either open or closed.

The high voltage from the secondary terminals *c* of the step-up transformer is supplied to the plates of the transmitting tubes *k* and *l* through the two 30-henry chokes *e*. The plates are connected to the oscillatory circuit through the blocking condensers *m*, which block the low-frequency, a.-c. supply from getting into the oscillatory circut and pass the radio-frequency currents. If it were not for the blocking condensers *m* there would be a short circuit across the entire secondary winding *c* of the high-voltage transformer.

These blocking condensers have a value of .002 microfarad and it is worth while to consider, mathematically, just how efficiently they block the 500-cycle current and allow the radio-frequency current to pass. Let it be assumed that the oscillatory circuits are adjusted for transmission at 600 meters. This would mean a frequency of 500,000 cycles per second. (Since the frequency $=300{,}000{,}000 \div$ wavelength, it is also true that wavelength $=300{,}000{,}000 \div$ frequency.)

The reactance of a .002 microfarad condenser to current having a frequency of 500 cycles per second, is equal to

$$\frac{1}{2\pi fC}\text{ohms}$$

in which f = frequency, in cycles per second;
π = 3,1416
C = capacity, in farads.

Thus it follows that the reactance is equal to $1\div(6.28\times500\times2\times10^{-9})$. The result is 160,000 ohms, approximately. Since the frequency of the currents in the oscillatory circuits is 1,000 times greater than the frequency of the current from the supply generator, it follows that the reactance to these high-frequency currents will be equal to $1\div1{,}000$ of the reactance to the 500-cycle current, or 160-ohms, which value is derived by substituting 500,000 for the frequency in the above equation in place of 500.

Therefore, although the blocking condensers do not totally prevent 500-cycle current, they do limit it to a very few milliamperes and they do prevent a short circuit on the step-up transformer secondary *c*. The reactance of the condensers *m* to the radio-frequency currents, 160 ohms at 600 meters, is sufficiently low to pass these currents efficiently.

Both grids are tied together and connected to the grid coil *n*, through the parallel combination of grid leak and grid condenser *o*. This leak is of the order of 10,000 ohms and the condenser has a value of .002 microfarad. The condenser by-passes radio-frequency currents around the grid leak and blocks off direct grid current so that it has to pass through the leak, thus producing the proper negative bias on the grids of the tubes.

The grid inductance *n* and the open-circuit inductance *p* are designed to work on all of the standard spark wavelengths as well as the standard wavelengths for cw. transmission. There is a double-pole, double-throw switch *q* that connects either the spark or the tube set to the antenna and there is a common indicating device at *r* for showing the value of the radio-frequency current in the antenna circuit.

The oscillatory circuit is of the Meissner type, the plate coil being shown at *p* and the grid coil at *n*, the latter coil being inductively coupled to the former to produce the proper amount of grid excitation. Of course, it is possible to shunt condensers across the grid coil *n*, if desirable, for increasing the grid excitation available with a given coupling to the plate coil *p*. The antenna is directly coupled to the coil *p* and by virtue of this fact, the frequency of the current in the circuit of which coil *p* is a part is a function of the antenna capacity as well as the inductance of the coil *p*.

It might be well to point out, in connection with the spark circuit shown in Fig. 26, that, although the tube set is directly coupled to the antenna system when the switch *q* is set for tube transmission, the spark set is inductively coupled to the antenna when the switch is thrown for spark transmission.

It is usual, in converting the 2-kw. spark transmitter for spark and tube transmission, to employ two 250-watt tubes. This permits a power of 500 watts in the antenna. The UV-204-A tubes have a filament rating of 3.75 amperes at 11 volts and a plate-voltage rating of 2,000 volts. Since the terminal voltage of the secondary winding *c* of the high-voltage transformer is of the order of 12,000 volts, or 6,000 volts to each tube, it is necessary to cut this down for applying to the plates of the transmitting tubes *k* and *l*. The antenna current varies from 6 to 12 amperes on ships with antennas having a natural period of 300 meters and a capacity of .001 microfarad.

COMMERCIAL 1-KW. SHIP TUBE TRANSMITTER

The 1-kw. tube transmitter is found on a great many of the larger ships. The schematic diagram, Fig. 27, shows that it is of the tickler-coil type with inductive plate coupling.

Four 250-watt tubes *a* are used as oscillators and they are connected in parallel. The plates of these tubes are all connected to the 2,000-volt d.-c. supply *B* through the plate coupling coil *b*. The grid of each tube is connected to a common grid lead through an individual choke coil *c*. The function of these small choke coils is to prevent parasitic oscillations in the local circuits between the elements of the tubes. Parasitic oscillations are those of extremely high frequency, and are due to the inductance, capacity, and coupling between the elements of the tubes.

The grid choke coil *d* prevents radio-frequency current from passing through the resistance *e*, which, owing to the direct current passing through it, provides the necessary negative bias on the grids of the tubes for efficient operation. The grid condenser *f* is a coupling condenser by means of which the proper grid excitation is supplied to the grides of the tubes to keep them oscillating. The amount of grid excitation is a function of the point where the lead from condenser *f* is tapped on the inductance *g*; the value of the capacity of condenser *f* is also to be considered, since the lower this value is made, the greater the amount of capacity reactance that it offers to he radio-frequency current; hence, the greater the voltage drop across it for a given amount of current.

The constants of the antenna circuit determine the wavelength of the transmitted signals, which is a somewhat undesirable feature because swinging of the antenna, with subsequent variations in antenna capacity, will be

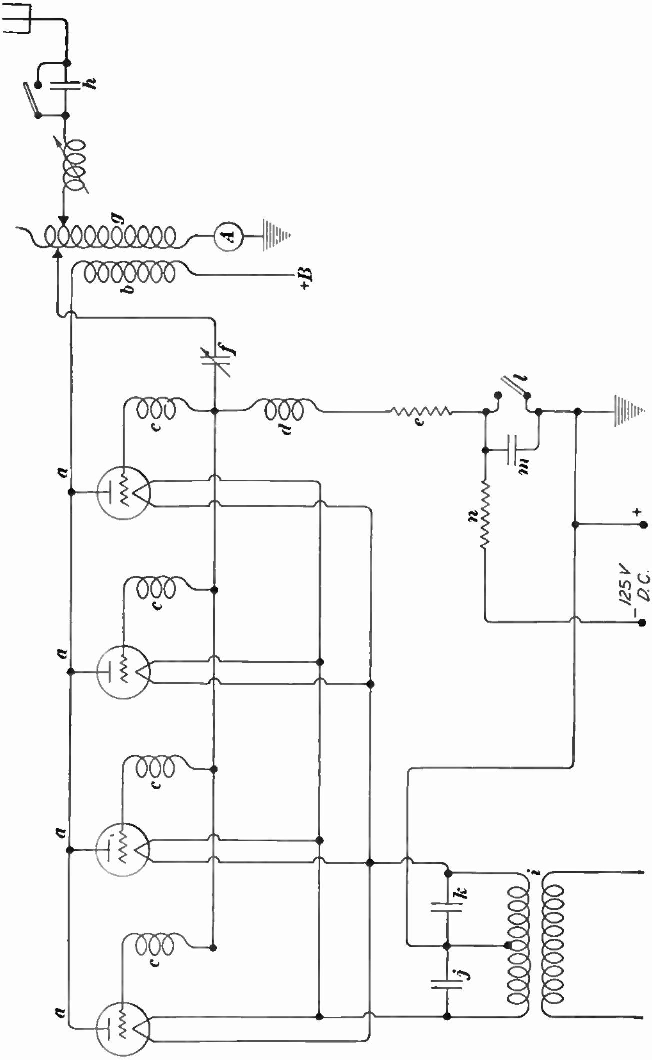


FIG. 27

manifested by variations in the wavelength of the transmitted signals. This is overcome in transmitters of more recent design and will be taken up at a later point in this text. The condenser *h* in the antenna circuit is used where it is desired to transmit signals on a wavelength lower than the fundamental of the antenna system.

The filaments of the four oscillator tubes are supplied with filament heating current from the secondary winding of a step-down transformer *i*, which is capable of supplying 3.75 amperes to each tube and maintaining 11 volts across the filament terminals of each tube. The condensers *j* and *k* are connected in series across the filament transformer secondary and their function is to bypass radio-frequency currents.

Keying is accomplished by a telegraph key, or relay, *l* connected directly in series with the grid-bias circuit. The contacts of this key are shunted by a condenser *m*. When the key is open, the grids of the tubes become highly negative because the blocking condenser *m* is then connected in series with the grids of the transmitting tubes and ground. There is a negative 125-volt potential applied to the grids of the tubes, through the keying resistor *n*, this negative potential functioning as a holding bias. The blocking condenser *m* effects the initial blocking of the transmitting tubes, and the 125-volt negative bias holds them blocked. The keying resistor *n* functions, when the key is down, to prevent short-circuiting of the 125-volt d.-c. bias supply. When the key is closed, the proper operating bias is applied, and the tubes oscillate, which results in a cw. signal being emitted from the antenna.

COMMERCIAL 200-WATT CW. AND ICW. VACUUM-TUBE TRANSMITTER

A schematic wiring diagram of a 200-watt tube transmitter in use on ships is shown in Fig. 28. Three UV-211 tubes are used in this unit. One tube *a* is used as a master oscillator and the other two tubes *b* are used as power-amplifier tubes.

The oscillating circuit in the master oscillator is of the Colpitts type. The radio-frequency energy that is generated in the master-oscillator circuit is used to excite the grids of the two power-amplifier tubes *b*. The voltage drop across the .002-microfarad condenser *c*, the latter being in the master oscillator tank circuit, is applied to the grids of the two amplifiers, through the power-amplifier grid condenser *d* and the feed resistance *e*. The parasitic resistances *f* are inserted in series with each of the two power-amplifier grids to prevent high-frequency oscillations locally. There is a parasitic resistance *g* in series with the master oscillator grid to prevent high-frequency local oscillations. The proper operating bias for the grid of the master-oscillator tube is obtained by means of the master-oscillator grid biasing resistance *h*. The positive side of the grid-bias resistance *h* is connected to the negative plate supply through the contacts of the chopper *i*. The chopper functions to produce icw. There is a sparking resistance *j* and condenser *k* across the chopper contacts.

The power-amplifier grid choke coil *l* keeps radio-frequency current out of the grid-bias circuit and passes the direct grid current through the power amplifier biasing resistance *m*, thus effecting the proper negative potential on the grids of the two power-amplifier tubes. The positive side of this biasing resistance is also connected to the negative plate supply through the chopper contacts;

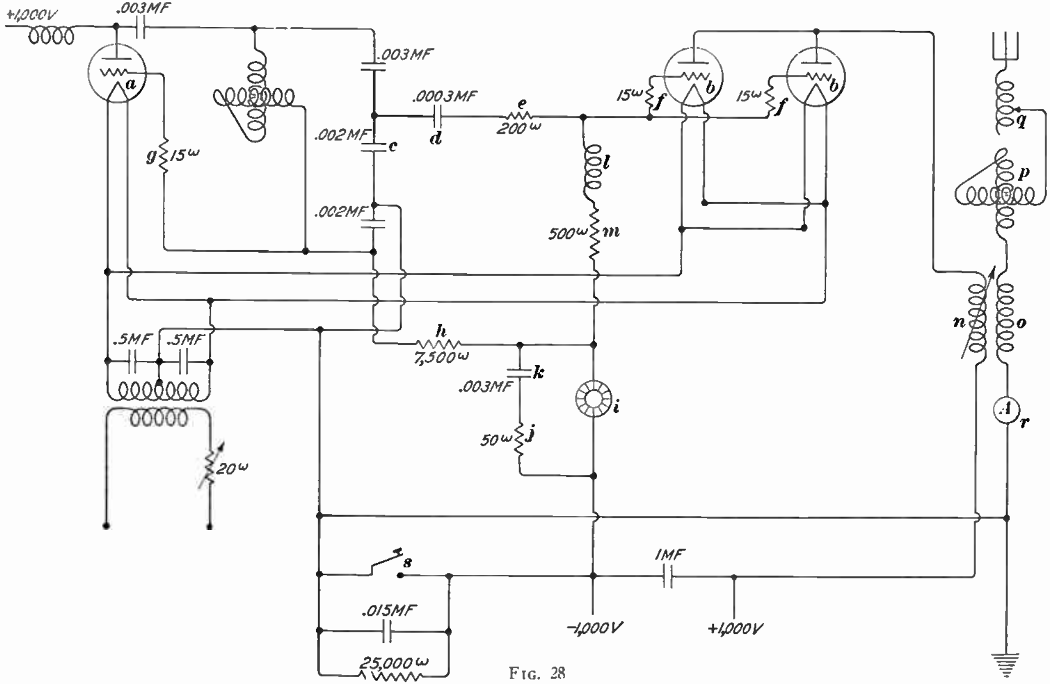

+1,000V
.003MF
.003MF
.0003MF
.002MF
.002MF
a
b
b
c
d
e
200ω
15ω
15ω
f
f
g
15ω
l
500ω
m
h
7,500ω
k
.003MF
i
50ω
j
.5MF
.5MF
20ω
q
p
n
o
r
s
1MF
.015MF
25,000ω
-1,000V
+1,000V

FIG. 28

hence, the chopper contacts are connected in series with the grid circuits of all the tubes.

The two power-amplifier plates are connected in parallel and then to the high-voltage plate supply through the antenna coupling coil *n*. This coupling is variable and it is by this means that the radio-frequency energy generated by the master oscillator and amplified by the power-amplifier tubes is induced into the antenna circuit for radiating. A tuning variometer *p*, a loading inductance *q*, and a radio-frequency ammeter *r* are also included in the antenna circuit.

Keying is accomplished by opening and closing the plate circuit, since the telegraph key *s* is connected in series with the plate lead. There is a sparking condenser and resistance across the key contacts. At first glance it may not be apparent that the key is connected in series with the plate circuit as some may consider the plate circuit as that portion of the circuit between the positive *B* supply and the plate terminals of the tubes. The complete plate circuit, in this case, is traced from the +1,000-volt terminal to the plates of the three tubes, through the tubes to the center tap of the secondary of the filament-supply transformer, to the key *s*, and then to the −1,000-volt lead.

When keying is effected with the contacts of the chopper *i* short-circuited, cw. signals are radiated, but when the chopper motor is started up, icw. signals are transmitted. The chopper simply breaks up the emitted signals into undamped wave trains, the frequency of which is a function of the number of contacts on the chopper disk and the speed at which the disk rotates past the stationary contact. The chopper has a stationary contact and a rotating disk containing a number of contacts with insulating material between them so that, as the chopper disk rotates, the stationary contact is first on metal and then on insulation; thus, the circuit through the chopper contacts is closed one instant and open the next.

With this transmitter, when transmitting on cw., between 600 and 900 meters, and using an antenna having a resistance of 4 ohms and a natural period of 300 meters, there should be 7 amperes of radio-frequency current in the antenna with 600 milliamperes of plate current, keeping the filament voltage at 10 and the plate voltage down to 1,000.

Accompanying is a list of values that were taken with this 200-watt transmitter working under normal conditions. All these values were taken with the transmitter working into an antenna having a resistance of 4 ohms, and a natural period of 300 meters.

WORKING VALUES

	λ	I_a	W_a	I_p
Cw.	600	7.3	213	590
Icw.	600	5.6	125	460
Cw.	960	7.2	206	570
Icw.	960	5.0	100	475

in which λ = wavelength, in meters;
I_a = radio-frequency antenna current, in amperes;
W_a = antenna watts;
I_p = total direct current to plates, in milliamperes.

COMMERCIAL 500-WATT C.W. TUBE TRANSMITTER

A schematic wiring diagram of a commercial 500-watt cw. tube transmitter which is used for cw. transmission on wavelengths from 300 up to 800 and from 1,800 up to 2,400 meters is shown in Fig. 29. There are eight UV-211 (50-watt) tubes in this transmitter. The tube *a* is a master oscillator, the tube *b* is a bias rectifier tube, and the other six *c* are power-amplifier tubes. The master oscillator has the Hartley type of oscillatory circuit where the grid and plate terminals of the oscillator tube *a* are connected to the

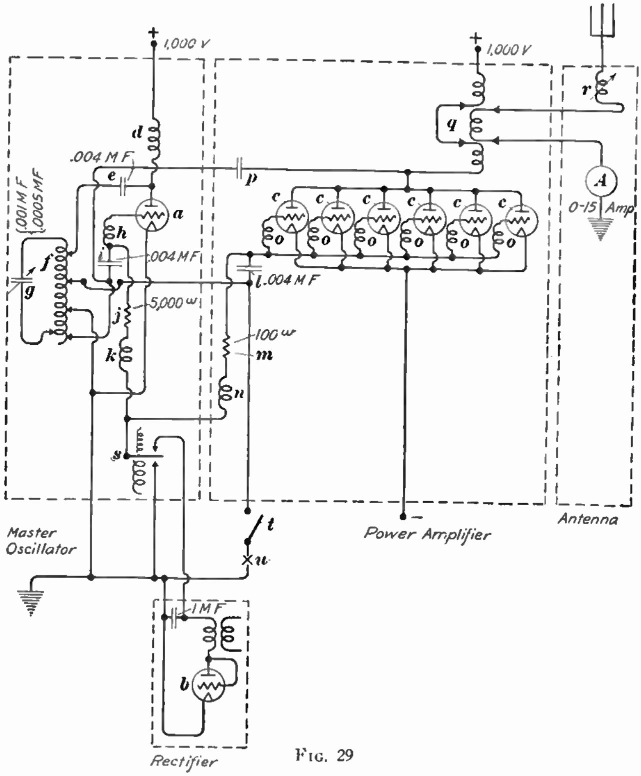


FIG. 29

extremities of a coil; and the ground, or filament lead, is brought to a point between them. The grid excitation is a function of the number of turns between the point on the coil where the grid is tapped on and the point that is grounded.

The high-voltage, d.-c. plate supply is fed to the master-oscillator plate through a radio-frequency choke coil *d*. The .004-microfarad blocking condenser *e* keeps the high voltage direct current out of the oscillatory circuit. The oscillatory circuit for the master oscillator consists of the coil *f* and the condenser *g*. The grid terminal of the master oscillator is connected to the oscillatory-circuit inductance through the parasitic choke *h* and the grid blocking condenser *i*. The direct current passes down through the grid biasing resistance *j*. The choke coil *k* keeps the radio-frequency currents out of the biasing circuit, thus preventing losses of this nature.

The grid excitation for the power-amplifier tubes is obtained by tapping on the coil *f* at the desired potential above ground and bringing this lead to the grids of the amplifier tubes through the blocking condenser *l*. The condenser *l* prevents the direct current from the grids of the power-amplifier tubes, from getting back into the master-oscillator circuit and incidentally makes it go through the power-amplifier grid biasing resistance *m* and the radio-frequency choke coil *n*. The six power-amplifier grids are connected to the common grid lead through six separate parasitic choke coils *o*. These small choke coils prevent oscillations of very high frequency from existing locally between the elements of the tubes.

The blocking, or neutralizing, condenser *p* prevents reaction of the amplifier on the master oscillator due to the internal capacity of the power-amplifier tubes. Plate current from the 1,000-volt supply is fed to the plates of the power-amplifier tubes, which are all connected in parallel, through the primary winding of the radio-frequency transformer *q*. The secondary of this transformer is connected in series with the antenna circuit and it is by this means that the radio-frequency energy generated by the master oscillator and amplified by the six power-amplifier tubes is induced into the antenna circuit. The variable loading coil *r* is used for tuning the antenna system and the ammeter is used to indicate the value of radio-frequency current flowing in the antenna circuit.

Keying is accomplished by means of the keying relay *s*, which is operated by the hand key at the operator's desk. When the operator's key is pressed down, the tongue of the keying relay engages the contact that is connected to ground. Since the leads from the master-oscillator and power-amplifier grid-bias circuits are connected to the tongue of the relay, they are grounded when the operator's key is pressed down. This means that the proper operating bias is applied to the grids of the tubes in question and a cw. signal is sent out from the antenna.

When the operator's key is opened, the tongue of the relay *s* engages the contact that is connected to the negative terminal of the bias rectifier tube *b*, the positive terminal of the bias rectifier tube being connected to ground; thus, in this position of the keying relay, there is a negative potential of 250 volts (the potential of the rectified output from the rectifier) applied to the grids of the master-oscillator and power-amplifier tubes.

For icw. transmission the signal switch *t* is closed. This connects the chopper *u* into the circuit. The chopper motor is started and the amplifier feed is grounded intermittently, the number of times per second that it is ground being a function of the speed of the chopper motor and the number of metallic segments in the chopper disk. When the circuit is closed through the chopper contacts, the grid excitation to the amplifier tubes is grounded and there is no radio-frequency energy radiated from the antenna; thus, in the course of icw. transmission, when the key is closed, wave trains of continuous amplitude are sent out into the ether and the wave-train frequency is usually between 500 and 1,000 cycles per second.

It was previously mentioned that this transmitter was for cw. and icw. transmission on wavelengths between 300 and 800 meters and 1,800 and 2,400 meters. This is accomplished by means of a 7-pole double-throw switch that is mounted in the front panel of the transmitter assembly. This switch is eliminated in the schematic diagram of Fig. 29 to facilitate the explanation of the functioning of the transmitter. When the wave-change switch is thrown upwards, the circuit arrangement and constants are as shown in the figure. In this position, the short-wave tuning inductance coil *f* tunes the master-oscillator circuit to any wavelength between 300 and 800 meters. The short-wave coupling transformer *q* is used and the short-wave antenna tuning coil *r* is capable of tuning the antenna system to any wavelength within the 300- to 800-meter waveband.

When the 7-pole double-throw wave-change switch is thrown down, the short-wave master-oscillator tuning circuit *f* and *g* is disconnected from the circuit and a long-wave system, consisting of a long-wave coil and condenser, is substituted; this combination being capable of covering the waveband between 1,800 and 2,400 meters. Thus, three of the poles of the 7-pole switch must be used to perform this operation; one pole for the master-oscillator grid, one for the master plate, and one for the power-amplifier grid feed. These three leads can be connected to either the short-wave or the long-wave tuning system.

The only other change in going from the short-wave band to the long-wave band is to change the output transformer *q* and the antenna tuning coil *r*. Four poles of the 7-pole switch are used to perform this function.

One pole is connected to the positive 1,000-volt supply and another to the common amplifier plate lead. Thus by means of these two poles it is possible to change from the primary winding of the short-wave output transformer *q* to the primary winding of the long-wave output transformer.

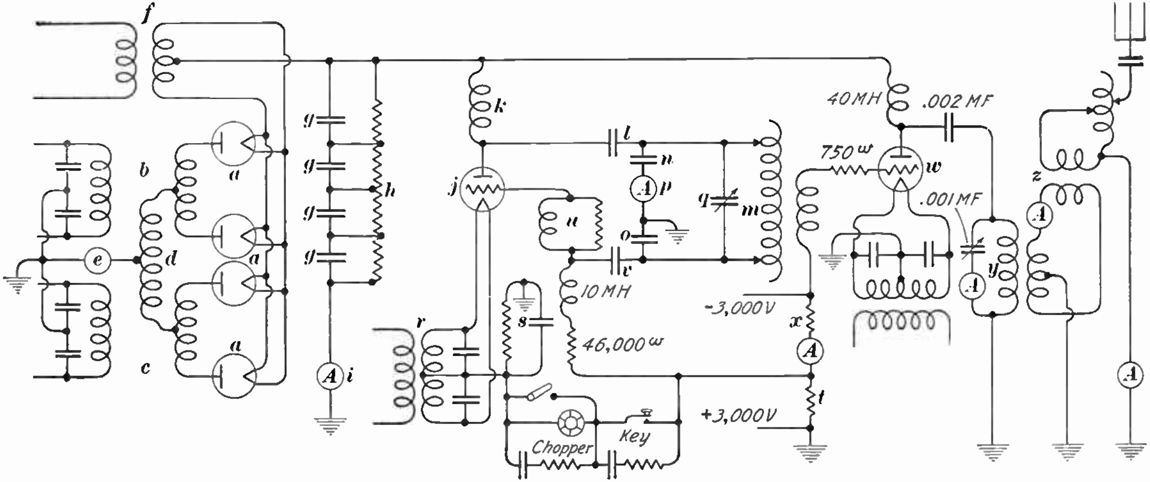
One of the two remaining poles is connected to the high side of the antenna ammeter, which is in the ground lead, and the other pole is connected to the antenna. Hence, by means of these two poles it is possible to change from the series combination of the secondary of the short-wave output transformer *q* and the short-wave antenna tuning coil *r* to the long-wave output-transformer secondary winding and long-wave antenna tuning coil, these two coils being connected in series, and thence to the antenna-ground leads through two poles of the 7-pole switch.

With the above transmitter, it should be possible to get 11 amperes radio-frequency current into an antenna having a capacity of .002 microfarad, 40 microhenries inductance, and 4 ohms resistance. These figures are given to show what the normal antenna current should be in a normal ship's antenna system.

COMMERCIAL 10-KW. TUBE TRANSMITTER

The schematic wiring diagram of Fig. 30 is one of a high-power tube transmitter that is used for commercial telegraph communication with ships at sea on 600 and 700 meters as well as on the band between 1,800 and 2,400 meters.

One 1-kw. master oscillator is used to generate and supply grid excitation to a 10-kw. tube. The 10,000-volt plate supply is obtained from a two-phase rectifier unit, which uses two 2.5 kw. rectifier tubes (UV-218) in each phase, making a total of four rectifier tubes, shown



f
b
c
d
e
a
g
h
A
i
j
k
l
n
p
q
m
o
v
u
r
s
10 MH
46,000ω
Chopper
Key
-3,000V
+3,000V
x
t
40 MH
.002 MF
750ω
w
.001 MF
y
z

Fig. 30

at *a*. Two tubes are arranged for full-wave rectification on one phase and the other two for full-wave rectification on the second phase.

The step-up transformer *b* is in phase No. 1 of the two-phase 60-cycle alternating-current supply, which supplies plate potential to two rectifier tubes. The e.m.f. on the primary side of this transformer is about 110 volts and that on the secondary side is about 25,000 volts, but the secondary winding is tapped at its mid-point, which means that 12,500 volts are applied to each plate.

The step-up transformer *c* is in phase No. 2, which steps the 110-volt supply up to 25,000 volts and supplies 12,500 volts to the plate of the other rectifier tubes. The winding *d*, which is connected between the mid-points of the two high-voltage secondary windings, is an interphase reactor that is inserted in the circuit to increase the overall efficiency of operation. The mid-point of the interphase reactor is connected to ground through a 0- to 1-ampere meter *e*. This meter shows the total plate current to all the tubes.

The step-down transformer *f* reduces the supply voltage from 110 to 11 volts for application to the filament terminals of the rectifier tubes. Each one of the rectifier tubes *a* draws 14.75 amperes filament current.

Four .5 microfarad condensers *g* are connected in series between the positive lead from the rectifier assembly and ground to function as smoothing condensers, thus giving a total value of .125 microfarad for smoothing. A 400,000-ohm resistance *h* is connected in parallel with the four smoothing condensers, so that there is 100,000 ohms across each condenser, thus effecting an equal potential distribution across the four condensers. The lower end of this resistance is connected to ground through a 0- to 50-milliampere milliammeter *i*. Thus the combination of high resistance and milliammeter forms a means of determining the value of the plate-supply voltage to the oscillator and amplifier tubes.

If the milliammeter *i* indicates a current of 30 milliamperes the plate-supply voltage, which is the voltage across the 400,000-ohm resistance *h*, is equal to $I \times R$ or $.03 \times 400{,}000 = 12{,}000$ volts. Also, if the milliammeter reads 25 milliamperes, the plate potential is 10,000 volts.

The high voltage is supplied to the plate of the master oscillator tube *j* through a 40-millihenry radio-frequency choke coil *k*. The plate of this tube is connected to the Colpitts oscillatory circuit through the .001-microfarad blocking condenser *l*. The oscillatory circuit consists of the tuning inductance *m*, the .0004-microfarad plate condenser *n*, and the .003 microfarad grid condenser *o*. The grid excitation is the a.-c. drop across the condenser *o*.

The 0- to 25-ampere ammeter *p* indicates the value of the radio-frequency current in the master-oscillator tank circuit. The mid-point between the plate and grid condensers *n* and *o* is grounded. The .0001-microfarad condenser *q* is used for fine tuning.

The filament transformer *r* is used to step the supply voltage down from 110 volts to 11 volts for heating the filament of the master-oscillator tube *j*. This tube draws 14.75 amperes filament current. Two .5-microfarad bypass condensers are connected in series across the master-oscillator filament terminals and their mid-point is carried to a radio-frequency ground through the .02 microfarad condenser *s*. This is not a direct-current ground, however, and the master-oscillator plate current has to pass through the 46,000-ohm resistance connected across condenser *s* when the transmitting key is open, and through the 2,000-ohm resistance *t* to ground, when the transmitting key is closed.

The master-oscillator grid is connected to the oscillating circuit through the parasitic trap *u* (.03 millihenry and 250 ohms, in parallel) and the blocking .002-microfarad condenser *v*. The biasing circuit is traced from the grid side of the blocking condenser *v* through the 10-millihenry radio-frequency choke coil, the 46,000-ohm biasing resistance, the transmitting key, the chopper contacts, to the mid-point of the filament winding.

Grid excitation for the power-amplifier tube *w* (UV-207) is obtained from the master-oscillator tank circuit by means of the secondary winding of coil *m*. The 750-ohm resistance in series with the amplifier grid is to choke out any local oscillations of very high frequency.

The low side of the amplifier-grid coil is connected to ground through the 40,000-ohm resistance *x* and 2,000-ohm resistance *t*. Potential from a 3,000-volt generator is applied across this resistance to function as bias for the grid of the power-amplifier tube. A 0- to 100-milliampere milliammeter is in series with the amplifier grid to indicate the d.-c. current in its grid circuit This meter is of the zero-center type, so that it is possible to determine whether the grid current is positive (grid to filament) or negative (filament to grid). The latter is called reversed grid current and is highly undesirable, as it causes a drop in potential across the biasing resistance, which tends to make the grid of the tube positive. The action is cumulative, so that it would be quite possible to have the tube destroyed were this condition allowed to exist. It indicates improper adjustment and should be remedied immediately.

The tube *w* draws 52 amperes filament current. High potential is supplied to the plate of the power-amplifier tube through a 40-millihenry choke coil. The plate of this tube is connected to the output circuit through a .002-microfarad blocking condenser. The power-amplifier output circuit is tuned by means of the coil *y* and the .001-microfarad condenser. A 0- to 50-ampere ammeter is included in this circuit.

In this particular transmitter the antenna is located at a point remote from the transmitter itself, so there is a feed-line between the transmitting apparatus and the point where the antenna is located. In this case, the length of the feed-line is about $\frac{1}{8}$ of a mile. The secondary of coil *y* feeds energy into the feed-line and the transformer *z* transfers the energy from the feed-line to the antenna circuit. Tuning adjustments are made to make the current in the antenna circuit maximum and that in the feed-line minimum. Currents in both cases are indicated by the ammeters in the circuits.

Keying is effected in rather a unique manner in this circuit and it is worth while to consider this point somewhat in detail. When the transmitting key is closed, the grid biasing circuit of the master-oscillator tube *j* is traced from the grid terminal, through the parasitic choke coil *u*, the 10-millihenry radio-frequency choke coil, the 46,000-ohm biasing resistance, the key contacts and the contacts of the chopper switch (the latter being closed for cw. transmission), the mid-point of the secondary winding of the master-oscillator filament transformer *r*, and from filament to grid within the tube. That completes the circuit. Under this condition, the proper operating bias for the master oscillator is effected by the grid current through the 46,000-ohm biasing resistance. When the key is closed, the plate current to the master-oscillator tube passes through the resistance *t* and the 46,000-ohm resistance across condenser *s*, in parallel, on its way from filament to ground. The complete path of the plate current is traced from the plate of the master-oscillator tube *j* to the filament, the mid-point of the secondary winding of the filament transformer *r*, to ground through the resistances just mentioned, the plate current meter *e*, the interphase reactor *d*, secondary windings of the high-voltage transformers *b* and *c*, the rectifier tubes *a*, the mid-point of the rectifier-filament supply winding *f*, the plate choke coil *k*, to the plate terminal of the master-oscillator tube *j*. This completes the circuit.

When the key is opened, the direct current in the grid circuit of the master-oscillator tube *j* can no longer go directly from the filament, through the transmitting key to the 46,000-ohm biasing resistance, and thence to the grid of the tube, but it has to go in a roundabout way; namely, from the filament, through the 46,000-ohm resistance across condenser *s* to the ground and from the ground through the 2,000-ohm resistance *t* to the 46,000-ohm grid biasing resistance and the 10-millihenry coil to the grid of the tube.

Passage of grid current through these additional resistances tends to make the grid of the master oscillator more negative, but that is not what causes the tube to block instantaneously. The real reason for this sudden blocking is primarily due to the fact that the current to the plate of the master oscillator must also pass through the resistance across condenser *s*, to the ground. This plate current is of the order of 100 milliamperes and, when this current passes through the 46,000-ohm resistance, there is a drop in potential of 4,600 volts, so, for an instant, there is a negative bias on the grid of the master-oscillator tube *j* of several thousand volts. This bias, as has been previously mentioned, is only instantaneous because the tube immediately blocks, which means that the plate current becomes zero and it also means that the grid current becomes zero, so there is no longer any grid bias due to grid and plate current.

The tube would start to oscillate again if it were not for the holding bias that is effected through the medium of the potential drop across the resistance *t*, which is a part of the 3,000-volt drop in potential across the power-amplifier biasing resistance. This holding bias is of the order of 150 volts. When the key is closed, the holding bias across the resistance *t* is neutralized by the plate current through this resistance, which current is through the resistance *t* in a direction opposite to that of the current due to the 3,000-volt potential.

COMMERCIAL 20KW. SHORT-WAVE TELEGRAPH TRANSMITTER

Oscillating Crystals.—In the short-wave transmitter about to be described, a crystal is used as a source of radio-frequency energy, so it is well to discuss the action involved in generating radio-frequency energy by this method, before taking up the discussion of the transmitter itself.

The fact that a piece of Rochelle salts changes its shape when it is placed between two metal plates and a difference of potential is established between the plates, was discovered many years ago. It was also found that the action just stated can be reversed. For instance, if a mechanical force is applied to the surfaces of a crystal of Rochelle salts, its surfaces become electrically charged.

Thus, if one of these crystals is distorted or squeezed by the application of an instantaneous value of an electromotive force, it tends to return to its normal shape when the potential pulse has passed. In so doing it swings past it original form and expands, thus establishing on its surfaces electrical charges of a polarity opposite to that originally applied. The crystal still has a tendency to return to normal and swings back the other way, again swinging past its original shape and establishing an electric charge of reversed polarity on its surfaces. Thus, the crystal oscillates back and forth just the same as a metal disk oscillates or rings when you strike it with a hammer. If the crystal is set into oscillation and then isolated, the oscillations will gradually die out, but if the crystal is connected in the proper circuit, the oscillations can be maintained.

The effect just described is termed the *Piezoelectric effect.* Rochelle salt has the greatest effect of this sort and quartz has a relatively small one, but, owing to the mechanical characteristics of quartz, it is generally used.

Quartz crystals are the kind used in commercial radiotelegraph practice. The natural period of vibration, of these crystals, is a function of their thickness. The greater the thickness of the crystal, the lower the natural frequency of oscillation; and the thinner the crystal, the higher the natural frequency.

Crystal-Controlled Short-Wave Transmitter.—Schematic wiring diagrams of an 18-meter transmitter that is capable of putting 20 kilowatts of radio-frequency energy into the antenna are shown in Figs. 31 and 32. A quartz crystal is used as the source of radio-frequency energy, because of its outstanding inherent characteristic, which is the generation of constant frequency energy.

In Fig. 31 are shown the harmonic amplifiers. A 144-meter crystal *a* is connected across the grid-filament terminals of a 5-watt tube *b* (UV-210). An auxiliary 8-volt *C* battery is used in the crystal circuit to insure dependable oscillation, since it is more difficult to make a crystal oscillate below 200 meters than above. A radio-frequency choke coil is connected in series with the *C* battery to prevent any loss in the bias circuit of the minute radio-frequency energy generated by the crystal.

All radio-frequency leads must be made as short as possible and this is the thought involved in the location

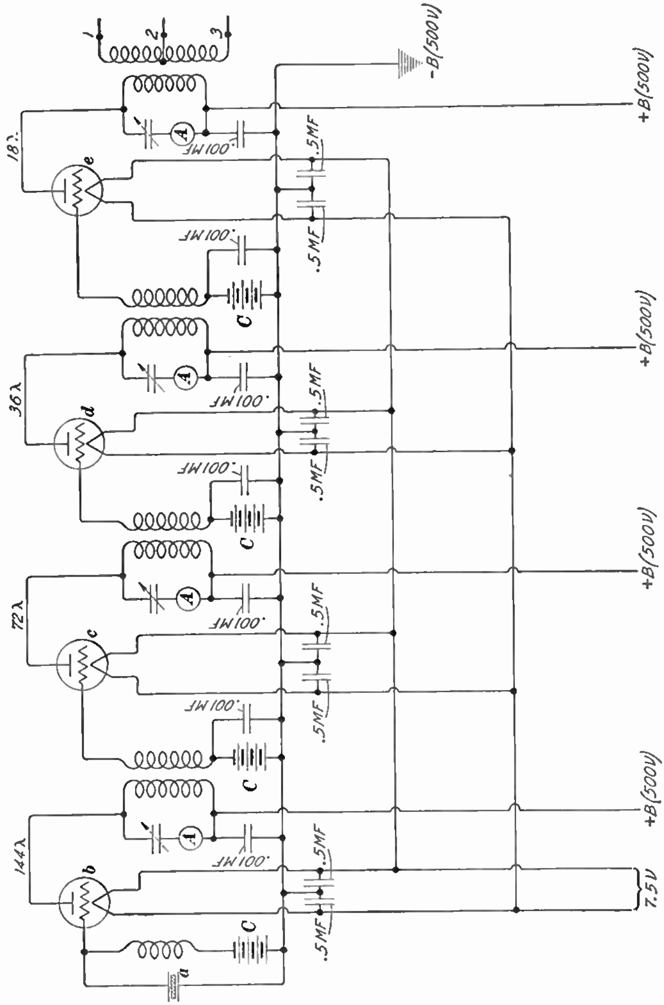

1
2
3
-B(500V)
+B(500V)
+B(500V)
+B(500V)
+B(500V)
7.5V
18λ
36λ
72λ
144λ
e
d
c
b
a
A
C
.001MF
.5MF

Fig. 31

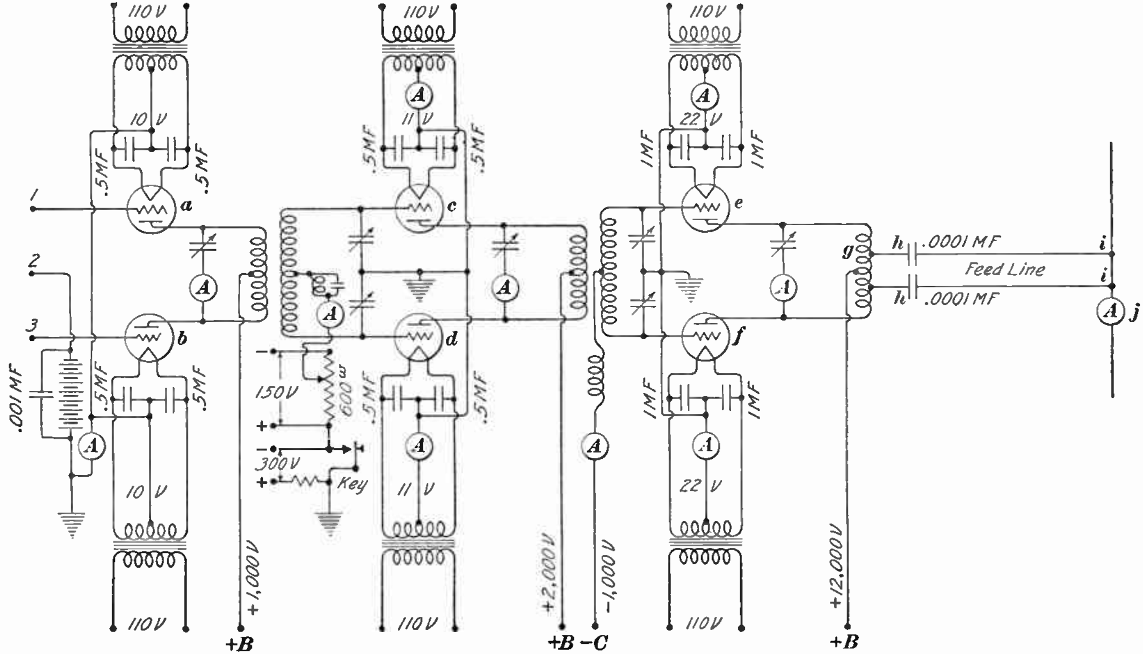

110 V
10 V
11 V
22 V
.5 MF
1 MF
.001 MF
.0001 MF
Feed Line
150 V
300 V
600 w
Key
+1,000 V
+2,000 V
−1,000 V
+12,000 V
+B
+B −C
+B
a
b
c
d
e
f
g
h
i
j
1
2
3

FIG. 32

of the .5-microfarad by-pass condensers right at the filament terminals. These two condensers are connected in series and their mid-point is grounded. The plate circuit of the first 5-watt tube *b* is tuned to the fundamental of the crystal, which is 144 meters.

The radio-frequency current in the tuned plate circuit of tube *b* is indicated by a 0- to 1-ampere thermo-ammeter. There is a .001-microfarad by-pass condenser from the low side of the tuned plate circuit to the ground, so that the radio-frequency current does not have to follow the lead to the plate supply.

Energy is induced into the grid circuit of the second 5-watt tube *c* by means of inductive coupling. The filament terminals of tube *c* are connected to the common 5-watt tube filament supply. The output circuit of tube *c* is tuned to 72 meters or the second harmonic of the crystal. This 72-meter energy is applied to the grid of the third 5-watt harmonic-amplifier tube *d*. The output circuit of this tube is tuned to 36 meters.

The tube *e* is the fourth harmonic amplifier and its output circuit is tuned to 18 meters, which is the wavelength of the signals transmitted. From this point in the circuit, on, the tubes are all *linear amplifiers*, or *power amplifiers*, as they are also termed.

The points *1*, *2*, and *3*, Fig. 31, are connected to similarly numbered points in Fig. 32. Points *1* and *3* are connected to the grids of the two 50-watt (UV-211) push-pull amplifier tubes *a* and *b*. Point *2* is connected to ground through a *C* battery.

The output of the 50-watt push-pull amplifier is delivered to the 1 kw. push-pull amplifier.

Grid excitation for the two 1-kw. push-pull amplifier tubes *c* and *d* is increased by virtue of the fact that the input circuit is tuned. The mid-point of the input coil of tubes *c* and *d* is connected to ground through a radio-frequency trap, a zero-center 0- to 300-milliampere milliammeter, a bias battery, and a telegraph key or relay. Thus, keying is effected in this circuit, so at this point in the discussion, the keying of this transmitter will be considered.

When the transmitting key is open, there is a negative bias of 450 volts applied to the grids of the two 1-kw. push-pull amplifier tubes *c* and *d*, thus effectively blocking them. This bias is supplied from a 150-volt d.-c. source across a 600-ohm resistance and a 300-volt d.-c. source across the key. When the key is closed, the 30-volt bias is shorted, and the 150-volt operating bias is applied to the tubes. The lead from the grids of the two tubes, in this stage of amplification, to the bias battery is connected to the movable contact which engages the 600-ohm resistance that is connected across the 150-volt bias supply. This arrangement makes it possible to regulate the operating bias on the 1-kw. tubes to any potential between 0 and 150 volts.

The output of the 1-kw. push-pull stage of amplification supplies the grid excitation to the two 20-kw. (UV-207) amplifier tubes *e* and *f*. The mid-point of the grid coil is connected to a 1,000-volt negative bias supply through a radio-frequency choke coil and a 300-0-300-milliampere milliammeter, which shows the grid-current value.

The filaments of all the tubes have their separate transformers, which supply the necessary amount of current at the proper voltages. A voltage of 12,000 is supplied to the plates of the last two tubes through the mid-point of the coil *g*.

The feed-line to the antenna is directly connected to the coil *g*, and the blocking condensers *h* keep the high-voltage direct current out of the antenna system. The feed line is

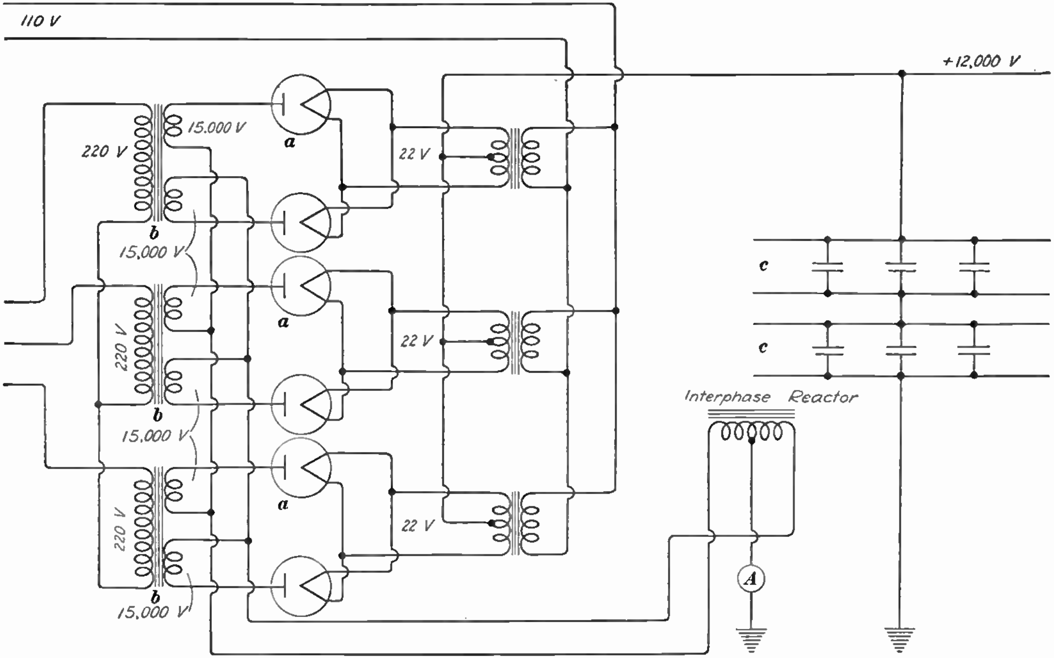

110 V
+12,000 V
15,000 V
220 V
a
b
22 V
15,000 V
c
c
Interphase Reactor
A

FIG. 33

directly coupled to the antenna at the points *i*. The distance between these two points is quite critical and the impedance of the wire between these points should be such that it gives the effect of a transmission line of infinite length, which means that there will be no reflections, hence no radiation, or very little, from the line. The antenna is $\frac{1}{2}$ a wavelength long and has a resistance of 80 ohms. This resistance may seem high, but it is practically all radiation resistance and that is what counts in getting signals out.

The 0- to 20-ampere thermo-ammeter *j* is located right in the antenna system, just to one side of the point where the feed line is coupled on, so it is necessary either to have good eyesight in determining the value of antenna current, or else to use a spy glass. About 15.8 amperes in the antenna means 20-kw. output.

In Fig. 33 is shown the schematic wiring diagram of the circuit for obtaining the 12,000-volt plate potential for the 20-kw. stage of push-pull amplification described in the foregoing description of the high-power short-wave transmitter. There are six rectifier tubes *a*, type UV-209, rated at 12.5-kw. output, each, operating on a 220-volt three-phase supply, two tubes in each phase. About 15,000 volts alternating current is supplied to the plate of each tube through the step-up transformers *b*. The three transformer primaries are connected in a star arrangement.

The filament of each rectifier tube is supplied with 52 amperes at 22 volts. Owing to the high potential, it is customary to use a series-parallel arrangement for the connection of the smoothing condensers *c*.

VACUUM-TUBE TELEPHONE TRANSMITTERS

PRINCIPLES OF TELEPHONE TRANSMISSION

In tube telegraph transmitters radio-frequency energy is generated and amplified by three-electrode tubes, and a means is provided for turning the radio-frequency antenna current on and off, in accordance with the characters in the Continental Code which make up the alphabet and the numerals.

In radio-broadcast transmitters radio-frequency energy is generated and amplified but is not turned on and off in the antenna circuit. It is on continuously, but the amplitude of the radio-frequency variations in the antenna

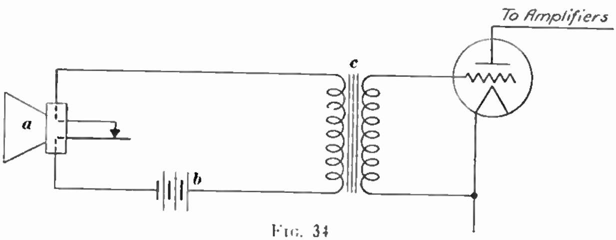


FIG. 34

current is changed at an audio-frequency rate in synchronism with the sound waves.

The first thing to do is to change the sound waves to be transmitted into electric currents, so that they may be made to modulate the radio-frequency output of a tube transmitter. This is done by means of a microphone, of which there are several standard types.

The circuit arrangement in Fig. 34 shows a *single-button type* of carbon-granule microphone. The microphone *a* in question has a diaphragm, which is actuated by the sound waves reaching it and which thereby changes the pressure exerted on the carbon granules within the microphone. The two terminals of the microphone are located on either side of the chamber enclosing the carbon granules, and, as the pressure on these granules varies, the resistance which they constitute varies accordingly. Thus, varying currents are established in the microphone

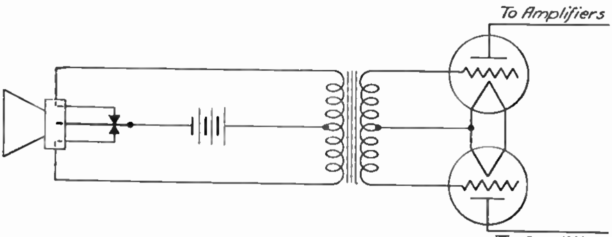


FIG. 35

circuit, which includes the battery *b* and the primary winding of the microphone transformer *c*. Alternating currents are established in the secondary winding of the microphone transformer, the frequency of which varies in accordance with the frequency of the sound waves that strike the microphone diaphragm. All that remains to be done with these audio-frequency currents is to amplify them to the point where they can be used to modulate the radio-frequency output of the transmitter.

In Fig. 35 is shown the circuit arrangement used with the *double-button type* of microphone. This is a sort of push-pull arrangement. The diaphragm, which is actuated by the sound waves to be transmitted, is so situated that, as it increases the resistance of the carbon granules in a chamber on one side, it decreases by the same amount the resistance of the granules on the opposite side.

Thus, this type of microphone can be used in a circuit where the outside terminals of the unit are connected to the extremeties of the primary winding of a microphone transformer, and the microphone diaphragm is connected through a battery to the mid-point of the same winding. Units of this type are used in many of the modern broadcast transmitting stations.

The audio-frequency currents in the secondary winding of the microphone transformer can be amplified through several stages of push-pull amplification and then applied to the grids of the modulator tubes.

The condenser type of microphone is shown in Fig. 36. This unit consists of a condenser, one of whose plates is the diaphragm of the microphone, and whose capacity changes when sound waves are applied to the diaphragm.

It is assumed that the microphone condenser plates *a* are stationary, and that the condenser is fully charged through the medium of charging current supplied from the positive *B* battery lead through the resistances *b* and *c*. When sound waves actuate the diaphragm of the micro-

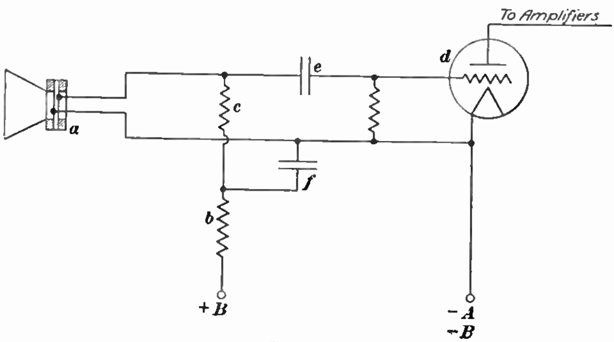


FIG. 36

phone, the capacity changes and there is an electron displacement throughout the microphone circuit. This redistribution of electrons causes varying potentials across the resistances *b* and *c*, the variation occurring at an audio-frequency rate in synchronism with the audio-frequency sounds that strike the microphone diaphragm. The potential variation is transferred to the grid of the tube *d* through the by-pass condensers *e* and *f*. These condensers also block the *B*-battery potential out of the grid and filament circuit. In the case of the condenser type of microphone, the audio-frequency sound waves striking the microphone diaphragm are changed into electric currents of audio-frequency and are applied to the grid of a three-electrode tube.

The way in which modulation is accomplished can best be explained in the course of describing the action of a standard transmitter.

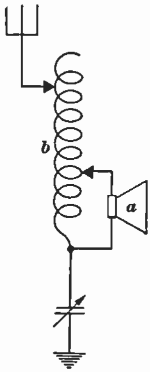


FIG. 37

MODULATION BY ANTENNA ABSORPTION

Modulation by antenna absorption in the course of radio telephone transmission is inherently a poor method, from the standpoint of both quality and efficiency. However, it is included in this discussion for two reasons; first, for its historic importance; and, second, for its attractiveness to amateurs for application to low-power radiotelephone transmitters (5 watts or so), owing to its economy.

One way of effecting modulation by this method is shown schematically in Fig. 37. A microphone *a* is connected across a few turns of the antenna tuning coil *b*. Starting with the microphone connected across several turns, the number of turns is increased until the received signal shows evidence of increasing distortion. A receiver can be connected up locally to monitor the output of the radio-telephone transmitter undergoing adjustment, or some nearby friend can tune the signal in on his radio receiver and report results. A simple crystal receiver will serve the purpose.

The correct number of turns to use is that number which produces the best results, it being remembered that the number of turns cannot be increased beyond that point at which the microphone shows evidence of overheating.

MODULATION BY GRID-VOLTAGE VARIATION

Modulation by grid-voltage variation is effected by varying the average (biasing) grid voltage of the oscillator tube in accordance with the electrical variations in the microphone circuit, which are due to the varying sounds that are directed at the microphone diaphragm.

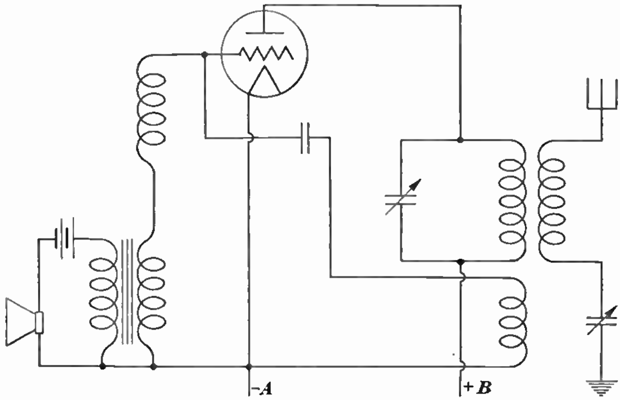


FIG. 38

This system, like the one previously described, is inherently a poor one, but is included here because of its historic value and because it is interesting to amateurs, owing to its economy.

The schematic circuit arrangement for effecting modulation by varying the average grid potential on the oscillator tube is shown in Fig. 38. This system is only applicable to transmitters employing two or three 5-watt tubes.

The biasing grid voltage is varied in accordance with the audio-frequency variations which it is desired to transmit. The aim is to effect similar variations in the radio-frequency energy in the output circuit (plate circuit), but this cannot actually be attained because the relation between the grid biasing voltage and the output energy is by no means linear, which it would have to be to effect good modulation.

WESTERN ELECTRIC 500-WATT BROADCASTING TRANSMITTER

The Western Electric 500-watt transmitter is one of the most popular types of broadcast transmitters. It is shown schematically in Fig. 39. There are four 250-watt tubes. The tubes *a* are used for *modulators* and the tubes *b* for *oscillators*. The audio-frequency currents from the speech amplifier are applied to the grids of the two 250-watt modulator tubes *a* through the primary and secondary windings of the input transformer *c*. The ammeter *d* indicates the grid current that passes to the modulator grids. The grid-return lead from the modulator tubes is connected to the movable contact arm on the potentiometer *e*, which is connected in series with the low side of the plate supply. The drop across this resistance is of the polarity as shown. The greater the amount of this resistance that is embraced in the grid-filament circuit by the movement of the contact, the greater will be the amount of negative bias applied to the modulator grids.

The modulator plate potential is supplied through the iron-core choke coil *f*, the plate ammeter *g*, and the separate choke coils *h*, one of which is located in series with each of the modulator plates.

The oscillator tubes *b* generate the radio-frequency energy that is to be modulated and radiated. The oscillatory circuit is of the Meissner type with tuned plate.

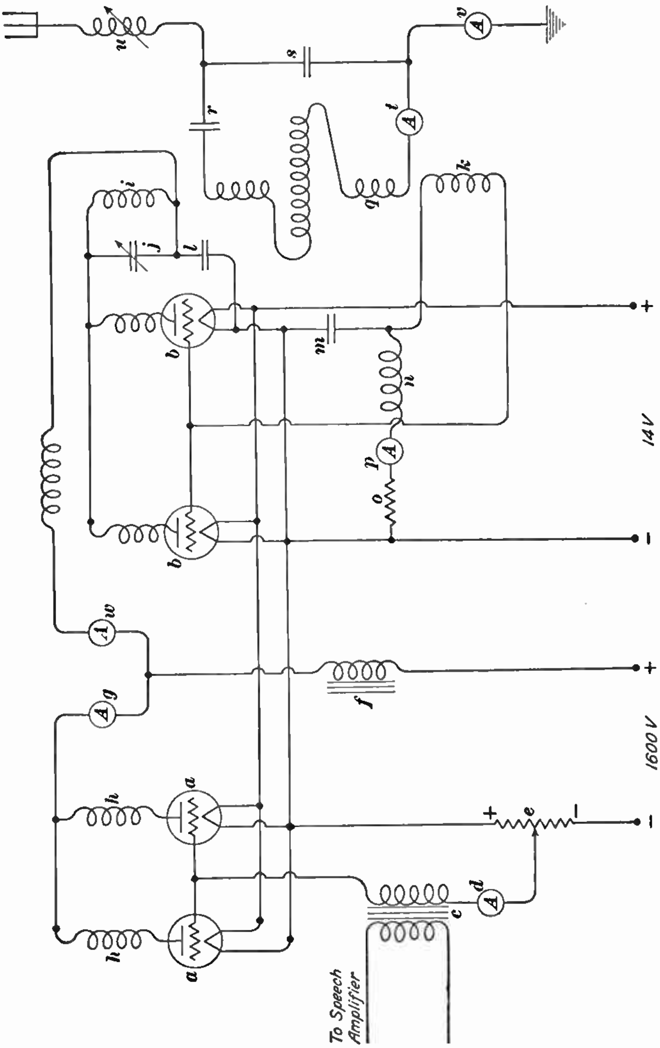


FIG. 39

The wavelength, or the frequency of the oscillations generated by the tubes *b*, is determined chiefly by the constants of the inductance coil *i* and the condenser *j*. The grid excitation is supplied by the coil *k*. The radio-frequency by-pass condensers *l* and *m* act also as blocking condensers. The coil *n* is a radio-frequency choke to keep the high-frequency energy out of the bias circuit, the resistance *o* is the biasing resistance, and the ammeter *p* shows the grid current to the two oscillator grids.

There is a closed oscillatory circuit, consisting of the coil *q* and the condensers *r* and *s* between the oscillator-tubes output circuit and the antenna. This circuit is termed a *tank circuit* and its function is to minimize the reaction of the antenna on the output circuit of the oscillator tubes. Should the antenna swing in a heavy gale, its capacity might change, and if it were connected directly to the oscillatory circuit, where the radio-frequency oscillations are generated, a change in its capacity would change the frequency of these oscillations, or in other words, the wavelength of the transmitted signals. This is undesirable and is minimized by inserting a link circuit as shown in this case. The ammeter *t* indicates the tank current.

The condenser *s* is used to couple the tank to the antenna system. The coil *u* is used for antenna tuning and the ammeter *v* shows the radiation amperes.

The plate current to all four tubes, modulators *a* and oscillators *b*, passes through the iron-core choke coil *f*. This current divides and passes through the ammeters *g* and *w*, following the former path to the modulator plates and the latter to the oscillator plates. The inherent characteristic of a choke coil, such as *f*, is to oppose any change in the current through it. This means a practically constant current through coil *f*.

If there is a positive potential applied to the modulator grids at any instant, owing to the applied audio-frequency current, there will be a tendency for the modulator plates to draw more plate current. Because there is a constant current through coil *f*, the only chance of the modulators getting more current is to take some of the current passing to the plates of the oscillator tubes, and that is just what does happen. The current through the choke *f* remains unchanged, but as the modulator plates draw more current, because of the potential applied to their grids, the oscillator plates draw less current, and vice versa. It is in this manner that the amplitude of the radio-frequency current in the antenna circuit is made to vary at an audio-frequency rate.

TRANSATLANTIC RADIO TELEPHONY

Theory of Side Bands and Carrier.—The first time that the human voice was ever transmitted across the Atlantic ocean was in 1915. It was accomplished by the American Telephone and Telegraph Co. by means of radio. Speech was transmitted from the navy station at Arlington, Va., to the Eiffel Tower, in Paris, but it was only received at occasional intervals, when transmitting conditions were exceptionally favorable.

In March, 1926, commercial two-way radio-telephone conversation was carried on between the United States and England and the type of transmitter used is the subject of the discussion at this point. It is termed a *single side-band eliminated-carrier transmitter.*

When the continuous waves generated by a tube transmitter are modulated, the radiated power is distributed over a frequency range that may be considered in three parts. First, energy at the carrier frequency; second, energy distributed throughout a frequency band, extending from the carrier upwards and covering a band equal to the band of audio-frequencies with which the carrier is modulated (this is termed the upper side band); third, energy distributed throughout a frequency band, extending from the carrier downwards, covering a band of width equal to the width of the frequency band used for modulation (this is termed the lower side band).

Another way of stating the fundamentals involved in the preceding paragraph, is as follows:

When a constant amplitude wave of frequency C is modulated by a constant amplitude wave of frequency S, the resultant modulated wave can be considered to be made up of three waves of constant amplitude, of frequencies, $C+S$, C, and $C-S$.

The energy radiated from the standard type of broadcasting station is composed of the carrier frequency and the two side bands. The power at the carrier frequency itself makes up somewhat more than $\frac{2}{3}$ of the total power, even when modulation is as complete as possible, and this energy can in itself convey no message; therefore, in the transmitter about to be described the carrier is eliminated.

Each of the two side bands transmits power representing the complete message and it is therefore unnecessary to transmit both, so one of them is eliminated in the single side-band transmitter; thus, only half the normal frequency band is utilized.

All the important speech frequencies are included in the frequency band between 300 and 3,000 cycles per second; so, if all of this frequency band can be transmitted and received, the speech issuing from the receiver output will be of good quality.

Description of Transmitter.—In Fig. 40 is shown a schematic wiring diagram of the 200-kw. single side-band carrier-eliminated transmitter that was designed and built

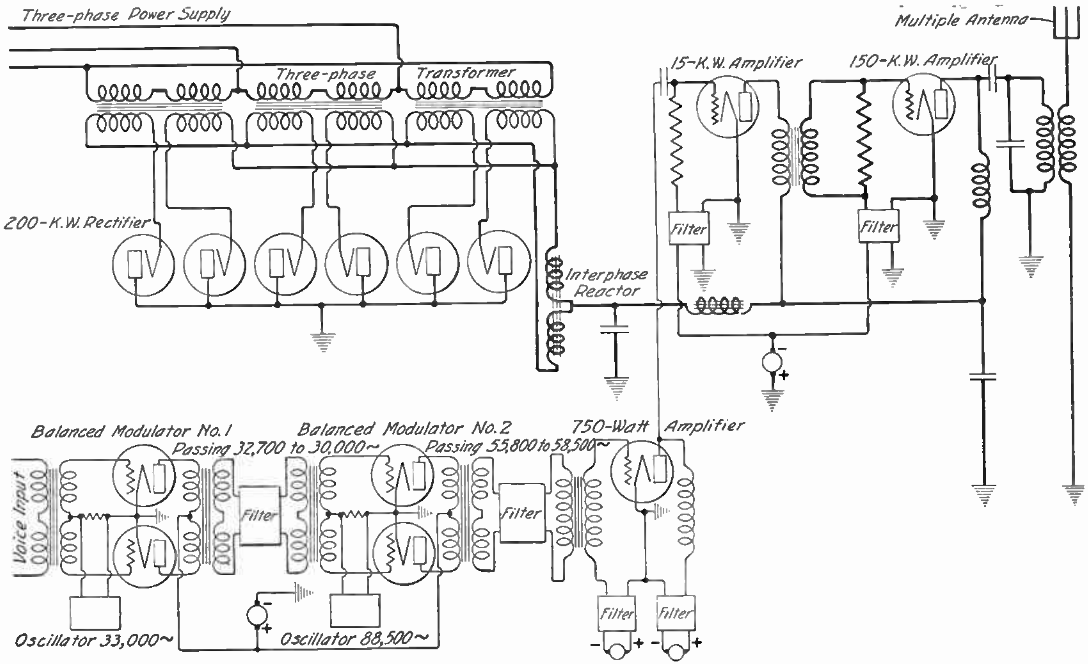

Three-phase Power Supply
Three-phase Transformer
200-K.W. Rectifier
Interphase Reactor
15-K.W. Amplifier
150-K.W. Amplifier
Multiple Antenna
Filter
Filter
Balanced Modulator No. 1
Passing 32,700 to 30,000~
Balanced Modulator No. 2
Passing 55,800 to 58,500~
750-Watt Amplifier
Voice Input
Filter
Filter
Oscillator 33,000~
Oscillator 88,500~
Filter
Filter

FIG. 40

by the American Telephone and Telegraph Co., at the Rocky Point Radio Station of the Radio Corporation of America. The voice input to this transmitter covers a band of frequencies that lie between 300 and 3,000 cycles. These audio frequencies are passed into the first balanced modulator, where they are modulated with a carrier current having a frequency of 33,000 cycles per second. The inherent function of a balanced modulator is to suppress the carrier frequency and pass the two side bands, thus the 33,000-cycle carrier frequency does not appear in the output circuit of modulator No. 1, only the two side bands, which are the upper side band (33,300 to 36,000) and the lower side band (32,700 down to 30,000).

These two side bands are passed on to a band filter, which selects the lower side band, passing it on to balanced modulator No. 2. In this second modulator, the carrier frequency is 88,500 cycles, and the two side bands that appear in the output circuit of this unit are the upper, 118,500 to 121,200, and the lower, 58,500 down to 55,800. These two side bands are passed on to the second filter, where the lower band is selected, namely, 55,800 to 58,500.

One of the thoughts involved in the use of the second modulator is to produce two side bands that are widely separated, thus facilitating the efficient exclusion of one side band and the selection of the other. Thus, the frequency band between 55,800 and 58,500 cycles per second is the one to be radiated, and, by dividing 300,000,000 by the two frequency values given, the wavelength limits of the transmitted signal are obtained. Both values are slightly over 5,000 meters.

In Fig. 41 is shown a graphical representation of the changes in frequency that occur in the preparation of the side-band currents at low power for transmission. Now will be considered the stages of amplification that are

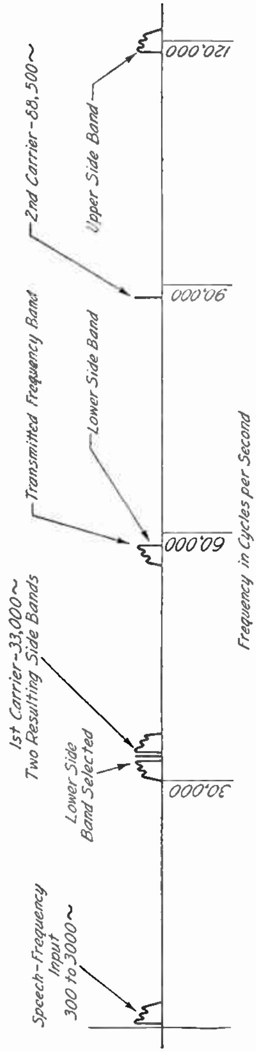


Fig. 41

necessary to produce 150 kilowatts of radio-frequency energy in the antenna. The schematic wiring diagram shown in Fig. 40 only includes the basic fundamentals of the transmitter and this diagram is shown, rather than a complete detailed diagram, to facilitate the comprehension of the functioning of the circuit in question.

The output of the second filter passes into a 5-watt stage of amplification, then through a 50-watt stage, and finally into a 750-watt stage consisting of three 250-watt tubes operating at a plate potential of 1,500-volts. This means that the output of this stage of amplification is 750 watts and, although there are several tubes in this amplifier, only one is shown for the sake of simplicity in the appearance of the diagram.

The output of the 750-watt amplifier is applied to the input circuit of a 15-kw. amplifier. This stage of amplification employs two water-cooled tubes in parallel operating at 10,000-volts plate potential. This stage of amplification produces enough power to supply grid excitation to the grids of the tubes in the 150-kw. amplifier which constitutes the next stage of amplification. This 150-kw. amplifier consists of 20 water-cooled tubes (two banks of 10 each), which operate at a plate potential of 10,000 volts. The output of this last stage is supplied to the antenna system.

The high voltage for the plates of the power amplifier tubes is supplied from a 200-kw. rectifier consisting of 12 water-cooled tubes. Full-wave rectification is effected from a 3-phase 60-cycle supply. The two sets of rectified waves from each full-wave rectifier (two tubes) are combined by means of the interphase reactor, which serves to smooth out the resultant current, and, by distributing the load between tubes of adjacent phases, increases the effective load capacity of the rectifier unit. The ripple is further reduced by means of the filtering retardation coil and the condensers.

This transmitter is one of the latest developments in modern radio telephony and the following are some of the advantages that are inherent in this type of transmitting unit.

1. Conservation of frequency range due to using only one side band.
2. Conservation of power due to the fact that all the radiated energy in this system is useful; whereas, in the type of transmitter that radiates the carrier and two side bands, only $\frac{1}{3}$ of the radiated energy is useful in carrying the message.
3. Although this type of transmitter has other advantages, the two just given are the outstanding ones.

CARRIER CURRENTS

PRINCIPLES OF CARRIER SYSTEMS

INTRODUCTION

Arrangements have been developed whereby the efficiency of an open-wire line may be increased in that additional circuits are provided over the existing wires. Systems employing these arrangements are called *carrier systems*. By the use of these systems it is possible to transmit a number of messages simultaneously over one pair of wires. This is accomplished by employing different alternating currents at frequencies above the voice range, each individual to its own message, and having its wave shape modified in accordance to the message that it transmits. These alternating currents are, therefore, spoken of as *carrier currents* because each one may be said to carry its own message. The path followed, from the sending end to the receiving end, by any one of the several messages transmitted simultaneously over the same pair of wires is called a *channel*. At the receiving end the various carrier currents must be separated by means of proper selecting circuits.

The successful transmission of these various messages by carrier currents over a single circuit depends on the successful functioning of five distinct elements: (1) Sources of carrier current of suitable frequency for each channel. (2) Means for impressing upon each carrier current the specific variations identified with a particular telephone or telegraph current. In the carrier-telephone systems this apparatus is called a *modulator* and its effect upon the carrier current is termed *modulation*. (3) The transmission circuit connecting the central offices. (4) Means whereby the various modulated carrier currents can be separated according to their various individual frequencies. The circuits whereby this is accomplished are called selecting circuits, or *filters*, and the process of so separating them is called *filtering*. (5) Means for reproducing the original lower-frequency modulating current from the carrier current upon which it has been impressed, thereby

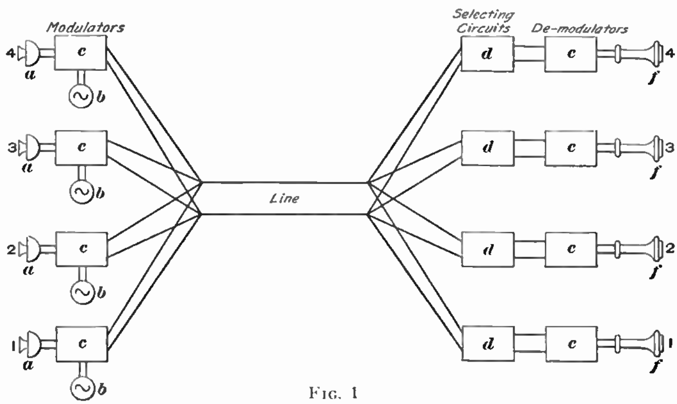


FIG. 1

obtaining the original message. In the carrier-telephone systems the apparatus which accomplishes this is called a *demodulator* and the process that of *demodulation*.

A schematic diagram showing the elements of a simple one-way carrier-telephone system is given in Fig. 1. It consists of four channels, each channel requiring at the sending end a transmitter *a*, a high-frequency generator *b*, and a modulator *c*. At the receiving end each channel requires a selecting circuit *d*, a demodulator *e*, and a receiver *f*. By having each of the high-frequency genera-

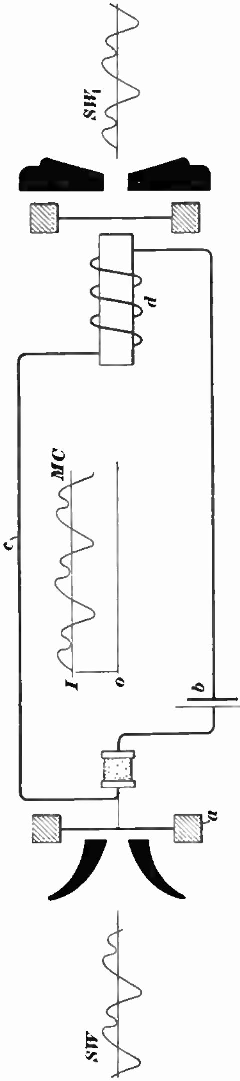


FIG. 2

tors *b* producing alternating currents at different frequencies, and the selecting circuits *d* so designed that each one allows only a certain band of frequencies related to the generator frequency to pass, each receiver will receive its message through its own channel without interference from the others.

MODULATION AND DEMODULATION

Modulation in Direct-Current Circuit.—A careful analysis of the electrical actions of carrier systems brings out the facts that modulation, which causes the amplitude of the carrier current to follow the variations of the signaling or voice current, makes it equivalent to a complex wave made up of components of several frequencies. By considering the action of a simple circuit consisting of a transmitter, a battery, a line, and a receiver, from the viewpoint of modulation and demodulation certain pr nciples can be established which will later be seen to underlie the action of carrier systems and be of material assistance in understanding these systems.

In Fig. 2 is shown diagrammatically a granular-carbon transmitter *a* through which a steady current passes from the battery *b* over the line *c* and through the electromagnetic receiver *d* at the distant station. Before conversation the battery *b* causes a constant steady current *I* in the circuit. This current is modulated by the action of the voice on the transmitter, causing variations in the resistance of the carbon granules due to the pressure variations in the sound waves *SW* striking the diaphragm and these resistance variations cause practically similar variations in the current. The variations in the current cause corresponding variations in the pull exerted by the receiver magnet on its diaphragm, which generates new sound waves SW_1 in the air corresponding to the original spoken words. The steady state or unmodulated value of the current is given by the height of the line *I* above the reference line *o*. The original sound waves *SW* therefore modulate the current *I* into the varying, or modulated, current *MC* which, operating the receiver, produces the sound waves SW_1. From this it is seen that the component parts of a simple telephone circuit can be considered to be: A transmitter, or modulator, of a steady or carrier current; a battery, or a source of power; a line, or transmitting channel; and a receiver, or demodulator, for the modulated current.

When no sound waves are impressed on the transmitter *a*, the battery *b* sends a certain definite amount of current through the circuit. The value of this current depends on the voltage of the battery *b*, divided by the combined resistance of the transmitter *a*, line *c*, and receiver *d*. The sound waves *SW* acting on the transmitter cause a displacement of the transmitter diaphragm. The transmitter is so constructed that the change in the resistance of the transmitter is proportional to the displacement of the diaphragm. The current in the circuit

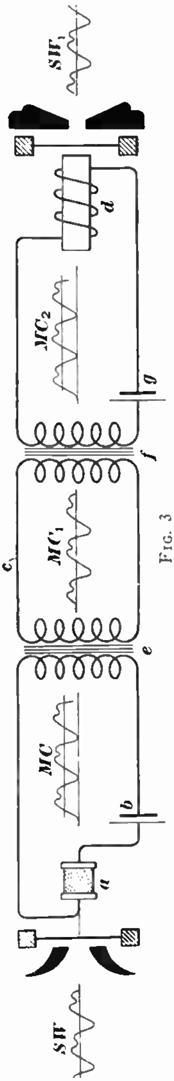


FIG. 3

therefore follows all the variations in the sound waves. The varying current passing through the receiver produces a pull on the diaphragm proportional to the square of the current, because that is the law governing the pull of an electromagnet on its armature at low saturation.

Modulation in Circuit With Induction Coils.—Since most telephone circuits employ an induction coil in connection with the transmitter, the connections of Fig. 2 would become those of Fig. 3. The transmitter *a*, battery *b*, line *c*, and receiver *d* are the same as in the preceding figure. In addition to these, there are two induction, or repeating, coils *e* and *f* and a local battery *g*. Steady current normally passes in the transmitter circuit, including the transmitter *a*, the battery *b*, and the primary winding of the coil *e*. The sound waves *SW* produce the current fluctuations *MC* in the transmitter circuit, and the coil *e* produces the alternating line current MC_1.

Now suppose that the induction coil *f* and the battery *g* were omitted, and the line current passed through the electromagnetic receiver *d*. The pull would consist of a constant pull and a double-frequency pull, which would produce a double-frequency sound wave or cause complete distortion, and therefore would not be satisfactory. The double-frequency pull is produced by the complete reversal of the line current, when a pull is created by the current in each direction. This is corrected by employing the coil *f* and the battery *g*. This causes the current MC_2 in the receiver circuit to be the same as that in the transmitter circuit. The wave shapes *SW* and SW_1 are practically identical, so that speech is reproduced. In practice, instead of using an electromagnetic receiver *d* and the battery *g*, a permanent-magnet receiver is more often used. The stronger the permanent magnet, within certain limits, the more sensitive the receiver and the less distortion and the better articulation it will cause.

The difference between the schemes corresponding to Figs. 2 and 3 lies in the fact that the first one transmits the carrier current, whereas the second one does not. Consequently, the carrier current, it is seen, need not be transmitted as long as it is reintroduced at the receiving end, thus enabling the receiver to produce sound waves that are identical in wave shape with the sound waves actuating the transmitter diaphragm. This gives rise to two types of carrier systems, one in which the carrier current is transmitted and one in which the carrier current is suppressed.

Modulation and High-Frequency Carrier.—To fix the principles underlying the two types of transmission systems shown in Figs. 2 and 3, a similar procedure will be followed in circuits having high-frequency currents. If the battery *b*, Fig. 2, is replaced by an alternating-current generator *b*, Fig. 4, delivering a high-frequency voltage, then the variations of the carbon transmitter *a* caused by the sound waves will modulate the carrier current in the line. The sound waves of wave shape *SW* will strike the diaphragm of transmitter *a*, varying the carbon resistance so the modulated current of wave shape *MC* will pass in the line circuit *c*. Passing through the receiver *d*, this current will produce the sound waves of shape SW_1.

The line current *MC* consists of three components; namely, the carrier current, the carrier current minus the voice frequency, and the carrier current plus the voice frequency. This means that if the carrier frequency is taken as 15,000 cycles per second and a typical voice frequency as 800, there will be three frequencies in the line as a result of the modulation, having values of 15,000 cycles per second, or the carrier frequency; 15,000 −800 = 14,200 cycles per second, or the difference between the carrier and the voice frequencies; and 15,000 + 800 = 15,800 cycles per second, or the sum of the carrier and the voice frequencies. The frequencies above and below the carrier frequency are called the *upper* and the *lower modulation component*, respectively. In actual telephone transmission, instead of there being a single voice frequency of 800 there is, of course, a series of frequencies all the way from very low frequencies up to several thousand cycles per second, and in some carrier systems reasonably satisfactory results have been obtained by transmitting a band of frequencies lying between 200 and 2,000 cycles per second. The modulation components, therefore, are spread over a

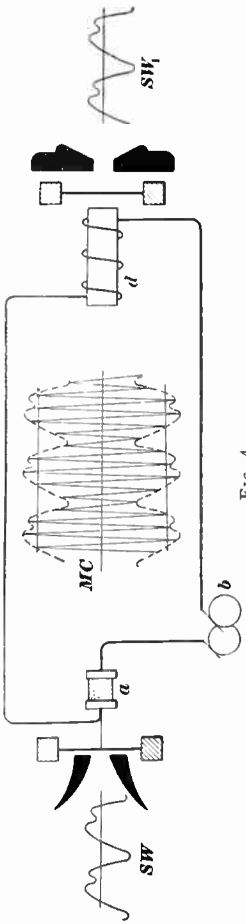


FIG. 4

band of frequencies, the upper from 15,200 to 17,000 cycles per second and the lower from 13,000 to 14,800 cycles per second. They are now spoken of as *upper side band* and *lower side band.*

From this it is seen that, unless means is taken to prevent their transmission, the line will have a number of alternating currents in it of frequencies including the carrier frequency, the upper side band, and the lower side band, spread over a complete range of about 4,000 cycles per second. Now it is a fact that the transmission of either side band alone is sufficient to carry the charactristics of the voice to the receiver circuit, provided the carrier current is either also transmitted or else reintroduced separately at the demodulator.

Assuming the voice frequency to be 800 cycles per second and the carrier frequency to be 15,000 cycles per second as previously assumed, the line current and therefore the receiver current will, in the case under consideration, have two components, one of a frequency of 15,000 cycles per second and the other of a frequency of 14,200 cycles per second. The demodulation action of the telephone receiver will, however, produce a pull on the receiver diaphragm, which has constant components together with those having frequencies in cycles per second corresponding to 30,000, 28,400, 29,200, and 800. The constant pulls will produce no sound waves, whereas the double-frequency terms of 30,000, 28,400, and 29,200 will produce sound waves above those that are audible, leaving only the 800-cycle frequency to reproduce the original sound. In actual practice the unwanted products of demodulation are prevented from entering the listener's receiver by the insertion of electrical filters, as will be explained later.

The diagram of connections in Fig. 5 could be employed for a system in which the carrier frequency is suppressed.

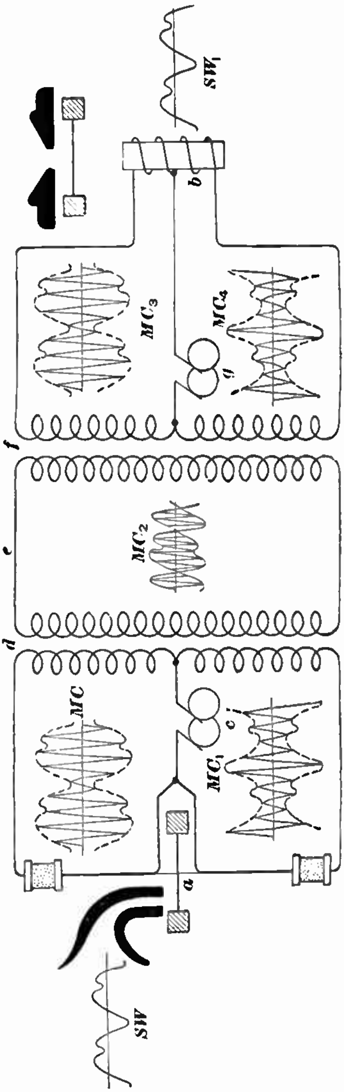


FIG. 5

To accomplish the results, the transmitter *a* that is used must be a differential one using a double carbon button as shown, and the receiver *b* must also be a differential electromagnetic one. The connections are such that when the transmitter diaphragm is at rest the carrier current from the generator *c* divides equally, so that each button and its local circuit has the same value of carrier current through it. Owing to the connections, the magnetizing effect in the induction coil *d* is zero and no current is induced in the secondary and the line *e*. When the diaphragm vibrates, one carbon button has its resistance increased at exactly the same time that the other has its resistance decreased, producing exactly opposite current fluctuations in the primary coils. These, because of the connections, are additive in their effect in the secondary, so that these current fluctuations are induced in the line *e* and pass through the primary of coil *f*. These fluctuations are transformed into the secondaries of induction coil *f*, modulating the carrier currents from the generator *g*. These modulated halves of the carrier current pass through the two windings of the receiver *b*, where the carrier-current halves neutralize each other's effect and those of the modulations become added. To summarize the various actions, it is seen that a sound wave *SW* produces modulated carrier currents *MC* and MC_1 in the transmitter circuits. These produce both modulation components with suppressed carrier or the current variations MC_2 in the line circuit *e*. These in turn modulate the carrier current reintroduced from the generator *g*, so that the current variations MC_3 and MC_4 result in the receiver circuit, and by their action on the receiver diaphragm produce the sound waves SW_1.

VACUUM-TUBE CIRCUITS

Simple Vacuum-Tube Circuits.—The actions of vacuum tubes in carrier-current circuits will be more easily understood after a study of the characteristics of the tubes. In

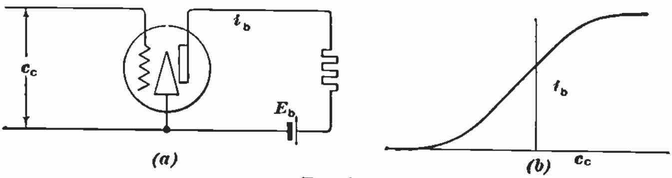


FIG. 6

Fig. 6 (*a*) is shown a simple vacuum-tube circuit, with the filament of the tube connected directly to the grid and the plate return leads; in the sketch the filament battery is omitted. The plate-current characteristic curve of the tube, connected as shown in view (*a*), is given in view (*b*). The plate current may be obtained by the formula

$$i_b = k(E_b + \mu e_c)^2$$

in which i_b = plate current, or output current;
k = a constant, depending on the construction of the tube, arrangement of electrodes, and temperature of the filament;
E_b = plate voltage;
μ = amplification factor;
e_c = instantaneous grid, or input, voltage.

If the tube is used in connection with a grid battery, as it usually is, then the diagram of its connections becomes

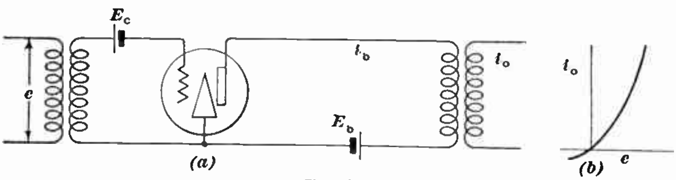


FIG. 7

that of Fig. 7 (*a*). The grid voltage in this case is $E_c + e$ where E_c is the voltage of the grid battery, and e is the external input voltage. The current in the plate circuit now becomes

$$i_b = k(E_b + \mu E_c + \mu e)^2 \qquad (1)$$

Squaring the parenthesis, gives

$$i_b = k(E_b + \mu E_c)^2 + 2k(E_b + \mu E_c)\mu e + k\mu^2 e^2 \qquad (2)$$

If the tube is operated with constant plate and grid batteries and at constant filament temperature, then k, E_b, E_c, and μ can be called constants and the first term in the preceding formula will represent a steady direct current in the output circuit of the tube, which will not appear in the secondary of the output transformer.

Calling i_o the current in this secondary, its equation must be,

$$i_o = 2k(E_b + \mu E_c)\mu e + k\mu^2 e^2 \qquad (1)$$

The only varying quantity in the first term of the output current i_o is e and in the second term it is e^2. Substituting for the constant terms the letters a_1 and a_2, respectively, gives

$$i_o = a_1 e + a_2 e^2 \qquad (2)$$

Formula 2 and view (*b*) give the relation existing between the input voltage e and the output current i_o of a single three-element vacuum tube with its input and output transformers. It shows that the output current contains two components, one proportional to the input voltage and the other proportional to the square of the input voltage. If the tube is properly constructed and has its associated circuits and batteries properly adjusted, the constant a_1 will be so large compared with a_2 that the second term is negligible with respect to the first. A tube under these conditions is best suited to be used as an amplifier. Formula 2 then becomes formula 3.

$$i_o = a_1 e \qquad (3)$$

If, on the other hand, a_2 is so large compared with a_1 that the first term of formula 2 becomes negligible with respect to the second, then formula 2 becomes formula 4.

$$i_o = a_2 e^2 \qquad (4)$$

Under these conditions the tube is best suited to be used as a modulator.

Balanced Tube Circuit for Complete Squaring.—A very good arrangement for a modulator is to employ two identically constructed three-element vacuum tubes with their circuits interconnected as shown in Fig. 8. If an input voltage e is now applied, it may be seen from the connections that if the grid voltage of tube T_1 is increased, that of tube T_2 will be decreased by the same amount. The output current of tube T_1 will be

$$i_o = a_1\frac{e}{2} + a_2\frac{e^2}{4} \qquad (1)$$

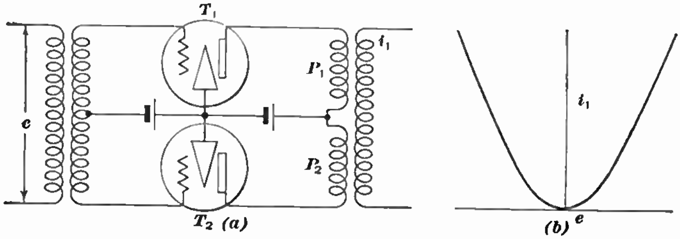


FIG. 8

and that for tube T_2 will be

$$i_o = -a_1\frac{e}{2} + a_2\frac{e^2}{4} \qquad (2)$$

If the primaries P_1 and P_2 of the output transformer are so connected that the effects they produce in the secondary are additive then the output current will be the sum of formulas 1 and 2, or

$$i_o = \tfrac{1}{2}a_2e^2 \qquad (3)$$

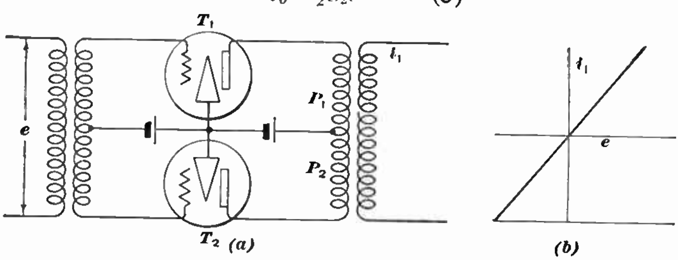


FIG. 9

Balanced Tube Circuit for Complete Amplification. Again, if the primaries of the output transformer are con-

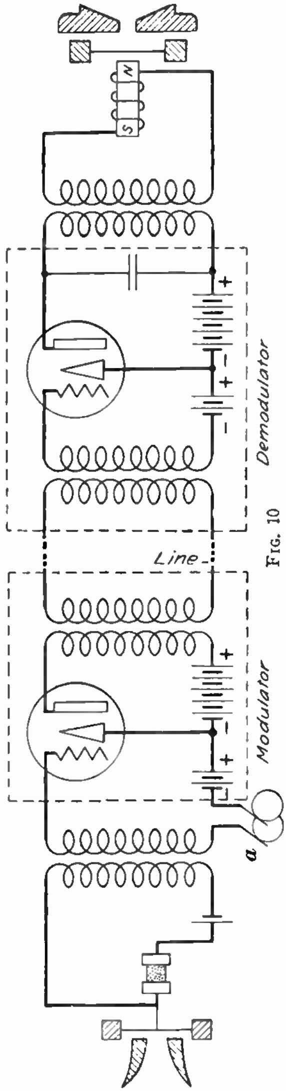


FIG. 10

nected as shown in Fig. 9 so that their effects on the secondary oppose each other, then the total output current will be

$$i_1 = a_1 e$$

and the arrangement becomes best for amplification, being of the push-pull type.

Vacuum-Tube Modulation and Demodulation.—In actual practice, there are many objections to having the carbon transmitter act as a modulator, and the receiver as a demodulator in carrier-current circuits. These could be partially overcome by using mechanical repeaters. A better method, however, is to use vacuum tubes as modulators and demodulators.

To get a clear conception of the action of a vacuum tube as a modulator and a demodulator, consider the circuit shown in Fig. 10. In the input, or grid, circuit of the modulator tube are found two frequencies, namely, the voice frequency and the high frequency of the generator *a*. In the output circuit of the modulator the following frequencies are in evidence; namely, the carrier, twice the carrier, carrier plus the voice or the higher modulation component, carrier minus the voice or the lower modulation component, twice the voice, and the voice frequencies. If the modulator receives a carrier frequency of 15,000 modulated by a voice frequency such as 800 cycles per second, the output circuit of the modulator would carry currents of the following frequencies: 800, 15,000, 1,600, 14,200, 15,800, and 30,000. In actual practice, by means of filters, whose action will be explained later, only one side band with or without the carrier frequency, as desired, is selected and transmitted, so that the resultant action of a single three-element tube is the same as that of the transmitter-generator combination shown in Fig. 4. By the use of filters the output of the modulator may be so modified as to include only the carrier and the lower frequencies component (carrier minues voice frequency).

FILTERS AND SELECTING CIRCUITS

Functions of Filters.—In carrier-current systems either one side band or one side band with the carrier is transmitted. In either system a larger number of frequencies would reach the carrier line than are desired to be transmitted in practice if the unwanted ones were not suppressed by the actions of electrical filters inserted in their paths. Such filters are used at each end of the line. An electrical filter is a network composed of coils and condensers so designed as to offer practically no loss to currents of frequencies within a certain range, while offering a very high loss to currents whose frequencies lie outside of that range. A filter is therefore said to pass currents of certain frequencies and to suppress others.

Types of Filters.—Filters may be divided into four general classes; namely, low-pass filters, high-pass filters, band-pass filters, and low- and high-pass filters or band-elimination filters.

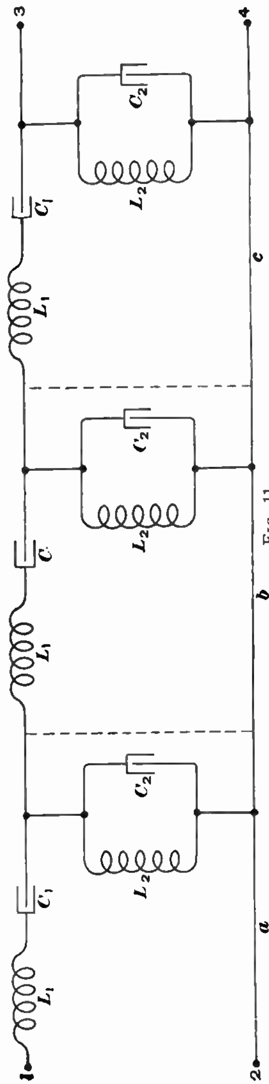


Fig. 11

A low-pass filter is a network that passes currents of all frequencies from zero up to a certain frequency called the cut-off frequency (designated by f_c) and suppresses all currents whose frequency is above the cut-off frequency.

A high-pass filter is a network that passes currents of all frequencies above a definite frequency called the cut-off frequency and suppresses currents of all frequencies below this cut-off frequency.

A band-pass filter is one that passes currents whose frequencies are included between two cut-off frequencies and suppresses currents of all frequencies outside of this range.

A low- and high-pass filter or band-elimination filter is one that suppresses currents whose frequencies are included between two cut-off frequencies and passes all currents of all frequencies outside of this range.

General Filter Circuit.—It is common to build filter networks of identical sections, and one type of design is shown in Fig. 11. In this figure three identical sections *a*, *b*, and *c* are shown, each made up of coils having inductances L_1 and L_2 and condensers having capacitances C_1 and C_2. Points *1* and *2* are the input terminals of the filter, and points *3* and *4* are the output terminals. This may be called the most general form of this type of filter. By assigning proper values to the inductances and capacitances L_1, C_1, L_2, and C_2, filters of various characteristics can be obtained.

A *low-pass filter* is obtained from Fig. 11 by giving suitable values to L_1 and to C_2 and then short-circuiting C_1 and open-circuiting L_2. A *high-pass filter* is obtained by giving suitable values to L_2 and to C_1 and then short-circuiting L_1 and open-circuiting the circuit of C_2.

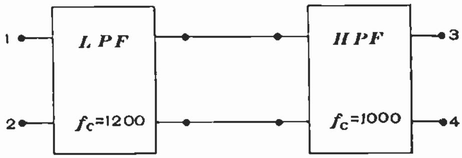


FIG. 12

Construction of Band-Pass Filter.—A band-pass filter can be constructed by connecting a low-pass filter in series with a high-pass filter, provided the cut-off frequency of the high-pass filter is lower than the cut-off frequency of the low-pass filter. Let Fig. 12 be a schematic diagram showing a low-pass filter *LPF* having a cut-off frequency of 1,200 connected in series with a high-pass filter *HPF* having a cut-off frequency of 1,000. A current having a frequency below 1,000 will be suppressed by the high-pass filter and a current having a frequency above 1,200 will be suppressed by the low-pass filter. Currents having frequencies between 1,000 and 1,2000, however, will not be suppressed by either one.

Construction of Band-Elimination Filter.—Connecting a low-pass filter in shunt with a high-pass filter, provided the cut-off frequency of the high-pass filter is higher than the cut-off frequency of the low-pass filter, will result in a band-elimination filter. Considering Fig. 13, which is a schematic diagram of connections of this case, it is seen that currents having a frequency below 1,000 can pass through the low-pass filter and those above 1,200 can pass through the high-pass filter, but those whose frequencies fall between 1,000 and 1,200 can pass through neither.

In carrier telegraph systems it is not necessary to employ a selecting circuit as complicated as a filter, the selectivity

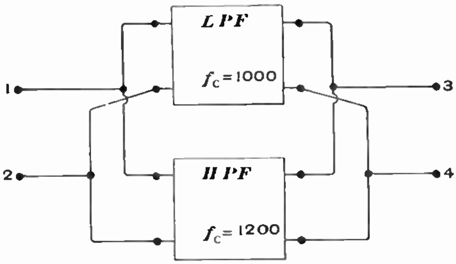


FIG. 13

being obtained by the use of resonant or tuned circuits composed each of a single coil and one or more condensers.

Transmission Unit.—In Fig. 14 is given a graphical representation of the characteristics of the circuits just described. The abscissas are given in kilocycles and the ordinates in transmission units (TU). The transmission unit is a unit for expressing losses or gains in communication circuits. The nature of the unit and the reason for its use may be seen by considering the transmission of an alternating current over a very long line.

Assume an infinitely long uniform line over which an alternating current is being transmitted. In such a line the resistance per unit length, inductance per unit length,

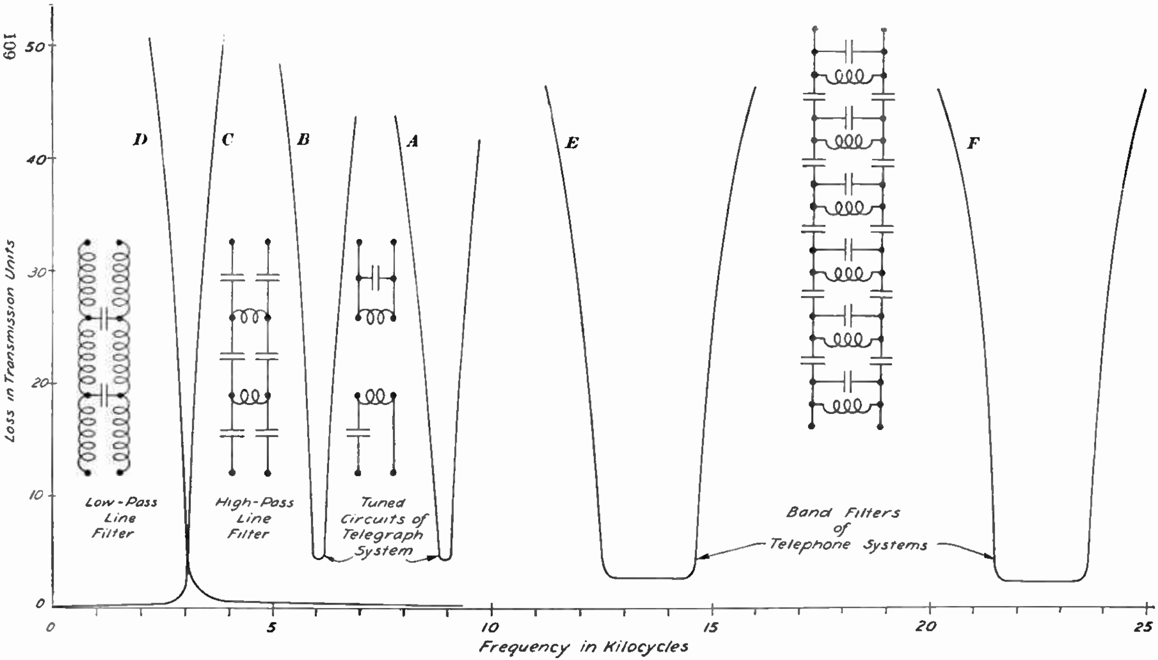

50
40
30
20
10
0
Loss in Transmission Units
D
C
B
A
E
F
Low-Pass Line Filter
High-Pass Line Filter
Tuned Circuits of Telegraph System
Band Filters of Telephone Systems
0
5
10
15
20
25
Frequency in Kilocycles

FIG. 14

capacitance per unit length, and leakance per unit length are all of constant value throughout its entire length. The transmitted line current, on account of charging currents and leakage currents, will be attenuated from point to point along the line. Imagine the line being made up of sections, each of unit length. If the line current entering any given section is denoted by I_e and the line current leaving that section by I_l, their ratio, denoted by r, will be the same for every section, as given by equation 1.

$$r = \frac{I_e}{I_l} \qquad (1)$$

If, now, I_1 is the line current entering any given section and I_2 is the line current leaving a later section, say the nth, then the ratio of these two currents will be n of these factors multiplied together, or r to the nth power, so that

$$r^n = \frac{I_1}{I_2} \qquad (2)$$

Since n may also represent the distance between the points where the values of the line current are taken, the number of sections n can be replaced by the distance l, giving

$$r^l = \frac{I_1}{I_2} \qquad (3)$$

Now it can be proved that in an indefinite uniform line, the ratio of the power delivered at the point 1 to that delivered at the point 2 is equal to the square of the ratio of the line currents at these points, so that

$$\frac{P_1}{P_2} = \left(\frac{I_1}{I_2}\right)^2 \qquad (4)$$

By combining equations 3 and 4,

$$\frac{P_1}{P_2} = \left(\frac{I_1}{I_2}\right)^2 = (r^l)^2 = r^{2l}$$

Therefore,
$$\frac{P_1}{P_2} = r^{2l} \qquad (5)$$

The power ratio for l miles is, therefore, r^{2l} and for 1 mile it is r^2, since l equals 1 in this case. Thus, for every mile the power is changed by a factor r^2, and to obtain the ratio for l miles this factor must be raised to the lth power. That is, r^{2l} can be considered as $(r^2)^l$. If l is a large number, this process cannot be performed easily except by the use of logarithms. Therefore, take the logarithm of both sides of equation 5.

Then
$$\log \frac{P_1}{P_2} = l(\log r^2) \qquad (6)$$

It may be seen that the logarithm of the power ratio for l miles is l times the logarithm of the power ratio for 1 mile. This suggests the convenience of using the logarithm of the power ratio as a basis for the unit of loss or gain in electrical circuits. Then, if the power ratio of 1 mile corresponds to N units, the power ratio of l miles corresponds to lN units. Such a unit is called the transmission unit (TU). The two powers P_1 and P_2 differ by N transmission units when the following equation is satisfied:

$$N = 10 \log \frac{P_1}{P_2} \qquad (7)$$

The factor 10 is used simply to obtain a unit of convenient size. Let N represent the loss in 1 mile and N_l the loss in l miles. Then for 1 mile, by equations 6 and 7, $N = 10 \log \frac{P_1}{P_2} = 10 \times 1\ (\log r^2) = 10 \log r^2$, since l equals 1.

Also, for l miles, $\log \frac{P_1}{P_2} = l\ (\log r^2)$ and $N_1 = 10 \log \frac{P_1}{P_2} = 10\ l\ (\log r^2) = l\ (10 \log r^2) = lN$. Therefore, equation 6 can be replaced by

$$N_1 = lN \qquad (8)$$

On account of this introduction of a logarithmic unit of loss, losses may be combined by addition, whereas, if the power ratios were used, the losses would have to be combined by more laborious multiplication.

To determine the magnitude of the power ratio corresponding to one TU, let N in equation 7 equal unity. Then,

$$1=10 \log \frac{P_1}{P_2}$$

$$\log \frac{P_1}{P_2}=\frac{1}{10}=.10000$$

$$\left.\begin{aligned} \frac{P_1}{P_2}&=1.259 \\ \frac{P_2}{P_1}&=\ \ .794 \end{aligned}\right\} \qquad (9)$$

From this it is seen that the loss of one transmission unit corresponds to a reduction in the power to approximately 80 per cent. of its initial value. In general, equation 7 gives the number of transmission units by which the powers P_1 and P_2 are said to differ. Assuming the values for N_{TU} in the first column of Table I, the corresponding values of $\frac{P_1}{P_2}$ have been calculated by equation 7 and placed in the second column and the values in the other columns have been determined from them. From this table it is seen that if there are 3 transmission units loss, the power delivered at point 2 is only 50 per cent., or one-half, of the power delivered at point 1. By memorizing the percentages or the fractions corresponding to 1, 2, and 3 TU's the percentage or fraction corresponding to any higher number of TU's can be approximately determined mentally. For example 4 TU's are 3+1 TU's, giving $\frac{1}{2}$ of 80 per cent., or 40 per cent., and 8 TU's are 3+3+2 TU's, giving $\frac{1}{2}$ of $\frac{1}{2}$ of 63 per cent., or 16 per cent.

Characteristics of Filters.—Curves *A* and *B*, Fig. 14, illustrate the action of two tuned circuits, *A* resonant at 9 kilocycles and *B* at 6 kilocycles. It is seen that for frequencies of only a few hundred cycles from the resonant

TABLE I

RELATION OF TRANSMISSION UNITS AND POWER RATIO

N_{TU}	$\frac{P_1}{P_2}$	$\frac{P_2}{P_1}$	$\frac{P_2}{P_1}$ in Approximate Per Cent.	$\frac{P_2}{P_1}$ in Approximate Fraction	N_{TU}
1	1.259	.794	80	$\frac{4}{5}$	1
2	1.585	.631	63	$\frac{2}{3}$	2
3	1.995	.501	50	$\frac{1}{2}$	3
4	2.512	.398	40	$\frac{2}{5}$	4
5	3.162	.316	32	$\frac{1}{3}$	5
6	3.981	.251	25	$\frac{1}{4}$	6
7	5.012	.200	20	$\frac{1}{5}$	7
8	6.310	.159	16	$\frac{1}{6}$	8
9	7.943	.126	13	$\frac{1}{8}$	9
10	10.00	.100	10	$\frac{1}{10}$	10
15	31.62	.032	3	$\frac{1}{30}$	15
20	100.0	.010	1	$\frac{1}{100}$	20
25	316.2	.003	$\frac{3}{10}$	$\frac{1}{300}$	25
30	1,000.	.001	$\frac{1}{10}$	$\frac{1}{1000}$	30

frequency a considerable loss is introduced that prevents currents of these frequencies from being transmitted. In the cases shown, a variation of one kilocycle would make the loss about nine times that at resonance. Several of these tuned circuits, each tuned to one of the various frequencies as used in a carrier telegraph system, may be connected to a common line in parallel. A current of a particular frequency will therefore find its way most easily through the circuit tuned to the same frequency and only in negligible amount through the circuits resonant to other frequencies.

Curve *C* illustrates the action of a certain low-pass filter, showing that there is little or no loss up to almost 3 kilocycles per second, but from there on the loss introduced into the circuit by the filter increases very rapidly as the frequency is increased, so that all currents whose frequencies are above 3 kilocycles are effectively suppressed.

Curve *D* illustrates the action of a certain high-pass filter, showing its action to be complementary to that of the low-pass filter whose curve is *C*. The curve *D* is seen to pass the frequencies above 3 kilocycles and shut out those below that figure. Used together, one end of each of these two filters would be connected to the common line, so that the low-frequency voice currents would pass from the line through the low-pass filter into the ordinary telephone connections, whereas the high-frequency carrier currents would pass through the high-pass filter and so to the carrier apparatus.

Curves *E* and *F* show the action of two band filters; *E* transmitting 14 to 16 kilocycles and *F* transmitting 23 to 25 kilocycles per second. Either one of these would be used for transmitting the side band and effectively shutting out all other currents.

PRACTICAL CARRIER SYSTEMS

CARRIER SYSTEM WITH CARRIER TRANSMISSION

Terminal Arrangement of One Channel.—A schematic diagram of connections showing how one channel of a carrier-transmission system is superimposed on an ordinary telephone circuit employing an open-wire line is shown in Fig. 15. The subscriber's circuit connected to one channel of the carrier system connects to terminals *1* and *8* of a

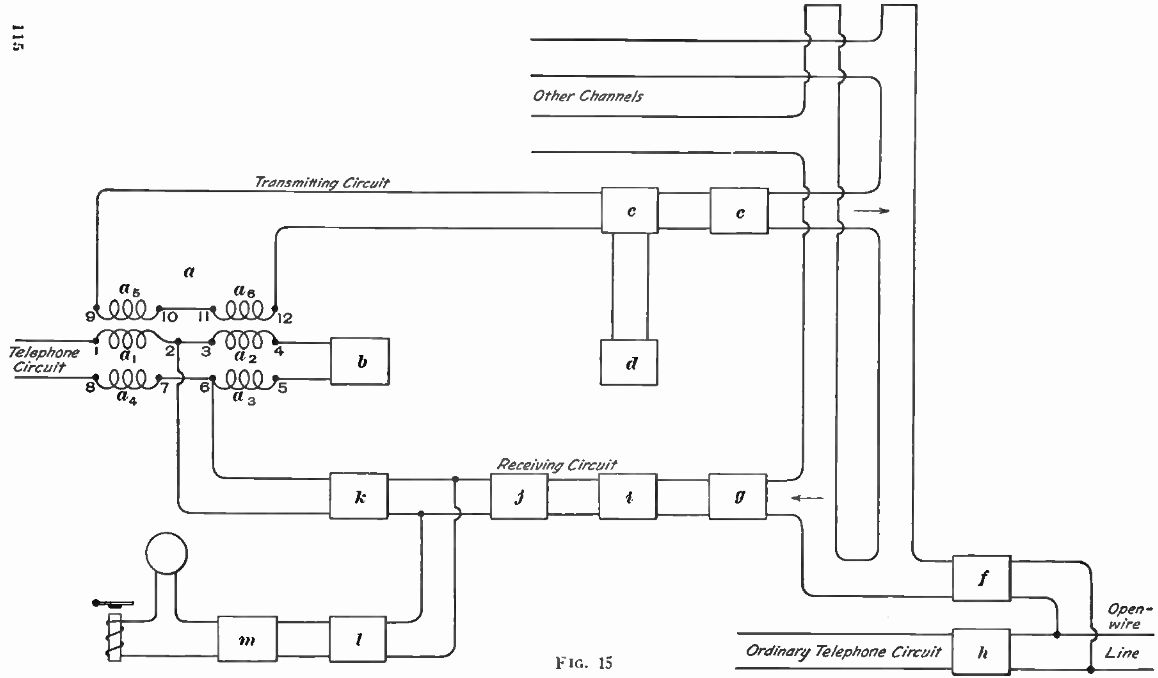

Other Channels
Transmitting Circuit
c
c
a
a5
a6
9
10
11
12
Telephone Circuit
1
a1
2
3
a2
4
b
d
8
a4
7
6
a3
5
Receiving Circuit
k
j
i
g
f
m
l
Open-wire Line
Ordinary Telephone Circuit
h

FIG. 15

hybrid coil a, or three-winding transformer. The line winding of this transformer consists of four coils a_1, a_2, a_3, and a_4; while its modulator input winding consists of two coils a_5 and a_6. Between terminals *4* and *5* a balancing net work b is connected that is adjusted so that its impedance is practically identical with that of the line connected between terminals *1* and *8*. The four primary coils are also practically identical and so wound that current passing from *1* to *8* through the four primary coils and the balancing network in series will produce magnetic lines of force in the core.

An alternating current entering by terminals *1* and *8* will, therefore, produce a voltage in the secondary, or modulator, windings. On the other hand, an alternating current entering by the terminals *2* and *6* will divide equally, half passing through coils a_1 and a_4 and the subscriber's loop and the other half through coils a_2 and a_3 and the balancing network b, so that no magnetization results and, therefore, no voltage is induced in the modulator coils a_5 and a_6. By this arrangement, therefore, the voice current in the telephone circuit enters the hybrid coil at terminals *1* and *8*.

The currents passing through coils a_1 and a_4 induce a corresponding current in coil a_5, which is impressed on the input of the modulator c. This current, passing through coil a_6, induces a voltage in coils a_2 and a_3, which acts in such a way as to prevent any of the current entering at terminals *1* and *8* from passing into the balancing network b. The currents impressed on the modulator c modulate the carrier current coming from the carrier oscillator d. The output currents from the modulator have a band filter e inserted in their path so that only the carrier current and one of its side bands pass through the high-pass filter f to the open-wire line, and so to the proper channel at the receiving end. These currents cannot affect the demodulator, since the band filter *g* does not allow them to pass.

A message intended for the subscriber connected to points *1* and *8* arrives over the open-wire line. The low-pass filter *h* in the ordinary telephone circuit will not pass the carrier current and the side band coming from the other station, but these frequencies will pass through the high-pass filter *f* of the carrier receiving circuit. They then pass through the band filter *g* to the demodulator *i*. The carrier current and the voice current in the output circuit of the demodulator *i* are amplified by the amplifier *j* and reach a low-pass filter *k* and high-pass filter *l*. The voice current passes through a low-pass filter *k*, being shut off from the signaling circuit by the action of the high-pass filter *l*, and reaches terminals *2* and *6*, where it divides, half going to the subscriber connected to terminals *1* and *8* and the other half passing through the balancing network *b*. No voltage is induced between points *9* and *12* because of the balanced arrangement and so no effect is produced on the modulator *C* by this incoming voice current.

The carrier current in the receiving circuit, being blocked by the low-pass filter *k*, passes through the high-pass filter *l* and the rectifier *m*, and is used for signaling purposes.

Terminal Arrangement of Several Channels.—In Fig. 16 is shown a schematic diagram including only hybrid coils *a*, balancing networks *b*, modulators *c*, oscillators *d*, band filters *e*, high-pass line filter *f*, band filters *g*, low-pass line filters *h*, and demodulators *i* arranged for three carrier channels in addition to the regular telephone circuit. From the numbers noted for the frequencies to be passed by the several band filters *e* and *g* it is seen that each channel uses two carrier currents, one for the outgoing

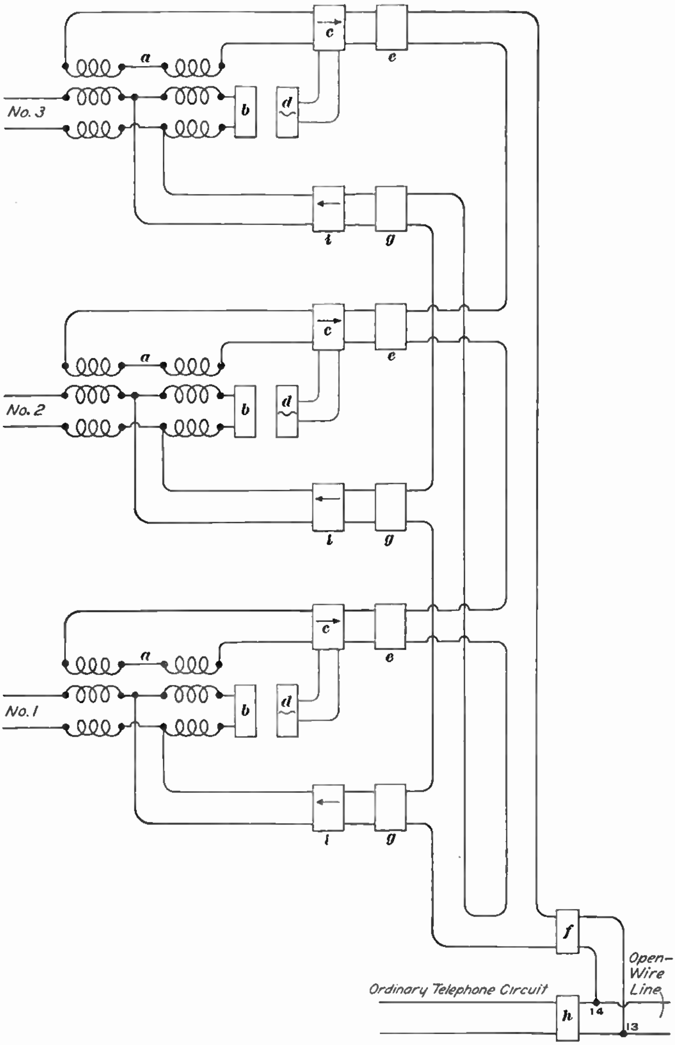

a
b
c
d
e
No. 3
i
g
a
b
c
d
e
No. 2
i
g
a
b
c
d
e
No. 1
i
g
f
h
Open-Wire Line
Ordinary Telephone Circuit
14
13

FIG. 16

message and another of different frequency for the incoming. The open-wire line therefore carries six different carrier currents and six side bands of frequencies from 4 to 23 kilocycles as well as the voice current whenever conversation takes place over the regular telephone circuit.

CARRIER SYSTEM WITH CARRIER SUPPRESSION

Terminal Arrangement of One Channel.—The outstanding feature of this system is the suppression of the carrier current. To accomplish this it makes use of modulators and demodulators of the balanced type (also called the push-pull type). It also uses the same frequencies for transmission in both directions as distinguished from the previous system. This necessitates balancing the line through the agency of a hybrid coil and balancing network in order not to have outgoing currents cause any interference in the paths of incoming currents.

A schematic diagram of connections on one channel of this system is given in Fig. 17. The subscriber's voice current enters the hybrid coil a at terminals *1* and *8* passing through the primary coils a_1 and a_4 to points *2* and *6* and thence into the demodulator circuit, where it produces no effect, because of the balancing network b. In passing through coils a_1 and a_4 it produces a voltage in the coils a_5 and a_6 affecting the grid potential of the modulator c and thereby modulates the carrier current from the oscillator d. The output of the modulator c is next amplified, to allow for the line losses, by the amplifier e and then passes through the band filter f, where the proper side band is selected, and then proceeds to points *3* and *7* of the hybrid coil g. Here the current divides, half passing through the coils g_1 and g_4 and the balancing network h, and half passing through the primary coils g_2 and g_3, through the

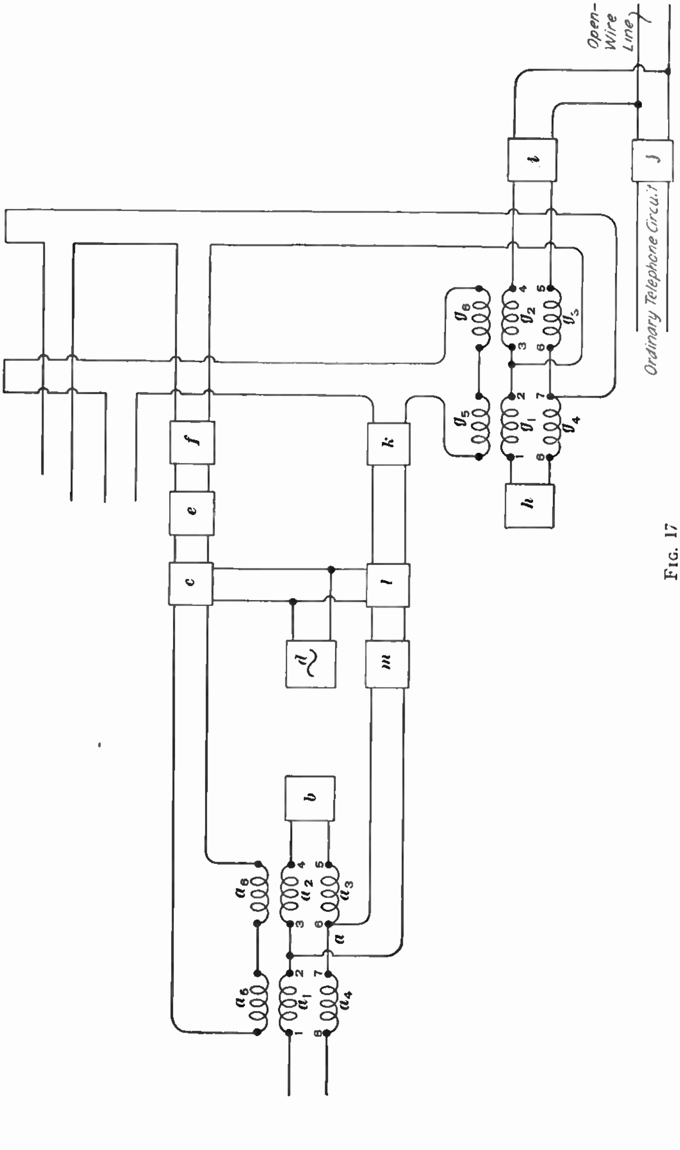

Open-
Wire
Line
Ordinary Telephone Circuit
j
t
h
g1
g2
g3
g4
g5
g6
k
f
e
c
l
m
d
b
a
a1
a2
a3
a4
a5
a6

FIG. 17

high-pass filter *i*, and out on the open-wire line to the other station. The balancing network *h* has its impedance so adjusted that for all practical purposes the impedance between points *1* and *8* external to the hybrid coil *g* is identical with that between points *4* and *5* through the high-pass filter *i* and out on the line. This arrangement causes no voltage to be induced in the secondary coils g_5 and g_6 and so no effect in the demodulator circuit. The energy of the current passing through the balancing network *h* is merely dissipated, whereas the current passing out on the open-wire line carries the message to the other station. The low-pass filter *j* prevents this current from entering the ordinary telephone circuit whose currents are at voice frequency.

The incoming message being carried by the lower side band is likewise prevented from entering the ordinary telephone circuit by the low-pass filter *j*, Fig. 17, and so passes through the high-pass filter *i* and the coils of the hybrid coil *g* and the band filter *k*. Under these conditions a voltage is induced in the demodulator input windings, which produces a current corresponding to the lower side band. These currents pass through the band filter *k* and enter the circuits of the demodulator *l* where the oscillator *d* supplies the carrier current so that the demodulator delivers the voice current in its output circuit. The amplifier *m* amplifies the voice current, to allow for the apparatus and receiving-circuit losses, to the proper strength. This voice current now enters the hybrid coil *a* at the points *2* and *6*, half going to the listening subscriber's circuit and half having its energy dissipated in the balancing network *b*.

Terminal Arrangement With Four Channels.—In this system a complete set of terminal apparatus provides four superimposed telephone channels. A simplified schematic diagram is shown in Fig. 18, which, however, only shows the necessary hybrid coils *a*, balancing networks *b*, modulators *c*, oscillators *d*, filters *e*, and *f*, demodulators *g*,

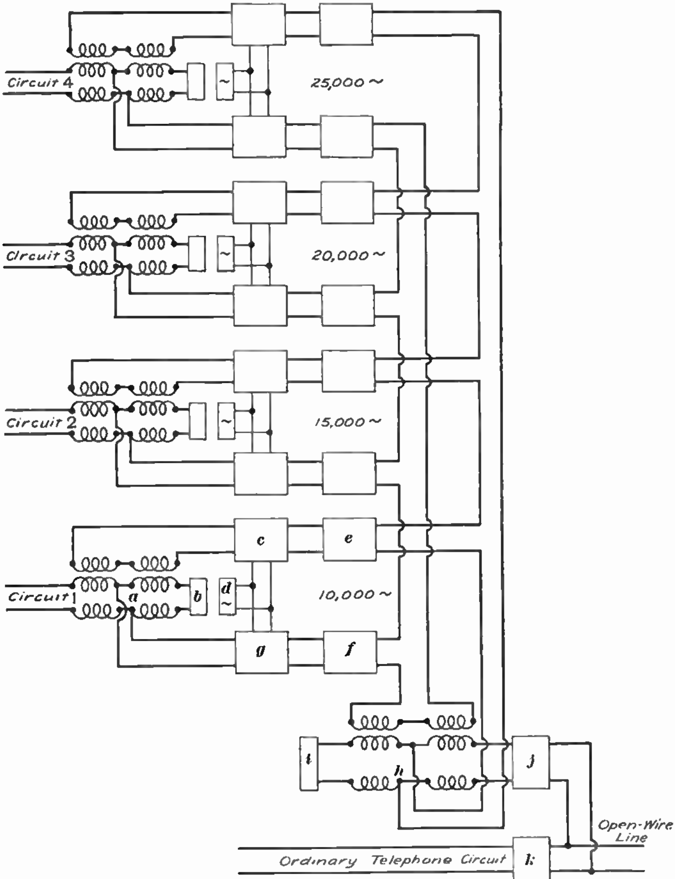


FIG. 18

and the apparatus common to all channels, including coil *h*, network *i*, and the filters *j* and *k*, much other apparatus being omitted for the sake of simplicity.

The carrier frequencies are 10,000 cycles per second for the first channel, 15,000 for the second, 20,000 for the third, and 25,000 for the fourth. The band filters *e* and *f* of the first channel pass frequencies between 8,000 and 10,000, those being the values for the lower side band. The filters in other channels pass frequencies corresponding to their respective lower side bands. The hybrid coil *h* and the balancing network *i* are necessary, because the same frequencies are employed for transmitting in both directions, so as to keep the outgoing and incoming paths from interfering with each other. They can, however, be dispensed with where only two channels are desired by using different frequencies in opposite directions for the same channel, employing what is called *two-way two-carrier operation.*

COMPARISON OF THE TWO SYSTEMS

A comparison of these two systems of carrier telephony brings out the facts that the one with the carrier suppressed is more complex and employs more auxiliary terminal apparatus common to all channels than the other. On the other hand, it has two important advantages:

1. It operates on smaller line currents and therefore does not tend to overload apparatus such as repeaters to the same extent.

2. The transmission equivalent of the system is more constant, so the voice transmission is more uniform, being less affected by the variations in the transmission constants of the line due to weather changes or other causes. This is because the carrier frequency is not transmitted and will become easily understood by considering the system with carrier transmission. Here any change, due to the weather or any other cause, in the transmission constants of the

line will change the side band current in a given ratio and the carrier current in practically the same ratio. Now since the magnitude of the voice current in the output of the demodulator is proportional to the product of the side band and the carrier amplitudes, the voice current will be more nearly changed in the square of this ratio. When the carrier is not transmitted but is supplied at the receiving terminal, any changes in it are generally small, so the output of voice current varies directly instead of as the square of the attenuation of the side band.

CARRIER-TELEGRAPH SYSTEM

Arrangement of Apparatus.—The principles upon which carrier-current telephone systems are based can also be applied to the production of carrier-current telegraphy. In the ordinary telegraph circuit the signals are obtained by breaking up the steady current into a series of pulses, representing the dots and the dashes, separated by intervals of no current or oppositely directed current, representing the spaces. In a carrier-telegraph system the ordinary telegraph signaling current coming from the local telegraph trunk or from a long-distance telegraph line, operates a relay that controls the sending of the carrier current over the high-frequency line during the times of the dots and the dashes of the telegraph messages. At the receiving terminal this high-frequency current is usually amplified and then rectified by the action of vacuum tubes. The resulting rectified current operates a relay that opens and closes a direct-current telegraph circuit from which the signals are read.

Principle of Operation.—A schematic diagram illustrating such a system is shown in Fig. 19. The sending polar relay *a*, actuated from its direct-current circuit, short-circuits and opens the output of the oscillator by

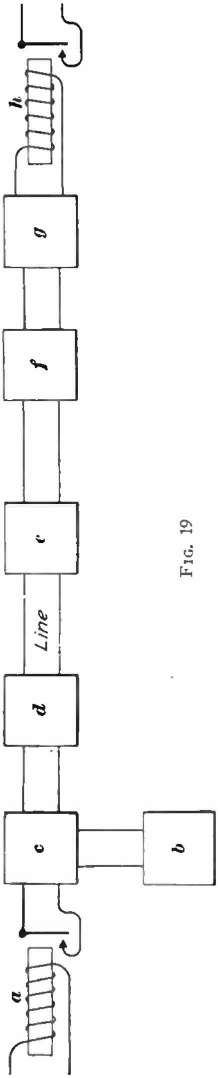


Fig. 19

closing and opening the armature contact. The carrier current from the oscillator *b* is amplified by the amplifier *c* whose output passes out on the line after passing through the sharply tuned selective circuits *d*. At the receiving end of the line the current passes through the sharply tuned selective circuits *e*, being first amplified by the amplifier *f*, and then rectified by the detector *g* so as to be unidirectional, when it actuates the receiving relay *h* by passing through its windings. The opening and closing of the contact of relay *h* repeats the telegraph message into the telegraph loop at the receiving station.

CARRIER-CURRENT INSTALLATIONS

The carrier apparatus is installed in the central office in the same manner as the ordinary telephone apparatus, being mounted on racks that are lined up in rows. Where several carrier systems are placed on the same pole line, it may be necessary to increase the number of transpositions in order to avoid cross-talk between the carrier systems.

The filament currents for the vacuum tubes are usually obtained from the 24-volt telephone batteries, whereas the plate currents are usually obtained from the 130-volt plate batteries. The grid batteries, where used, are dry cells.

The carrier telephone channels are terminated in jacks in the long-distance switchboards like ordinary toll lines, so that the long-distance operators make the necessary connections with the regular toll cords. The operation of ringing is performed by the operator in the standard manner and the signals are automatically relayed as previously described. In fact, to the operators, there is no difference between the carrier channels and the ordinary long-distance trunks.

As the terminal apparatus involved in carrier transmission is expensive, only the longer circuits can be economically operated by carrier currents. The greater the gauge of the wire employed, the greater is the permissible distance between repeaters. In most cases carrier systems provide circuits over 250 miles in length. On sufficiently long circuits a cost study of the situation will often show considerable saving in annual charges in favor of the carrier system, although there might be room for stringing additional open wires on the existing pole line.

Again, where existing wire leads become so congested that additional open wires would require sufficient construction work or possibly even a new pole line, it is usual to install an aerial cable to take the place of the open wire. The first cost of a long toll cable is so high, however, that the deferring of the cable by the installation of the carrier system may therefore be economical. Additional carrier systems are added until it is no longer economical, at which time the cable is installed. Because the cable, when installed, must take care of future growth, and the carrier system merely takes care of the immediate demands, the carrier system will prove more economical in the beginning of the turnover. Under these conditions the use of the carrier system is an intermediate and temporary plan between the use of the open-wire and the final cable circuits. When the cable is installed the carrier apparatus is released for use under another similar case, since its life is usually longer than the time involved during the change over of the plant from open-wire circuits to cable circuits.

The carrier-telegraph circuits are among those used by the Bell System to furnish leased wire service, which is a service that allows of no interruption and demands high-grade transmission.

CARRIER TELEPHONY ON POWER LINES

FUNCTIONS OF TELEPHONE IN POWER DISTRIBUTION SYSTEMS

With the growth of electric power systems to the extent of a single system including several widely separated generating stations, a number of substations or distributing centers, and distributing networks covering large areas, it has become necessary, in order to direct and control the operation of such a system properly to have a reliable system of communication so that the various operators can keep well in touch with one another.

This is done either by having privately owned telephone lines or by making use of public service telephones. Where a power company desires to have a privately owned telephone system, one way in which it may be provided is by means of a carrier system that uses the conductors of the power line itself upon which to superimpose the carrier current of the telephone system. Using the power-line wires without a ground return makes it possible to secure telephone communication free from noise and as good as that of a commercial toll circuit. In what follows some of the feautres of the carrier system adopted by the

Western Electric Company, after exhaustive study and experimentation, and used in a large number of installations, are pointed out.

CARRIER FREQUENCIES

Two-way, or duplex, operation is obtained by making use of two different carrier frequencies for transmission in opposite directions. The frequencies selected lie between 50 kilocycles and 150 kilocycles, because at these frequencies efficient coupling to the power lines can be obtained, and also because it has been found that below 50 kilocycles the power transformers of the system may introduce excessive attenuation for particular frequencies and below 10 kilocycles transfer considerable carrier-frequency power into their secondaries. Above 50 kilocycles and up to 150 kilocycles the attenuation is not excessive and is independent of the conditions on the secondary side of the power transformers.

Since the two wires of the carrier system cannot be directly connected to the high-voltage power wires, the coupling of the two systems is brought about through the capacitance of condensers. The coupling condensers may be either of the usual concentrated type or else of the distributed capacity type. The distributed capacity type consists of two coupling wires suspended parallel to the power wires for a distance of 1,000 feet or so, each coupling wire acting as one plate of a condenser and the adjacent power wire or wires as the other plate.

A carrier system in which the carrier and both side bands are transmitted was decided upon, because at the previously mentioned frequencies, for the carrier current it was difficult to provide the proper filters for suppressing the unwanted frequencies due to the modulation in a suppressed-carrier system.

LAYOUT OF INSTALLATION

Coupling and Protective Apparatus.—A schematic wiring diagram of one terminal of a carrier system employing high-voltage coupling condensers is shown in Fig. 20. These condensers are indicated at *a*. Those shown are about .003-microfarad capacitance each, made up of a large number of small condensers in parallel, the entire assembly being immersed in transformer oil. The double horn-gap arrester, shown at *b*, is for the purpose of limiting the voltage to ground. The filter coil unit is shown at *c*, and the filter and protector unit at *d*.

A circuit diagram of the protection circuits including the filter-coil unit and the filter and protector unit is shown in Fig. 21. The terminals *a* are connected to the power-line coupling wires or condensers. The air-gap arrester *b* limits the voltage to ground and insures that the fuses *c* will not arc over should the coupling capacitance break down. The filter-coil (*c*, Fig. 20) consists of the series coils *d*, the impedance coil *e*, and the condensers *f*. The coil *e* has its midpoint grounded and is of low impedance to the power frequencies so that any 60-cycle potentials would be drained off. The filter-coil unit allows the carrier frequencies to pass.

The filter and protector unit (*d*, Fig. 20) begins with a fused switch *g* and surge arrester *h* such as are commonly employed for protection of telephone lines exposed to power lines. The fuses actually form the blades of the switch while the protector *h* is a 1,500-volt break-down spark gap to ground. Next comes a 500-volt break-down vacuum gap *i* across the line and the series coils *j* followed by series condensers *k* of about .007 microfarad each and capable of withstanding 7,500 volts. The 500-volt vacuum gaps *l* are to protect the winding of the repeating

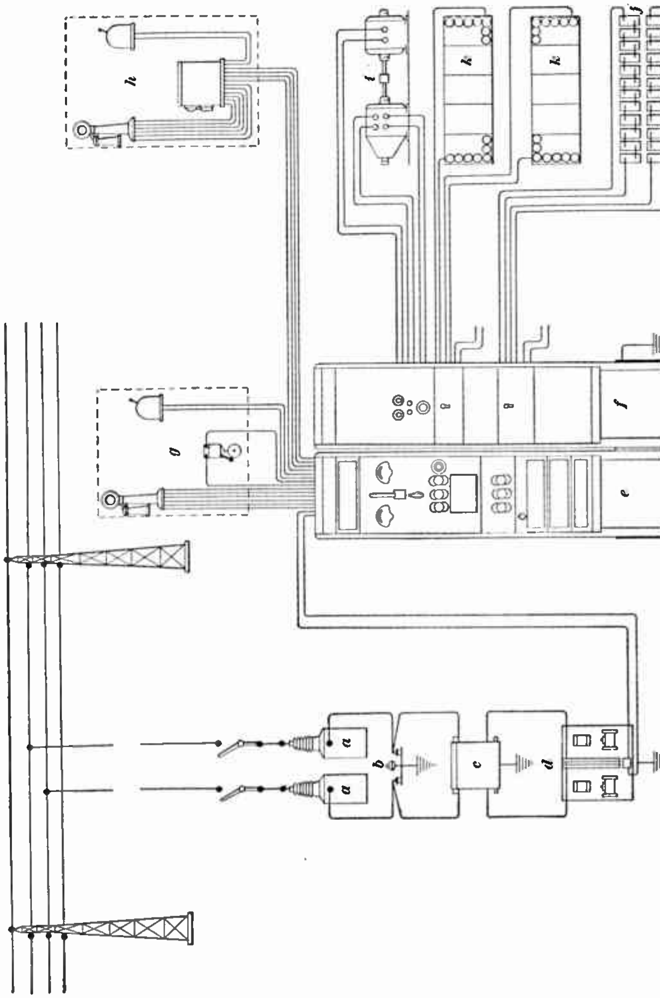


FIG. 20

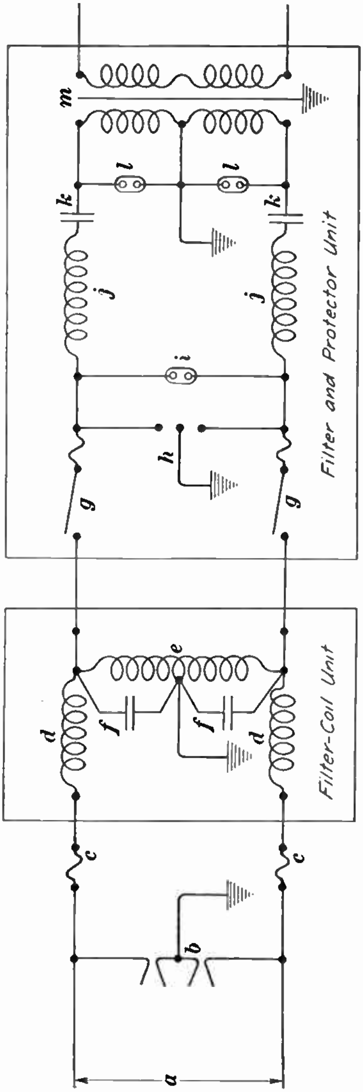


FIG. 21

coil *m*, which has the midpoint of its line side winding grounded. As a final protection this repeating coil is built with a grounded shield between its windings.

Carrier and Power Panel.—The carrier panel and the power panel are shown, respectively, at *e* and *f*, Fig. 20, and illustrated in Fig. 22.

On the carrier panel is mounted at *a* a high-pass filter that only allows frequencies above 100 kilocycles to pass. The vacuum tube *b* is used as a 50-watt amplifier. The vacuum tube *c* acts as a speech amplifier or modulator. The vacuum tube *d* acts as a Hartley oscillator with inductive feedback. The vacuum tube *e* acts as a high-frequency amplifier. These tubes are in the transmitting circuits.

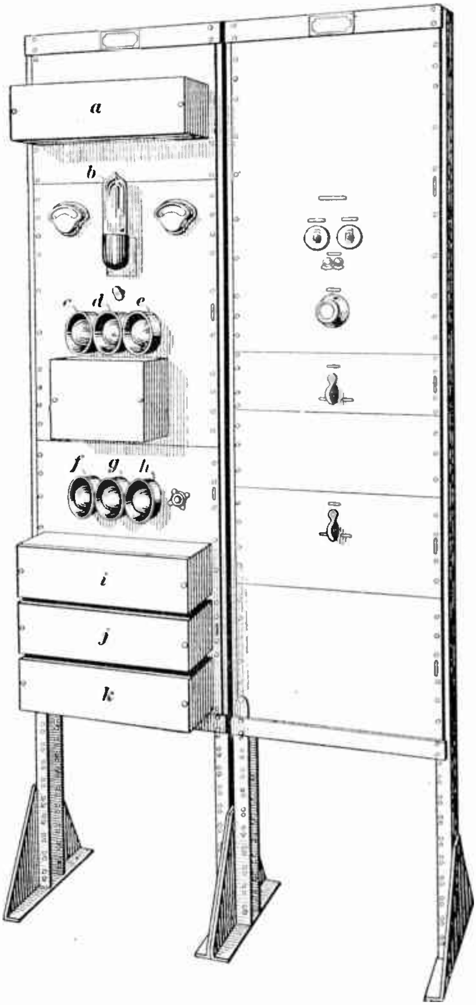


FIG. 22

The 50-watt amplifier *b* is normally disconnected but thrown in by a simple switching arrangement when the normal output of one watt is not sufficient on account of faulty power-line conditions. When this tube is used the output of the normal transmitting circuit is impressed on its grid, so that the output becomes fifty times the normal.

The modulation by the voice current, instead of becoming effective in the output of the oscillator tube *d* as ordinarily, does so in the output of the high-frequency

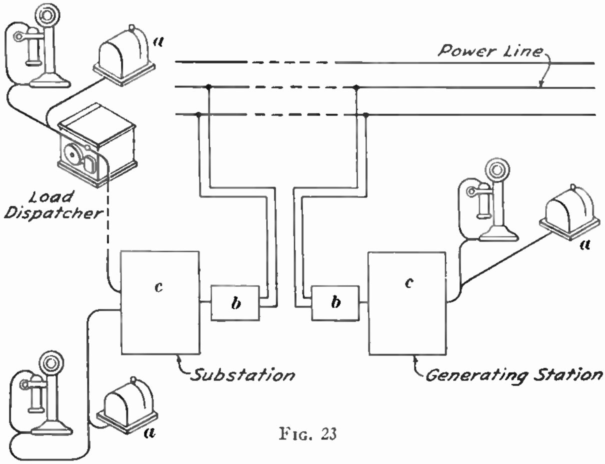


FIG. 23

amplifier tube *e*, thereby increasing the modulated power without overloading the amplifier. Since two-way operation is obtained by transmitting at two different carrier frequencies, one in each direction, and since the lower frequency is always assigned to the calling station, it becomes necessary that the transmitting circuit be able to operate at two different frequencies; below 80 kilocycles when the station is the calling one, and above 100 kilocycles when it is the called one. This is accomplished automatically by the operation of a relay that changes the capacitance in the oscillating circuit and so its frequency. Tubes *f*, *g*, and *h* are in the receiving circuit, being, respectively, a carrier-frequency amplifier, a detector, and an audio-frequency amplifier. At *i*, *j*, and *k*, respectively, are mounted the signaling and voice-frequency equipment, the remote control equipment, and the low-pass filter, which only passes carrier frequencies below, say, 80 kilocycles.

Signaling Arrangement.—Ringing or signaling is accomplished by sending spurts of carrier frequency out on the

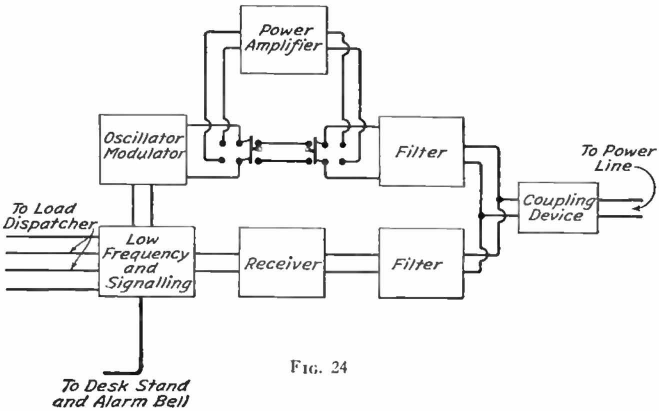


FIG. 24

line. This is caused by operating the relay in the oscillating circuit. These spurts will be either below 80 kilocycles or above 100 kilocycles, depending on which filter is connected to the transmitting circuit at that time. In the normal or non-operated state, each carrier terminal is arranged to receive a signal on a frequency below 80 kilocycles. When the telephone receiver is lifted from the switchhook the carrier terminal corresponding to this telephone receiver has its circuits automatically arranged to transmit on a frequency below 80 kilocycles and to receive on a frequency above 100 kilocycles. When the ringing key is operated at the calling station, spurts of frequency below 80 kilocycles are sent out on the line to all the other stations. The called station is the only one that will have its selector relay operate and ring the bell. When the called station answers by lifting his receiver, his carrier terminal is automatically arranged to transmit on a frequency above 100 kilocycles and to receive on a frequency below 80 kilocycles. The voice-frequency circuits are those employed in the ordinary commercial telephone circuits. The operator's and dispatcher's telephone sets are shown, respectively, at *g* and *h* of Fig. 20. The power supply for operating this system is usually obtained from a motor-generator set *i*, which delivers direct current at 800 volts required by the plate circuit of the high-power amplifier. The motor-generator set is driven from the 24-volt storage batteries *j*. The 150-volt storage batteries *k* furnish potentials for the plate circuits of the receiver tubes, and the low-power transmitter tubes. The 24-volt batteries besides running the motor-generator set furnish the filament currents for the vacuum tubes. In Fig. 23 is shown a schematic diagram of a carrier system for power lines. The selective ringing keys are shown at *a*, the coupling condensers at *b*, and the carrier equipment at *c*. The carrier equipment is shown in more detail in Fig. 24.

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Vol. IV

Radio Receivers and Servicing

RADIO RECEIVERS

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SERVICING OF RADIO RECEIVERS

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PREFACE

The popular interest in radio is due chiefly to the reception of programs transmitted by radio broadcasting stations. An immense industry has been built around this branch of radio, giving employment to thousands who by their training and experience are qualified to serve it.

This volume was prepared especially to acquaint the reader with the fundamentals of radio reception and with methods of locating and overcoming the difficulties in radio reception. The instruction on Radio Receivers begins with the crystal detector and is followed logically by regenerative receivers, radio-frequency amplifiers, neutrodyne sets, reflex set, superheterodyne receivers, short-wave receivers, single-side-band receiver, power amplifiers, a.-c. receivers, and loud speakers.

The Section on Servicing of Radio Receivers contains practical instructions for locating and remedying troubles in radio receivers, loud speakers, power units, and accessories.

This instruction will be helpful to the men in the industry, such as operators, set builders, dealers, salesmen, and service men. In fact, every set owner will profit by this instruction inasmuch as it will acquaint him with the possibilities and limitations of his own set and teach him how to obtain the utmost service from the equipment he may have.

INTERNATIONAL CORRESPONDENCE SCHOOLS

CONTENTS

RADIO RECEIVERS AND SERVICING

RADIO RECEIVERS

FUNDAMENTAL THEORY OF OPERATION

In the course of radio reception, the receiving antenna is subjected to the field of a traveling wave emanating from a radio transmitting station, and radio-frequency currents are induced in the antenna system. This radio-frequency energy is very feeble and some appreciation of this fact may be derived from the following discussion.

A non-directive radio transmitting station will be considered. Since it is not directive, energy is radiated from this transmitter with equal strength in all directions. At a given distance from the transmitter the energy radiated is scattered over the entire surface of a sphere having a radius corresponding to the distance from the transmitter. Owing to the relative size of the receiving antenna, the latter can only cover an extremely small fraction of the sphere in question, hence the minuteness of the induced currents.

At the receiving station the antenna functions to intercept the traveling waves from the transmitting station and the action is manifested by the very feeble radio-frequency currents in the antenna circuit. The problem at this point is to establish a means of sensing the interception of radio waves. In regard to the feasibility of visualizing the current in the antenna circuit, it should be considered that a radio-frequency milliammeter would not be sufficiently sensitive to indicate the value of the current. Even if it could, it would have too slow an action to follow the dots and dashes of the telegraph code at the speed with which they are transmitted in normal operation. In the case of radio telegraph communication, if a meter of sufficient sensitivity could be produced whose indicating element could follow the dots and dashes of the code, the signals could be read by the eye, but this is extremely impractical and it has been found that aural reception of radio telegraph signals must first be effected.

It might be stated at this point that in large commercial radio telegraph receiving stations these received audio-frequency signals are amplified and then rectified, producing dots and dashes in the form of unidirectional pulses. These pulses are applied to sensitive recorders that record the dots and dashes in ink on a moving tape. This makes it possible for the receiving operator to receive by either the eye or the ear or both.

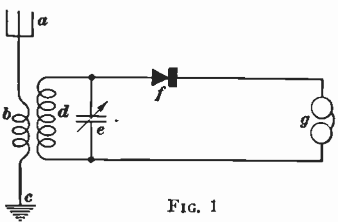


FIG. 1

In the case of radio telephone reception, visual reception would be unintelligible, so this necessitates aural reception. Thus in the case of radio telegraphy and radio telephony aural reception is necessary. A fundamental receiving circuit is shown in Fig. 1. The antenna a is connected to one end of the coupling coil b, and the ground c is connected to the other end. The radio-frequency currents induced in the antenna pass to ground through the coil b. The antenna circuit is not tuned to any particular wavelength, hence it is considered aperiodic.

The two coils *b* and *d* constitute a radio-frequency step-up transformer. This is desirable, owing to the fact that the feeble energy in the antenna circuit consists of a relatively high current and low potential, and what is desired for application to the detector is a low current at a high potential. Thus, the potential available across the coil *b* is stepped up to a relatively high potential, which is available across the coil *d*. This potential is still further increased by shunting a condenser *e* across the coil *d* so that the combination may be tuned to the frequency of the incoming wave. This tuning operation not only produces maximum voltage cross the coil *d* and the condenser *e* at the desired wavelength, but it also selects the wavelength desired and tends to suppress the application of signal voltages on other wavelengths to the detector circuit.

The function of the detector *f* is to change the radio-frequency signal into an audio-frequency signal that can be applied to the phones *g*. The thought arises at this time, why not connect the phones directly in series with the antenna circuit. If there is enough energy in the output circuit of the receiver shown in Fig. 1 to actuate the diaphragm of the telephone receivers, or phones, *g* there should be sufficient energy to accomplish this operation in the antenna circuit. A consideration of Fig. 2 will help explain why the phones cannot be made to function in the antenna circuit.

A series of wave trains that are sent out from a damped-wave radio-telegraph transmitting station, such as a quenched-spark transmitter, are shown in Fig. 2 (*a*). Each time the transmitting key is pressed down, wave trains are sent out at an audio-frequency rate, possibly 1,000 per second. Each one of these wave trains is made up of radio-frequency oscillations that are of the order of 500,000 cycles per second, if the wavelength is 600 meters.

Even if there were sufficient current in the antenna circuit, caused by the incoming signal, to operate the receiver diaphragm, the diaphragm could not follow the radio-frequency changes in current because it has a period of its own and also possesses a certain inertia which prevents it from vibrating at such a high rate. Even if it

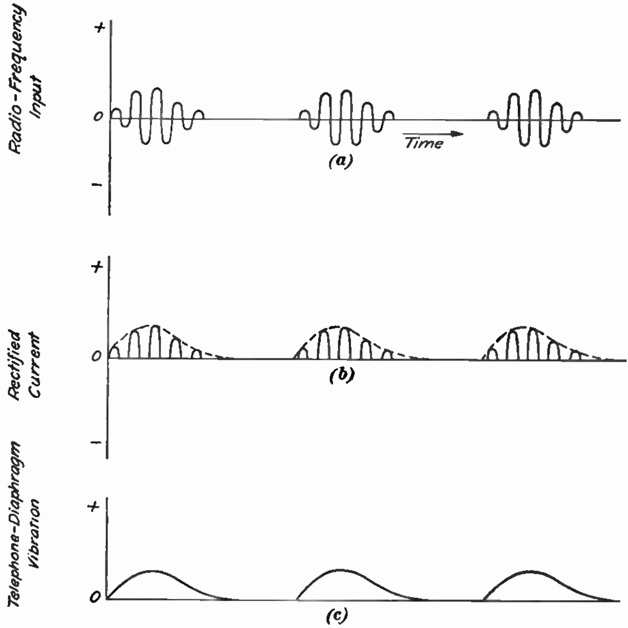


FIG. 2

could vibrate at such a high rate, the human ear would not be affected, since the highest frequencies audible to the human ear are between 16,000 and 20,000 cycles per second.

It might then be reasoned, why does not the telephone receiver connected in series with the antenna circuit follow the average change in current. The answer is, it does.

The average change in current is zero, as will be noted from a consideration of Fig. 2 (*a*). The radio-frequency variations in current go as far in the positive direction as in the negative direction and the average is zero. The function of a detector is to change the nature of the radio-frequency in such a manner that its average value will not be zero, and it does this by rectifying the radio-frequency input as shown in view (*b*).

The detector is a device that has unilateral conductivity. It allows the passage of current in one direction only. The nature of the current in the output circuit of the detector is shown by view (*b*). The detector suppresses the negative waves, and the average of the positive waves results in a positive current that is applied to the phones. The telephone-diaphragm vibrations for each wave train are indicated by view (*c*). The pulses of current indicated in Fig. 2 occur at an audio-frequency rate, 1,000 per second, hence the diaphragm in the telephone receivers can respond to the current variations and vibrates in synchronism with the current pulses. This vibration sets up sound waves that are sensed by the ear. Thus, every time that the transmitting key is depressed a 1,000-cycle note is heard in the phones.

In the case of radio telephony, the radio-frequency oscillations vary in accordance with the audio-frequency signals which it is desired to transmit. The radio-frequency input to the receiver is in the nature of a radio-frequency current whose amplitude is varying at an audio-frequency rate. The negative halves of the radio-frequency oscillations are chopped off by the action of the detector, and the phones record the audio-frequency variations in the current in the detector output circuit. The term *detector* is misleading. This device is virtually a *rectifier* and the phones detect the incoming signal.

CRYSTAL DETECTORS

There are a number of crystals that have unilateral conductivity; that is, they offer a high resistance to the passage of a current in one direction and a low resistance to the passage of current in the opposite direction. The following is a list of some of the crystals that have this property: iron pyrite, galena, molybdenum, bornite, and carborundum. A characteristic curve for crystals of this type is shown in Fig. 3. It will be noted that the voltage applied to the detector is plotted horizontally and the resultant current through the detector is plotted vertically.

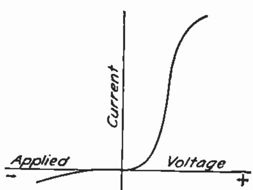


FIG. 3

A consideration of the characteristic crystal curve will reveal that, if an incoming oscillation produces approximately equal and opposite potential variations across the detector, the output current during the negative half cycle is negligible as compared with the output current during the positive half of the cycle. This effects detector action, or rectification.

VACUUM-TUBE DETECTORS

DIODE DETECTOR

A three-electrode vacuum tube may be used as a detector or an amplifier or as a combination of both, according to the method of making connections. When it is used as a detector alone, it functions as a diode, or two-element tube, and not as a triode, or three-element tube, so it follows that a two-electrode vacuum tube can also be used as a detector.

The method of connecting a three-electrode vacuum tube to make it function as a detector in a receiving circuit, without using its amplifying propensities, is shown in

Fig. 4. The vacuum tube with its plate and grid connected together is inserted in place of the crystal detectro as previously explained. The plate-grid connection forms one terminal of this type of detector and the negative filament connection is the other detector terminal. In the course of broadcast reception, there is small chance of distortion occuring in the detector circuit when this scheme of connections is used.

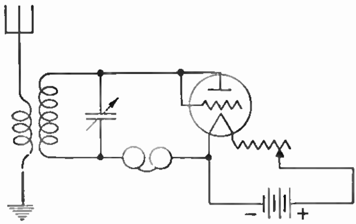


FIG. 4

BIAS DETECTOR

The scheme of connections for the bias detector are shown in Fig. 5, and the characteristic plate-current grid-voltage curve for a three-element tube is shown in Fig. 6. The grid of the tube is held sufficiently negative by means of the bias, or *C*, battery, Fig. 5, to cause the incoming signal voltage to operate on the lower bend of the plate-current curve as shown in Fig. 6. The operating point on the plate-current curve is such that the negative half of an incoming potential oscillation causes far less change in the plate current than the positive half of the oscillation. A train of oscillations applied to the grid of this type of detector tube causes an average change of plate current which is positive, hence detector action and amplification are both effected. One of the advantages of this type of detector

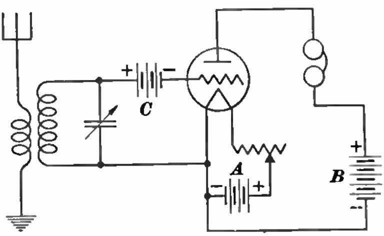


FIG. 5

is experienced in the course of radio broadcast reception. The output of this type of detector is quite free from distortion caused by overloading, because the grid of the tube is held negative. Detector action takes place by virtue of the fact that the negative half of the incoming potential cycle operates from the lower bend of the plate current curve downwards, and the positive half of the incoming oscillation operates from the lower bend upwards. Thus, it would be necessary for the grid voltage to be such as to carry the plate current to a value on the upper end of the characteristic curve to produce distortion.

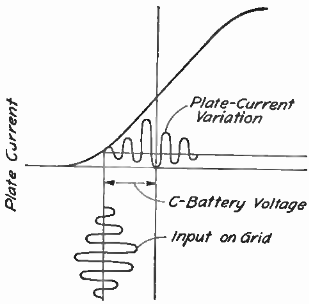


FIG. 6

Another advantage of this type of detector over the diode type is that in the diode the unilateral impedance characteristic of the tube is the only feature that is made use of, whereas, in this case, its ability to amplify is made use of and the incoming signal voltage is applied to the grid of the tube; thus, its effect is multiplied in the plate circuit by the amplification factor of the tube.

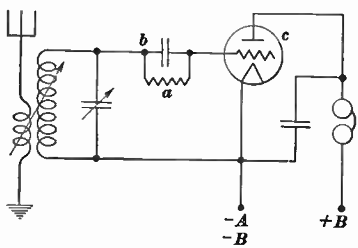


FIG. 7

DETECTOR USING GRID CONDENSER AND GRID LEAK

A schematic circuit arrangement for effecting detector action by using a grid leak *a* and grid condenser *b* is shown in Fig. 7. The action is shown graphically in Fig. 8. The incoming signal voltage is applied to the grid of the tube *c*, Fig. 7, and the grid is alternately positive and negative. When the grid goes positive, it not only causes an increase in current to the plate of the tube, but the grid itself accumulates some of the electrons that are flowing from the filament toward the plate. When the grid goes negative it does not lose

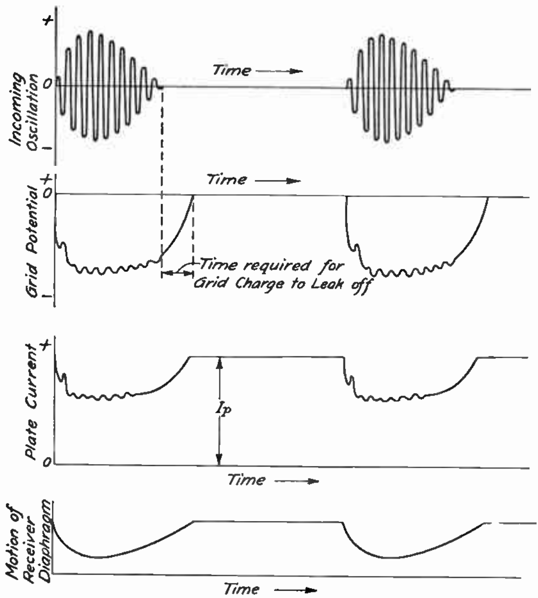


FIG. 8

all of the electrons that it has accumulated, owing to the fact that it takes longer for any appreciable amount of electrons of leak off, than the time duration of the negative half of the cycle of the oscillatory signal input, this being a function of the value of grid leak used. Thus, before the electrons leak off from the grid, the latter goes positive, again and accumulates more electrons. It is in this manner that the grid gradually becomes more and more negative during the passage of a wave train. The subsequent effect is to cause an average change in the plate current that is less than normal and it is in this manner that detector action is effected in this type of detector. The function of the grid leak *a* is to allow the negative charge on the grid to leak off between wave trains and, to prevent the electrons from leaking off between oscillations.

RECEPTION OF UNDAMPED WAVES

The fundamental circuits discussed have all been for the reception of waves whose amplitude changes at an audio-frequency rate. For instance, in the case of the signals from a quenched-spark transmitter, the wave-train frequency is, say, 1,000 cycles per second; therefore, the amplitude of the radio-frequency waves reaches its maximum value and its minimum value 1,000 times per second, and it is by virtue of this fact that the detector is able to produce the desired sound which is heard in the ear phones.

In the case of icw. (interrupted continuous wave), the continuous waves generated at the transmitter are cut in and out at an audio-frequency rate by means of a chopper. If the chopper turns the radio-frequency oscillations of continuous amplitude on and off 1,000 times per second, the amplitude of the transmitted wave will reach its maximum and minimum 1,000 times per second. It is by virtue of this fact that detector action at the receiver produces audio-frequency sounds through the medium of the ear phones.

In the case of radio-telephone transmission and reception, the amplitude of the radio-frequency oscillations generated varies at an audio frequency rate according to the frequency of the speech or music that it is desired to transmit. It is by virtue of this fact that detector action changes the modulated radio-frequency input into audio-frequency currents.

The reception of undamped, or continuous, waves differs somewhat from the foregoing. An undamped wave is one

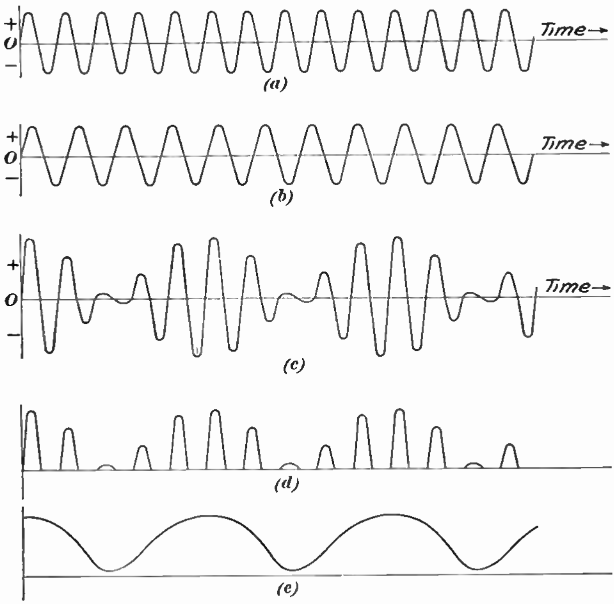


FIG. 9

whose amplitude remains constant and it is necessary that the amplitude of the radio-frequency signal applied to the detector should vary at an audio-frequency rate in order that the detector can function. To change the input into the audio-frequency desired, in the case of cw. it is necessary to provide means at the receiver of changing the amplitude of the radio-frequency input at an audio-frequency rate so that its presence may be manifested by sounds in the ear phones.

In Fig. 9 (*a*) is shown the nature of the incoming cw. signal that is applied to the detector in the circuit shown in Fig. 10, which is a schematic wiring diagram of a circuit for the reception of undamped-wave signals. The traveling wave is intercepted by the antenna. The induced currents in the antenna system pass through the antenna coil *a*, setting up a magnetic field around this coil. This magnetic field threads through the coil *b*, inducing currents therein of the same frequency as the induced currents in the antenna circuit. Owing to the fact that coil *b* and condenser *c* are tuned to the same frequency as that of the incoming wave, there will be maximum voltage across the coil *b* and the condenser *c*.

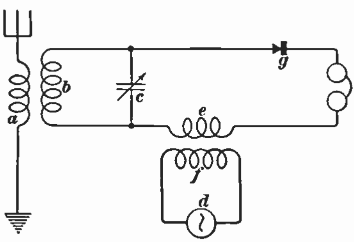


FIG. 10

There is a local generator *d* of radio-frequency oscillations having a frequency 1,000 cycles greater (or less) than that of the incoming signal. Energy at this frequency is induced into the detector circuit by means of the coupling coils *e* and *f*. The current generated by the local oascillator is represented in view (*b*), Fig. 9. Thus these two frequencies are superimposed one upon the other and there is a resultant beat frequency, shown in view *c*, which is equal to the difference between the two radio frequencies, or 1,000 cycles. The amplitudes of views (*a*) and (*b*) are simply added for each interval of time, and the result, as shown in view (*c*), is an alternating current of periodically increasing and decreasing amplitude, the alternating current being at radio frequency, and the rate of change of its amplitude, from maximum to minimum, being at audio frequency. The nature of the current in the output circuit of the detector is shown in view (*d*). The negative half of each radio-frequency oscillation is chopped off; hence, the average change in the rectified current occurs at an audio-frequency rate, and it is this audio-frequency change in the rectified current, shown in view (*e*), that actuates the diaphragm of the telephone receivers.

Considering Fig. 10, a vacuum tube could be used at *d* to generate the radio-frequency oscillations and a crystal detector at *g*. Again, a single three-electrode tube could be used in a circuit to function as a detector, an amplifier, and an oscillator, as will be explained later.

INTERCEPTION AND DETECTION

From the foregoing discussion it is found that the reception of radio signals is fundamentally a case of interception and detection. There must be a means of intercepting the electro-magnetic waves travelling through the ether and a means of changing the radio-frequency currents induced in the antenna system into audio-frequency currents so that they may in turn be changed into sounds of audio frequency intelligible to the human ear. The crystal detector changes the radio-frequency current into an audio-frequency current and the telephone receivers effect the change from audio-frequency currents to audio-frequency sound waves.

Greater sensitivity, or reception from a greater distance, is effected by increasing the amount of signal energy applied to the detector. This can be accomplished by increasing the efficiency of the antenna system or by amplifying the radio-frequency input before application to the detector.

Greater output volume with a given amount of signal energy available in the detector output circuit is a function of the amount of audio-frequency amplification effected.

The fundamental elements involved in radio reception have now been considered. The next consideration will be the different types of receivers, so that it may be learned how the fundamental elements are embodied in the various receivers designed for different wavelengths and duties.

REGENERATIVE RECEIVERS

SINGLE-CIRCUIT RECEIVER

The schematic wiring diagram of a single-circuit receiver is shown in Fig. 11. The detector input circuit is tuned by means of the inductance coil *a* and the condenser *b*. The antenna lead is connected directly to the grid input coil *a*, and the ground is connected directly to the low end of this coil. The grounded end is also connected to the rotor plates of the tuning condenser *b*.

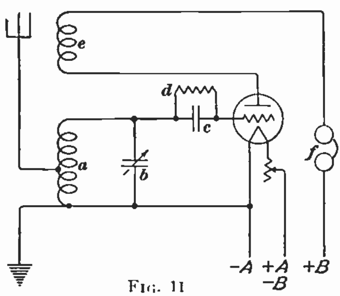


Fig. 11

A grid condenser *c* and grid leak *d* are connected in series with the grid lead to effect detector action. The grid return is connected to the negative filament terminal. This is the scheme of connections when using a UX-200-A detector tube. With some other types of tubes slightly better results are obtained by bringing the grid return to the positive filament terminal.

The plate of the tube is connected to the positive *B*-battery terminal through the feed-back coil *e* and the phones *f*. It is by means of the inductive relation between the feed-back coil *e* and the input coil *a* that regeneration is effected. Regeneration is the feeding back of the radio-frequency signal energy from the plate circuit to the grid circuit, thus allowing it to be reamplified, or boosted, again. This regenerative effect may be carried to the point of oscillation. This point is where the tube starts to oscillate, thus generating oscillations of continuous amplitude and of a frequency that is determined by the constants of the tuned input circuit, consisting of the coil *a* and the condenser *b*.

A circuit of this type can be used to receive damped or undamped radio telegraph signals or it can be used for radio telephone reception. With all the elaborate receiving circuits that are in existence today, there are many that can not equal the performance of this little single-circuit receiver that was one of the first types of broadcast receivers to appear.

300- TO 19,000-METER COMMERCIAL RECEIVER

A schematic wiring diagram of a standard commercial receiver that is used on ships for the reception of telegraph and telephone signals on wavelengths between 300 and 19,000 meters is shown in Fig. 12. The receiver proper provides adequate switching arrangement for covering all wavelengths between 300 and 8,000 meters, employing either a crystal detector or a vacuum-tube regenerative detector. There is a long-wave attachment for this set that allows for tuning in signals on wavelengths as high as 19,000 meters. There is also a two-step amplifier attachment for increasing the output volume of the received signals.

The antenna is connected to a contact arm that can be moved to different taps on the primary winding *a*. The

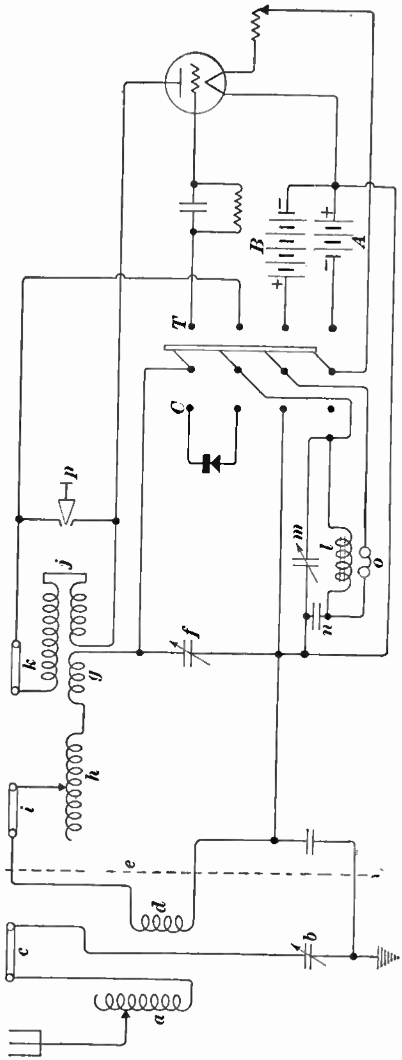


FIG. 12

low end of this winding is connected to the stator plates of a .00045-microfarad variable tuning condenser *b* through two external terminals *c*. These two external terminals are jumpered together when the receiver is being used on the 300- to 8,000-meter band, but when it is desired to tune in stations between 8,000 and 19,000 meters a primary loading coil is inserted at this point in the circuit. The rotor plates of the primary tuning condenser *b* are connected to ground.

The secondary circuit is coupled to the primary circuit by means of the coupling coil *d*, which is inductively coupled to coil *a*. Other than the coupling just mentioned, there is no coupling between the primary and secondary circuits. A shield *e* is inserted between the two circuits.

The .00032-microfarad secondary tuning condenser *f* is shunted across the three coils *d*, *g*, and *h*. Coil *d* is the coupling coil between the primary and secondary circuits; coil *g* is the coupling coil between the plate and grid of the detector tube (when such is used) to effect regeneration; and coil *h* is the tapped secondary tuning coil. Two external terminals *i* are connected in series with the secondary inductance coils to allow for the insertion of a secondary loading inductance for tuning above 8,000 meters.

The stator plates of the secondary tuning condenser *f* are connected to one of the poles of a four-pole double-throw switch, which is used to change from a crystal detector to a vacuum-tube detector. The two positions of this switch may be designated by *T* and *C*, *T* being the tube position and *C* the crystal position. When the switch is in the tube position, the high side (stator plates) of the condenser *f* is connected to the grid of the tube through the grid leak and grid condenser unit. When the switch is in the crystal position, the high side of the condenser is connected to one terminal of the crystal detector.

The plate of the vacuum tube is connected to the feed-back coils *j*, the two external terminals *k* for the long-wave tickler, and the contacts of the change-over switch. These contacts connect the reactance *l* to the plate of the tube in the tube position, and to the second terminal of the crystal detector in the crystal position.

This reactance *l* is tuned by means of the condensers *m* and *n* to the frequency of the signal energy in the output of the detector (audio frequency). The other end of this reactance *l* is connected through the phones *o* to the positive *B*-battery terminal or to the rotor plates of the secondary tuning condenser *f*, according to whether the change-over switch is in the tube or the crystal position. One of the filament leads to the vacuum tube passes through the contacts of the change-over switch, so that the tube filament is not energized when the crystal detector is being used. A push button *p* is provided, which, when depressed, short-circuits the plate coil *j*. This is known as the oscillation test.

This type of receiver is to be found on the majority of ships at sea at the present time. There may come a time within the next few years when the same receiver will be used with a stage or two of radio-frequency amplification ahead of it, but results obtained with this set are at present of such a high standard that it will be some time before it will be superseded by a later model.

REGENERATION BY TUNED-PLATE METHOD

In Fig. 13 is shown a method of effecting regeneration without establishing inductive coupling between the plate and the grid coils. The antenna circuit is aperiodic (untuned), and the grid input circuit is tuned to the incoming signal by means of the inductance coil *a* and the condenser *b*.

Regeneration is effected by tuning the plate circuit to the incoming signal by means of the inductance coil *c* and the condenser *d*. The feed-back from the plate to the grid circuit of the tube is effected by virtue of the capacity coupling between the grid and the plate that is inherent within the tube itself.

RADIO-FREQUENCY AMPLIFIERS

UNTUNED-TRANSFORMER COUPLED RADIO-FREQUENCY RECEIVER

A schematic wiring diagram of a receiver that has three stages of radio-frequency amplification ahead of the detector is shown in Fig. 14. This receiver employs

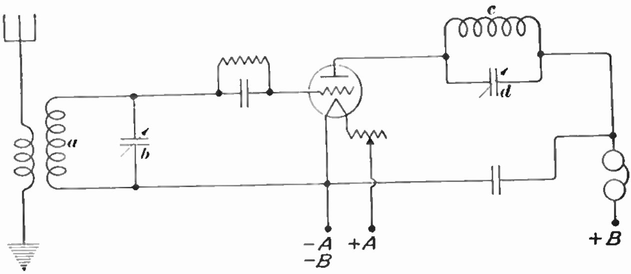


FIG. 13

untuned transformers between the stages of radio-frequency amplification. The antenna is connected to one side of the primary winding of the first radio-frequency transformer *a* and the ground lead is connected to the other end of the same winding. One side of the secondary winding is connected to the grid terminal of the first radio-frequency amplifier tube *b* and the other end of the same winding is connected to the movable contact arm of the 400-ohm stabilizing potentiometer *c*. The extremities of this potentiometer are connected across the *A*-battery supply leads.

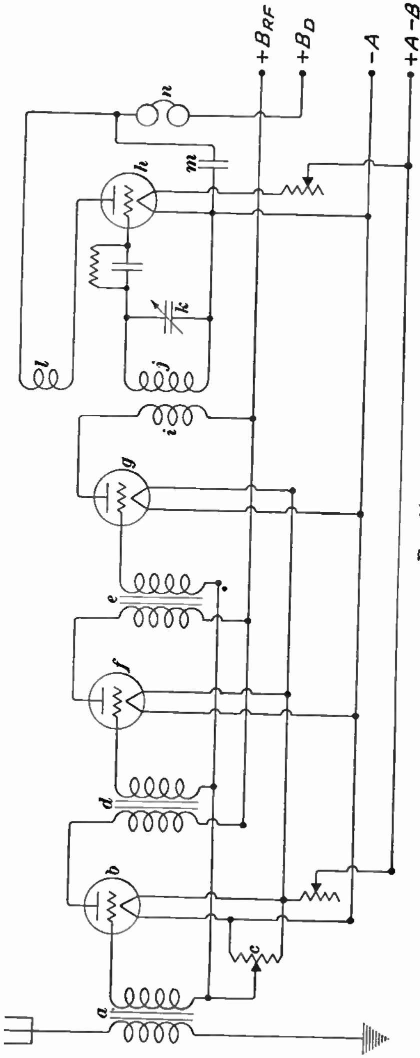


FIG. 14

The two remaining radio-frequency transformers *d* and *c* have their primary windings connected in series with the plates of the two radio-frequency amplifier tubes *b* and *f*, respectively, and their secondary windings in series with the grid circuits of the two radio-frequency amplifier tubes *f* and *g*, respectively.

The low side of the secondary winding of each of the three radio-frequency transformers is connected to the movable contact arm of the stabilizing potentiometer *c*. The function of the stabilizing potentiometer is to afford a means of supplying a small positive potential to the grids of the three tubes in question, which tends to keep them from oscillating.

There is no frequency selection ahead of the detector tube in a receiving circuit of this type. All energy induced in the receiving antenna is passed on to the first radio-frequency amplifier tube and thence to the two succeeding stages, where all incoming radio signals are boosted in voltage for application to the detector tube. The function of the radio-frequency amplifier system in this circuit is to step up the voltage of all the radio-frequency signals that reach it through the medium of the antenna.

The input to the detector is tuned. It is here that a selection is made of the particular signal that it is desired to receive. The tube *g* may be considered the output tube of the radio-frequency amplifier. The output circuit of this tube is coupled to the grid circuit of the detector tube *h* through the plate coil *i* and the grid coil *j*. The detector input circuit is made selective by means of the tuned circuit consisting of the coil *j* and the condenser *k*. The wavelength range depends on the values of the inductance and capacity of these devices.

Regeneration is effected in this circuit by means of the coil *l* in series with the detector plate circuit and coupled to the detector input circuit by means of the inductive relation between the coils *j* and *l*. The condenser *m* is a radio-frequency by-pass condenser, which functions to by-pass the radio-frequency currents in the plate circuit of the detector tube around the phones *n* and the *B* battery, as they offer a relatively high impedance to the passage of currents at radio frequencies. The impedance of the path for radio-frequency currents in the plate circuit of a regenerative detector tube should be as low as possible so as to effect regeneration, if desirable, to a value just below the oscillating point.

ONE-STAGE TUNED RADIO-FREQUENCY WITH FEED-BACK

Circuit Connections.—It was previously pointed out that the old single-circuit receiver with regeneration was one that would offer good competition to many of the elaborate receivers that have been produced since the inception of radio broadcasting. A modification of this receiver is shown in Fig. 15. There is one stage of tuned radio-frequency amplification which boosts the signal voltage before application to the detector tube and also selects the frequencies desired. Regeneration is effected by a feed-back from the plate circuit of the radio-frequency amplifier tube to the antenna circuit by means of the coupler *a*.

The grid circuit of the radio-frequency stage is really a radio-frequency filter. It effects the greatest voltage for application to the grid of the radio-frequency amplifier tube at that frequency to which it is tuned. It will also pass frequencies several thousand cycles greater and several thousand cycles less than that frequency to which it is tuned, but with less and less efficiency, depending on the number of cycles difference between the frequency in question and the fundamental frequency and on the sharpness of tuning of the circuit containing the inductance coil *b* and the condenser *c*. This sharpness of tuning is a function of the amount of resistance in the tuned circuit; the less the resistance the sharper the tuning and the greater the resistance the broader the tuning.

In the course of radio broadcast reception the receiving antenna is subjected to the field of a traveling wave consisting of a carrier frequency with side bands usually up to 5,000 or 10,000 cycles on either side of the carrier. The carrier is the radio frequency that is generated by the

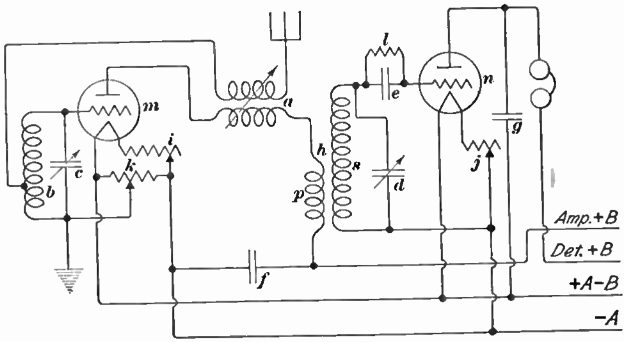


FIG. 15

apparatus in the transmitter and upon which the audio frequencies that are to be transmitted are superimposed. The audio frequencies that are usually transmitted in the course of a radio broadcast are those up to 5,000 cycles. The superimposition of this 5,000-cycle audio-frequency band on the carrier effects the transmission of what is termed the upper side band, with limits of the carrier frequency and the carrier frequency plus 5,000, and the transmission of what is termed the lower side band, with limits of the carrier frequency and the carrier frequency minus 5,000 cycles. Thus it can be seen that it is necessary to pass a 10,000-cycle band through the tuning circuits.

It is very fine to have sharpness of tuning, or selectivity, which means the passage of a narrow band of frequencies, but it is not desirable to have too great a degree of selectivity, as this would mean that some of the frequencies in the side bands would be chopped off and distortion would ensue. In order to effect undistorted reception the loud speaker must reproduce all the audio frequencies that are transmitted by the broadcasting station, it being assumed that the broadcasting station is putting out an undistorted signal.

List and Description of Parts.—It is important in considering the construction of radio broadcast receivers to obtain the best apparatus. If inferior apparatus is used,

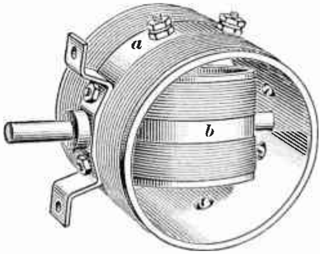


FIG. 16

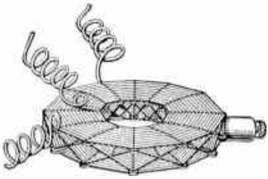


FIG. 17

it may work well for a short time, but there is no assurance that satisfaction will be long-lived. In Fig. 15 the following apparatus is required:

a—Variocoupler. This device consists of two coils, a stator *a*, Fig. 16, and a rotor *b*. Coil *a* is wound with 30 turns No. 24 d.c.c. (double-cotton covered) wire on a 3-inch form. Coil *b* is wound with 30 turns No. 24 d.c.c. on a form that is free to turn within the 3-inch form of coil *a*.

b—Inductance coil, Fig. 15. This is a 44-turn spiderweb coil tapped at fourth turn for the antenna connection, and wound with No. 24 d.c.c. on a 2-inch form, as shown in Fig. 17.

c and *d*—Variable condensers, Fig. 15, .00035 microfarad.

e—Grid condenser, fixed, .00025 microfarad.

f—By-pass condenser, fixed, .1 microfarad.

g—By-pass condenser, fixed, .002 microfarad.

h—Radio-frequency transformer. The secondary winding *s* is a 44-turn spider-web coil, No. 24 d.c.c. on a 2-inch form. The primary winding *p* consists of 6 turns, No. 24 d.c.c. wound on the outside of the secondary coil.

i and *j*—10-ohm rheostats.

k—400-ohm potentiometer.

l—Grid leak, 3 megohms.

m—Vacuum tube, UX-201-A and socket.

n—Vacuum tube, UX-200-A and socket.

In addition to the foregoing, it will be necessary to have a panel; a base board; about 15 feet of bus wire; control knobs for the variable condensers, rheostats, potentiometer, and variocoupler; the required *A* and *B* batteries, (*A*, 6 volts, *B* 90 volts, tapped at center for detector-plate connection); and a pair of telephone receivers (2,000 ohms). If a two-stage audio-frequency amplifier is used in conjunction with this receiver, it is permissible to have the radio- and audio-amplifier tube filament temperature controlled by the same rheostat.

TWO-STAGE TUNED RADIO-FREQUENCY RECEIVER

Circuit Diagram and List of Parts.—The one-step tuned radio-frequency receiver is the first step beyond the single-circuit tuner, and the two-step tuned radio-frequency receiver is the next step beyond the former. It is quite easy to construct a receiver having a single stage of radio-frequency amplification that will operate with satisfactory stability, but it is not so easy to effect stable operation with two stages of radio-frequency amplification, because the inductive and capacitive feed-backs between the radio-frequency stages tend to cause the radio-frequency amplifier tubes to oscillate.

The inductive feed-back is caused mostly by the inter-linking of flux from the tuning coils in the radio-frequency amplifier stages, and the capacity feed-back is caused mostly by the inherent electrode capacity within the tubes themselves. In this receiver the inductive coupling between successive radio-frequency stages has been minimized by the use of closed field coils. These coils are termed D-coils, or figure-8 coils.

A schematic wiring diagram of the receiver under consideration is shown in Fig. 18. The actual apparatus used in the construction of this set is shown in Fig. 19. The following is a list of the material.

a—D-Coil, 3-inch diameter with 14-turn primary and 56-turn secondary.

b—D-Coil 3-inch diameter with single 56-turn winding (tapped at turn 14).

c—D-Coil 3-inch diameter with 14-turn primary and 56-turn secondary.

d—Audio-frequency transformer (6 to 1).

e—Audio-frequency transformer (2 to 1).

f—Output transformer (1 to 1).

g—.0005-microfarad variable condenser.

h—.0005-microfarad variable condenser.

i—.00025-microfarad variable condenser.

j—.0005-microfarad variable condenser.

k—.00025-microfarad grid condenser.

l—.002-microfarad by-pass condenser.

m—Four .1-microfarad by-pass condensers.

n—200-ohm potentiometer.

o—6-ohm rheostat.

p—10-ohm rheostat.

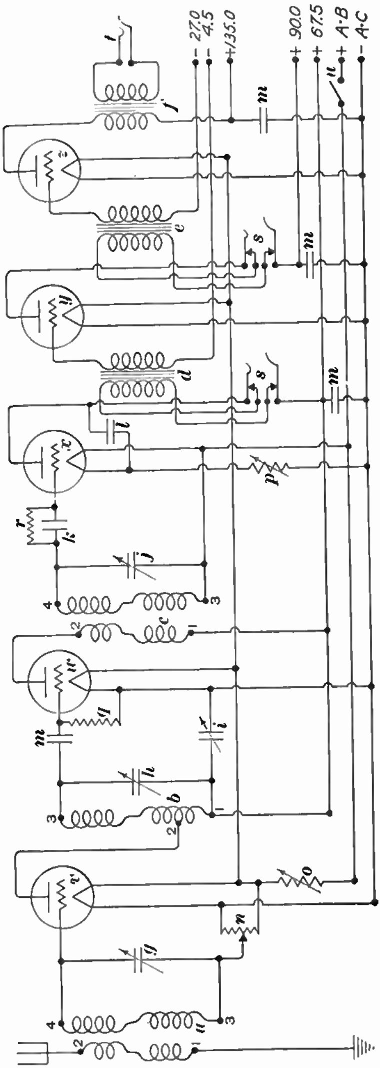


FIG. 18

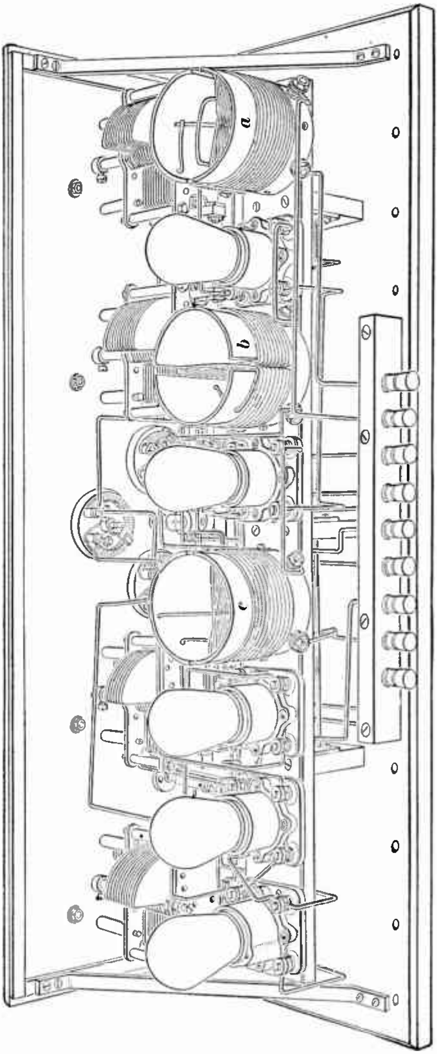


FIG. 19

q—5-megohm grid leak.
r—3 megohm grid leak.
s—Two double-circuit output jacks.
t—Single-circuit output jack.
u—Filament switch.
v and *w*—Two UX-201-A amplifier tubes and sockets.
x—UX-200-A detector tube and socket.
y—UX-201-A amplifier tube and socket.
z—UX-171- power-amplifier tube and socket.

The above is a list of the material that was used by the writer in the construction of a receiver to aid in the description of the functioning of this particular type of set.

Construction of Radio-Frequency Transformers.—The main feature in the receiver shown in Figs. 18 and 19 is the type of radio-frequency transformer used to minimize interstage inductive coupling, and, although this type of coil has been used commercially for some time, the writer had the honor of being the first to present them to the broadcast public through the medium of radio magazines. When the first receivers of this type were constructed there were no coils on the market that were of the particular type embodied in this set, so it was necessary for the set builder to construct them himself. Therefore, the construction of a radio-frequency transformer of the D-coil or figure-8 type will be discussed and this discussion and subsequent theory should give one a good idea of their inherent characteristics.

The following is the description of the construction of the D-coil: Procure a piece of bakelite tubing 3 inches in diameter and 3¼ inches long. Cut a slit ½ inch wide through the side of the tube extending from one end to within ¾ inch of the other end. Cut a similar slit directly opposite. The transformers *a*, *b*, *c*, Fig 19, show the physical characteristics of the D-coil. Four terminals,

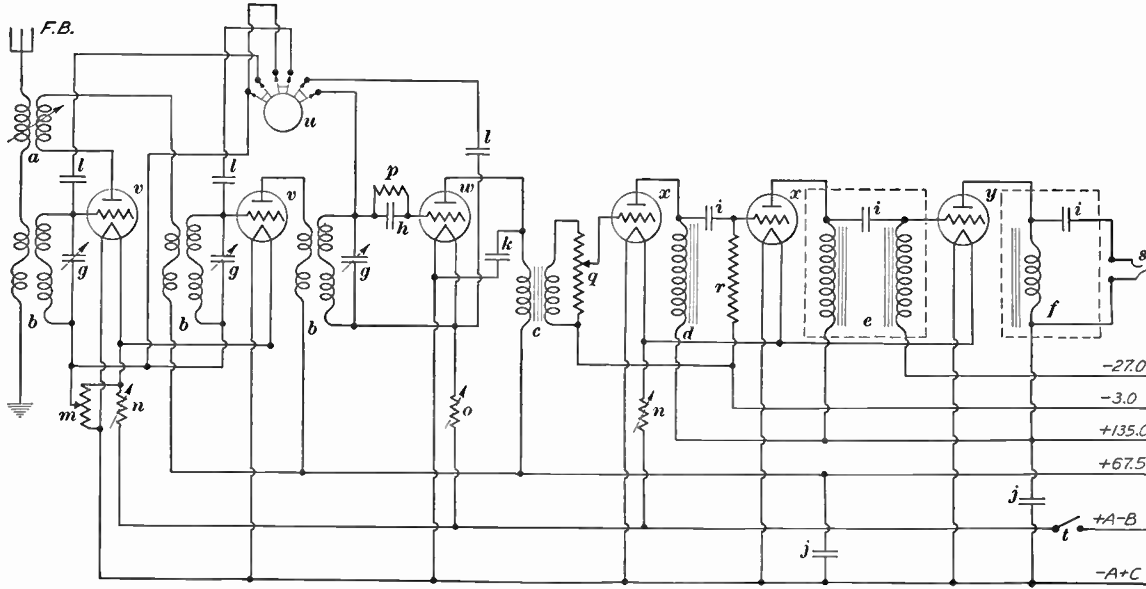


Fig. 20

which may be labeled 1, 2, 3, and 4, are located around the end of the tube that is not slit. The reason for putting them at this end is because there is space that is free from the winding and this end is more solid, as there is no slit in it. Two of the four binding posts on each transformer are shown in Fig. 19.

Use No. 24 d.c.c. copper wire. A half-pound spool will have enough wire for all three transformers. When preparing to wind either transformer *a* or *c* cut off 20 feet of the wire from the spool for the primary coil. Fasten one end of this primary wire to the inside of terminal 2. Fasten one end of the wire left on the spool to the inside of terminal 3. This wire will form the secondary coil. Wind both of these wires together through a slit and first around one half of the form, then through the opposite slit and around the other half of the form. This is continued until 14 complete turns have been wound on the form, whereupon the free end of the primary winding is brought to terminal 1 and connected thereto. The secondary winding is continued until 56 turns have been wound. The free end of the secondary winding is then connected to terminal 4. The terminals *1*, *2*, *3*, and *4* of transformers *a* and *c*, Fig. 18, are connected in the circuit as indicated in the figure.

The coil *b*, Fig. 19, is wound in a manner similar to coils *a* and *c*, except there is only one winding made up of 56 turns of No. 24 d.c.c. Coil *b* is tapped at the fourteenth turn and from there is connected to the plate of the tube *v*, Fig. 18.

Radio-Frequency Receivers With Figure-8 Coils.—A circuit digram of a receiving set with two stages of radio-frequency amplification, a detector, and three stages of transformer and choke-coil coupled audio-frequency amplification is shown in Fig. 20. The construction of this set is shown in Fig. 21. The following is a list of parts indicated in Fig. 20.

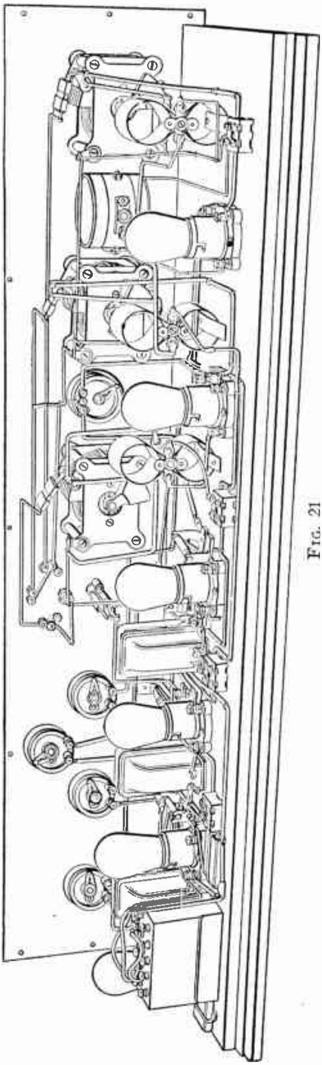


Fig. 21

a—Feed-back coupler.

b—Three figure-8 radio-frequency transformers.

c—Audio-frequency transformer (6 to 1).

d—200-henry impedance.

e—Double-impedance coupler.

f—Speaker filter.

g—Three .00035-microfarad straight-line frequency condensers.

h—.00025-microfarad grid condenser.

i—Three .05-microfarad fixed condensers.

j—Two .1-microfarad by-pass condensers.

k—.002-microfarad by-pass condenser.

l—Three .00025-microfarad fixed condensers.

m—200-ohm potentiometer.

n—Two 6-ohm rheostats.

o—10-ohm rheostat.

p—3-megohm grid leak.

q—500,000-ohm potentiometer.

r—100,000-ohm grid leak.

s—single-circuit output jack.

—Filament switch.

u—6-point switch.

v—Two UX-201-A amplifier tubes and sockets.
w—UX-200-A detector tube and socket.
x—Two UX-201-A amplifier tubes and sockets.
y—UX-171 power amplifier tube and socket.

Since the main feature of the receiver shown in Fig. 20 as well as of that shown in Fig. 18 is its ability to minimize inductive interstage coupling, it will be well to find the reason for this effect. The drawing shown in Fig. 22 will aid in the explanation of the theory of the closed-field coil in question. This theory applies to both the double-D and the figure-8 coils.

A current through the secondary winding of this transformer passes in one direction through the winding on the side marked *a* and in the opposite direction through the winding on the side marked *b*. The lines of force emanating from section *a* and those emanating from section *b* are in opposite directions. These lines are additive through the centers of section *a* and *b*. The effects of the stray lines of force in opposite directions from sections *a* and *b*, in the area surrounding the coil, have a tendency to neutralize, as may be observed from the arrowheads on the lines representing the lines of force in Fig. 22.

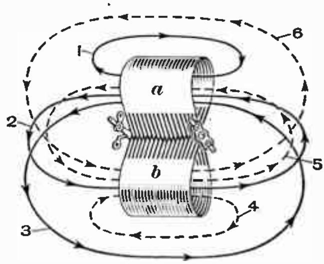


FIG. 22

The flux density, caused by the current through the windings of the sections *a* and *b*, is greatest through the centers of the two sections and is a minimum around the outside of the coil. This is the reason why this type of coil is termed a close-field coil. The field is closed through the center of the two sections. The foregoing discussion also shows why the external field is a minimum.

NEUTRODYNE RECEIVER

Neutrodyne-Receiver Theory.—If efficient and stable operation in a radio-frequency amplifier system is desired, it is necessary to eliminate both the inductive and capacitive feed-back. The D-coil or figure-8 coil type of receiver shows one method of eliminating, to a great extent, the inductive feed-back. In the neutrodyne receiver a method of neutralizing the capacity feed-back is put into practice.

Thus, with the inception of capacity neutralization for receiving sets it became possible to eliminate both the inductive and the capacitive feed-back. A combination figure-8 coil receiver with capacity neutralization constitutes a decidedly worthwhile receiver. In the majority of the standard neutrodyne receivers, which feature capacity neutralization, inductive coupling is minimized by setting the coils at a definite angle to each other. The position of the coils causes the lines of force emanating from one coil to pass through the other coils in a direction parallel to the wires that constitute the winding of the coil through which the flux lines are passing. As long as the lines of force from one coil remain parallel to the wires in the winding of a second coil, there will be no flux interlinkage and the inductive coupling will be zero.

A schematic wiring diagram of a section of a radio-frequency amplifier is shown in Fig. 23, the radio-frequency amplifier tubes being shown at *a* and *b*. The input circuit of tube *a* is tuned to the frequency of the incoming signal by means of the inductance coil *c* and the condenser *d*. The condenser *e*, shown by dotted lines, represents the internal plate-grid capacity of the tube *a*. The output circuit of tube *a* is tuned to the incoming signal by virtue of the close coupling between the coils *f* and *g*, the latter coil in parallel with the condenser *h* being tuned to the same frequency as the combination of coil *c* and condenser *d*. The condenser *i* is a by-pass condenser for radio-frequency current from the positive *B*-battery terminal to the negative *A*-battery terminal.

The maximum signal voltage in the output circuit of tube *a* can be considered as existing across the inductance coil *f* in view of the fact that the lower end of the coil marked *2* is practically at ground potential, owing to the radio-frequency by-pass condenser *i*, which is of sufficiently large value to offer very little impedance to the passage of radio-frequency currents.

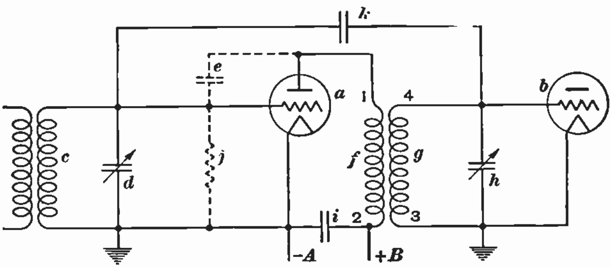


FIG. 23

This maximum signal voltage that exists across the coil *f* also exists across the internal plate-grid capacity of the tube, represented at *e*, and the effective resistance of the grid-filament circuit, represented at *j*. The two quantities in question are connected in series from the upper and lower terminals of coil *f*, shown at *1* and *2*. The reason why the grid to filament circuit can be considered an effective resistance *j* is due to the fact that the voltage that is considered is the voltage that is applied across the coil *f*, and the frequency of this voltage is the frequency to which the combination *cd* is tuned. Therefore, for this frequency (the resonant frequency), the capacity reactance and the inductive reactance of the circuit *cd* neutralize, and the resistance of the circuit is all that is left to impede the passage of current at its resonant frequency.

If the frequency of the voltage across the coil *f* were greater than the resonant frequency of the circuit *cd*, the latter would be an effective capacity, and if the frequency of the voltage across the coil *f* were less than the resonant frequency of the circuit *cd*, the latter would be an effective inductance.

When the capacity *e* is quite small, its reactance is quite large, capacity reactance being expressed by the formula

$$X_c = \frac{1}{2\pi f C} \text{ ohms}$$

in which X_c = capacity reactance, in ohms;
π = constant 3.1416;
f = frequency, in cycles per second;
C = capacity, in farads.

From the foregoing it can be seen that the potential at the grid terminal of tube *a*, due to the voltage across coil *f*, is above that of the ground by virtue of the current from filament to grid, but is nearer the lower end *2* of coil *f*, owing to the fact that the voltage drop across condenser *e* is much greater than the drop from grid to filament.

If at any instant the polarity at point *1* is positive, then the polarity at point *2* is negative, the two points being 180° out of phase. The grid, being nearer to point *2* than to point *1*, will be negative when point *1* is positive, and this is the condition for regeneration, for here is a voltage on the grid of the tube *a* that is of the same frequency as the voltage in the plate circuit of the tube and, furthermore, this voltage on the grid is negative when the voltage at the plate is positive. It is to be noted that this also is the condition for self-oscillations: excitation voltage on the grid, 180° out of phase with the plate voltage.

It might be interesting to note why the tube has a greater tendency to oscillate on the lower wavelengths, during the course of patrolling the broadcast wave band, than on the higher waves. As the wavelength decreases the frequency increases. As the frequency increases the reactance of the internal plate-grid tube capacity decreases. Both of these facts can be substantiated by considering the formula for converting wavelength to frequency, in which

$$f=\frac{300{,}000{,}000}{\text{wavelength}}$$

and the formula for capacity reactance, in which

$$X_c=\frac{1}{2\pi fC}$$

As the reactance of the tube capacity decreases the voltage drop across it also decreases and the potential on the grid becomes higher, hence more grid excitation, greater regeneration, and, subsequently, greater tendency to oscillate.

One method of applying a neutralizing condenser to a stage of radio-frequency amplification is shown at *k*. The neutralizing scheme is virtually a wheatstone bridge. The neutralizing condenser *k* is connected from the grid terminal of tube *b* to the grid terminal of tube *a*. The points *2* and *3* are at the same potential, so far as the high-frequency currents are concerned, owing to the fact that point *2* is a radio-frequency ground, through the medium of the radio-frequency by-pass condenser *i*, and point *3* is metallically connected to the negative filament lead, which is at ground potential.

The signal voltage that is being fed back from the output circuit of tube *a* can be considered, in this case, as existing across the points *1* and *4* with the intermediate points *2* and *3* at ground potential. If the coil *f* is equal to coil *g*, the point *2* or *3* is midway between the extremities *1* and *4*; hence if the grid is also made midway between *1* and *4*, as far as the voltage across the coils *f* and *g* is concerned, the grid will be at ground potentials with respect to the feed-back voltage, because the points *2* and *3* are at ground potential. In this case, this can be accomplished by making the neutralizing condenser *k* equal to the plate-grid capacity *e*.

In receiving tubes of the UX-201-A type the plate-grid capacity is of the order of 6 micro-microfarads, thus the neutralizing condenser *k* should have nearly the same capacity. However, in most radio receivers employing tuned radio-frequency amplification, there is more inductance in the coil *g* than there is in the coil *f*. This is due to the fact that there is a step-up ratio effected in the coupling transformer between the output circuit of the tube *a* and the input circuit of the tube *b*. The reason for this is to boost the signal voltage available in the output circuit of one tube, through the medium of the coupling transformer, for application to the grid of a succeeding tube.

If the inductance of the coil *g* is four times the inductance of the coil *f*, four-fifths of the voltage drop from *1* to *4* will occur across coil *g*, and in order that condenser *k* should function to maintain the grid at the same potential as the points *2* and *3*, there should be the same voltage drop across it that there is across coil *g*. This can be effected by making the value of condenser *k* one-fourth that of condenser *e*, for the capacity reactance varies inversely as the value of the capacity, the equation for

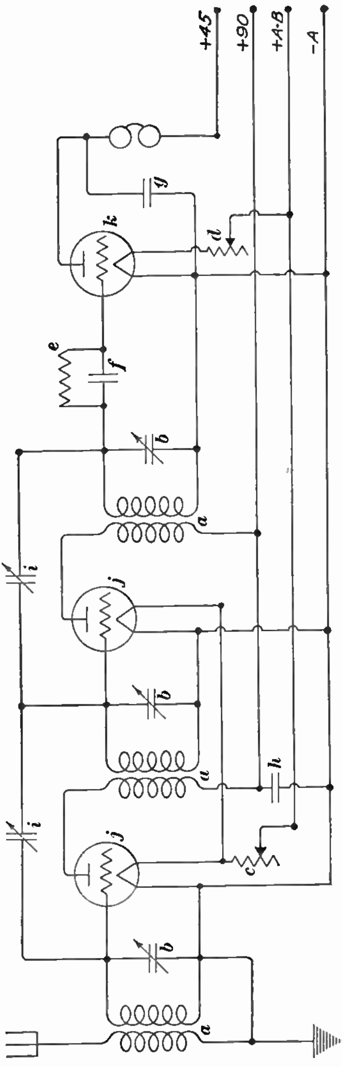


FIG. 24

capacity reactance being, $X_c = \frac{1}{2\pi fC}$, whereas the inductive reactance varies directly as the value of inductance, the equation being, $X_l = 2\pi fL$.

Therefore, if the value of the capacity of *k* is one-fourth that of *e*, the reactance of the former will be four times greater than that of the latter and the voltage drop across the former will subsequently be four times greater than the voltage drop across the latter. This is the condition that must exist to maintain the grid at the same potential as points *2* and *3*, which means that it is at ground potential as far as the feed-back voltage is concerned. If condenser *e* has a capacity value of about 6 micro-micro-farads, then 1.5 micro-microfarads will be required at *k* for complete neutralization.

Standard Neutrodyne Receiver, 200 to 300 Meters.—A schematic wiring diagram of a standard neutrodyne receiver is shown in Fig. 24. The following is a list of the receiving-circuit constants as well as a list of the material needed in the construction of this set.

a—Three radio-frequency transformers, the primary of which consists of 13 turns No. 24 d.s.c. (double-silk covered) on $2\frac{3}{4}$-inch form and the secondary of 50 turns No. 24 d.s.c. on the same form.

b—Three .0005-microfarad variable condensers.

c—6-ohm rheostat.

d—12-ohm rheostat.

e—3 megohm grid-leak resistance.

f—.00025-microfarad grid condenser.

g—.002-microfarad radio-frequency by-pass condenser.

h—.1-microfarad by-pass condenser

i—Two 1.5-micro-microfarad neutralizing condenser.

j—Two UX-201-A amplifier tubes and sockets.

k—UX-200-A detector tube and socket.

The antenna lead, Fig. 24, is connected to one end of the primary coil of the first radio-frequency transformer, the other end of which is connected to ground. The secondary winding of this transformer is tuned by means of the .0005-microfarad variable condenser *b*. The ground lead is connected through to the negative filament lead. The rheostats are in the positive filament lead.

The primary winding of the second-radio-frequency transformer is in series with the plate circuit to the first radio-frequency amplifier tube. The secondary winding of this transformer is also tuned by means of a .0005-microfarad variable condenser.

The *B*-battery supply for the plates of the radio-frequency amplifier tubes *j* should be between 67.5 and 90 volts.

The neutralizing condensers *i* are connected from grid to grid. From a consideration of the preceding discussion of neutrodyne theory the value of these condensers should be of the order of 1.5 micro-microfarads, if the internal plate-grid capacity of the tubes *j* is of the order of 6 micro-microfarads. It is a good idea to use variable condensers at *i* of such a maximum value that it is possible to pass through the optimum point.

The solenoidal type of coils used in this receiver have a large stray field and it is necessary to minimize the effect to as great an extent as possible. The figure-8 type transformers do not have a large stray field, but when solenoidal transformers are used, the inductive effect between the transformers must be in some way controlled. One method of doing this is shown in Fig. 25.

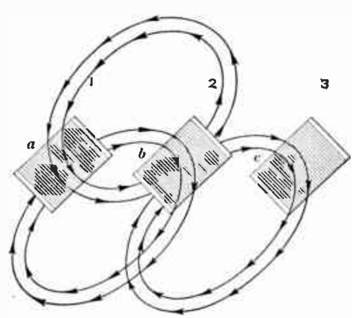


FIG. 25

The three transformers *a*, *b*, and *c* are tilted. The line of force emanating from coil *a* pass through the winding of coil *b* in such a direction that they are approximately parallel to the wires that constitute the winding of coil *b*. If the lines of force from coil *a* do not cut through any of the winding of coil *b*, there will be no coupling effected between the two coils.

The lines of force emanating from coil *b* pass through the winding of coil *c* approximately parallel to the wires in that winding and the lines of force from coil *b* also pass through coil *c* approximately parallel to the wires that constitute the latter coil. In this manner inductive coupling is minimized but it is not eliminated entirely. It is worth while to have the coils mounted in such a manner that they can be tilted at any angle, from zero to 90° with the horizontal. If this is done it is possible to orient the coils to the point of minimum inductive coupling and this angle is somewhat critical.

Other Methods of Stabilizing Radio-Frequency Amplifiers.—Besides the potentiometer and neutrodyne methods of suppressing oscillations, there are other ways of obtaining similar results. In a large number of commercial receivers, *grid resistors* are used in the radio-frequency stages to minimize the tendency to self-oscillation. The grid resistors, as the name implies, are connected in the grid circuits of the radio-frequency amplifier tubes. The most common position is between the grid of the tube and the stator plates of the tuning condenser. A resistance of about 1,000 ohms in each of the radio-frequency stages will in most cases maintain the amplifier in a stable condition.

Another favorite method of stabilizing radio-frequency amplifiers is to change the overall efficiency of the set by controlling either the filament or the plate current of the radio-frequency tubes. In a large number of sets the rheostat controlling the filament current of the radio-frequency tubes acts also as a volume control and, incidentally, as an effective means of reducing the energy to the point where the set remains stable.

Then, there are the so-called "losser" methods. A shorted coil mounted near the tuning coil will absorb sufficient energy to effect stable operation. Similarly, by mounting the tuning coils near the variable condenser, sufficient energy will be dissipated in eddy currents to obtain the same results.

The proper use of the shield-grid tube will eliminate any tendency to self-oscillation and, at the same time, obtain extremely high amplification. The manufacturer's instructions accompanying this tube should be followed in all cases.

There are numerous other ways of preventing radio-frequency amplifiers from oscillating and introducing distortion into the receiver. Most of these are based on the introduction of opposing voltages, on proper balancing, on losses, and on changing the phase relation between the individual circuits.

Shielding.—Shielding is a means of confining the magnetic fields of coils and conductors to a restricted area. To be effective, shielding must be designed with proper relation to the parts to be protected. When correctly applied, it increases the sensitivity and selectivity of a receiver because the shields exclude external disturbances an minimize internal interference.

Electromagnetic shielding, to be effective, must be complete. The smallest crack or opening is sufficient to spoil the whole receiver and it is imperative, therefore, that great pains be taken with the work. Shielding is not purely a mechanical operation, as it requires technical design as well, based on the action of the radio-frequency circuits in the set.

The following facts compiled by the Aluminum Company of America apply to the art of shielding:

1. Within limits, the effectiveness of shielding increases with the frequency and with the conductivity and thickness of the metal sheet used.

2. At frequencies in the broadcast range, relatively thin sheets of aluminum or copper are satisfactory. Number 20 B. & S. gauge and heavier is used.

3. Aluminum and copper of the same thickness are equally efficient, for practical purposes, in radio-frequency shielding.

4. Complete metal shields of the can or box type, well grounded are the most effective.

5. Such shields should make good electrical contact at the joints, and the holes or outlets should be kept as few as possible.

REFLEX RECEIVER

In a reflex receiver, the amplifier tubes are made to function as radio-frequency amplifiers and as audio-frequency amplifiers also. The neutrodyne receiver lends itself best for reflexing, since the radio-frequency amplifier circuits are so well neutralized that 90 volts can be applied to the plates of the tubes without danger of unstability of operation. It is also to be noted that the normal voltage for an audio-frequency amplifier, using UX-201-A type tubes, is 90 volts. A radio-frequency receiver that is so unstable in operation that no more than 45 volts can be applied to the plates of the radio-frequency amplifier tubes without making them oscillate is not particularly adapted for use as a reflex receiver, since the maximum allowable plate voltage would be limited to 45 volts by the radio-frequency amplifier tubes. This would mean that the audio-frequency amplifier tubes would have to be operated at this potential, which would not be conducive to efficient reflex amplification, and a separate audio-frequency amplifier should be used.

The schematic wiring diagram, Fig. 26, shows a receiver employing three tubes *a*, *b*, and *c*, having two stages of radio-frequency amplification, a detector, and two stages of audio-frequency amplification. The constants that applied in the case of the neutrodyne receiver, apply here as well, with the addition of two-audio-frequency transformers and several fixed condensers. The transformer *d* has a 6 to 1 ratio of turns, while the transformer *e* has a 2 to 1 ratio of turns.

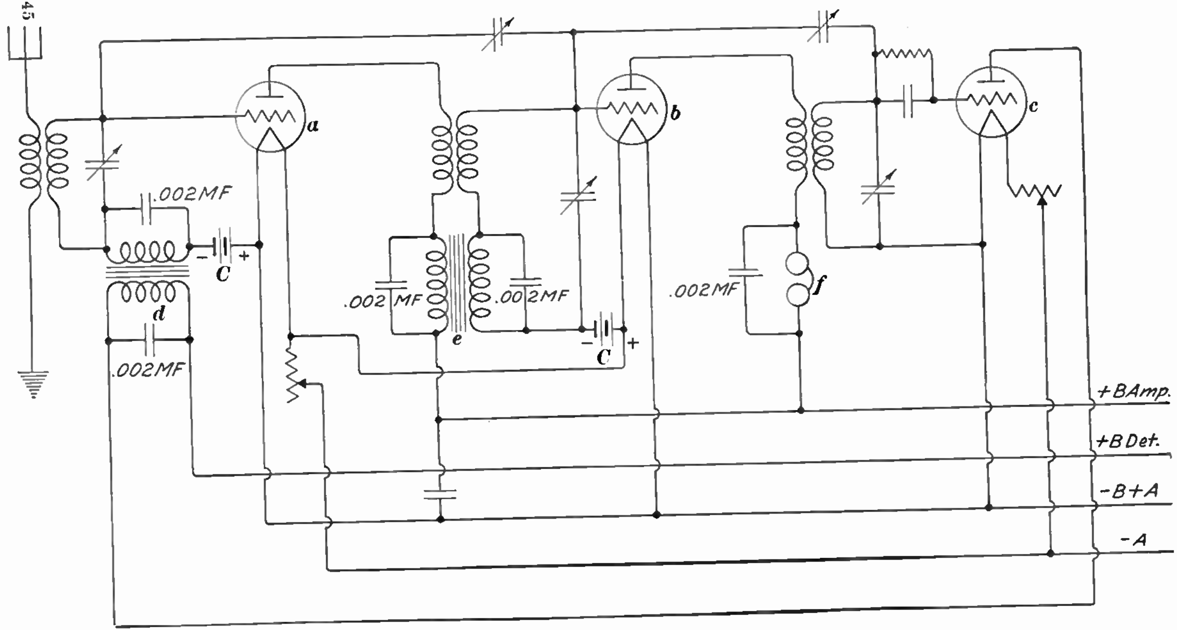


FIG. 26

The radio-frequency circuits have already been discussed, hence the audio-frequency circuits which are reflexed, will now be considered.

The plate terminal of the detector tube *c* is connected to one end of the primary winding of the first audio frequency transformer *d*. There is a .002-microfarad radio-frequency by-pass condenser across this winding. If desirable, regeneration may be effected in the detector plate circuit by means of a variometer connected in series with the detector plate lead. This variometer should be capable of tuning the plate circuit in question to the various frequencies in the wave band for which the receiver is designed.

The secondary winding of the first audio-frequency transformer *d* is connected in series with the grid return lead from the tube *a*. There is a .002-microfarad radio-frequency by-pass condenser across the secondary winding of the audio transformer. The function of this condenser is to offer a low impedance path for the radio-frequency currents in this part of the circuit. In some types of audio-frequency transformers the secondary winding of itself has sufficient capacity to by-pass the radio-frequency currents without the application of the by-pass condenser.

In cases where a radio-frequency by-pass condenser is desired in circuits carrying audio-frequency currents, the value of the by-pass condenser must not be so large as to by-pass audio-frequency currents as well. The larger the value of a condenser the lower its impedance to the passage of alternating currents. The higher the frequency of the alternating currents the less the impedance of the condenser to the currents of that frequency. Thus, a condenser could have such a value that it would offer a low impedance to the high-frequency current but would offer a fairly high impedance to the low-frequency current.

The primary winding of the second audio-frequency transformer *e* is connected in the plate circuit of the tube *a*. The secondary winding of this transformer is connected in series with the input circuit of the tube *b*. Each winding has a .002-microfarad radio-frequency by-pass condenser across it.

The tuning condenser in the second stage is connected from the grid terminal of the tube *b* to the $-C$ terminal, or, in other words, across the series combination of the secondary winding of the radio-frequency transformer and the secondary winding of the audio-frequency transformer *e*. As far as the tuning is concerned, it is approximately the same, whether the tuning condenser is connected across the extremities of the secondary winding of the radio-frequency transformer or as shown in the figure.

Considering the functioning of this type of circuit it is found that the radio-frequency input is amplified by the tube *a*, then passed on to the tube *b*, where it is again amplified and passed on to the detector tube *c*. In the detector tube *c* the radio-frequency energy is changed into audio-frequency energy and as such it is applied back on the grid of the tube *a*, which amplifies this signal at audio frequency and passes it on to the second stage of audio-frequency amplification, which is effected by the tube *b*. The audio-frequency output is taken out of the plate circuit of the second amplifier tube *b*. The phones or loudspeaker *f* are connected in the plate lead of the tube *b* and are shunted by a .002-microfarad radio-frequency by-pass condenser.

SUPERHETERODYNE RECEIVER

Principle of Operation.—The graph in Fig. 27 shows the fundamental circuits of the superheterodyne receiver. The name is derived from the fact that the incoming signal is *heterodyned* by a local oscillator. The beat frequency between the incoming signal and the local oscillator is amplified before application to the detector which changes the signal into audio frequency.

It will be assumed that the wavelength of the received signal is 300 meters, which corresponds to 1,000 kc., one kc. (kilocycle) being the equivalent of 1,000 cycles. A local radio-frequency oscillator *a* is coupled to the input circuit of the high-frequency detector *b*, so that the signal frequency and the local oscillator frequency beat together to give a frequency that is equal to the sum of the two frequencies in question, and another frequency that is equal to the difference of the two frequencies in question. It is the latter that will be considered.

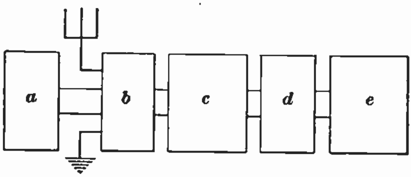


FIG. 27

The local oscillator *a* is so adjusted that the beat frequency will be that frequency to which the intermediate-frequency amplifier *c* is resonant. In this case the intermediate frequency amplifier is resonant to energy having a frequency of 30 kc., which corresponds to a wavelength of 10,000 meters. Thus the local oscillator is adjusted to a frequency of either 1,030 kc. or 970 kc.; in either event the difference or the beat frequency is 30 kc. This gives the reason why it is possible with a superheterodyne receiver to tune in a particular station at two different settings of the local oscillator.

The function of the high-frequency detector *b* is to rectify the radio-frequency input so that the beat frequency will appear in the output circuit as an alternating current, having a frequency in this case of 30 kc. This

30-kc. signal is applied to the input circuit of the intermediate-frequency amplifier *c*. The intermediate-frequency amplifier is the heart of the superheterodyne receiver, for the fundamental principal involved is that a signal of the order of 300 meters can be amplified to a greater degree and with less chance of producing unstability in the receiver circuits if it is changed to a 10,000-meter signal and amplified at that wave length.

In the case of a radio-telephone signal from a broadcasting station, the fundamental frequency would be accompanied by frequency bands 5,000 cycles wide on either side of the carrier. In order to produce an undistorted signal in the audio-frequency amplifier output it is necessary that the intermediate-frequency amplifier be broad enough to pass all the frequencies in the side bands, which means that the intermediate-frequency transformers should be capable of passing a frequency band 10,000 cycles wide, or from 8,570 meters to 12,000 meters. An intermediate-frequency transformer that will only pass wavelengths between 9,000 and 11,000 meters is too sharp, because it will chop off some of the side bands in the broadcast signal, which will be manifested by distortion in the audio-frequency output unit. This is the reason for the fact that some superheterodyne receivers produce a distorted signal. Their intermediate-frequency circuits are too selective and they exclude a vital part of the incoming signal. True sound reproduction is obtained only when all the side bands (and nothing more) appear in the loudspeaker output.

The function of the low-frequency detector *d* is to rectify the intermediate-frequency signal to produce one of the 5,000 cycle frequency bands for amplification in the audio-frequency amplifier *e*. The current in the output circuit of the detector tube *d* follows the audio-frequency variations in the amplitude of the 30,000-cycle current, which is due to the modulation frequency at the transmitting station.

Schematic Diagram.—A schematic wiring diagram of a superheterodyne receiver is shown in Fig. 28. This set has one stage of radio-frequency amplification ahead of the high-frequency detector, three stages of intermediate-frequency amplification ahead of the low-frequency detector, and two stages of audio-frequency amplification. In this receiver there is a jack connection *a* that allows for plugging in either an antenna-ground system or a loop. There is also a change-over switch *b*, which can be placed in either one of two positions. In one position of the switch the receiver functions as a tuned radio-frequency receiver with a feed-back in the antenna circuit, employing four tubes; one radio-frequency amplifier tube, a detector, and two audio-frequency amplifiers. When the change-over switch is thrown to the other position, the receiver functions as a superheterodyne receiver.

The antenna-ground or the loop connections to the receiver are made through the medium of a plug to the radio-frequency input jack *a*. The rotor of the feed-back coupler *c* and the primary winding of the first radio-frequency transformer *d* are connected in series with the jack.

The secondary winding of the input transformer *d* is tuned to the broadcast wave band by means of a .0005-microfarad variable condenser. The input transformer *d*, in this case, is of the figure-8 type so as to minimize the possibility of picking up signals directly on this coil. A receiver of this type is very sensitive and if the solenoidal type of transformer is used in the input circuit, considerable of the signal is picked up directly by the input transformer. Thus, in this case, if a loop is used for external

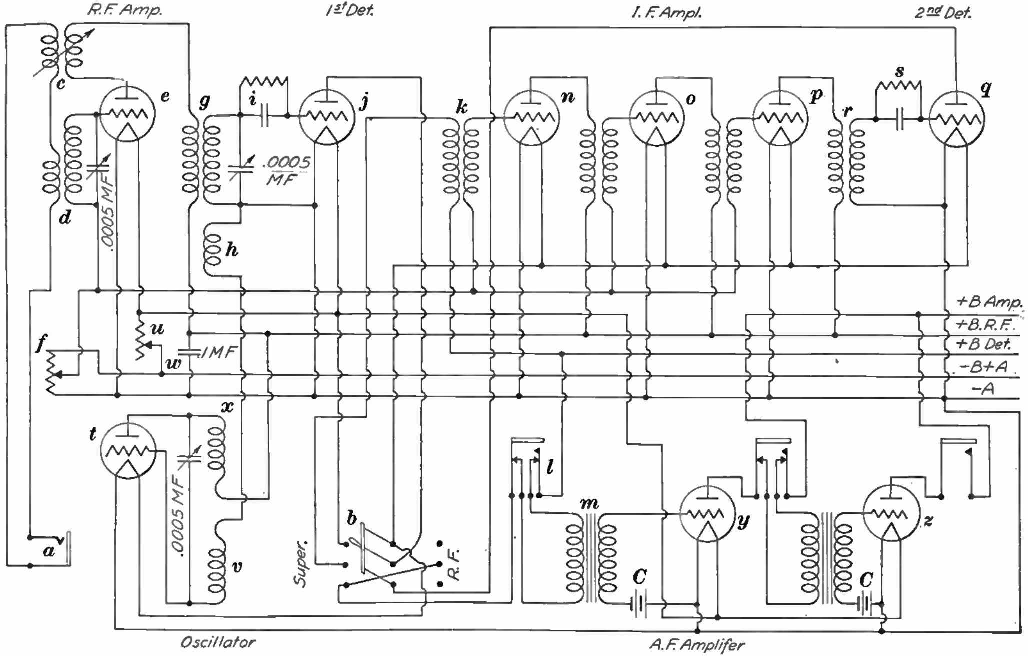

R.F. Amp.
1st Det.
I.F. Ampl.
2nd Det.
.0005 MF
.0005 MF
.0005 MF
.1 MF
+B Amp.
+B.R.F.
+B Det.
-B+A
-A
Super.
R.F.
Oscillator
A.F. Amplifer

FIG. 28

pick-up its directive properties will be impaired, owing to the pick-up within the set. The figure-8 type of transformer minimizes the possibility of direct pick-up within the receiver at this point in the circuit. The grid return of the first radio-frequency amplifier tube *e* is brought to the contact terminal of the stabilizing potentiometer *f*.

The plate of the first radio-frequency amplifier tube *e* is connected to one end of the stator winding of the feed-back coupler *c*, the other end of this winding being connected to the primary winding of the second radio-frequency transformer *g*. The other end of this latter winding is connected to the positive terminal of the *B*-battery supply for the radio-frequency amplifier tubes.

The secondary winding of the radio-frequency transformer *g* is tuned by means of a .0005-microfarad condenser. It is at this point in the circuit that energy from the local oscillator is introduced. This is effected by means of the coupling coil *h*, which is in the oscillating circuit of the separate oscillator and is inductively coupled to the secondary of transformer *g*. The grid-condenser (.00025 microfarad) and the grid-leak (2 megohms) combination *i* is put in series with the grid lead to the detector tube *j* to cause this latter tube to effect detector action.

The plate of the detector tube *j* is connected to the change-over switch *b*. In the superheterodyne position the plate lead is connected to one end of the primary winding of the first intermediate-frequency transformer *k*. In the radio-frequency position of the switch the plate lead is connected to the detector *B*-battery supply through the contacts of the jack *l* and the primary winding of the first audio-frequency transformer *m*.

The lower end of the primary of the transformer *k* is connected to the positive *B*-battery supply for the detector tubes. The secondary terminals of this intermediate-frequency transformer *k* are connected to the grid of the first intermediate-frequency amplifier tube *n* and the contact terminal of the stabilizing potentiometer *f*.

The output of tube *n* is coupled to the input of the second intermediate-frequency amplifier tube *o* through the medium of the second intermediate-frequency transformer. The output of tube *o* is applied to the grid of the third intermediate-frequency amplifier tube *p*.

The output of the third intermediate-frequency amplifier tube *p* is applied to the grid of the second detector tube *q* through the medium of the tuned intermediate-frequency transformer *r*. The grid-leak (2 megohms) and grid-condenser (.00025 microfarad) combination *s* causes the tube *q* to function as a detector. The grid-return lead of the second detector tube *q* is brought to the negative filament terminal. The plate of the second detector tube *q* is connected to the triple-pole double-throw switch *b*. In the superheterodyne position the plate of tube *q* is connected to the detector *B*-battery supply through the contacts of jack *l* and the primary winding of the first-audio-frequency transformer *m*. The first, or uppermost, pole of the blade of the change-over switch *b* is connected to the positive filament terminals of the three intermediate-frequency amplifier tubes *n*, *o*, and *p*, the detector tube *q*, and the oscillator tube *t*. The terminal that this pole engages in the superheterodyne position is connected to the positive *A*-supply lead through the rheostat *u*.

The local oscillator tube *t* has a tuned Hartley oscillating circuit. The fact that the .0005-microfarad tuning condenser is connected from plate to grid insures the fact that the two elements of the tube in question will always be 180° out of phase, which is the condition for self-oscillation. The grid excitation for the oscillator tube *t* is that voltage which exists across the grid coil v. The circuit through the inductive branch of the oscillating circuit might be traced from the grid of tube t through the grid excitation coil v, the coupling coil h to the negative filament terminal. There is a .1-microfarad radio-frequency by-pass condenser u from the negative filament lead to the positive radio-frequency B-battery lead. The circuit is traced from the positive radio-frequency B battery through the plate coil x to the plate terminal of oscillator tube t. In effect, the coils v and x are joined together at their inner ends by virtue of the radio-frequency by-pass condenser w, and this point is at ground potential as far as radio frequency is concerned. The condenser w also functions as a blocking condenser in the oscillator circuit, allowing the plate potential to be supplied at the mid-point between plate and grid, the condenser w blocking the d.-c. potential from being applied to the grid of the oscillator tube t.

When the change-over switch b is thrown to the superheterodyne position, all the tubes shown in the figure are in operation. The condenser in the radio-frequency and first-detector circuits tune their respective circuits to the incoming radio-frequency signal and the oscillator condenser is set to give the desired 30-kc. beat frequency, the intermediate-frequency amplifiers functioning at this frequency.

For local reception, the change-over switch b is thrown to the radio-frequency position, thereby cutting off the filament-current supply to the tubes n, o, p, q, and t. The plate of tube j is cut off from the primary winding of the first intermediate-frequency transformer k and is connected to the detector B-battery supply through the contacts of the jack l and the primary winding of the first audio-frequency transformer m, and the plate of tube q is disconnected from its output circuit. Thus, only the tubes *e*, *j*, *y*, and *z* are left in operation, functioning as one stage of radio-frequency amplification, detector, and two stages of audio-frequency amplification, respectively. This will be found to be adequate for the satisfactory reception of local signals.

List and Constants of Parts.—The parts used in the construction of the set shown in Fig. 28 may be purchased; some of them, however, may be readily constructed by the experimenter. The rotor and stator of the coupler *c* are each wound with 30 turns of No. 24 d.s.c. wire, the stator on a 3-inch form and the rotor on a form to fit inside the 3-inch form.

The transformer *d* is of the twin-8 or double-D type. The primary has 15 turns No. 24 d.s.c., and the secondary has 50 turns No. 24 d.s.c. wire.

The transformer *g* has three windings. The primary winding consists of 13 turns No. 24 d.s.c. wire wound on a $2\frac{3}{4}$-inch form; the secondary, 50 turns; and the oscillator coupling coil *h*, 2 turns, all wound on the same form.

The intermediate-frequency transformers should have a working range between 8,000 and 12,000 meters.

The oscillator coils *v* and *x* are wound on a $2\frac{3}{4}$-inch form with No. 24 d.s.c. wire, the grid coil *v* having 27 turns, and the plate coil *x*, 28 turns.

The three variable condensers have each a capacity of .0005 microfarad. The condenser *w* has a capacity of .1 microfarad. The two detector grid condensers are .00025 microfarad each. The grid leaks are 2 to 3 megohms each. The potentiometer *f* is of the 400-ohm type. The rheostat *u* has a resistance of 6 ohms.

SHORT-WAVE RECEIVERS

Peculiarities of Short-Wave Reception.—The four most popular short-wave bands at the present time are the 20-, 40-, 80-, and 100-meter bands. The logical thing to do is to use a separate coil for each of the three first-mentioned wave bands in the list of four here given. It will be found that the coil for the 80-meter band will also suffice for the 100-meter band.

In short-wave reception it is not desirable to use a tuning condenser having a maximum value of capacity greater than .00025 microfarad. Probably a tuning condenser saving a maximum capacity value below .0002 microfarad is still more desirable because the tuning in the short-wave band is far different from the tuning in the broadcast-wave band. This can be explained by the following facts that were received from actual practice.

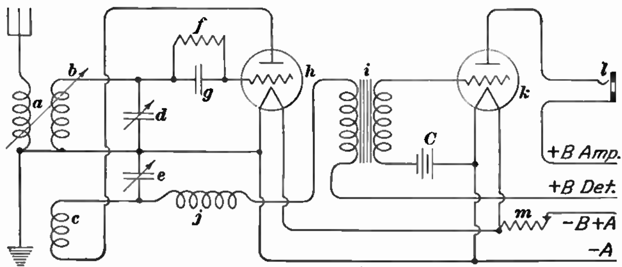
A .00025-microfarad variable condenser is shunted across a coil of such an inductance value that the combination tunes to 20 meters with the condenser dial set at 10. This combination tunes the circuit to 21 meters with the condenser dial set at 11. The frequency of a 20-meter wave is $300,000,000 \div 20 = 15,000,000$ cycles per second which is 15,000 kc. The frequency of a 21-meter wave is found to be 14,300,000 cycles, or 14,300 kc. Thus, by rotating the tuning condenser through 1 division of the dial, a 700-kc. frequency band has been covered.

Since the signals from a radio broadcasting station cover a frequency band about 10,000 cycles, or 10 kc. wide, the 20-meter broadcaster would be passed over with a rotation of the tuning control of $\frac{1}{70}$th of a dial division.

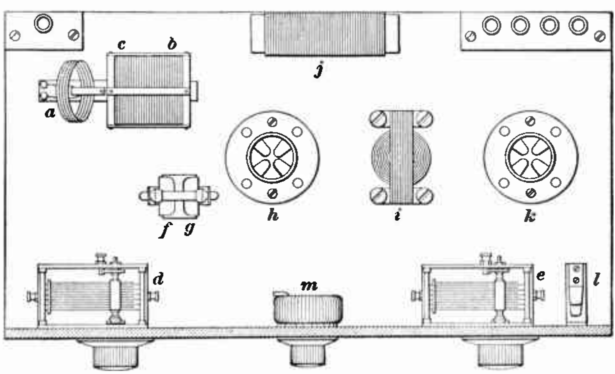
On the other hand, consider the tuning around 500 meters. With the same .00025-microfarad tuning condenser and a coil of proper inductance the circuit is tuned to a wavelength of 500 meters with the condenser dial at 80. This is approximately the dial setting for this wavelength in the standard type of broadcast receiver. Now, if the tuning condenser is rotated through 2.6 divisions to 82.6, the wavelength will be increased to 508 meters. The frequency at 500 meters is 600 kc. and the frequency at 508 meters is 590 kc., the difference being 10 kc., or the frequency band of a broadcasting station. Thus, it can be seen that the tuning condenser dial must be rotated through 2.6 divisions to pass through the signals from a 500-meter broadcasting staton. A consideration of the foregoing analysis will afford a good idea of the reason why broadcast signals appear to afford much sharper tuning on the shorter wavelengths. In the realm of the extremely short waves the tuning condenser must not be too large or tuning will be very difficult.

The consensus of opinion, among the uninitiated, is that there are only radio telegraph signals on the short waves, but this idea is fallacious. It is true that most of the activity on the short waves is radio telegraph communication, but the fact remains that there are also some broadcasting stations operating on the short waves. For instance, the Pittsburgh station KDKA broadcasts programs on 26.3, 42.95, and 62.5 meters and WGY at Schenectady broadcasts on 35 meters. It is quite customary for both of the stations just mentioned to broadcast the same program on a short wave that is being broadcasted on their normal broadcasting wavelength. There is less static on the short waves and often a broadcast program can be heard on the short wavelength of a station that can hardly be heard or not picked up at all on its normal broadcasting wavelength.

Short-Wave Receiver With Interchangeable Coils.—In Fig. 29 (*a*) is shown a schematic wiring of a short-wave receiver that can be used to receive signals between the limits of 17 and 130 meters. The arrangement of parts is shown in view (*b*). The same reference letters are used in both views to indicate corresponding parts.



(*a*)



(*b*)

FIG. 29

The 10-turn coil *a* is the coupling coil in the aperiodic, or untuned, antenna circuit, through the medium of which the radio-frequency energy picked up by the antenna system is induced into the coil *b*, which forms part of the tuned circuit. The coupling between the coils *a* and *b* is variable.

The ground lead is connected through to the low, or filament, side of the secondary coil *b* so as to reduce body capacity. However, it will be found that there will be less interference from local sources such as street lighting circuits, subways, street cars, and elevated systems, and alternating-current induction from house lighting circuits if the ground is not connected through to the negative filament lead.

The feed-back coil *c* is closely coupled to the filament end of the secondary coil *b*. Tuning is effected by means of the condenser *d*. Regeneration is controlled by means of the condenser *e*. This method of effecting regeneration is quite similar to the capacity-controlled regenerative circuit and it is used because of the fact that the regeneration control varies only slightly with frequency, so that a single setting of the control in question may be used for a wide band of wavelengths. This feature is conducive to a small amount of variation in the tuning due to the adjustment of the feed-back circuit. It follows, then, that, since there are only the two controls *d* and *e*, if the latter is such as to require a very small amount of adjustment, the receiver becomes practically single control, which is quite a desirable feature for a short-wave receiver.

The grid leak *f* should be made as large as possible and the grid condenser *g* as small as possible. A satisfactory combination is 5 megohms and .0001 microfarad, respectively. The positive potential for the plate of the detector tube *h* is supplied through the primary winding of the audio-frequency transformer *i*, the radio-frequency choke *j*, and the coil *c*. The function of the radio-frequency choke *j* is to keep all radio frequency out of the audio-frequency circuit, where it might cause howling, and also to prevent the distributed capacity of the phones or the primary winding of the audio-frequency transformer from shorting the radio-frequency currents around the oscilation-control condenser *e*.

The tube *k* with its auxiliary apparatus provides a stage of audio-frequency amplification. The jack *l* constitutes a convenient means of connecting the phones or loud speaker in the output circuit. The filament current for both tubes is controlled by the rheostat *m*.

The constants that remain unchanged for all the wavelengths between 17 and 130 meters are given herewith.

a—10 turns No. 24 d.c.c. wire, 3-inch diameter, solenoid winding.

d—.00014-microfarad variable condenser.

e—.00025-microfarad variable condenser.

f—5-megohm grid leak.

g—.0001-microfarad fixed condenser.

h—UX-200-A detector tube and socket.

i—Low-ratio audio-frequency transformer.

j—200 turns No. 36 d.s.c. wire, 1-inch diameter, solenoid winding.

k—UX-201-A amplifier tube and socket.

l—Output jack.

m—10-ohm rheostat.

From a consideration of the foregoing list it will be seen that the only elements that change for covering the different wave bands within 17 to 130 meters are the secondary inductance *b* and the feed-back coil *c*. Their constants are as follows:

20-Meter wave Band

b—3 turns No. 18 bare copper wire, 3-inch diameter, spaced the diameter of the wire.

c—2 turns No. 24 d.c.c. wire, 3-inch diameter, no spacing.

40-Meter Wave Band

b—8 turns No. 18 bare copper wire, 3-inch diameter, spaced the diameter of the wire.

c—4 turns No. 24 d.c.c., 3-inch diameter, no spacing.

80-Meter Wave Band

b—19 turns No. 18 bare copper wire, 3-inch diameter, spaced the diameter of the wire.

c—6 turns No. 24 d.c.c., 3-inch diameter, no spacing.

In Fig. 30 are shown the wavelength callibration curves for the 20-, 40-, and 80-meter bands, the respective coils designated for those particular wave bands being used.

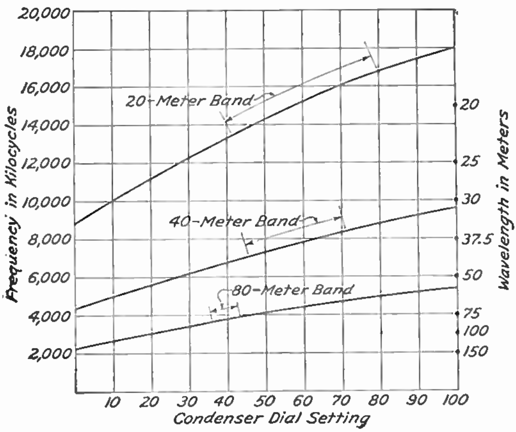


FIG. 30

These curves were made with a straight-line frequency condenser at *d*, Fig. 29; thus any straight-line-frequency condenser having the same maximum and minimum capacity limits will give practically the same shape of curve. If a condenser having a straight-line capacity curve is used, having the same maximum and minimum limits as the condenser used for obtaining the curves shown in Fig. 30, the range will be the same but the shape of the curves will be different.

With the 20-meter coil in operation it is possible to tune from 8,900 kc. (33.7 meters) to 18,000 kc. (16.7 meters).

The majority of transmitters in operation on the 20-meter band will be tuned in between the two vertical lines on the curve in question, namely, between 18 meters (16,700) kc.) and 22 meters (13,600 kc.).

With the 40-meter coil in circuit, it is possible to tune from 4,300 kc. (69.8 meters) to 9,500 kc. (31.6 meters). The active part of this curve is that within the so-called 40-meter band, which is that part of the curve included between the two vertical lines, namely, between 36 meters (8,330 kc.) and 42 meters (7,150 kc.).

With the 80-meter coil in operation it is possible to tune from 2,200 kc. (136 meters) to 5,400 kc. (55.5 meters). The active part of this curve is that portion which is designated as the 80-meter band and which includes the wavelengths between 77 meters (3,900 kc.) and 83 meters (3,620 kc.).

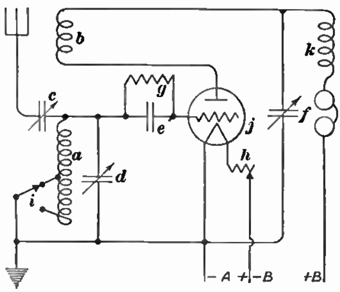


FIG. 31

Short-Wave Throttle Tuner, 17 to 90 Meters. In Fig. 31 is the schematic wiring diagram of a receiver for covering the 20-, 40-, and 80-meter wave bands. As discussed in the case of the preceding receiver, it is quite essential that a method of regeneration be effected that has little effect on the tuning of the receiver input circuit, and it is also desirable that this feed-back be controlled in such a manner that it will not need a great deal of adjustment over a wide variation in tuning. In the preceding circuit arrangement a special method of regeneration control was effected having the desired characteristics. In this circuit the feature is the *throttle method* of regeneration control.

There are only two tuning ranges with this receiver and one set of constants. The two ranges are effected through the medium of a single-pole double-throw switch. The following is a list of the receiver constants.

a—10 turns No. 18 d.c.c. wire, $3\frac{1}{4}$-inch diameter, no spacing, tapped at fifth turn.

b—4 turns No. 18 d.c.c. wire, $1\frac{1}{4}$-inch diameter, no spacing.

c—.00001-microfarad variable condenser.

d—.00018-microfarad variable condenser.

e—.0001-microfarad fixed grid condenser.

f—.00025-microfarad variable throttle condenser.

g—5-megohm grid leak.

h—10-ohm rheostat.

i—Single-pole, double-throw switch.

j—UX-200-A tube and socket.

k—200-turns No. 36 d.s.c., 1-inch diameter, solenoidal winding.

The only thing about this receiver that needs particular explanation is the construction of the two coils *a* and *b*. They are both of the low-loss type. In constructing these coils, scribe a circle $3\frac{1}{4}$ inches in diameter on the surface of a piece of wood, the latter being preferably about $\frac{1}{2}$ inch to $\frac{3}{4}$ inch thick. Locate 11 equidistant points around the circumference of this circle, as shown *1* to *11*, Fig. 32, and fasten a 2 by $\frac{3}{16}$-inch stud at each one of these points. These studs can be made by hammering through a $2\frac{3}{4}$-inch nail at each of the eleven points.

In winding the coils begin at *a* and pass the No. 18 d.c.c. wire, on the outside of the first stud, on the inside of studs *2* and *3*, on the outside of stud *4*, etc., always passing the winding outside of one stud and inside of the succeeding two studs. The coil *a*, Fig. 31, is composed of 10 turns, with a tap at the mid-point. The coil *b* is composed of 4 turns.

The antenna is coupled to the receiver input circuit through the .00001-microfarad condenser *c*, Fig. 31. This little coupling condenser may be variable or it may be fixed. Possibly some advantage may be derived by having a variable condenser.

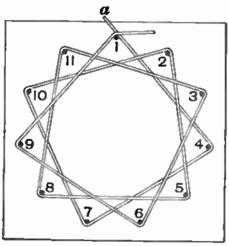


FIG. 32

The coil *a* is tuned by means of the .00018-microfarad variable condenser *d*. It is possible to tune through two ranges of wavelengths by means of the double-throw switch *i* and the tapped coil *a*. With the switch *i* connected to the fifth-turn tap on the 10-turn coil *a*, it is possible to tune from 18 to 51 meters with the tuning con-

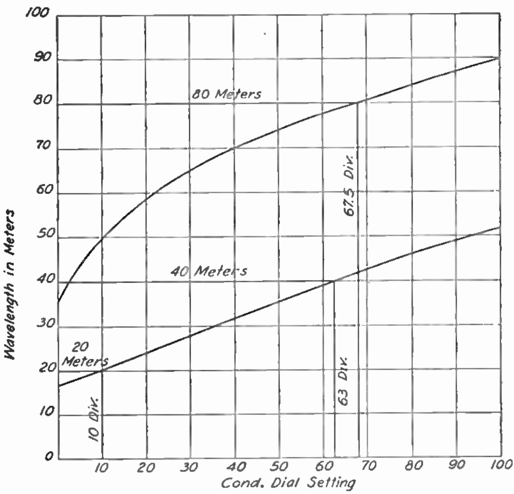


FIG. 33

denser *d*. With the switch *i* engaging the tenth turn on coil *a* it is possible to tune from 35 to 90 meters.

The coil b has a fixed inductive relation to the coil a, the former being located 2 inches from the grid end of the latter. This amount of coupling is sufficient to effect the minimum degree of regeneration, and, from this point up to the maximum, is controlled by means of the throttle condenser f.

The radio-frequency choke k prevents the distributed capacity of the phones or primary winding of the first audio-frequency transformer, when used, from shorting the radio-frequency energy around the throttle condenser f.

A chart showing the two wavelength curves for the two settings of the wave-change switch i is shown in Fig. 33. The lower curve covers the 20- and 40-meter band and the upper curve covers the 40- and 80-meter bands.

SINGLE-SIDE-BAND RECEIVER

In view of the outstanding advantages of the single-side band eliminated-carrier system for long-distance radiotelephone communication, the American Telephone and Telegraph Co. have established a commercial radiotelephone system wherein this system is used at the transmitting end, and a receiver designed for the reception of signals of this character is used at the receiving end. It seems logical to assume that this type of transmission and reception will be used more and more during the coming years and it is probable that broadcast programs will be sent out at some future time by single-side-band transmitters.

In the discussion concerning the transmitter, the circuit constants given were those of the transmitter that was used in the successful two-way transatlantic radio telephone tests, the transmitter being later used for commercial transatlantic telephone communication. In order to link up the receiver discussion with that of the transmitter, the receiver-circuit constants given herein will be for the reception of signals emanating from the transmitter in question, it being the most powerful single-side-band eliminated-carrier transmitter in operation at the present time, having a radio-frequency output of 200 kw.

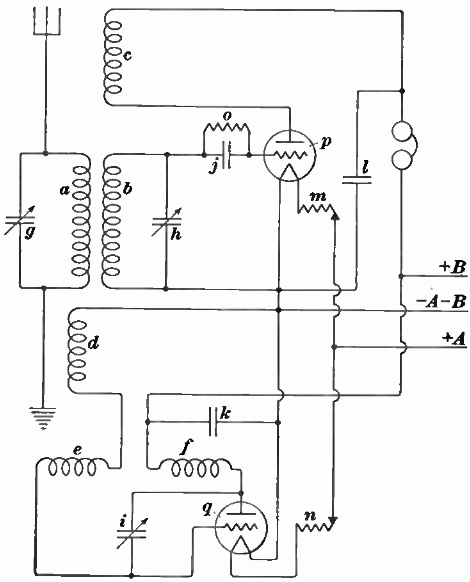


FIG. 34

A schematic wiring diagram of a simple receiver of this type that was used to pick up the signals during the transatlantic tests is shown in Fig. 34. The circuit constants are as follows:

a—500-turn honeycomb coil.
b—750-turn honeycomb coil.
c—300-turn honeycomb coil.
d—25-turn honeycomb coil.

e—300-turn honeycomb coil.
f—500-turn honeycomb coil.
g—.0005-microfarad variable condenser.
h—.0005-microfarad variable condenser.
i—.0005-microfarad variable condenser.
j—.00025-microfarad grid condenser.
k—.1-microfarad fixed condenser.
l—.002-microfarad fixed condenser.
m—12-ohm rheostat.
n—12-ohm rheostat.
o—3-megohm grid leak.
p—UX-200-A detector tube and socket.
q—UX-201-A amplifier tube and socket.

Considering the schematic diagram in Fig. 34, the antenna is connected to one side of the tuned circuit composed of the 500-turn coil *a* and the .0005-microfarad tuning condenser *g*. The other side of this parallel combination is connected to ground. It is by means of this circuit that the antenna-ground system is tuned to resonance with the incoming side band.

The energy in the antenna system is induced into the detector-tube input circuit by means of the inductive coupling between the antenna coil *a* and the grid coil *b*. The latter is a 750-turn coil and is tuned by means of the .0005-microfarad tuning condenser *h*. Detector action is effected by means of the combination of leak *o* and condenser *j*. Regeneration is obtained with the feed-back coil *c*. The .002-microfarad by-pass condenser *l* shorts the radio-frequency energy in the detector plate circuit around the phones or the primary winding of the first-audio frequency transformer, if such is used. The receiver, as described so far, will function quite well in the reception of single-side-band signals if the degree of regeneration is increased to the point of oscillation.

The single side band that is intercepted by the receiving antenna has a frequency band of from 55,800 cycles to 58,500 cycles. In meters, this is 5,370 meters to 5,120 meters. It is to be remembered that the function of the transmitter in this case is to transmit good quality speech but not necessarily music or frequencies higher than the speech frequencies. Good quality speech can be transmitted with a frequency band of from 300 to 3,000 cycles.

The received signal only occupies a 2,700-cycle frequency band, whereas, in normal transmission on this wavelength where the carrier and both the upper and lower side bands are transmitted, the frequency band would be twice as wide.

If the constants of the receiving circuit are adjusted so that the detector sets up oscillations having a frequency of 55,500 cycles, this frequency will remodulate, or beat, with the received side band of 55,800 to 58,500 cycles, and a difference-frequency band of 300 to 3,000 cycles, or the voice-frequency band will result. Thus, there is nothing complicated necessary in the reception of signals of this type, the old regenerative detector circuit being quite capable of giving satisfactory results.

It is possible to carry the development of this receiver a step farther and use a separate oscillator at the receiving station to beat with the incoming signal to produce the voice-frequency band. The application of the separate oscillator is also shown in the figure, but is not considered entirely necessary for satisfactory results.

The oscillatory circuit for the separate oscillator is of the tuned Hartley type, the grid of the oscillator tube *q* being connected to one end of the oscillatory-circuit inductance *edf* and the plate to the other end. The filament-ground is connected to an intermediate point on the inductance in question. Tuning is effected by means of a

.0005-microfarad variable condenser k shunted across the entire oscillatory-circuit inductance *edf*. The 500-turn coil *f* is the plate coil and the 300-turn coil *e* is the grid excitation coil. A 25-turn coil *d* is used for coupling the oscillator to the receiver input circuit.

Although the simple arrangement described in the preceding paragraphs is satisfactory for amateur work, it is not quite elaborate enough for a commercial installation, and a receiver of the superheterodyne type is used. The general outline of a commercial type of single-side-band receiver is shown in Fig. 35.

The radio waves are intercepted by the loop *a*, and this energy is applied to the input circuit of a high-frequency

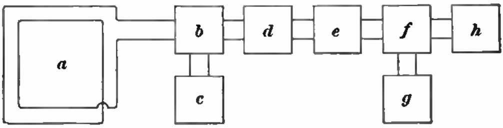


FIG. 35

detector *b*. Energy from a separate 90,000-cycle oscillator *c* is applied to the same input circuit. The difference-frequency band of 31,500 to 34,200 cycles that appears in the output circuit of the detector tube is passed through the band-pass filter *d* to the intermediate-frquency amplifier *e*, As before, there is only one side band, 31,500 to 34,200 cycles, the frequency of the 90,000-cycle supplied carrier, and the upper side band due to the beating of the 90,000-cycle frequency with the signal input having been eliminated by the band-pass filter.

The single-side-band output of the intermediate-frequency amplifier is passed on to a low-frequency detector *f*. Another oscillator *g* at this point in the circuit supplies a 34,500-cycle carrier, which beats with the 31,500- to 34,200-cycle side band, the result in the detector output circuit being the voice-frequency band, 300 to 3,000 cycles. From the second detector, the audio-frequency energy passes to the audio-frequency amplifier *h*.

AUDIO-FREQUENCY AMPLIFIERS

TYPES OF AUDIO-FREQUENCY AMPLIFIERS

After taking up the discussion of the different types of detector and radio-frequency amplifier circuits, consideration will now be given to the various methods of obtaining efficient audio-frequency amplification.

There are three fundamental types of audio-frequency amplifiers; namely, transformer coupled, resistance coupled, and impedance, or choke-coil, coupled. The writer has personally constructed each of the audio-frequency amplifiers that are discussed in the following pages, and a list of the circuit constants and the apparatus used, in each case, is provided.

TRANSFORMER-COUPLED AUDIO-FREQUENCY AMPLIFIER

The first audio-frequency amplifier circuit to be considered is that of a transformer-coupled unit. When the proper parts are used in a properly designed circuit, this type of audio-frequency amplifier is paramount. The schematic wiring diagram for this amplifier is shown in Fig. 36 and the following is the list of material that was used in its construction, as well as the circuit constants.

a—High-ratio audio-frequency transformer (6 to 1).

b—Low-ratio audio-frequency transformer (2 to 1).

c—Output transformer (1 to 1).

d—.002-microfarad radio-frequency by-pass condenser.

e—Five 1-microfarad audio-frequency by-pass condensers.

f—6-ohm rheostat.

g—Two 500,000-ohm potentiometers.

h—UX-200-A detector tube and socket.
i—UX-201-A amplifier tube and socket.
j—UX-171-A power amplifier tube and socket.

The output circuit of the detector tube *h* is shown in the drawing to facilitate the explanation of the method of coupling the output of the detector tube to the amplifier input. A variometer may be connected in the detector output circuit to tune the plate circuit to the frequency of the incoming radio-frequency signal and thus effect regeneration. In this case it is necessary to have a radio-frequency by-pass condenser *d* from the high side of the primary winding of the first audio-frequency transformer *a*

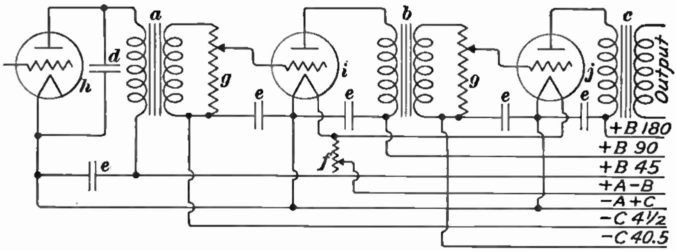


FIG. 36

to the negative filament terminal, in order to by-pass the radio frequency in this part of the circuit around the primary winding of the transformer *a* and the *B* battery.

The condenser *e* in the plate circuit of the detector tube *h* functions to by-pass audio-frequency currents around the detector *B* battery. There is a 500,000-ohm potentiometer *g* whose extremities are connected across the terminals of the secondary winding of the first audio-frequency transformer *a*. The contact terminal of this potentiometer is connected to the grid terminal of the first audio-frequency amplifier tube *i*. This potentiometer functions not only as a volume control (because the value of the signal voltage applied to the grid of tube *i* can be varied by moving the contact terminal from the low voltage end of the resistance element to the high-voltage end), but it also tends to flatten out the transformer characteristic and make the transformer amplify all frequencies alike.

There is an audio-frequency by-pass condenser *e* from the low side of the secondary winding of transformer *a* to the negative filament terminal, or, in other words, across the *C* battery for this tube. There is another audio-frequency by-pass condenser *e* from the low side of the primary winding of the second audio-frequency transformer *b* to the negative filament terminal of the tube *i*, or, in other words, across the *B*-battery supply for the tube *i*.

The connections of tube *j*, or the second amplifier tube, are practically the same as for the tube *i*. The output of the amplifier tube *j* is obtained through the medium of the output transformer *c*. This transformer has a one-to-one ratio and functions to pass the amplified audio-frequency signal on to the loudspeaker unit and at the same time keep the high-potential direct current in the plate circuit of the last tube from passing through the windings of the loudspeaker field coils. This latter effect is undesirable from the standpoint that the current, if in the wrong direction, will tend to demagnetize the permanent magnetism of the speaker field-coil core, and will tend to bias the diaphragm of the speaker unit, thus effecting distortion.

If the tubes mentioned in the material list are used, the *A*-battery potential is 6 volts and the *B*- and *C*-battery potentials are as indicated in Fig. 36. It is necessary to use some sort of power tube in the second audio-frequency amplifier stage to prevent distortion due to overloading of the tube in question; therefore, in this case a UX-171-A tube with 180 volts on the plate and -40.5 volt bias has been used.

IMPEDANCE-COUPLED AUDIO-FREQUENCY AMPLIFIER

Before the development of audio-frequency transformers for use in radio-broadcast receivers reached its present stage of perfection, the thought took root in some sections that transformer-coupled audio-frequency amplification was not conducive to good quality, although it was admittedly the best as far as voltage amplification was concerned. However, when the general broadcast public began to give up the quest for DX reception and expressed a desire for good quality reception, the transformer manufacturers put their engineers on the problem of producing a better audio-frequency transformer that would allow for undistorted amplification. In the meantime the impedance-coupled and the resistance-coupled audio-frequency amplifiers sprang up as an answer to the problem of obtaining distortionless audio-frequency amplification. In both cases it was admitted that they were not as efficient as transformer-coupled amplifiers from a standpoint of voltage amplification, hence more stages were required, but it was claimed that they were capable of producing a better quality output than the transformer-coupled amplifiers that employed the audio-frequency transformers on the market at that time. This was probably true. The impedance-coupled and resistance-coupled amplifiers probably did procure a better-quality output signal than could be obtained from the coupling transformers that were available for radio broadcast fans in the early days of broadcasting.

A schematic wiring diagram of a choke-coil coupled audio-frequency amplifier is shown in Fig. 37. The following is the list of the parts that were used by the author in the construction of a three-stage impedance-coupled audio-frequency amplifier.

a—Four 200-henry choke coils.

b—.002-microfarad radio-frequency by-pass condenser.

c—Three 1-microfarad audio-frequency coupling condensers.

d—Two 1-microfarad grid by-pass condensers.

e—Three 1-microfarad plate by-pass condensers.

f—Ouput transformer (1 to 1).

g—6-ohm rheostat.

h—Two 500,000-ohm potentiometers.

i—UX-200-A detector tube and socket.

j—Two UX-201-A amplifier tubes and sockets.

k—UX-171 power-amplifier tube and socket.

The amplifier shown schematically in Fig. 37 is capable of producing about the same output volume as that shown

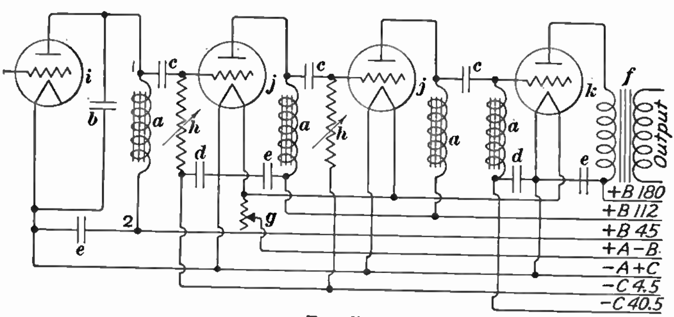


FIG. 37

in Fig. 36, thus one more tube is required in an impedance-coupled amplifier than in a two-stage transformer-coupled audio-frequency amplifier to obtain the same amount of volume.

If there is a feed-back for radio frequency in the plate circuit of the detector tube *i*, Fig. 37, the condenser *b* is required to by-pass radio frequency in this circuit around the plate choke *a* and the detector *B* battery.

The maximum audio-frequency signal input is available across the first 200-henry choke coil *a*, hence across the points *1* and *2*. There is another circuit between the points *1* and *2* besides that afforded by the choke coil *a*; namely, that circuit extending from point *1* through the audio-frequency coupling condenser *c*, the grid resistance *h*, the audio-frequency by-pass condenser *d* to the negative filament lead, the audio-frequency by-pass condenser *e* to point *2*. If the combined capacity reactance of the coupling condenser *c* and the by-pass condenser *e* is small relative to the grid resistance *h*, the signal voltage across the coil *a* is practically apparent in its entirety across the grid resistance *h*, owing to the fact that the voltage drop across the condensers named is negligible and the signal voltage across the coil *a* is impressed across the series combination mentioned.

Thus it can be seen that the audio-frequency by-pass condensers should offer a low resistance to the passage of audio-frequency currents. The value of the capacity reactance of a condenser is equal to $\frac{1}{2}\pi fC$, where π is the constant 3.1416, f is the frequency in cycles per second, and C is the capacity in farads. Since, for a given value of capacity, the lower the frequency the higher its reactance, in choosing the proper value of capacity to use as an audio-frequency by-pass condenser, it is well to consider the lowest frequency that it is called upon to by-pass, which is in the neighborhood of 50 cycles.

With the frequency term fixed at 50 cycles per second in the formula for capacity reactance, the capacity term can be varied and the change in reactance noted. It will be found that a condenser having a capacity of .01 microfarad offers a reactance of over 300,000 ohms, whereas, a 1-microfarad condenser brings this reactance value down to 3,000 ohms, approximately. The resistance *h*, which is in series with the coupling condenser *c* as far as the signal voltage is concerned, has a maximum value of 500,000 ohms, so it can be seen that the reactance of condenser *c* is negligible if it has a value of 1 microfarad when signal frequencies of the order of 50 cycles are being put through the amplifier circuit.

The upper limit of the frequency band in the audio-frequency signal that is received from a broadcasting station is of the order of 5,000 cycles and a .01-microfarad condenser offers a reactance of only 3,000 ohms at 5,000 cycles and a 1-microfarad condenser, 32 ohms at the same frequency. Thus, while a .01-microfarad coupling condenser is adequate for the higher frequencies in the received audio-frequency band, it is too small to be conducive to the satisfactory amplification of the lower frequencies in the received band, and if these low frequencies are omitted the signal quality is impaired.

The variable resistance *h* functions as a grid leak. It prevents the coupling condenser *c* from charging up to a sufficient degree to block the tube *j*; in other words, it allows electrons to leak off as fast as they arrive. Having this element in the circuit, a variable, allows for getting the most volume out of the amplifier.

An output transformer *f* is used to supply the amplified audio-frequency signal to the loudspeaker field coils, at the same time keeping the high-potential direct current from passing through these windings.

If the tubes used in this amplifier are as listed in the material list, the *A*-battery potential is 6 volts and the *B* and *C* battery potentials are as indicated in the figure.

It is to be noted that the values of the bias-battery potentials for the different plate potentials are less in this case than in the case of the transformer-coupled amplifier, because there is a greater drop in potential through the choke-coil winding in the plate circuit of an amplifier tube than there is through the primary winding of an audio-frequency transformer. This means that in the case of choke-coil coupling the effective plate potential will be lower, hence a lower value of biasing potential is required than in the case of transformer coupling. Bearing this fact in mind it will be noted that the bias-battery values in the case of a resistance-coupled amplifier are still lower for the same values of plate potential, than in the case of the transformer-coupled amplifier and the choke-coil coupled unit.

TRANSFORMER-RESISTANCE COUPLED AUDIO-FREQUENCY AMPLIFIER

A resistance-coupled amplifier, like an impedance-coupled amplifier, is conducive to obtaining good-quality output signals. One stage of transformer-coupled and two stages of resistance-coupled amplification are quite a popular circuit arrangement. Such a circuit arrangement is shown in Fig. 38 and the following is the list of the material used, as well as the circuit constants.

a—First-stage audio-frequency transformer (6 to 1).
b—Output transformer (1 to 1).
c—.002-microfarad radio-frequency by-pass condenser.
d—1-microfarad audio-frequency by-pass condenser.
e—Two 1-microfarad coupling condensers.
f—Two 1-microfarad grid by-pass condensers.
g—Two 1-microfarad plate by-pass condensers.
h—6-ohm rheostat.
i—Two 100,000-ohm variable resistances.
j—One 500,000-ohm variable resistances.
k—UX-200-A detector tube and socket.
l—Two UX-201-A amplifier tubes and sockets.
m—UX-171 power-amplifier tube and socket.
n—200-henry choke coil.

As shown in the schematic wiring diagram, the transformer *a* is connected in the circuit in the same manner as previously described. In the resistance-coupled circuits the output resistances *i* perform the same function as the impedance coils in the impedance-coupled amplifier described in the preceding text. It is convenient to have the resistances in the resistance-coupled amplifier variable, as this allows for getting the optimum degree of efficiency possible, although a properly designed fixed resistance gives excellent results.

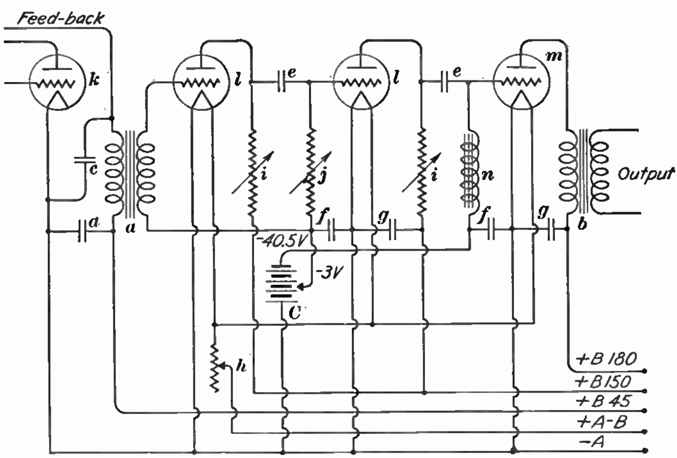


FIG. 38

If the tubes used in this amplifier are as listed, the *A*-battery potential is 6 volts and the *B*- and *C*-battery potentials are as indicated in Fig. 38. A relatively small amount of bias is required for the grids of the amplifier tubes whose plates are supplied with potential through coupling resistances, owing to the high potential drop through the resistances in question. This drop is so great that, even though the plate-supply sources are 150 and 180 volts, the actual effective potential at the plate terminals is considerably less than this.

POWER AMPLIFIERS AND POWER PLATE SUPPLY

ADVANTAGES OF POWER AMPLIFIERS

The design of audio-frequency transformers for use in broadcast receiving sets has reached such a high degree of perfection that, if the right ones are used in the proper circuits, excellent reproduction of broadcast programs may be obtained.

If a signal of sufficient volume to operate a loudspeaker so that it can be heard all over a six-room home is taken out of the plate circuit of a tube of the UX-201-A type, there is bound to be distortion and it does not necessitate a very critical ear to notice it. This distortion is due to the fact that the output tube is being overloaded.

The UX-201-A type tube was designed for use as a radio-frequency amplifier, detector, and audio-frequency amplifier (up to a certain degree), but real power cannot be obtained from anything less than a power tube. It is true that tubes of the UX-171 type were designed to answer the requirements of a power tube in a receiving set, but if high-quality amplification is desired with plenty of volume, it is necessary to use a tube of the UX-210 type, which is a 7.5-watt power tube. This tube with 500 volts on its plate and a bias of 40.5 volts is capable of producing a high degree of distortionless output energy.

Tubes of the UX-201-A type are capable of producing a distortionless signal of relatively low value, above which value the signal becomes distorted, owing to the overloading of the tube. By overloading is meant that the amplitude of the signal voltage applied to the grid of the tube is sufficient to produce a value of plate current that is off the straight part of the plate-current grid-voltage characteristic curve of that type of tube. As long as the voltage swing of the grid is low enough to keep the values of plate current along the straight part of the characteristic curve, a certain amount of positive potential on the grid of the tube will produce the same amount of plate-current change that the same amount of negative grid potential will cause. However, when the swing of the grid potential is boosted to an abnormal value by trying to obtain too great a signal output from too small a tube, the plate-current values are carried off the straight part of the characteristic curve, and grid swings in the positive direction will cause different changes in the plate current than are caused by equal swings in the opposite direction. This is manifested by distortion in the signal output.

Thus, a tube of the UX-201-A type is satisfactory for a certain amount of volume and beyond this value of volume it will distort the signal, no matter how good the audio-frequency transformers are and no matter how good the loudspeaker is. The thing to do is to use a power tube and put a high potential on its plate and an adequate bias on the grid.

It is not economical to obtain the 500 volts for the plate supply to a UX-210 tube from a dry-battery source. The logical manner in which to obtain this high d.-c. potential is to step a 110-volt a.-c. supply up to approximately 550 volts by means of a step-up transformer. This high-voltage alternating current can then be rectified and passed through a filter circuit, which will smooth it out to approximate direct current to the extent that it can be used as a source of constant potential for the plate of the tube in question.

Thus, what is needed for the final stage of amplification to produce great volume with a high degree of quality in the course of reception of broadcast programs, is a rectifier for supplying a high d.-c. voltage to a UX-210 type tube, the latter being used in a properly designed stage of audio-frequency amplification. This constitutes what is termed a *power amplifier*.

POWER AMPLIFIER AND POWER SUPPLY WITH FULL-WAVE RECTIFICATION

In Fig. 39 is shown the schematic wiring diagram of the circuit arrangement for a power amplifier and power supply, or *B*-eliminator, which is supplied with high-voltage direct current from a full-wave rectifier circuit. The following is a list of the material used by this writer in the construction of the unit to be described, as well as the circuit constants.

a—200-watt power transformer with two 10-volt secondary windings, one 1,100-volt secondary winding with a mid-tap, and one 110-volt primary winding.

b—Two 30-henry choke coils.

c—Audio-frequency low-ratio transformer, (2 to 1).

d—Output transformer, (1 to 1).

e—2-microfarad, 750-volt, filter condenser.

f—4-microfarad, 750-volt, filter condenser.

g—6-microfarad, 750-volt, filter condenser.

h—Four 1-microfarad, 200-volt, audio-frequency bypass condensers.

i—1-microfarad, 200-volt, grounding condenser.

j—2-ohm, 2.5-ampere rheostat.

k—7-ohm, 1.25-ampere rheostat.

l—500,000-ohm potentiometer.

m—2,500-ohm variable resistance.

n—400-ohm potentiometer.

o—25,000-ohm heavy-duty resistor.

p—7,000-ohm heavy-duty resistor.

q—8,000-ohm heavy-duty resistor.

r—10,000-ohm heavy-duty resistor.

s—25-ohm variable resistance.

t—Switch.

u—Two UX-216-B (or UX-281) tubes and sockets.

v—UX-210 power amplifier tube and socket.

w—Tell-tale lamp.

x—Two-single-contact jacks.

1 to *8*—Terminals.

9 to *12*—Terminals on double-terminal blocks.

The above material is the nucleus of a power amplifier that is very satisfactory for reproducing broadcast programs. The 110-volt alternating current is supplied to the power input receptacle through the medium of an ordinary power plug. The terminals of the input receptacle are connected to the primary terminals of the power transformer, one of the leads in question being connected through a single-pole single-throw switch *t*. The function of this switch is to turn the unit on and off. When the amplifier is in operation, there is approximately 1 ampere drawn at 110 volts from the a.-c. supply line. This means that the switch *t* must have a current-carrying capacity of at least 1 ampere. Thus, the ordinary filament switch will answer the purpose very nicely.

The rectifier filament-supply winding has a no-load terminal voltage of 10, so a 2-ohm rheostat *j* is connected in series with the filament supply to the rectifier tubes *u*. These tubes are of the UX-216-B type and draw a filament current of 1.25 amperes at 7.5 volts. The rectifier filament-supply winding must be insulated for voltages of the order of 750 volts, for the mid-point of this winding is the source of the rectified but unfiltered d.-c. supply. There is alternating current at 550 volts (R. M. S.) applied to the rectifier plates, and the value of the rectified voltage is of the order of 525 volts. The letters R. M. S. mean *root mean square,* which in turn indicate that this voltage value, which is indicated by an a.-c. voltmeter, is equal to

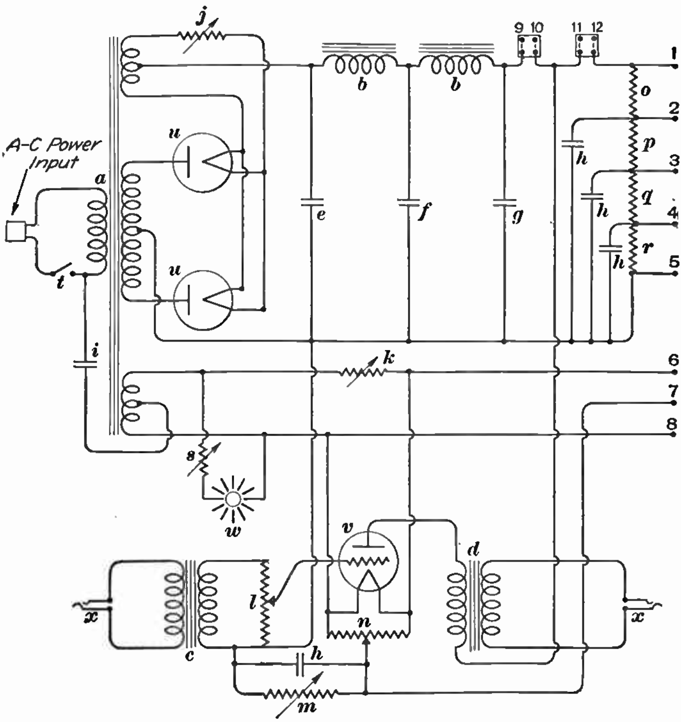


FIG. 39

the square root of the mean of the square of all the instantaneous values of voltage in one cycle of the a.-c. potential.

The effective value of the a.-c. potential is only .707 of the maximum, or the peak, value that is reached in every half cycle. Thus, in order to calculate the maximum value of potential that is applied to the plates of the rectifier tubes, it is necessary to multiply by 1÷.707, or 1.41. This gives 550×1.41=775.5 volts, and this is the peak value of voltage that is applied to the rectifier plates when an a.-c. voltmeter indicates 550.

Now there is some drop in potential through the rectifier tubes, and if this drop is 25 volts, the resultant will be 525 volts of rectified voltage. This rectified voltage, at this point in the circuit is unfiltered; that is, it is not smoothed out, and has the characteristics of an a.-c. potential with the negative half of the cycle eliminated by

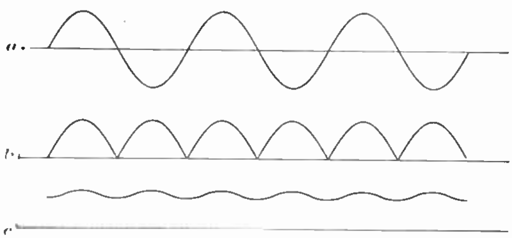


FIG. 40

the action of the rectifier tubes. With full-wave rectification there is a pulsating potential that looks like an a.-c. sine wave with all the negative half cycles inverted so that they are on the positive side.

The changes that take place in the rectifier and filter circuits are shown graphically in Fig. 40. Curve *a* shows the characteristics of the applied a.-c. voltage. After passing through the rectifier, which has unilateral impedance (allows the passage of current in one direction only) the voltage has a pulsating characteristic as shown in curve *b*. This pulsating voltage is applied to the filter circuit, which is composed of a large amount of inductance and capacity that tend to keep the voltage from dying down to zero in the course of its pulsations, owing to the charging and discharging of the condensers through the filter chokes. The output voltage from the filter circuit is thus of the nature shown in curve *c*. It is so close to a d.-c. voltage that it can be termed such.

The high-voltage secondary winding on the power transformer *a*, Fig. 39, has a potential of 1,100 volts between its extremities, and there is a mid-tap on this winding. The extermities of this high-voltage winding are connected to the plates of the two rectifier tubes *u*. The mid-tap of this winding is the source of the negative terminal of the high-potential direct current and in this case is connected to one side of all the filter condensers *e*, *f*, and *g* and to the output terminal *5*. Lead *5* is grounded through the receiving set.

The source of the positive terminal of the rectified but unfiltered *d.-c.* supply is at the mid-point of the rectifier filament-supply winding. A lead from this point is connected to the first filter condenser *e* and to one end of the first filter choke *b*. The other end of the first filter choke *b* is connected to the second filter condenser *f* and one end of the second filter choke. The other end of the second choke is connected to the last filter condenser *g* and terminal *q* of the double-terminal block. There is normally a jumper between terminals 9 and 10.

Terminal *10* is connected to terminal *11* of the next double-terminal block. It is also connected to the plate of the power amplifier tube *v* through the primary winding of the output transformer *d*. There is a jumper between terminals *11* and *12*. The function of the two double-terminal blocks is to afford an expedient means of inserting a milliammeter in the high-voltage supply circuit from the rectifier to determine the following:

1. The total d.-c. drain on the rectifier.
2. The current to the plate of the amplifier tube *v*.

3. The direct current through the *B*-eliminator output resistances.
4. The maximum voltage available at the output of the rectifier filter circuit.

All of the above values may be determined by taking two readings, one with the 50-milliampere milliammeter connected to terminals *9* and *10*, and a second reading with the milliammeter connected to terminals *11* and *12*. In each case when the meter reading is taken the jumper is removed from the two terminals to which the meter is connected, and after the readings have been taken the jumper is connected back again. The first reading mentioned, indicates the total direct current drawn from the rectifier circuit. The second reading shows the current through the *B*-eliminator output resistances *o*, *p*, *q*, and *r*. It is to be noted that there should be no external connections to the terminals *1*, *2*, *3*, *4*, or *5* when the current readings are being taken.

The difference between the two readings is the value of the current to the plate of the power amplifier tube *v*. The maximum voltage available at the filter output is equal to the product of the current through the output resistances, in terms of amperes, and the total value of the output resistance, in terms of ohms, the product being the voltage drop across the resistances in question, which is the output voltage of the rectifier filter circuit.

It is very important to check, quite often, the current from the rectifier circuit, as there is a great possibility of overloading the rectifier tubes, or of passing too much current through the filter chokes, or of operating the amplifier tube with too great a value of plate current. The maximum d.-c. load current for a UX-216-B rectifier tube is 65 milliamperes and for a UX-281, 110 milliamperes. This means that with half-wave rectification it would only be possible to draw 65 milliamperes from the rectifier circuit of the UX-216-B and 110 milliamperes from UX-281 without overloading the rectifier tube. In full-wave rectification the two tubes are operated in parallel to supply direct current to the load, each tube supplying half the load; therefore, with two UX-216-B tubes it is possible to draw 130 milliamperes from the rectifier circuit without overloading the rectifier tubes, and with two UX-281 tubes, 220 milliamperes may be drawn.

There is something else to bear in mind, and that is also a limiting factor for the current in the case of full-wave rectification, as well as the capacity of the rectifier tubes. The standard types of filter chokes are designed to carry up to 60 milliamperes, but beyond this point they are being overloaded. This overload is manifested in heat, which may become of sufficient temperature to melt the insulating compound out of the chokes or burn out the wire.

Another point to bear in mind is the fact that the higher the value of the current through the rectifier filter chokes, the less the effective inductance, the greater the voltage drop through this part of the circuit, and the less the available output voltage for the *B*-eliminator circuit and the plate of the power-amplifier tube. Standard chokes for this sort of circuit have a d.-c. resistance of the order of 600 to 1,000 ohms. If the minimum value of 600 ohms be multiplied by 2, since there are two chokes in series in the filter circuit, the effective d.-c. resistance will be 1,200 ohms. Now, if the current drain on the rectifier is kept down to 30 milliamperes, the drop across the filter chokes will only be $.03 \times 1{,}200$, or 36, volts. But, if the current is raised to 60 milliamperes, the drop across the filter chokes is increased to 72 volts.

The UX-210 power-amplifier tube *v* with 500 volts on its plate and a 45-volt bias, should draw about 30 milliamperes, and care should be taken to see that the bias is sufficient to hold the plate current down to this value. The plate of the tube will get hot when drawing 30 milliamperes at 500 volts, because there is a plate dissipation of $500 \times .03 = 15$ watts. The fact being kept in mind that the UX-210 is a 7.5-watt tube, it can be expected to show a little color when it is made to dissipate 15 watts. An analysis of the foregoing facts shows how important it is to have a milliammeter in series with the lead from the rectifier circuit.

As long as the rectifier and filter must be provided to supply high-voltage direct current to the plate of the power amplifier tube *v*, it follows that this supply might just as well be made use of in effecting a *B*-eliminator circuit, since the latter simply means the connecting of the proper resistances across the rectifier output. In this case, the resistances *o*, *p*, *q*, and *r* function as the B-eliminator resistances with a total resistance of 37,000 ohms. This limits the current through these output resistances to approximately 12 milliamperes. This is the current through these resistances when there is no external load to a receiving set. If the current from the rectifier circuit is kept low enough it is possible to maintain a potential of 500, 135, 90, and 45 volts at the terminals *1*, *2*, *3*, and *4*, respectively, for supplying *B*-battery potential to a four- or five-tube receiving set.

The condensers *h* in the output of the power supply are audio-frequency by-pass condensers across the plate supply to the receiving set that is connected to the B-eliminator terminals. If the power-amplifier B-eliminator unit is located at a great distance from the receiving set, as in another room, for example, the by-pass condensers in question should be located right at the receiver.

The filament of the power amplifier tube *v* is supplied with energy from a separate 10-volt winding on the power transformer. This voltage is stepped down to the proper terminal voltage (7.5) for a UX-210 tube by means of the 7-ohm rheostat *k*, which must have a current-carrying capacity of 1.25 amperes, as this is the normal current to the filament of a UX-210 tube at 7.5 volts.

The tell-tale lamp *w* is connected across the 10-volt amplifier filament supply, in series with a 25-ohm resistance *s*. This little light is mounted on the front panel and is a means of indicating when the amplifier is *on* or *off*.

The audio-frequency signal is supplied to the jack *x* through an ordinary radio plug. The terminals of this jack are connected to the extremities of the primary winding of the input transformer *c*. The secondary terminals of this transformer are shunted by a 500,000-ohm potentiometer *l* the contact terminal of which is connected to the grid terminal of the power-amplifier tube *v*. This resistance not only functions to aid the transformer in being impartial to all the audio frequencies that are passed through it, but it also functions as a volume control by virtue of the fact that the grid can be connected to any point along the resistance element of the potentiometer *l*. Maximum signal voltage is applied to the grid of the amplifier tube when the potentiometer contact terminal is moved to the upper end of the resistance element, and minimum signal voltage when the contact is moved to the lower end.

The biasing resistance *m* is connected from the lower side of the secondary winding of the input transformer *c* to the mid-filament point, the latter being effected by means of the potentiometer *n* whose extremities are connected across the a.-c. filament supply, and the contact terminal of which is maintained at the mid-point of the filament supply There is a by-pass condenser *h* across the biasing resistance. The proper bias is applied to the grid of the power-amplifier tube *v* by the drop in potential across the resistance *m*, owing to the plate current to tube *v* through this resistance. The resistance can be varied and in this manner the grid bias can be changed.

It might be noted at this point that the two condensers *h* (near *m*) and *i* are very important from a standpoint of eliminating the hum from the signal output, and increasing the volume as well as bettering the quality. When the

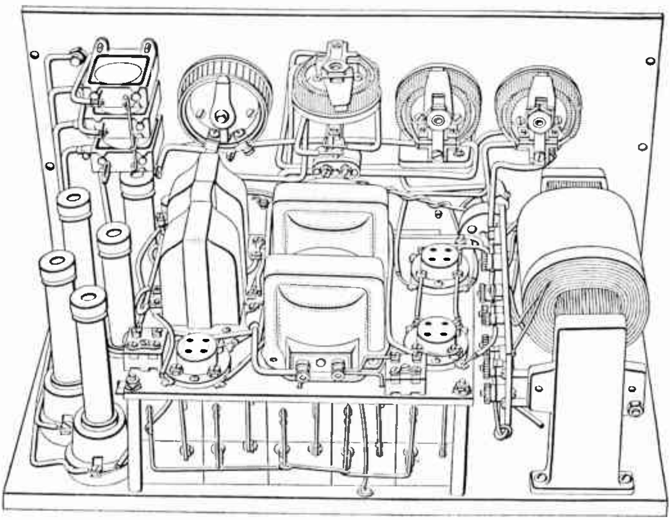


FIG. 41

amplifier is in operation, note should be taken of the amount of hum in the signal output with the power-supply lead inserted in one direction. Then the plug in question should be reversed and the hum again noted. Whichever way of inserting the power-supply plug produces the least amount of hum in the signal output, is the way which maintains the lead to which the condenser *i* is connected, at ground potential. There is a decided difference in the amount of hum in the signal output with this condenser in or out of the circuit.

Shunting an audio-frequency by-pass condenser *h* across the biasing resistance *m* increases the output volume and makes a decided improvement in the quality of the output signal. Shunting by-pass condensers from the ends of the potentiometer *n* to the contact terminal makes only a slight improvement, and they are not considered necessary.

The signal output is taken from the secondary winding of the output transformer *d* through the jack *x*.

A rear view of the amplifier-eliminator unit is shown in Fig. 41. The resistances and a few of the by-pass condensers can be seen mounted on the rear of the front panel. The filter condensers and the B-eliminator output resistances are mounted on the baseboard. The power transformer is mounted at the right of the baseboard. The tube sockets, filter chokes, double-terminal blocks, and audio-frequency transformers are mounted on the sub-panel.

POWER AMPLIFIER AND B AND C ELIMINATOR

In Fig. 42 is shown a schematic wiring diagram of a power amplifier that is supplied with plate potential from a half-wave rectifier unit. In this diagram, the detector and two stages of amplification are shown, with the connections from the eliminator unit. The second audio-frequency amplifier tube is the power-amplifier tube.

The following is a list of the constants, and the material needed for the construction of the eliminator and the two stages of audio-frequency amplification shown.

a—Power transformer with a 110-volt primary winding a_1, a 525-volt 60-milliampere secondary winding a_2, and two 8-volt 2-ampere secondary windings a_3 and a_4.

b—Rectifier tube.

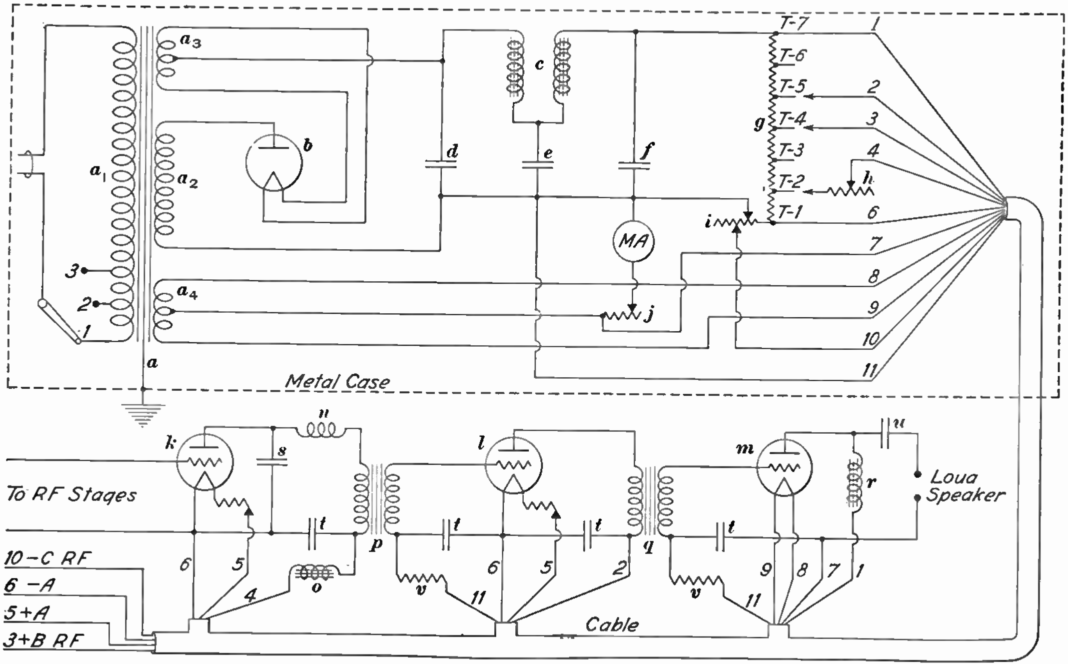

T-7
T-6
T-5
T-4
T-3
T-2
T-1
MA
Metal Case
To RF Stages
10-C RF
6 -A
5+A
3+B RF
Cable
Loud Speaker

FIG. 42

c—Two 60-henry choke coils.

d—2-microfarad 750-volt filter condenser.

e—4-microfarad 750-volt filter condenser.

f—2- to 8-microfarad 750-volt filter condenser.

g—Heavy-duty resistor in six sections, having resistances beginning from top of 9,000, 11,000, 4,500, 4,000, 3,500, and 9,000 ohms.

h—100,000-ohm variable resistance.

i—Two 2,500-ohm variable resistances in series.

j—2,500-ohm variable resistance.

k—Detector tube UX-200-A.

l—Amplifier tube UX-201-A.

m—Power-amplifier tube UX-210.

n—Radio-frequency choke coil.

o—Audio-frequency choke coil.

p—Audio-frequency transformer (3 to 1).

q—Audio-frequency transformer (4 to 1).

r—60-henry choke coil.

s—.001-microfarad by-pass condenser.

t—Four 1-microfarad by-pass condensers.

u—2- to 4-microfarad fixed condenser.

v—two $\frac{1}{4}$- to $\frac{1}{10}$-megohm grid leaks.

The biasing potential for the grid of the last-stage amplifier, or power-amplifier tube *m*, is obtained through the medium of the 2,500-ohm variable resistor *j*. The grid bias for the radio-frequency amplifier tubes is obtained from terminal *10* by means of the two 2,500-ohm variable resistors that are connected in series and designated as *i*, with two variable contact arms.

The potential to the plate of the detector tube *k* is lowered below the value of potential available at tap *T-2* by means of a high-resistance variable unit *h* connected to terminal *4*. The other connections will be apparent from a close inspection of the figure.

RECEIVERS WITH A.-C. TUBES

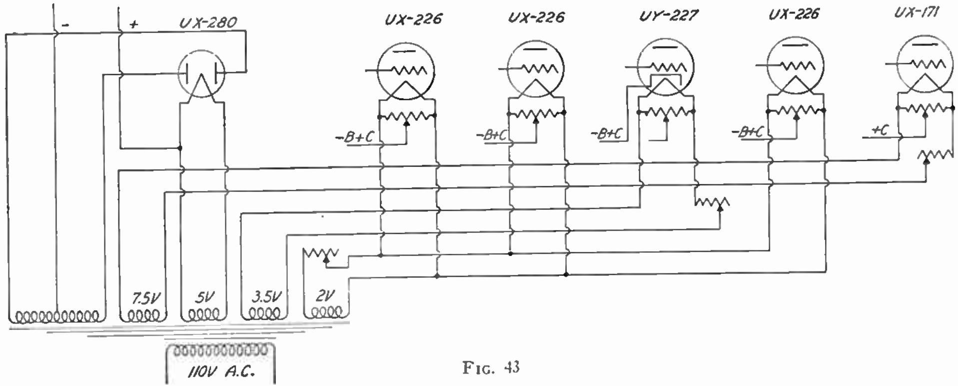
Desirability of A.-C. Operation.—In the operation of radio receiving sets the trend has been toward complete battery elimination. Many satisfactory plate-supply units operating from an a.-c. source have been developed, but filament operation from the same source has, for a time, presented more of a problem because of the larger currents required and increased expense in the rectifier and filter circuits.

The development of tubes that used raw alternating current in the filament circuit offered an excellent solution of this problem. The grid and the plate circuits do not offer any unusual problems. These are wired and connected in practically the same way as in any set that is operated by a *B* and *C* power unit. This discussion, will, therefore, be focused on the filament circuit.

Wiring Receiver for A.-C. Operation.—The characteristic features of the more common types of a.-c. tubes have been given in another Section. The manner in which the filament circuits are wired is shown in Fig. 43. In the radio-frequency stages and in the first stage of audio amplification, radiotrons UX-226 are used. Radiotron UY-227 is used as a detector, and radiotron UX-171 or 171A as a power amplifier. Potentiometers or center-tapped resistors are connected across the filament leads to eliminate the a.-c. hum.

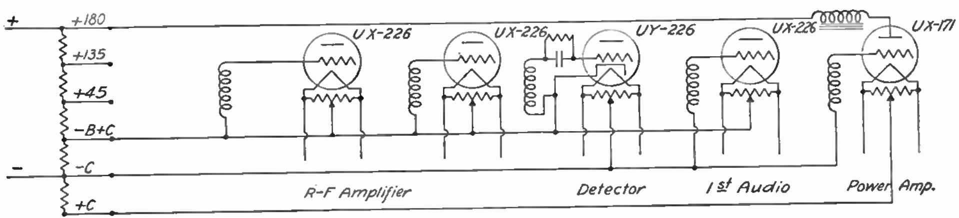
A double-wave rectifier tube UX-280 is connected in the high-voltage winding of the power transformer and the output of this tube is used in the grid and plate circuits of the receiver.

Grid Bias.—It is essential that the signal remain undistorted as it passes through the various tubes of the receiving set. In order to obtain quality reproduction the



-
+
UX-280
UX-226
UX-226
UY-227
UX-226
UX-171
-B+C
-B+C
-B+C
-B+C
+C
7.5V
5V
3.5V
2V
110V A.C.

FIG. 43



+
+180
+135
+45
-B+C
-
-C
+C
UX-226
UX-226
UY-226
UX-226
UX-171
R-F Amplifier
Detector
1st Audio
Power Amp.

FIG. 44

proper B and C voltages must be used. One method of biasing a five-tube receiver using a.-c. tubes is shown in Fig. 44. The correct biasing voltages are obtained from the output of the power unit. In the case of the detector tube, the cathode is positive ($4\frac{1}{2}$ volts) with reference to the filament. This is done to prevent the filament from attracting any of the electrons released by the cathode.

In the case of the power tube UX-171, the drop of potential in the tube itself and between $+C$ and $-C$ gives the necessary grid bias of -40 volts. The drop of potential between $-B+C$ and $-C$ is $4\frac{1}{2}$ volts, which is satisfactory for the first audio tube. The radio-frequency amplifier tubes require no biasing when the plate voltage is not in excess of 67 volts.

SOUND REPRODUCERS

TELEPHONE RECEIVERS

Fundamental Form.—In its simplest form, the telephone receiver, as shown in Fig. 45, consists of a thin, soft-iron diaphragm P mounted close to but not touching one pole of the permanent magnet NS. A fine wire C is coiled around one end of the magnet and the terminals of this coil are connected directly in the circuit in which the instrument is to be used. The diaphragm is rigidly supported at its outer edge, but the center portion is curved slightly toward the magnet because of the attraction between the diaphragm and the magnet. If a current is sent through the coil in such a direction that the lines of force set up by it coincide with those of the permanent magnet, the strength of the magnet will be increased and the diaphragm will be drawn closer to the

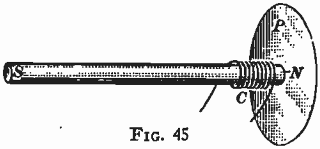


FIG. 45

pole. If, however, a current is sent through the coil in such a direction as to set up lines of force opposing those of the magnet, the strength of the magnet will be diminished and the diaphragm will spring away from the pole.

If a current that varies in value but is always in the same direction is sent through the coil, the lines of force induced in the magnet will increase while the current is increasing, and decrease while the current is decreasing. Thus, a varying pull on the diaphragm will cause vibrations that will be in harmony with the changes in current, whether the lines induced by the coil are in the same direction as those of the magnet or not.

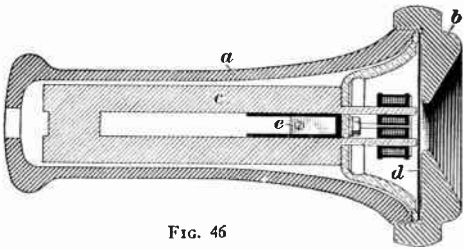
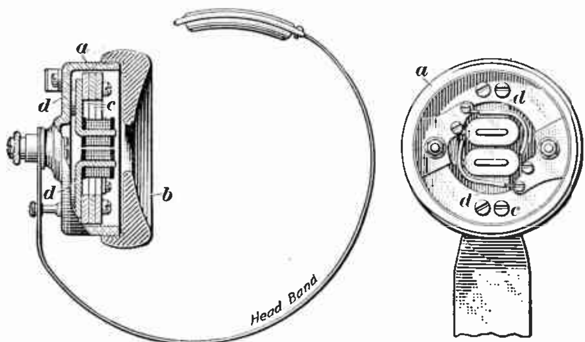


FIG. 46

The telephone receiver is affected by the fluctuating currents corresponding to sound waves and translates these currents into distinguishable sounds. The diaphragm of this simple device, like the diaphragm of the reproducer of a phonograph, is capable of emitting the most complex sounds; in fact, it is capable of imitating with a fair degree of accuracy practically all of the sounds of the human voice, of musical instruments, or other sounds made up of many complicated wave combinations.

Standard Type.—A cross-sectional view of a standard type telephone receiver is shown in Fig. 46. A barrel or shell *a* is used to protect the component parts of the receiver, and may be made of some insulating material or in some cases is made of metal finished with an enamel coating. The ear piece *b* screws onto the shell and serves to cover the diaphragm end of the receiver except for a small hole in its center through which sound waves are permitted to escape. The permanent magnet *c* is U-shaped, and has both poles projecting close to the diaphragm *d* to give as strong a pull as possible. The pole projections carry the windings, which are equally distributed between the two coils and which are connected to



(a) FIG. 47 (b)

the terminals at *e*, only one of which is shown. Bringing both poles of the permanent magnet close to the diaphragm increases the number of lines of force effective on the diaphragm and increases considerably the sensitiveness of the receiving unit.

Watch-Case Type.—The construction of a compact form of telephone receiver, known as the *watch-case* receiver, is shown in Fig. 47; view (*a*) shows a section and view (*b*) shows the end with the ear piece and diaphragm removed. When the receiver is equipped with a head band, as shown in view (*a*), it forms a *head set*, a name which is applied whether one or two receiver units are used.

Although the principle of operation is the same as in the larger hand receiver, the construction and design is necessarily varied to decrease both the size and the weight. The shell *a* consists of a case usually of metal, threaded externally to engage an internal screw-thread on the hard-rubber ear piece *b*. The magnets are built up of flat steel rings *c*, so magnetized that the opposite sides of their circumferences are of different polarities. The L-shaped pole pieces *d*, which reach nearly to the diaphragm and carry the magnet coils, are attached to the north and south poles of the steel rings. In many cases the magnets are not made of complete rings, but are approximately half circles. The extensions carrying the coils are then fastened to the ends of the permanent magnet. The diaphragm is of thin iron and is clamped between the body *a* of the shell and the ear cap *b*.

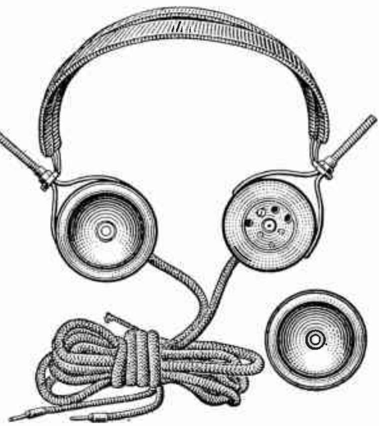


FIG. 48

Radio Headset.—A set using two watch-case receiver units is shown in Fig. 48. This particular type has a piece of soft iron mounted between the poles so that it is acted on by their magnetic field. The coil of wire carrying the received current is so located that it moves the iron armature in a manner corresponding to the current changes. The armature is connected by levers to a light diaphragm, often of mica, which is controlled by the armature to produce sound waves in the air. The lightness of the moving parts causes this receiver to be responsive to very weak signals.

In some instruments of this general type an adjusting screw is provided so that the sensitiveness of the signals may be controlled to a certain extent. For instance, if it is desired to weaken the signals, the armature is withdrawn from the magnets by the screw arrangement. Also, the tone or sound of the two receiver units may be exactly balanced for best operation. If no screw adjustment is furnished, the two receiver units should be adjusted at the factory so that the tone of each is the same.

SPEAKERS

Horn-Type Speaker.—Where it is desired to make the signals or message loud enough for a large group of people to hear, it is necessary to use a special type of receiver unit known as a *loud speaker*, or simply *speaker*. The operating unit of one type of horn speaker is shown in cross-section in Fig. 49, in which the magnet coils are shown at *a* and the metal diaphragm at *b*. The two coils are mounted on extensions of a permanent magnet. The diaphragm is in the form of a circular disk carefully mounted between rubber gaskets and so suspended that its surface rests but a small fraction of an inch above the extension pole pieces of the magnet.

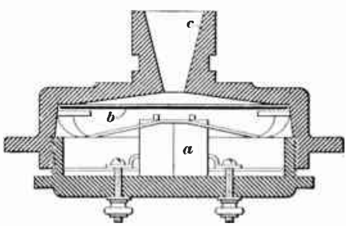


FIG. 49

When a signal current passes through the coils, it causes variations in the pull of the permanent magnet on the diaphragm. Accordingly, the diaphragm vibrates, and in doing so, sets up sound vibrations which emanate from the mouth of the speaker. The horn, of whatever type it may be, is attached to the piece *c*.

Cone-Type Speaker.—The principle of operation of a cone-type speaker may be seen in Fig. 50. This speaker consists essentially of a set of coils *a*, which when energized actuate the armature *b*. The armature is centered on the bar *c* and is free to swing in either direction. To one end of the armature is fastened a drive pin, *d*, the other end of the pin being connected to the thrust lever *e*, the connection being made with soft solder. The thrust lever is, in turn, connected to the apex of the cone *f*. Signal currents flowing in the coils *a* cause the armature *b* to vibrate. The vibration is transferred through the pin *d* and thrust lever *e* to the cone *f*. The vibration of the cone reproduces the music or speech transmitted from the broadcasting station. No permanent magnet is shown in the figure; in actual practice it is necessary to have it.

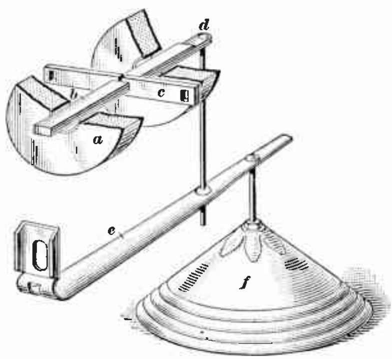


FIG. 50

Electro-dynamic Speaker With Power Amplifier.—In Fig. 51 is shown in schematic form an electro-dynamic reproducer *a* combined with a socket power unit containing a stage of power amplification. *B* and *C* voltages are also provided for the receiver that is used to drive the speaker. The reproducer *a* has two coils. The coil *b*, known as the field coil, forms part of the filtering system of the power supply. A movable coil *c*, known as the cone coil, inasmuch as it is rigidly fastened to the cone *d*,

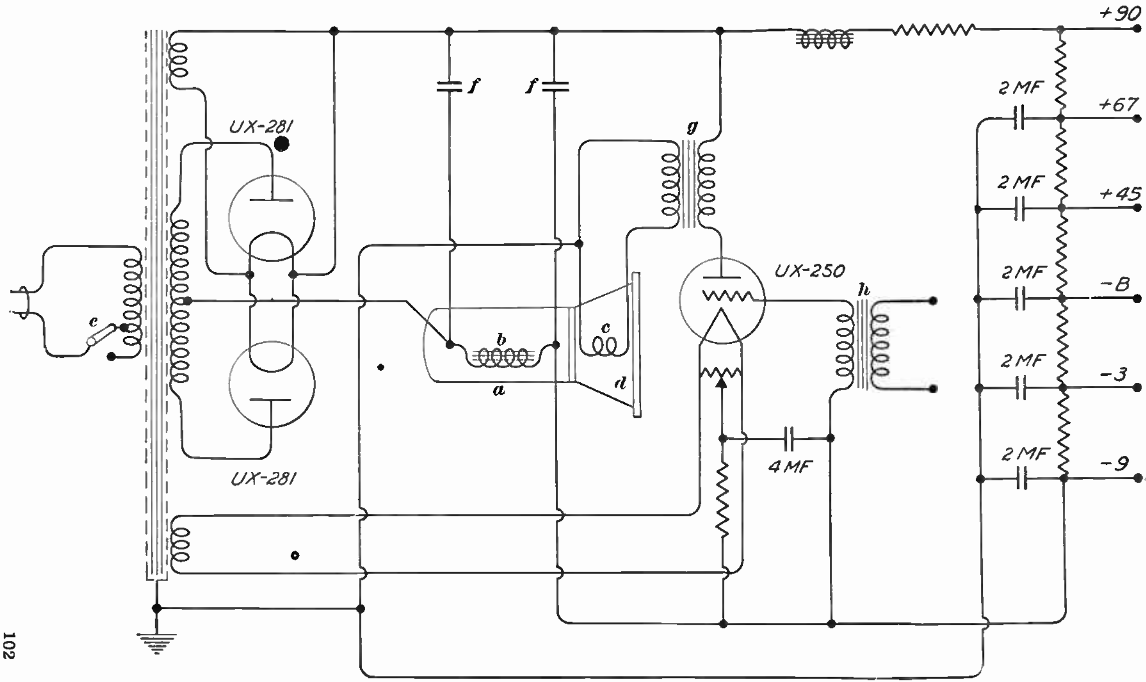

+90
2 MF
+67
2 MF
+45
2 MF
−B
2 MF
−3
2 MF
−9
UX-281
UX-281
UX-250
4 MF
f
f
g
a
b
c
d
e
h

FIG. 51

moves in the strong magnetic field of the coil *b* in accordance with the modulation of the received signal.

The entire unit is designed to operate from a 105- to 125-volt 60-cycle supply. A two-way switch *e* is used to regulate the input of the power transformer. Two UX-281 radiotrons are used as rectifiers and are connected in a full-wave rectifying circuit. The output of the rectifier tubes is smoothed out by means of the two 4-microfarad condensers *f* and the field coil *b* of the reproducer. The filtered energy is applied to the plate of the power amplifier tube UX-250 through the primary winding of the output transformer *g*. The open terminals of the input transformer *h* are connected to the output of the receiving set with which this unit is used. The secondary winding of the output transformer *g* is connected to the cone coil *c* of the reproducer *a*. The interaction between the field of coil *b* and that of coil *c* produces a movement of the cone, which, in turn, reproduces the broadcasted music or speech.

SERVICING OF RADIO RECEIVERS

GENERAL INSTRUCTIONS*

CLASSIFICATION OF RECEIVING SETS

Classification of Circuits.—Instructions covering the servicing of broadcast receivers are supplied by the manufacturer. These instructions, however, usually apply to individual sets and are of little value in general application. In this Section the service problems will be grouped under general specifications, followed by methods of diagnosing and correcting them.

In general, there are four basic pick-up circuits in use today: the so-called regenerative detector, the untuned radio frequency, the tuned radio frequency and the super-heterodyne. Any set on the market may be classified as using one of the foregoing types or possibly a combination of one or more. There are two additional types of pick-up circuits which have fallen more or less into oblivion and will not be found in general use in the broadcast receivers of today. They are the crystal detector and the straight audion detector, which employs no form of regeneration whatsoever.

Receiving sets consist of a pick-up circuit, a detector circuit, and an audio-frequency amplifying circuit. In the pick-up circuit radio-frequency amplification may be incorporated. The detector may be either a tube or a crystal. In the audio-frequency circuit from one to

*Abstract of article on "Servicing of Broadcast Receivers," by Lee Manley and W. E. Garity, in the Proceedings of the Institute of Radio Engineers.

three tubes are generally used. In multi-tube sets employing radio-frequency amplifiers, some arrangement of circuit is made to suppress or control the tendency of the tubes to oscillate, when the circuits are tuned to resonance. Any set on the market today may be grouped under one of the foregoing classes as to the circuit employed.

Classification of Failures.—In much the same way that receivers may be grouped under circuit classifications, their failure to operate may be grouped under certain general classes, namely:

Lack of operating experience on the part of the user.
Location.
Defective accessories.
Open circuit.
Short circuit.
High-resistance connection.

Lack of operating experience may be the result of not following out instructions carefully enough, or, as is sometimes the case, the instructions are not complete enough and are not entirely clear to the novice. It may be the result of insufficient instruction on the part of the service man who made the installation. Then, too, it may be the result of impatience on the part of the customer.

Under the caption of *location* many factors must be considered. The type of building in which the installation is made, the proximity to steel buildings, power lines, trolley and railway lines, and the geological and topographical conditions surrounding the installation are all important factors.

Under *defective accessories* may be included defective tubes, power units, batteries, loud speakers, antenna and ground installations, also improper battery connections. Many sets fail or are returned to the dealer as unsatisfactory because of poor antenna and ground installations.

Many a set of good quality and capable of delivering satisfactory results fails because the loud speaker that is used with it does not have the proper electrical characteristics to operate satisfactorily in conjunction with the receiver. Tubes will also cause trouble as they are subject to certain defects incidental to fragility.

Open circuits are generally found in the movable connections of the set such as a condenser pigtail, loop leads, loud speaker leads, and any other connection that is subject to movement or vibration in the normal operation of the set. Open circuits may also result from burned-out transformers or from mechanical failures in telephone jacks, rheostats, and switches.

If a set has been once tested and found to be O. K., *short circuits* rarely occur. When they do, it is the result of a mechanical failure of the moving parts or of tinkering with the mechanism of the set. It will sometimes happen that the pigtail of a moving element of the receiver will break and fall in such a way as to cause a short circuit of that element. This is particularly true of the pigtails of variable condensers. The principal cause of short circuits that occur in the normal operation of a set is in the tubes. If the filament of the tube should break there is a possibility of its falling in such a way as to cause a short circuit between itself and the plate and grid elements of the tube. When such a fracture of the filament occurs the B or C battery, as the case may be, is short-circuited through the conductors involved. This type of short circuit is generally of very brief duration as the filament will generally burn out as soon as the short circuit occurs. A contact between the grid and plate element of a tube is a more serious type of short circuit, resulting in the rapid deterioration of the B and C batteries, and may possibly cause a burn-out of the transformer windings in the circuits involved.

The foregoing troubles are relatively easy to check up as they are immediately apparent or can easily be located by a continuity of circuit test.

The most difficult type of failure to locate is that caused by a *high-resistance connection.* It is not only difficult to locate, but it is difficult to determine. This condition will cause the set to operate indifferently with rather unsatisfactory results. This condition is sometimes mistaken as location trouble. A high resistance is possible at any connection in the receiver. Soldered connections that are soldered with a corrosive flux that has not been properly treated after the soldering operation are probably the worst offenders. Weak mechanical springs in telephone jacks and switches may also introduce high-resistance connections.

PRECAUTIONS

All sets should be tested before they are sold. This takes but a few minutes and will surely pay well in avoiding dissatisfaction as well as time that is sometimes necessary to service a defective set. A radio receiver that is working properly today does not as a rule go bad tomorrow, and if such an installation does fail, the dealer may feel that the trouble is due to a defective accessory rather than the set itself. When the service man is called on to service such a set he has the confidence that the set is O. K. and he will immediately be able to concentrate on the real probability of failure rather than imaginary ones.

Then, too, if the dealer would acquaint the customer with the limitations of radio reception, what to expect and what not to expect, service problems would be minimized. Acquaint the customer as to the probable length of time his batteries and tubes will last. This is quite important, and if followed out, will avoid some very disagreeable service jobs.

SERVICE-SHOP EQUIPMENT

In order that satisfactory and efficient service may be given to patrons, the radio dealer must have a properly equipped service shop. The equipment should include the following items: Long-nose pliers; combination pliers; diagonal cutting pliers; 3-inch screwdriver; 6-inch screwdriver; heavy-duty screwdriver; insulated screwdriver; loud-speaker armature spacing tools; test leads with springs clips; testing outfit with a.-c. and d.-c. meters; a set of socket wrenches; 4- and 8-inch crescent wrenches; small claw hammer; dust brush; electric soldering iron and stand; spare-parts shelves; movable battery box or power unit; indoor antenna; antenna terminal; ground terminal; calibrated oscillator; headphones and cords; tool rack; series test lamp with leads and test points; hand drill with a selection of drills; small compass saw; small ball peen hammer; wire; socket contact adjusting tool; friction tape; rosin-core solder; polishing oil and cloth; pocket knife, and any other instruments and tools that will enable the man responsible for the service to do rapid and efficient work.

PORTABLE TOOL KIT

From the standpoint of service it is usually advisable to make all repairs on receiving sets directly on the owner's premises. In order to do this efficiently, the serviceman must have a well-equipped tool kit, so that he may be able to make all tests and repairs with as little delay as possible. A well-stocked tool kit should have the following items: Portable test set with a.-c. and d.-c. meters and the necessary test leads; ear piece with head band; loud-speaker armature spacing tools; set of tested tubes; long nose pliers; diagonal cutting pliers; friction tape; electric soldering iron and rosin-core solder; large and small screwdrivers;

insulated screwdriver; pocket knife; 4-inch and 8-inch crescent wrenches; small hammer; large piece of canvas; flashlight; and a selection of nuts, screws, wire, etc.

SERVICEMAN'S CONDUCT

When a service man goes into a customer's home he is usually going there as a representative of a commercial establishment. He should be instructed to be courteous and considerate. If he must take a set out of the cabinet for adjustment he should use a piece of cloth provided in his kit to protect the surface of the table he works on. He should answer all questions asked him no matter how absurd they may appear to him. The customer generally has one question that he would like to have answered, and in his mind the service man must be an expert, in order to be able to do such work, and so he unburdens his mind. The service man should respect this attitude on the part of the customer and should do his best to point out the fallacies tactfully and set the customer right in his ideas about radio. The service man should make the customer enjoy his visit and if this is done the service man becomes a valuable asset to a business and is a potential salesman.

OBTAINING INFORMATION FROM CUSTOMER

The service man, before he starts to make any adjustments other than turning on the set and trying the various controls, should question the customer as to how it happened, the time, place, and conditions surrounding the failure. He should have the customer re-enact the conditions at the time of failure. By getting all the symptons an astonishing amount of time may be saved in running down the difficulty. If sufficient questions are asked, the customer will generally give the real cause of trouble or he will suggest something in the course of inquiry that will point out just what the cause of failure was. Sets as a rule do not go bad of themselves. The failure usually occurs while some operation is taking place, such as plugging in the loud speaker, turning the condensers or making a change in the battery connections.

The length of time that a set has been in operation will be an indication of various types of trouble. A set that has recently been installed is subject to a certain type of failure, whereas a set that has been in operation for a year or more, is subject to other types of failure.

RELATION BETWEEN LENGTH OF SERVICE AND FAILURE

If a set has been installed for a period of two weeks or less, outside of the inability of the customer to procure the desired results, there are only a few reasons why the set should fail. They are:

A defective tube.

Defective battery, battery connection, or power unit.

Loud-speaker connection loose in telephone plug.

Burn-out of transformer.

Of course, there may be other reasons, but these are the most common and are given in the order of their probability of occurrence.

If the set has been in operation for a period of six months or a year, the possibilities of trouble will increase. If the failure in this type of installation has been gradual, the first thought would be that the tubes were becoming deactivated through continual use.

If the breakdown was sudden, a mechanical failure might be expected in one of the movable connections or pigtails. A burned-out transformer could be expected in difficulties of this sort. If the trouble is due to a noise condition, the failure might be ascribed to dust or dirt accumulations on the condenser plates or other important parts of the receiver. The defect might also be due to a soldered connection. It will require, as a rule, a rather long period of time for a soldered connection to corrode to such a degree as to cause this condition. The local atmospheric conditions under which the set has been operating may have some bearing on the cause of failure. If the set has been operating near the seashore and has been subjected to the action of salt atmosphere it may have caused sufficient corrosion of the connections or other metallic parts to introduce high resistance or leakage path.

If a set has been operating for a long period of time and has given satisfactory results and then develops noises and scratching sounds, one should not look for a loose connection in the wiring of the set, but rather look for an open circuit in the moving parts. Worn mechanical parts are often mistaken for loose connections in the wiring. The wiring is absolutely stationary and it is not at all likely that it will be disturbed in the ordinary use of the set so as to cause a failure due to a loose connection. Vernier drive shafts and vernier plates will wear loose, and while apparently they are making perfect contact to the metal surfaces of the condenser when the set is brought into a critical condition, as is the case when receiving distant stations, will cause noises that might be thought due to a loose connection in the wiring.

PROBABLE SOURCES OF TROUBLE

TROUBLE IN ACCESSORIES

When trouble is experienced in radio reception the general tendency seems to be to blame it on the set. However, in a large number of cases the trouble may be traced directly to a defective installation or to defective accessories. This includes the aerial and ground, the A, B, and C batteries or substitutes, the tubes, and the loud speaker.

The aerial may be grounded; it may be too long or too short; it may touch foreign objects; its connections may be corroded; its lead-in may be broken inside the insulation. The ground wire may be broken; it may be corroded at connection to water pipe or other ground; there may be an inefficient source of ground. The lightning arrester may be leaky or short-circuited.

The A battery may be discharged. This is indicated by a gradual dying out of the signals during reception. The electrolyte should be tested with a hydrometer. The connections at the terminals of the battery may be corroded. This results in noisy, intermittent, or weak reception. The terminals should be scraped bright and then coated with vaseline to prevent further corrosion. If an A-battery eliminator is used, the trouble will be found either in the rectifier or filter circuit. In all such cases it is best to report such trouble directly to the manufacturer.

Dry B batteries when run down cause reception to be weak and noisy. When the detector voltage is too low, the result may be a steady whistle. It is advisable to replace a 45-volt battery unit when it drops to 34 volts. The B-battery units may be wired incorrectly, resulting in wrong voltages being applied to the plates of the tubes.

Storage B batteries have the same peculiarities as storage A batteries. They should be tested periodically with a hydrometer and inspected for corrosion at the terminals.

The most common source of trouble in a B power unit is a defective rectifier, especially if it is a tube. There is also the possibility that the filter condensers have broken down, the filter chokes or the resistors in the voltage divider are shorted or open.

Defective tubes are another source of trouble. A tube may light and yet be dead so far as reception is concerned. Such a tube may sometimes be brought back to normal by reactivation. Sometimes the elements are shorted, which makes the tube unfit for reception. It happens also that the wrong type of tube is used.

The loud speaker has also peculiarities of its own. It may rattle, howl, or fail to produce any sound at all. Replacing the loud speaker with a pair of headphones will immediately determine whether the loud speaker or the set is at fault.

OUTSIDE INTERFERENCE

Sources of Outside Interference.—In addition to the complaints which the serviceman may find to be due to faulty equipment or installation, there are also many cases where unsatisfactory reception is due to interference originating outside the installation. These interferences manifest themselves in various ways. In order to determine whether a particular disturbance comes in from the outside it is necessary to disconnect the aerial and ground from the set and turn on the power. If the noise disappears or is very much reduced in strength, then the disturbance is undoubtedly due to something outside the set. Among the many outside sources of interference may be mentioned static, nearby oscillating receivers, radio telegraph stations, and defective power installations.

Much of the work in mitigation of electrical interference results in an improvement in the operation of the electrical devices or supply lines and is thus a double gain. There are, however, some electrical devices which, even when in perfect working order, cause disturbances that result in interference with radio reception. In many cases it is possible to provide filters, shields, chokes, etc., either at the source of disturbance or at the receiving set, which do much to relieve the difficulties.

Part of the disturbance from electrical devices is practically inevitable and must be regarded, like atmospheric disturbances, as part of the inherent limitation of radio reception. In other words, the limitation upon radio reception is not only the distance and the power of the transmitting stations and the sensitiveness of the receiving set, but also the omnipresent background of slight electrical disturbances which drown out signals below a certain intensity. This background of electrical disturbances is the underlying reason why reception from local stations is inherently superior to reception from distant stations.

Power-Line Induction.—A frequent cause of interference is the presence of alternating-current power wires near the antenna or receiving set. Low-frequency voltages (usually 60 cycles) are induced and the resultant current flowing in the receiving circuit causes a "humming" sound in the telephone receivers. The low pitch of the hum will usually identify this source of interference. A method of eliminating or at least reducing the magnitude of this interference is to place the antenna as far as possible from the wire lines and at right angles to them. When the interference can not be eliminated by such means, the proper choice of a receiving set may help. An inductively-coupled (two-circuit) receiving set is less susceptible to such interference than a single-circuit set. The use of one or more stages of radio-frequency amplification should also help to filter out the audio-frequency interference. It has been suggested that audio-frequency interference might be shunted around a receiving set having a series antenna condenser by connecting between the antenna and ground terminals of the set a high resistance, which will offer lower impedance to the audio frequency than will the receiving set itself.

Sparking Apparatus.—Sparks are produced in the normal operation of many types of electrical apparatus, such as motors, doorbells, buzzers, gasoline engines, X-ray apparatus, violet-ray machines, some forms of battery chargers, rural telephone ringers, and heating-pad thermostats. Sparks are also sometimes produced at defective insulators, transformers, etc., of electric wire lines. Sparks usually give rise to electric waves which travel along the electric power wires and by them are radiated out and are then picked up by radio receiving sets. The noise thus produced in a radio set may come from a disturbance that has traveled several miles along the electric power wires.

One remedy for such types of interference is to eliminate the spark. This is possible if the spark is an electrical leak and not necessary to the operation of the machine in which it occurs. Many very useful electrical machines, however, require for their operation the making and breaking of electrical circuits while they are carrying current, and whenever this happens a spark is produced. It is impossible to eliminate these machines, so that it is necessary to make the spark of such nature or so arrange the circuits that the radio-frequency current is reduced or prevented from radiating.

To prevent the radio-frequency current produced by a spark from getting on to the lines connecting the sparking apparatus, some form of filter circuit is necessary. A tested condenser, 1 microfarad, more or less, connected across the sparking points will short-circuit a considerable amount of the radio-frequency current, or a condenser connected from each side of the line to ground will serve the same purpose. A choke coil in each side of the line in addition to the condensers connected to ground forms a simple filter circuit that should prevent frequencies in the broadcast range from getting on the line. A high inductance, or choke coil, or a high resistance connected in each side of the line changes the characteristics of the circuit so as to reduce the amount of power radiated. If such a filter circuit is not effective or is impractical, the apparatus may in some cases be surrounded by solid metal sheet or wire screen that is thoroughly grounded. The screen should completely surround the apparatus. This may be difficult. For example, in shielding the ignition system of a gasoline engine the spark coils and all wires and other parts of the system must be enclosed in metal shields, and these must be very well grounded.

Location of Source of Interference.—The first thing to do in tracing the source of trouble is to make sure that it is not in the receiving set itself. The next thing is to open the electric switch at the house meter; if the interfering noise is still heard in the radio set, the source is then known to be outside the house. It is then desirable to report the situation to the electric power company. Many of the companies have apparatus for the purpose of following up complaints of this kind. Usually a sensitive receiving set with a coil antenna is used to determine the direction from which the interfering noise comes, and this outfit is taken from place to place until the source is found. The location of such sources is often a very difficult and baffling undertaking. The trouble sometimes comes from a spark discharge over an insulator to ground, or between a pair of wires, or it may be that the wire is touching some object such as a tree, pole, guy wire, etc. Such a spark discharge is a loss of power to the operating company and a potential source of serious trouble, and for these reasons the company is probably more interested in finding and eliminating this type of trouble than the radio listener. Large leaks and sparks may often be observed at night, especially in hot weather. However, sparks that are too small to be readily noticed may cause serious interference to radio reception.

Commutators.—Where d.-c. motors are in operation near a radio receiving set interference is sometimes caused, especially when the brushes on the motor are sparking badly. The sparking should be reduced as much as possible by cleaning the commutator and by proper setting of the brushes. The remaining interference is sometimes overcome by placing two condensers, about 2 microfarads each, in series across the power-supply line and connecting their mid point to a good ground system.

Bell Ringers.—Another source of interference is the ringing machine used in rural telephone exchanges. Telephone engineers can reduce or eliminate interference by connecting a filter between the machine and the ringing keys.

Precipitators.—Many cases of radio interference have been caused by electrical precipitators that are used to prevent smoke and noxious fumes or material from leaving the chimney. The precipitator operates by establishing a highly charged electric field, inside the chimney, of such a nature and direction that particles going up the chimney are charged and driven against the walls where they stick. Precipitators cause interference for the reason that the high voltage used in their operation is obtained from a rectifier that produces sparks and generates radio-frequency alternating current as well as the direct current which the precipitators need. If the precipitator is so designed and arranged that the distance between the rectifier and the chimney is only a few feet or if the entire apparatus including all leads is housed in a metal building, there is usually no trouble. But if the rectifier is separated from the chimney the wire which joins them forms a good antenna that will radiate and cause interference for 20 miles or more. Interference from these precipitators can be eliminated by placing a grounded wire screen entirely around these wires and thoroughly grounding the wire screen and the rectifier. If screening of the various parts is impracticable, damping resistances can be inserted at various points in the wire line, which will reduce the amount of power radiated. Tuned circuits connected across the spark gap of the rectifier will assist by absorbing the radio-frequency power.

TESTING OF RECEIVING SETS

WESTON A.-C. AND D.-C. TESTER

Purpose of Tester.—The Weston a.-c. and d.-c. tester, known as model 537, is designed for testing any type of receiving set, whether operated from a direct-current or an alternating-current source. It will measure the various voltages used in the radio set; it will test continuity and condition of circuits, and test the tubes under the same conditions as exist when the tubes are in their sockets. All tests can be made by using the regular voltages normally supplied to the set by its batteries or socket power, so that no auxiliary power supply is required.

A.-C. Voltmeter.—The test set, shown in Fig. 1, has two instruments, an a.-c. voltmeter *a* and a d.-c. voltmilliammeter *b*. It is provided with various switches, plugs, binding posts, cords, and adapters for properly connecting the instruments to the circuits under test.

The a.-c. voltmeter *a* has three ranges; namely, 150, 8, and 4 volts. Either of the two lower ranges is connected directly across the filament terminals when the switch *c* is set to *A. C.* The particular range depends on the position of the range selector switch *d*, whether turned to 8 or 4, or away or toward the operator, respectively. These ranges are for the purpose of measuring the filament voltages of tubes when the filaments are heated with raw alternating current. This voltmeter may be allowed to remain in the circuit during the tests for plate voltage, plate current, grid-bias voltages, and tube tests described later. This will enable one to follow any changes that may occur during tests due to changes in line voltage.

The 150-volt range is provided for measuring the line voltage and is available only at the two binding posts *e*. These are marked 150 and + on the instrument. This range is entirely insulated from all other circuits in the test set, and, therefore, while only one range can be used at a time to obtain correct readings, no damage to the set can result if both high and low ranges are connected simultaneously, and it may remain in the circuit during any other test, regardless of connections, without damage or error.

The low ranges are also available at the three binding posts *f*; these are stenciled 8, 4, and ×. The low-range binding posts must not be used when the plug *g* is connected in the radio set, on account of possible interconnections.

D.-C. Volt-Milliammeter.—The d.-c. volt-milliammeter *b*, Fig. 1, has four voltage ranges; namely, 600, 300, 60, and 8 volts, and two current ranges, 150 and 30 milliamperes. The 600- and 300-volt ranges are for plate voltage, the 60-volt range for grid bias, and the 8-volt range for filament voltage measurements. These ranges are all available at the plug *g* for tube-socket tests, by properly setting the dial switch *h*. The 600- and 60-volt ranges are also available at the three binding posts *i* shown on the right of the instrument, when the dial switch *h* is set to *Vm. B. P.* (voltmeter binding posts). All volt ranges have resistances of 1,000 ohms per volt, so that they may be used for measuring the voltages from socket power devices.

The 30- and 150-milliampere ranges are available at the plug for plate-current measurements by setting the dial switch to *Plate MA.*, and the range selector switch *j* away from the operator for 150 milliamperes, and toward the

FIG. 1

operator for 30 milliamperes. The 150-milliampere range is provided for measuring higher plate currents than 30 milliamperes and the output of rectifying tubes. The 600-, 300-, and 8-volt ranges may be read directly on the scales provided for them. The 60-volt and 30-milliampere ranges should be read on the 600 and 300 scales, respectively, dividing the indications by 10. The 150-

milliampere scale should be read on the 300 scale divided by 2. The 150-milliampere range is also available at binding posts *k* by setting the dial switch *h* to *MA. B. P.*

Dial Switch.—The dial switch *h*, Fig. 1, is a bipolar switch, and connects the d.-c. volt-milliammeter *b* to the various circuits designated on the dial. Two positions are available for plate-voltage tests, namely, 600 and 300 volts.

A.-C.–D.-C. Switch.—When the switch *c*, Fig. 1, is set toward the mark *A. C.*, or to the left, it connects the low ranges of the a.-c. voltmeter *a* across the filament terminals of the plug *g* for measuring filament or heater voltages of tubes supplied with raw alternating current. When the switch is set to the mark *D. C.*, or to the right, the low ranges of the a.-c. voltmeter are disconnected and the 8-volt range of the d.-c. voltmeter *b* can be used for filament voltage measurements of tubes supplied with direct current or rectified alternating current.

This switch has only the one function referred to, and all tests, either for a.-c. or d.-c. tubes, except filament voltage, are made on the d.-c. meter, including plate and grid-bias voltages and plate current, regardless of the position of this switch. When d.-c. filament voltage are to be measured, the switch *c* should be set to *D. C.* for the reason that both instruments will indicate and the a.-c. meter requires more current for its operation than the d.-c. meter, which may cause an error in the voltage indications. No harm, however, can result if the switch *c* is left on *A. C.*

Binding Posts.—Binding posts are provided for making voltage or current measurements directly on batteries or power units, or for any purpose for which the cord and plug are not adapted, as, for example, testing the heater voltage of tubes when the heater terminals are not in the base of the tube. The plug should be removed from the radio set when the binding posts are used.

Adapters.—The adapters are shown in the foreground of Fig. 1, on the right and left of the plug *g*. The set is provided with a plug and socket of the UX type. If the set is equipped with tubes or sockets other than the UX type it is necessary to select the proper adapters to make the test. A plug with cord and terminals attached is also provided for connection to a lamp socket for line-voltage tests.

TESTING BATTERY-OPERATED SETS

Preliminary Adjustments.—First see that the A, B, and C batteries are connected to the radio set and all tubes in place except in the socket to be tested. Then insert the plug *g*, Fig. 1, into the empty socket in the set, and the tube into the socket *l* of the tester. Set the switch *c* to *D. C.* and the switch *j* to *30* and proceed with the tests. In new radio sets not previously tested, before any tubes are inserted it is preferable to make a preliminary test of each socket in succession. This will reveal defects, if any, in manufacture and those due to shipment, and possibly save tubes.

In radio sets having phone or speaker jacks, it is necessary to plug in either a headphone or speaker before tests can be made on certain tube sockets, especially in the last stage, as the plate voltage is connected to the plate of the last tube through the phone circuit. In some sets the filament voltage also can not be applied to a tube until a plug is inserted in the corresponding jack.

Testing A Battery.—Turn the switch dial *h*, Fig. 1, to *A* or *A Rev.*, whichever gives a positive indication, and adjust to the filament voltage for the tubes, using the 8-volt scale on the instrument. If no indication can be obtained on the instrument, then there is either a broken or disconnected circuit or the A battery is entirely run down. If a slow indication results, then either the A battery is low or the contacts are poor in the sockets, or in the rheostat, or in the circuit connections. If an unsteady indication results, then some connection is loose. Loose or variable contacts are frequently found in the spring contacts in the tube sockets and in rheostats.

In the above tests, the voltmeter indicates the voltage across the filament. In order to measure the total A-battery voltage from the socket it is necessary to remove all the tubes from the set and tester and set the rheostat at or near its maximum position. Then the voltmeter indicates the A-battery voltage directly. With storage A batteries a more reliable test is obtained with a hydrometer.

Testing B Battery.—Turn the switch dial *h*, Fig. 1, to either B *300* or B *600*, depending on the voltage to be measured, and then read the indication on the corresponding scale. If the circuits are good, this indication will give the B-battery voltage less the drop in the primary of the transformer. For radio-frequency transformers this drop is negligible and for the average audio-frequency transformer, on account of the high sensitivity of the instrument, the indicated voltage will be within 1 per cent. of the actual B-battery voltage.

If no indication results, the following should be looked for:

(*a*) Disconnected battery.
(*b*) Run down battery.
(*c*) Spring contacts in socket out of place.
(*d*) Open circuit in primary of transformer.
(*e*) Open connection in some part of the plate circuit.

If low indication results, then look for the following:

(*a*) Partly run down battery
(*b*) Loose or corroded connection.

If a variable indication results, then look for a loose connection in some part of the circuit.

Testing C Battery.—Turn the switch dial *h*, Fig. 1, to *C* or *C-A Rev.*, depending on whether it was necessary to use *A* or *A Rev.*, respectively, when testing the A battery. The C-battery voltage is indicated on the 60-volt range and is read on the 600-volt scale divided by 10. The voltage read will be less than the actual C-battery voltage by the amount of the voltage drop in the secondary of the transformer. For radio-frequency circuits, when no grid resistors are used, this drop is negligible. For audio-frequency transformers the voltage indicated will be about 90 per cent. of the battery voltage. The C-battery circuit should be tested in the same manner as the B-battery circuit, it being remembered that the secondary of the transformer, instead of the primary, is in circuit.

Locating Circuit Defects.—When a defective circuit is indicated in the foregoing tests, a simple method for locating the defective part is to remove the plug *g*, Fig. 1, from the radio set, and connect the two cables furnished with the set to the binding posts on the instrument, one to − and the other to 600, the switch dial *h* being set to *Vm. B. P.* Then if the B-battery circuit is to be tested, the free end of the cable that is connected to the − binding post should be connected to the negative terminal of the B battery on the radio set, and with the free end of the remaining cable, the plate terminal or contact spring in the socket should be touched where the defective circuit was indicated. This circuit should be followed from one connection to another. When the defective part has been passed, the voltmeter will give an indication, showing that the defect is in the part of the circuit just passed.

The A- and C-battery circuits can be tested in the same manner as described for the B-battery circuit. It is better to use the high-voltage range for all of these circuits for the reason that if a high-voltage circuit is touched accidentally when tracing a low-voltage circuit, then no damage to the instrument or to the radio set will result.

Testing Batteries Directly.—To measure the voltage of a battery or battery substitute directly at its terminals, connect them to binding posts – and *60* or – and *600* on the tester, Fig. 1, depending on the voltage to be measured. Turn the switch dial *h* to *Vm. B. P.* This connects the binding posts to the instrument and makes it an ordinary double-range voltmeter.

Testing of Tubes.—Remove a tube from the radio set and place it in the socket *l*, Fig. 1, on the tester. Insert the plug *g* into the socket from which the tube was removed. For comparative tests of ordinary tubes it is desirable to select a socket having a B battery of about 90 volts and a C battery of 4.5 volts. If other sockets are also controlled by the same rheostat that controls the socket selected for the test, then these sockets must also contain tubes.

Power tubes, such as UX-120, UX-112A, UX-171A, UX-210, and UX-250 preferably should be tested from the socket in which they are regularly used on account of the higher voltage B and C batteries require.

If it is desired to test all the tubes directly from the sockets in which they are to be used, then all the tubes may be in place in the radio set except the one to be tested, and the plug in the tester inserted in the socket belonging to this tube. Then, by interchanging the tubes in succession, all can be tested. In this test it is preferable not to use the detector-tube socket.

The first test is to determine if the filament or grid is touching the plate. This is accomplished as follows:

1. Set the switch dial *h*, Fig. 1, to *B* and then to *C* to make sure that the B and C batteries are connected and

are of the correct values. The filaments may be lighted or not as is found necessary or convenient.

2. Then set the switch dial *h* to *Plate MA.*, and the range selector switch *j* to *30*, and insert the tube to be tested into the socket *l*. If the pointer on the instrument deflects violently to the right beyond the scale, it indicates that the filament or the grid is touching the plate. The tube should be immediately removed from the tester. In testing power tubes, the plate current resulting when tested without the proper grid bias will often be greater than the full-scale value on the instrument. This comparatively mild slamming of the pointer must not be mistaken for the violent slamming resulting from a defective tube.

If, after the foregoing tests, the plate-current test indicates approximately normal values on the scale, then the filament and grid are not in contact with the plate and further tests should proceed as follows: Set the switch dial *h* to *A* or *A Rev.*, as is found necessary, and adjust the filament voltage, for which the tube is designed by means of the proper rheostat in the receiving set. Change the switch dial *h* to *B* and read the B-battery voltage. It is necessary that all tubes be tested at the proper plate voltage, in order to obtain comparative readings. Then set the switch *h* to *Plate MA.*, and the range-selector switch *j* to *30* or to *150*, as is found necessary. This changes the instrument into a milliammeter having a full-scale value of 30 or 150 milliamperes. Read the plate current on the 300 scale divided by 10 for the 30-milliampere range, or divided by 2 for the 150-milliampere range.

To determine whether the grid of the tube is in operating condition and to indicate roughly the condition of the tube as an amplifier, set the dial switch *h* on *Plate MA.*, the range switch *j* at *30*, and press the key *m*. When the key *m* is up in its normal position the grid is connected to the C battery in the set, and the current indicated on the instrument is the normal plate current of the tube. When the key *m* is depressed, the grid is connected to the −A terminal, which gives zero grid voltage, with a consequent change in plate current. If the grid is functioning properly, the plate current will be increased upon pressing the key, and the increase in current, when properly interpreted, is a rough measure of the condition of the tube as an amplifier.

If no change in plate current occurs upon pressing the key, then the following may be the cause:

1. The radio set has no C battery.
2. The C battery, if used, is run down or disconnected.
3. The grid connection may be broken in the tube, or the grid may be touching the filament. In either case the tube should be replaced. The approximate plate current values for the different types of tubes are given in the printed circulars that accompany the tubes.

To measure the total current drain on the B battery connect the 150-milliampere binding posts *k* on the tester in series with the battery circuit at the −B terminal and set the dial switch *h* to *MA. B. P.*

TESTING A.-C. OPERATED SETS

Sets Using Raw A. C. for Filament Heating.—All radio sets, whether a.-c. or d.-c. operated, must have direct current for the plate and grid circuits. Therefore, if a.-c. operated, the plate and grid voltages must be obtained by rectifying and filtering the alternating current by means of suitable power units. All tests on plate and grid voltages and plate current must be made on the d.-c. volt-milliammeter *b*, Fig. 1, just as on sets operated by batteries or battery substitutes.

The filaments on a.-c. operated sets may be heated either directly by raw alternating current or by rectified and filtered alternating current. To test a set equipped with tubes using raw alternating current, the switch *c* should be set to *A. C.*; care should be taken to see that the power supply is properly connected to the set and that all tubes are in place except in the socket to be tested. Then the plug *g* should be inserted into the socket of the set and the tube into the socket *l*. Then the same procedure should be followed as is described for battery-operated sets, except for the following:

Read filament voltages on the 4-volt or the 8-volt range of the a.-c. meter *a*, and all other voltages and currents on the d.-c. meter *b*, using the dial switch *h* as previously described. A low or no reading means a defect in the power unit or in the connections.

To test the five-prong UY-227 detector tube by voltages from its own socket in the radio set, two adapters must be used; one to adapt the four-prong plug *g* to the five-hole socket in the set, and the other to adapt the five-prong tube to the four-hole tester socket *l*. The plug adapter is so designed that the cathode circuit in the radio-set socket is not connected to the tester. The heater current is supplied to the heater element in the tube through the usual filament connections in the plug *g*, and the cathode is connected to one of the filament terminals in the tube adapter. With this connection, the plate voltage, filament voltage, and plate current as they exist when the tube is in use are measured as for any other tube, but since no C voltage is available in the detector socket, a definite grid test cannot, in general, be made under these conditions.

As the currents required for the UY-227 and UX-226 tubes are comparatively large, there will be a slight drop in the connecting leads when their voltages are being tested.

To obtain the true values of the filament voltages at the transformer terminals add .16 volt to the indication of the UY-227 tube and .1 volt to the UX-226 tube.

Sets Using Rectified A. C. for Filament Heating.—Sets using rectified alternating current for heating the filaments may be divided into two general classes; namely, those in which the filaments are connected in parallel and those in which the filaments are in series. The sets in which the tubes are connected in parallel are tested in the same way as battery-operated sets.

In series-filament operated sets it is preferable to select a socket having about 90 volts plate potential, and connected in the radio-frequency or intermediate-frequency circuit, depending on the type of radio set. Insert the plug *g*, Fig. 1, into this socket, and the tube into the socket *l* of the test set. For the complete test the other tubes should be in their respective sockets.

Set the switch *h* to *A* or *A Rev.*, as is found necessary to give a positive deflection. Note the voltage, which is the voltage across the filament. Then test for plate current, plate and grid voltage and make the grid tests as for battery-operated sets. Try each tube in succession, removing each one from its socket and placing it into the socket on the tester, remembering to insert the tube just tested into the vacant socket.

If all the tubes are equally low in filament voltage, it is possible that the trouble lies in the power supply, or that in one or more of the tubes the grid is touching the filament. This can often be discovered by gently tapping the tube. If, however, voltages differ among the tubes, then the fault is most likely to be in the tube circuits. While changing tubes in making this test it is preferable to have the power supply shut off to prevent possible excessive voltage from being applied to other tubes.

No hard and fast rules can be given for these tests, as the sets differ so much in their construction and type of circuits. Anyone, however, familiar with the circuits of any one particular set can work out methods for using the tester, by following the general directions given herein.

The foregoing instructions have been prepared by the Weston Electrical Instrument Corporation and apply directly to the use of the test set just considered. These same instructions, however, are applicable, with certain modifications, when testing radio receivers with the ordinary a.-c. and d.-c. meters.

SPECIFIC TROUBLES AND ADJUSTMENTS

SIMPLE TESTING EQUIPMENT

Continuity Tester.—When a more elaborate instrument is not available, the simple arrangement shown in Fig. 2 may be used to test the continuity of circuits, windings of transformers, coils, etc., or to locate defective condensers,

FIG. 2

short circuits, and grounds. The tester consists of a pair of headphones *a*, a $4\frac{1}{2}$-volt battery *b*, and the test points *c*. In place of the headphones one may use a voltmeter with voltage sufficient to give a full-scale deflection when connected directly across the battery terminals. The use of the voltmeter is very convenient in checking the voltage drop in the circuits of a receiver. The intensity of the click in the phones or the indication of the voltmeter, whichever may be used, shows approximately the condition of the circuit under test.

Resistance Measurement.—In a large number of cases the serviceman is confronted with the problem of determining the values of resistors used in receivers and power units. According to Ohm's law, the resistance R of a circuit, in ohms, is equal to the electromotive force E, in volts, divided by the current I, in amperes, or

$$R = E \div I$$

When the current is given in milliamperes, the formula becomes

$$R = 1{,}000E \div I$$

From the foregoing one can justly reason that the resistance can be very readily calculated when the electomotive force and the current are known. A simple scheme for measuring these quantities is shown in Fig. 3. The measuring unit consists of a 6-volt battery a, a 30-ohm

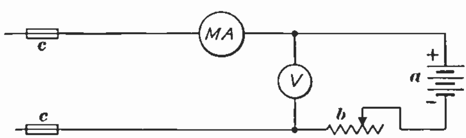


FIG. 3

rheostat b, a voltmeter V having a working range from 0 to 8 volts, a milliammeter MA with a scale of 1 to 250 milliamperes, and a pair of test points c, all connected as shown in the figure. To determine the voltage and current values, the test points c are placed on the terminals of the unit the resistance of which is to be measured and the rheostat adjusted until satisfactory readings are obtained. The resistance is then calculated as explained in the preceding paragraph.

Modulated Oscillator.—For certain radio adjustments it is necessary to have a source of modulated high-frequency energy to energize the radio-frequency circuits of the receiving set and produce an audible note in the phones or in the loud speaker. The most satisfactory generator of high-frequency energy is a vacuum-tube oscillator, a convenient type of which is shown in Fig. 4. The coil-condenser combination, *L* and *C*, respectively must be designed to cover the frequency range of the receiving set. For broadcast receiving sets the approximate frequency range is from 500 to 1,500 kilocycles.

The coil to be used with a .0005-microfarad tuning condenser to cover the broadcast range may be wound on

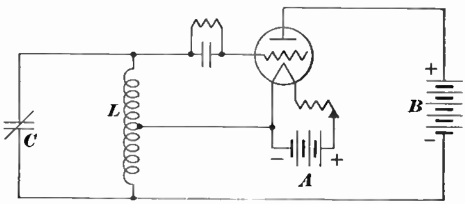


FIG. 4

a $2\frac{1}{2}$-inch bakelite tube with fifty turns of No. 20 double-silk-covered wire. The coil is tapped at the twenty-fifth turn and a connection made to the negative terminal of the *A* battery.

Type UX-199 tube is recommended for the oscillator, although the general purpose tube UX-201A may also be used. With a UX-199 type tube, a $4\frac{1}{2}$-volt C battery may be used to light the filament, or act as the A battery. A 30-ohm rheostat is used in the filament circuit. Two small $22\frac{1}{2}$-volt B-battery units may be used in the plate circuit. In this way it is possible to make the oscillator a self-contained unit.

The grid condenser may have a capacity of .00025 microfarad. The resistance value of the grid leak determines the pitch of the audible note produced by the oscillator. A 4- or 5-megohm leak will probably give the desired tone. If a higher tone is desired, a lower value of grid leak is used, and vice versa.

VARIABLE-CONDENSER TROUBLES

Possible Troubles.—Variable condensers are the tuning units in most of the present-day radio receiving sets. They are thus exposed to a lot of wear and tear, and, unless ruggedly constructed and well mounted, they will in time cause considerable trouble and inconvenience. The dials may slip out of position; the movable contacts, when not protected by pig-tail connections, may become dirty or loose, and introduce noises; the plates may become covered with dust, which also results in noises and lessened efficiency; the plates may be bent or the entire rotor or stator loosened, so that the condenser is shorted through part or the entire tuning scale; one of several condensers, when all are controlled by one tuning dial, may slip out of position and detune the entire assembly for all wavelength settings. The remedies for some of these troubles are quite obvious. The location and adjustment of many of these troubles, however, are not easy and should not be atempted by any one but those familiar with the correct procedure.

Shorted Plates.—Shorted plates are in some cases evidenced by a scraping noise when the condenser dial is turned. In most cases, however, it is necessary to test the condenser electrically to determine the nature of the trouble. The simple test set shown in Fig. 2 may be used for this purpose. Disconnect the condenser from its circuit and connect the test points *c* to the terminals of the condenser with the rotor plates entirely out of the stationary plates. A short circuit in the plates will be evidenced by a click in the phones when the condenser dial is turned.

A visual inspection will then reveal the difficulty. Bent plates can sometimes be straightened with the ordinary long-nose pliers. Wear at the bearings can be compensated by tightening the adjustments, when such are provided.

Body Capacity.—Sometimes the tuning of a set is affected by the operator's hand in contact with the condenser dial. This is known as body capacity. The most probable cause of this trouble is a reversal in the stator and rotor connections. The stationary plates should be connected to the grid terminal of the tuning transformer, and the rotary plates to the grid-return terminal. Shielding is also effective in removing this difficulty.

Misalinement of Multiple Condensers.—A large number of present-day receiving sets are equipped with single-control dials. In some of these there is no form of compensation for discrepancies in the tuning circuits, and all adjustments must be made at the main condensers. In other cases, vernier condensers are employed to bring the circuits to resonance when minor discrepancies in tuning develop.

When radio reception is very weak and it is positively known that the batteries, or power units, tubes, transformers, by-pass condensers, and their connections check O. K., the trouble may generally be ascribed to a misalinement of the tuning condensers. Wide discrepancies in the positions of the condenser plates can be determined by inspection. Minor discrepancies, however, can be determined only by suitable electrical tests.

When there is no provision for changing the position of either the rotary or stationary plates, the only remedy is the replacement of the entire condenser assembly. Condenser units with adjustable rotors or stators can be brought to resonance as follows:

Set the oscillator, Fig. 4, in operation with the dial set near one end of its scale. Place the receiving set also in operation with the aerial and ground disconnected. Tie one end of a 20-foot insulated wire around the grid coil of the detector tube and place the other end near the oscillator. Remove all the radio-frequency tubes and tune the receiver to maximum signal, setting the vernier controls, if used, in their mid-positions. The position of the dial for maximum signal is marked in a convenient location.

Remove the pick-up wire from the tuning coil of the detector tube, place it around the tuning coil of the last radio-frequency tube, and replace the tube in its socket. Tune the set as before, noting whether the position for maximum signal corresponds with that previously obtained. If there is a discrepancy, see whether it can be corrected with the vernier dial, if used. Otherwise, shift the tuning-condenser rotor or stator, whichever is adjustable, until the positions for maximum signal intensity correspond. Proceed in the same manner with the remaining radio-frequency circuits, working backwards from the detector tube to the first radio-frequency amplifier tube.

Then set the oscillator at the other end of its scale and repeat the foregoing tests and adjustments. Generally, when the set has been adjusted at one frequency it will be found satisfactory on all other frequencies, but it is well to check it and make readjustments when necessary.

TESTING FIXED CONDENSERS

The simplest way to test fixed by-pass or filter condensers is by the charge and discharge method. Disconnect the leads from the terminals of the condenser and connect the condenser for a brief interval across a suitable source of d.-c. potential, such as a B battery or the output of a power unit. Disconnect the condenser from the power source and connect a piece of wire across its terminals. If the condenser is in good condition a discharge spark should take place the instant the condenser terminals are shorted. If no discharge spark or a sharp crack takes place, the condenser is open, short-circuited, or leaky, and should be replaced.

ADJUSTMENT OF NEUTRALIZING CONDENSERS

In practically all radio receiving sets some form of balancing is employed to reduce the tendency to self-oscillation. When this adjustment is unbalanced, the receiver has a tendency to oscillate at practically all settings of the station selector dials. Before attempting to balance such a set it is well to check the filament plate and grid voltages, examine the grid circuits for opens, and test the tubes. The trouble is manifested by poor-quality signals and whistling and howling in the loud speaker.

There are two common methods of stopping oscillations; namely, by the use of grid resistors and by the neutrodyne system. Where grid resistors are used, the procedure is quite simple. Remove the resistor from its clips and test it with the unit shown in Fig. 3. If it is open, short-circuited, or of the wrong value, replace it with one of the correct resistance value.

In sets employing the neutrodyne system, small adjustable condensers are used to effect balancing. Should these get out of adjustment, they may be readily readjusted as follows: Procure a tube similar to those used in the radio-frequency stages and saw off one of the filament prongs. Place the receiving set in operation with the aerial and ground connected, and the oscillator, Fig. 4, near the aerial wire. Tune the oscillator and set to a low reading on the dials, adjusting the set to maximum loudness. Remove the first radio-frequency tube from the set and insert in its place the special tube. Now adjust the neutralizing condenser until the signal is minimum or disappears entirely. The adjustment of the neutralizing condenser is quite critical and should be done with care. When the first stage has thus been neutralized, remove the special tube and reinsert the good one. The remaining condensers are adjusted in the same manner. The adjustment is checked with the oscillator and set tuned to a high reading on their respective dials.

SERVICING OF POWER UNITS

Determining Whether Power Unit Is At Fault.—When radio reception is unsatisfactory and it is suspected that the B power unit is at fault, it is advisable first to check up on the other accessories, such as tubes, A battery, C battery, aerial and ground connections, and the loud speaker. If all these seem to be in good condition, it is well to substitute a set of B batteries for the power unit and note the difference in operation. If this test shows that the B unit is at fault, the first thing to do is to make sure that the socket power is on and to try a tested rectifier tube in place of the one that is in the power unit. If the new tube improves the operation of the set, obviously, the trouble has been corrected.

Testing the Power Unit.—If the new tube does not improve the operation, the power unit should be tested for opens, short circuits, and grounds. With a circuit diagram at hand, proceed to test the continuity of the circuits. The continuity tester shown in Fig. 2 may be used. The power should, of course, be turned off. The test would include the resistors and their shunting condensers in the output of the unit; the filter condensers; the filter choke coils; the windings of the power transformer, and all the connections and wiring in the unit.

An experienced serviceman has usually a few short cuts for locating trouble in power units. He knows from experience the points at which trouble is most likely to develop, and acts accordingly. With a steel screw-driver he can determine whether there is any current flowing in the chokes by noting the magnetic pull on the screwdriver. By short-circuiting the chokes and noting the effect on the receiver, he can determine whether the filter condensers are defective. There are many other practical methods of quickly determining the causes of certain troubles which the observant serviceman will gather in the course of his work. Such tests presuppose a familiarity with the equipment and should not be attempted by beginners.

SERVICING OF RADIO SPEAKERS

Horn-Type Speakers.—Before proceeding to examine any loud speaker for defects, it is well to test the output of the receiving set with a speaker that is known to be in good condition. This will help to confine the trouble to the proper source. When it has been determined that the speaker is at fault, the first thing to do is to test the continuity of the windings. If these are open or short-circuited, the speaker will not operate. Sometimes the defect is in the cord or in the connections to the terminals and may be determined by inspection or by tests.

A rattling sound is generally produced by the diaphragm or armature, if a direct drive is used, touching the magnet poles. This can usually be remedied on an adjustable unit by moving the coils away from the diaphragm. If the diaphragm is defective it should be replaced. In indirectly driven units the armature is connected to the diaphragm by means of a short pin. If the armature strikes the pole pieces a rattling sound will result. Some form of compensation is usually provided to center the armature, but when this does not correct the fault the adjustment should be loosened and a thin piece of card board place on each side of the armature between the pole pieces; then the pin between the armature and diaphragm should be loosened until it assumes a normal position. Fastening the diaphragm to the connecting pin in this unstrained position will usually eliminate the rattle.

The loud speaker may also develop other troubles, as, for example, weakened magnets, iron or dust particles on the pole pieces, worn or defective rubber gaskets, if used, loose diaphragm, etc. The remedy for any one of these defects is quite obvious.

Cone-Type Speakers.—In cone-type radio speakers trouble may develop in the electromagnetic operating unit, in the cone, or in the mechanical connection between the unit and the cone. The troubles previously considered in connection with the operating unit of the horn-type speaker apply also to the operating unit of the cone-type speaker. Open windings, armature not centered, dust particles between the armature and the pole pieces, are troubles common to both the horn- and cone-type speakers.

In some cases the cone may be improperly alined or adjusted, causing a strain to be placed on the driving pin. Poor reproduction is the result, and an inspection of the drive pin may indicate a slight torque or twist. This is most likely to happen when replacing a cone. Loose screws or nuts in the motor mechanism may also cause a rattle when the speaker is in operation. The proper remedy is to tighten all the nuts and screws.

Cone-type speaker troubles may be briefly summarized as follows:

No Signals.—No output from receiver; defective windings; defective cord; loose or broken connections; drive pin not connected.

Weak Signals.—Weak receiver output; dirt interfering with armature action; drive pin improperly connected; improperly alined cone; weak magnet.

Distorted or Noisy Signals.—Distorted output from receiver; improperly adjusted cone; loose screws or nuts in the assembly; armature striking pole pieces; excessive pressure on drive pin.

Howling.—Microphonic tubes; speaker too near the receiver.

Electrodynamic Speakers.—The electrodynamic speaker is supposed to be one of the truest reproducers of speech and music. Because of its cost, the owner expects first-class results, and justly so. Like all other types of speakers, however, the dynamic speaker is subject to troubles and defects which are just as annoying as those of other speakers. There are several types of these speakers, operating on similar principles, but with sufficient modifications to develop their own characteristic troubles. The symptoms and causes given here apply in a general way to all types.

No Signals.—No output from receiving set or amplifier; defective connections; defective field coil; defective cone coil.

Weak Signals.—Weak output from receiver or power amplifier; weak field.

Poor-Quality Signals.—Poor output from receiver; cone or reproducer unit not centered properly; cone coil or the connecting wires loose on cone.

CONCLUSION

The foregoing are just a few of the service problems encountered in every-day work. The classification and solution of these problems has been aided materially by referring to the service notes of a few representative radio manufacturers. The instruction was compiled to help the beginner to solve some of the more common service problems and it is hoped that it will also be of benefit to the more mature serviceman.

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Radio Library

Vol. V

Radio Measurements

RADIO MEASUREMENTS AND TABLES

By

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RADIO DEVELOPMENTS

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REGULATIONS OF THE NATIONAL BOARD OF FIRE UNDERWRITERS FOR RADIO EQUIPMENT

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PREFACE

A book or a series of books on radio communication would not be complete without a treatise on calculations and measurements. The "rule of thumb" method of designing and building radio equipment is no longer in vogue. All radio transmitting equipment is provided with suitable indicating instruments to permit of determining the actions that are taking place in the various circuits. Radio service men, dealers, installers, in fact, all those interested in building, selling, and maintaining radio equipment, are obliged to use meters of one sort or another to determine quickly and accurately the electrical conditions of radio sets and accessories. Familiarity with the different types of electrical measuring instruments is not only useful but absolutely necessary to all who are interested in radio from a standpoint somewhat greater than simply listening in. The formulas, tables, conversion factors, etc. are conveniently grouped in this volume for ready reference.

The Section on Radio Developments includes information on the transmission of pictures, printing telegraph systems, and a brief description of television. This instruction was compiled by a man who has helped materially in the development of these branches of radio transmission.

A handy compendium of the regulations of the National Board of Fire Underwriters for radio equipment will be found at the end of this volume.

INTERNATIONAL CORRESPONDENCE SCHOOLS

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RADIO MEASUREMENTS

RADIO MEASUREMENTS AND TABLES

MEASURING INSTRUMENTS

GENERAL CLASSIFICATION

Instruments are available for the measurement of practically all electric quantities. These instruments may be classified according to (1) the kind of current in the circuits on which they are used, as direct-current or alternating-current instruments; (2) the service for which they are intended, as switchboard or portable instruments; (3) their principle of operation, as D'Arsonval, electrodynamic, electrostatic, hot-wire, or thermoelectric instruments; (4) the methods of showing the results of measurements, as indicating, recording, or integrating instruments.

DIFFERENCE BETWEEN AMMETERS AND VOLTMETERS

The principal difference between most voltmeters and ammeters for use on either d.-c. or a.-c. circuits is as follows: The coil of a voltmeter consists of many turns of wire and is connected across the circuit with or without a resistance in series with it. The total resistance of the instrument circuit is large and the current very small, compared with that flowing through the main circuit.

The coil of an ammeter consists of a few turns of comparatively large conductor, and, for the measurement of small currents, is usually connected directly in series with one of the line wires of a circuit. For measuring larger currents the ammeter coil is connected in parallel with a much smaller resistance, called a *shunt*, which is connected directly in series in the circuit in which the current is to be measured. The resistance of the ammeter coil and the shunt, if one is used, is small and the entire current flowing in the circuit passes through the ammeter including the shunt.

In order that stray magnetic fluxes from neighboring conductors may not affect the indications of electric instruments, the working parts are often enclosed in an iron case.

HOW TO INCREASE RANGE OF VOLTMETER

A voltmeter can be used to measure voltages much higher than its maximum scale reading by connecting a suitable resistance in series with the instrument. Such a resistance is called a *multiplier*. Multipliers are made of such resistances that the scale reading must be multiplied by a certain number such as 2, 5, 10, etc., to obtain the voltage under test.

Let R be the resistance of the voltmeter, R_1 the resistance connected in series with it, E the highest reading of the voltmeter, and E_1 the highest reading desired, then

$$R_1 = R\left(\frac{E_1 - E}{E}\right)$$

When the resistance R_1 is connected in series with the voltmeter, the scale reading must be multiplied by $(E_1 \div E)$ to give the difference of potential across both the added resistance and the voltmeter, that is, across the circuit whose difference of potential is being measured.

EXAMPLE.—(*a*) What resistance must be connected in series with a voltmeter whose highest reading is 150 volts and whose resistance is 150,000 ohms in order to use it to measure up to 600 volts? (*b*) By what constant must its scale readings be multiplied to give the potential difference across both the voltmeter and added resistance?

SOLUTION.—(*a*) By substituting in the foregoing formula, $R_1 = 150{,}000 \times \left(\frac{600-150}{150}\right) = 450{,}000$ ohms. Ans. (*b*) The scale reading must be multiplied by $600 \div 150 = 4$. Ans.

HOW TO INCREASE RANGE OF AMMETER

The range of an ammeter may be increased by connecting a shunt across its terminals. Let R be the resistance of an ammeter, S the resistance of a shunt connected across the ammeter terminals, I the original highest reading of the ammeter, and I_1 the current range desired. To produce the same reading, the current and fall of potential through the ammeter itself must be the same with as without the shunt, the drop through the shunt will be exactly the same as that through the ammeter, and the current I_1 in the main circuit minus the current I in the ammeter, will be equal to the current $(I_1 - I)$ in the shunt.

To produce the same reading I with and without a shunt it is necessary that $S(I_1 - I) = RI$; hence

$$S = \frac{RI}{I_1 - I}$$

Therefore, to increase the range of an ammeter, having a resistance of R ohms, from I to I_1 amperes, a shunt S whose resistance may be calculated by the formula just given must be connected across the ammeter terminals. When shunted, the indicated reading must be multiplied by $(I_1 \div I)$ to give the total current flowing in the main circuit.

USE OF MILLIAMMETER AS VOLTMETER

Many laboratories have available a number of millivoltmeters and milliammeters which, with a number of different multipliers, would permit the application of the instruments on hand to many other uses. For example, a standard milliammeter having a scale of 0 to 1 milliamperes can be used as a very efficient voltmeter having convenient ranges from 1 to 1,000 or more volts by simply connecting in series with it multipliers of suitable resistance and calibrating or simply reading the scale in volts instead of in amperes. With 1,000 ohms in series, the range will be from 0 to 1 volt; with 10,000 ohms, 0 to 10 volts; with 100,000 ohms, 0 to 100 volts; with 1,000,000 ohms, 0 to 1,000 volts, etc. With similar multipliers, a milliammeter having a range of 0 to 1.5 milliamperes may be used as a voltmeter with a range of 0 to 1,500 volts, and higher. The resistors must, of course, be designed to carry safely the currents indicated on the milliammeter.

RESISTANCE MEASUREMENTS

RESISTANCE IN GENERAL

Electric resistance plays a dominating role in nearly all radio and electrical circuits. The resistance is usually considered a detrimental factor in wasting power; in many cases, however, the resistance effect is employed to give the desired operating conditions. Electric resistance is broadly applied to the factor offering opposition to the passage of a continuous direct current, and to an alternating current, provided other factors, such as inductance and capacity, may be considered as negligible.

OHM'S LAW

In case the voltage drop in the resistance and the current through the resistance are known, the value of the resistance may be calculated by Ohm's law. Briefly, the resistance in ohms equals the voltage drop, as measured by a voltmeter, divided by the current, as measured by an ammeter. This forms a convenient method of resistance measurement where the necessary apparatus is available.

MEASUREMENT OF RESISTANCE WITH VOLTMETER

A resistance can be measured by means of another resistance of known value, and a voltmeter. The known and unknown resistances are connected in series and to the terminals of a battery or other source of potential. The voltmeter is connected across the unknown resistance and across the known resistance in succession. The value of the unknown resistance is then equal to

$$R=\frac{R_1E}{E_1}$$

in which R = unknown resistance, in ohms;
R_1 = known resistance, in ohms;
E = voltmeter reading across unknown resistance, in volts;
E_1 = voltmeter reading across known resistance, in volts.

For example, if the voltage reading E across the unknown resistance is 36.9 volts, E_1 across the known resistance is 26 volts, and the known resistance is 2.6 ohms, then the value of the unknown resistance $R=\frac{2.6\times 36.9}{26}=3.69$ ohms.

HIGH-RESISTANCE MEASUREMENT WITH VOLTMETER

High-reading voltmeters may be used to measure very high resistances. The voltmeter, the battery, and the high resistance are all connected in series. The voltage of the battery may be as high as convenient, as long as it is within the range of the voltmeter. The resistance may then be calculated by the following formula:

$$R=r\left(\frac{e}{e_1}-1\right)$$

in which R = unknown high resistance, in ohms;
r = resistance of voltmeter, in ohms;
e = battery voltage, or reading of voltmeter with resistance short-circuited;
e_1 = reading of voltmeter with unknown resistance in the circuit.

EXAMPLE.—If the electromotive force of the battery, as measured by the voltmeter, is 100 volts, and the deflection, when the resistance to be measured is in circuit, is 40 volts, what is the value of that resistance in ohms if the resistance of the voltmeter is 18,000 ohms?

SOLUTION.—In this case $e = 100$, $e_1 = 40$, $r = 18{,}000$, then

$$R = 18{,}000 \times \left(\frac{100}{40} - 1\right) = 18{,}000 \times 1.5 = 27{,}000 \text{ ohms.} \quad \text{Ans.}$$

WHEATSTONE BRIDGE

Another method of resistance measurement makes use of a balanced circuit, or Wheatstone bridge. Essentially, the Wheatstone bridge consists of an input signal, a method of observing the signal intensity, and a set of resistances that may be varied to balance the resistance combination. The resistances shown at *a*, *b*, *c*, and *d*, in Fig. 1, form the bridge part proper, and may be adjusted to give the proper settings. In place of the battery *e* alone, a buzzer may be added to the battery circuit and the combination utilized as a signal source. In that event the galvanometer *f* would be replaced by a pair of telephone receivers. The key *g* is necessary to open and close the circuit while adjustments are being made. An additional key at *h* closes the galvanometer circuit to test for a condition of balance and should be closed each time after *g* is closed.

The circuit from the battery through the Wheatstone bridge comprises two parallel branches; namely, that through the resistances *a* and *b* in series, and that through the resistances *c* and *d* in series. The voltage drop through both paths must be the same, since they are connected together at their ends. The galvanometer will give a reading if there is a difference of potential between its terminals. Suppose the resistances *a* and *b* are equal, and that *d* is the resistance of unknown value. Resistance *c* may be varied until the galvanometer gives no deflection when keys *g* and *h* are pressed, which will mean that the resistances *c* and *d* must likewise be equal. If *c* is a calibrated decade resistance box, its reading under these conditions will be the resistance of the unit or device inserted at *d*.

Sometimes the resistance *c* is fixed and has a known value, and the arms *a* and *b* are formed of a continuous wire with the galvanometer connection adjustable along its entire length. When balance is secured, the ratio or relationship between *a* and *b* is used to determine the value of *d*, since this same radio exists between *c* and *d*. Explained as a formula this would be

$$d = c \times \frac{b}{a}$$

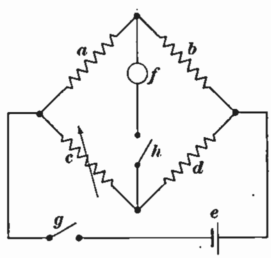


FIG. 1

The accuracy of results obtained with the Wheatstone bridge depends mainly on the care with which readings are taken. With suitable apparatus, this is one of the best ways of making resistance measurements, and also one of the most practical.

HIGH-FREQUENCY RESISTANCE MEASUREMENT

Skin effect may cause the resistance of a conductor to be considerably higher at radio frequencies than when measured with a direct current or with a relatively low-frequency alternating current. The radio-frequency resistance may be measured by connecting a part or the entire conductor to be measured in a test circuit containing inductance and capacity. The circuit should include a suitable ammeter for reading the current and should be coupled with a source of continuous-wave energy. The test circuit containing the unknown resistance is tuned to resonance with the circuit containing the source, by varying the condenser or inductance. The ammeter reading should be recorded. The unknown resistance may then be removed from the circuit and a variable non-inductive resistance substituted. The circuit should be retuned to resonance and the resistance varied to give the same ammeter reading as was noted previously. Under these conditions the reading of the variable resistance is equal to that of the unknown resistance.

The usual resistance may be secured by means of a Wheatstone bridge or by some other method. The difference between the high-frequency resistance and the direct-current resistance reading is due to the altered current distribution in the conductor and will be different for each high frequency that may be tried. The adjustable resistance should be of a non-inductive type or of a type that does not introduce any high-frequency variations of its own.

CAPACITY MEASUREMENTS

CAPACITY BRIDGE

The capacitance, or capacity, as it is more commonly called, of a condenser may be measured by means of a modified Wheatstone bridge. One of the arms of the bridge would have a variable condenser so that the bridge could be properly balanced with the unknown condenser in another arm. As shown by Fig. 2, the capacity bridge includes the two equal resistance arms *a* and *b*. The arm *c* now includes a variable condenser *c* which is used to secure a balance in the bridge both when only condenser *d* is connected in the circuit without the condenser *e* of unknown capacity, and when condensers *d* and *e* are connected in parallel. A small fixed condenser *d* is necessary so that a balance may be obtained and the reading of *c* noted without the unknown condenser *e* in circuit. After the unknown condenser *e* is added, the capacity of that branch is increased by the exact value of capacity of condenser *e*. When the circuit or bridge is again balanced, the reading of condenser *c* should be taken. The difference between the two readings of condenser *c* will be the capacity value of condenser *e*.

In order to secure an accurate balance with the bridge, it is necessary to connect a resistance, as *f*, in one or the other of the condenser arms, as may be found by trial. This will compensate for any resistance effect introduced by the condenser in the other condenser arm. The readings of this resistance, with and without the condenser *e*, are indicative of the losses in the condenser under test. The input circuit or signal source may consist of a buzzer, which should have a pure tone, at some convenient audio frequency. The buzzer is coupled with the bridge by a transformer *g*, and another transformer *h* serves to connect the bridge with a pair of head phones *i*.

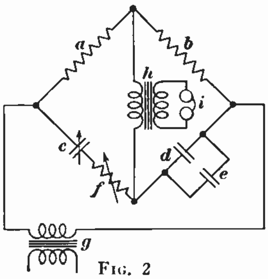


FIG. 2

SUBSTITUTION METHOD

The capacity of a condenser may be determined quite closely merely by comparison or substitution. A circuit containing an inductance and standard variable condenser is tuned to resonance with a suitable radio-frequency source, as indicated by a meter or other device. The condenser setting is noted and recorded. The unknown condenser is then connected across the calibrated condenser and the circuit retuned to resonance with the same signal as before. The difference between the two readings of the standard variable condenser gives the value of the unknown condenser capacity.

INDUCTANCE MEASUREMENTS

An inductance may be measured by placing it in a circuit tuned by a variable standard condenser. The circuit should be tuned to resonance with a meter or lamp to indicate when the resonance condition is reached. The signal may be secured by loose coupling with a wave meter energized by a vacuum tube or other oscillator. The condenser setting at resonance should be recorded as C_1, and the unknown inductance may be called L_1. The unknown inductance should be replaced by a known standard inductance L_2. Next the circuit should be retuned to resonance, the condenser setting being called C_2. The unknown inductance may be calculated from the formula

$$L_1 = \frac{L_2 C_2}{C_1}$$

TUBE CHARACTERISTIC BRIDGE

The characteristics of a radio tube may be ascertained from data of the plate-current curves. However, a bridge method of measurement of the amplification constant and plate impedance represents a much more convenient and rapid way of obtaining these values. One of the best types of circuits for this service is that called the Van der Bijl bridge, which is given in principle in Fig. 3. The tube *a* is supplied with its usual *A* and *B* batteries, and the filament rheostat *b*. The tone is introduced through the transformer c. The source of the tone, or signal, may be any type of oscillator or buzzer giving a clear signal of about 1,000 cycles per second free from appreciable harmonics. The resistances d and e should each be exactly 10 ohms, as the accuracy of the readings depends on their exactness. The switch or key f short-circuits resistance d when certain readings are to be taken, as explained later. The resistance g is of a type variable from 0 to 1,000 ohms in steps of .1 ohm. The telephone receivers h should have a low resistance so as not to cause an appreciable effect on the accuracy of the readings. The resistance i is variable over a range of 0 to 100,000 ohms in steps of 10 ohms. A switch at j removes and connects resistance i with the circuit as required.

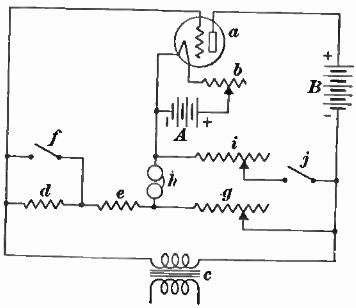


FIG. 3

The amplification constant is measured with the switch f closed and the switch j open. The resistance g is varied until there is no signal in the telephone receivers h. When this condition obtains, the amplification factor μ is given by the formula

$$\mu = \frac{r_g}{r_e}$$

Since the resistance r_e is fixed at 10 ohms the readings of the resistance box r_g may be divided by 10 to obtain the actual amplification factor.

The plate-to-filament impedance may be obtained by opening the switch f and closing the switch j. The setting of the resistance g as obtained for the amplification constant should be kept while the plate impedance is measured. The resistance *i* should be varied until silence is again obtained in the telephone receiver *h*. When the resistance *d* has a value of 10 ohms as specified, the reading of resistance *i*, at balance, is the same as the tube impedance in ohms. With a resistance box calibrated in ohms this is a very easy way to get the tube impedance reading. The mutual conductance may be secured by dividing the amplification factor by the plate impedance. The set just described does not include the instruments for reading the filament and plate voltages which would be necessary in accurate work. A grid bias, if desired, could be connected in the grid circuit adjacent to the grid terminal of the tube.

WAVEMETERS AND FREQUENCY METERS

GENERAL FEATURES

A wavemeter or a frequency meter is an instrument for measuring the wavelength or the frequency. The term wavelength is quite commonly used, although frequency is to be preferred. The wavelength is the length of a radio wave, usually expressed in meters. The frequency of a signal is the number of complete cycles of current per second; it being generally agreed that the frequency applies to a period of one second. In many cases a larger unit is advisable and the term kilocycle, or 1,000 cycles, is advantages. The relationship between the wavelength in meters λ and the frequency f in cycles per second is expressed by a formula as

$$\lambda = \frac{V}{f}$$

where V is the velocity of an electromagnetic wave. For most work it is satisfactory to use the value of 300,000,000 meters per second for this velocity, although the more exact figure is 299,800,000 meters per second.

WAVELENGTH DATA

The relationship in the preceding formula may be used to figure data for a table. The accompanying table gives the frequency corresponding with various wavelength figures and covers most of the useful range of wavelength commonly employed in radio. By reference to various sections of the table it should be possible to obtain any desired readings. Although the frequency corresponding with 17.5 meters is not shown, the frequency corresponding with 175 meters is tabulated. The value for 175 meters multiplied by 10 would give the frequency for 17.5 meters. This value can be checked approximately by noting the actual frequency at some wavelength setting near 17.5, say 15 meters, which should be close to the calculated value.

The oscillation constant (LC) represents the product of the inductance in microhenrys and the capacity in microfarads for a given wavelength or frequency. For instance, if the inductance of a coil is known, the oscillation constant may be divided by the coil inductance to give the necessary capacity for the desired wavelength. Similarly, if the inductance and capacity are known, their product may be used to give the wavelength by reference to the accompanying table.

TYPES OF WAVEMETERS

The wavemeter essentially consists of a fixed coil *a* as shown in Fig. 4, a variable condenser *b*, and an indicating device *c*. The coil acts as a pick-up device by coupling with the circuit under test and as a fixed inductance. The condenser gives a variable capacity to the wavemeter circuit so it may be tuned to resonance with the circuit under test. When the wavemeter is tuned to resonance, the current in its circuit is a maximum, which would

WAVELENGTH, FREQUENCY, AND OSCILLATION CONSTANT

Wave-length Meters	Frequency	*LC*	Wave-length Meters	Frequency	*LC*
1	300,000,000	.0000003	190	1,579,000	.01016
2	150,000,000	.0000011	195	1,538,000	.01071
3	100,000,000	.0000025	200	1,500,000	.01126
4	75,000,000	.0000045	205	1,463,000	.01183
5	60,000,000	.0000070	210	1,429,000	.01241
6	50,000,000	.0000101	215	1,395,000	.01301
7	42,860,000	.0000138	220	1,364,000	.01362
8	37,500,000	.0000180	225	1,333,000	.01425
9	33,333,000	.0000228	230	1,304,000	.01489
10	30,000,000	.0000282	235	1,277,000	.01555
15	20,000,000	.0000634	240	1,250,000	.01622
20	15,000,000	.0001126	245	1,225,000	.01690
25	12,000,000	.0001760	250	1,200,000	.01760
30	10,000,000	.0002533	255	1,177,000	.01831
35	8,571,000	.0003448	260	1,154,000	.01903
40	7,500,000	.0004503	265	1,132,000	.01977
45	6,667,000	.0005700	270	1,111,000	.02052
50	6,000,000	.0007039	275	1,091,000	.02129
55	5,454,000	.0008519	280	1,071,000	.02207
60	5,000,000	.001014	290	1,034,500	.02366
65	4,615,000	.001188	295	1,017,000	.02450
70	4,286,000	.001378	300	1,000,000	.02533
75	4,000,000	.001583	310	967,700	.02705
80	3,750,000	.001801	320	937,500	.02883
85	3,529,000	.002034	330	909,100	.03066
90	3,333,000	.002280	340	882,400	.03255
95	3,158,000	.002541	350	857,100	.03448
100	3,000,000	.002816	360	833,300	.03648
105	2,857,000	.003105	370	810,800	.03854
110	2,727,000	.003404	380	789,500	.04065
115	2,609,000	.003721	390	769,200	.04277
120	2,500,000	.004052	400	750,000	.04503
125	2,400,000	.004397	410	731,700	.04733
130	2,308,000	.004757	420	714,300	.04966
135	2,222,000	.005130	430	697,700	.05204
140	2,144,000	.005518	440	681,800	.05446
145	2,069,000	.005919	450	666,700	.05700
150	2,000,000	.006335	460	652,200	.05960
155	1,935,000	.006760	470	638,300	.06219
160	1,875,000	.007204	480	625,000	.06485
165	1,818,000	.007662	490	612,200	.06759
170	1,765,000	.008134	500	600,000	.07039
175	1,714,000	.008620	510	588,200	.07327
180	1,667,000	.009120	520	576,900	.07606
185	1,622,000	.009634	530	566,000	.07905

WAVELENGTH, FREQUENCY, AND OSCILLATION CONSTANT—(*Continued*)

Wave-length Meters	Frequency	LC	Wave-length Meters	Frequency	LC
540	555,600	.08208	990	303,100	.2759
550	545,400	.08519	1,000	300,000	.2816
560	535,700	.08836	1,010	297,000	.2870
570	526,300	.09139	1,020	294,100	.2927
580	517,200	.09467	1,030	291,300	.2986
590	508,500	.09801	1,040	288,400	.3045
600	500,000	.1014	1,050	285,700	.3105
610	491,800	.1047	1,060	283,600	.3161
620	483,900	.1082	1,070	280,400	.3222
630	476,200	.1117	1,080	277,800	.3283
640	468,700	.1154	1,090	275,200	.3345
650	461,500	.1188	1,100	272,700	.3404
660	454,500	.1225	1,110	270,300	.3467
670	447,800	.1263	1,120	267,900	.3531
680	441,200	.1302	1,130	265,500	.3595
690	434,800	.1341	1,140	263,100	.3660
700	428,600	.1378	1,150	260,900	.3721
710	422,500	.1419	1,160	258,600	.3787
720	416,700	.1459	1,170	256,400	.3853
730	411,000	.1501	1,180	254,200	.3921
740	405,400	.1540	1,190	252,100	.3988
750	400,000	.1583	1,200	250,000	.4052
760	394,800	.1626	1,210	247,900	.4121
770	389,600	.1668	1,220	245,900	.4190
780	384,600	.1712	1,230	243,900	.4260
790	379,800	.1756	1,240	241,900	.4326
800	375,000	.1801	1,250	240,000	.4397
810	370,400	.1847	1,260	238,100	.4469
820	365,900	.1893	1,270	236,200	.4541
830	361,400	.1941	1,280	234,400	.4610
840	357,100	.1985	1,290	232,600	.4683
850	352,900	.2034	1,300	230,800	.4757
860	348,800	.2082	1,310	229,000	.4831
870	344,800	.2132	1,320	227,300	.4906
880	340,900	.2179	1,330	225,600	.4978
890	337,100	.2229	1,340	223,900	.5053
900	333,300	.2280	1,350	222,200	.5130
910	329,700	.2332	1,360	220,600	.5208
920	326,100	.2381	1,370	218,900	.5281
930	322,600	.2434	1,380	217,400	.5359
940	319,100	.2487	1,390	215,800	.5438
950	315,900	.2541	1,400	214,300	.5518
960	312,500	.2595	1,410	212,800	.5598
970	309,300	.2647	1,420	211,300	.5674
980	306,100	.2704	1,430	209,800	.5755

WAVELENGTH. FREQUENCY, AND OSCILLATION CONSTANT—(*Continued*)

Wave-length Meters	Frequency	*LC*	Wave-length Meters	Frequency	*LC*
1,440	208,300	.5837	1,890	158,700	1.006
1,450	206,900	.5919	1,900	157,900	1.016
1,460	205,500	.5998	1,910	157,100	1.027
1,470	204,100	.6081	1,920	156,300	1.038
1,480	202,700	.6165	1,930	155,400	1.049
1,490	201,300	.6250	1,940	154,600	1.060
1,500	200,000	.6335	1,950	153,800	1.071
1,510	198,700	.6416	1,960	153,100	1.081
1,520	197,400	.6502	1,970	152,300	1.092
1,530	196,100	.6590	1,980	151,500	1.104
1,540	194,800	.6677	1,990	150,800	1.115
1,550	193,600	.6760	2,000	150,000	1.126
1,560	192,300	.6849	2,050	146,300	1.183
1,570	191,100	.6938	2,100	142,900	1.241
1,580	189,900	.7028	2,150	139,500	1.301
1,590	188,700	.7118	2,200	136,400	1.362
1,600	187,500	.7204	2,250	133,300	1.425
1,610	186,300	.7295	2,300	130,400	1.489
1,620	185,200	.7387	2,350	127,700	1.555
1,630	184,100	.7480	2,400	125,000	1.622
1,640	182,900	.7573	2,450	122,500	1.690
1,650	181,800	.7662	2,500	119,000	1.760
1,660	180,700	.7756	2,550	117,700	1.831
1,670	179,600	.7852	2,600	115,400	1.903
1,680	178,600	.7946	2,650	113,200	1.977
1,690	177,500	.8037	2,700	111,100	2.052
1,700	176,500	.8134	2,750	109,100	2.129
1,710	175,400	.8231	2,800	107,100	2.207
1,720	174,400	.8329	2,850	105,300	2.287
1,730	173,400	.8422	2,900	103,500	2.366
1,740	172,400	.8520	2,950	101,700	2.450
1,750	171,400	.8620	3,000	100,000	2.533
1,760	170,500	.8720	3,100	96,770	2.705
1,770	169,400	.8821	3,200	93,750	2.883
1,780	168,500	.8916	3,300	90,910	3.066
1,790	167,600	.9018	3,400	88,240	3.255
1,800	166,700	.9120	3,500	85,910	3.448
1,810	165,700	.9223	3,600	83,330	3.648
1,820	164,800	.9327	3,700	81,080	3.854
1,830	163,900	.9425	3,800	78,950	4.065
1,840	163,000	.9530	3,900	76,920	4.277
1,850	162,200	.9634	4,000	75,000	4.503
1,860	161,300	.9741	4,100	73,170	4.733
1,870	160,400	.9841	4,200	71,430	4.966
1,880	159,600	.9948	4,300	69,770	5.204

WAVELENGTH, FREQUENCY, AND OSCILLATION CONSTANT—(*Continued*)

Wave-length Meters	Frequency	*LC*	Wave-length Meters	Frequency	*LC*
4,400	68,180	5.446	8,800	34,090	21.79
4,500	66,670	5.700	8,900	33,710	22.29
4,600	65,220	5.960	9,000	33,330	22.80
4,700	63,830	6.219	9,100	32,970	23.32
4,800	62,500	6.485	9,200	32,610	23.81
4,900	61,220	6.759	9,300	32,260	24.34
5,000	60,000	7.039	9,400	31,910	24.87
5,100	58,820	7.327	9,500	31,590	25.41
5,200	57,690	7.606	9,600	31,250	25.95
5,300	56,600	7.905	9,700	30,930	26.47
5,400	55,560	8.208	9,800	30,610	27.04
5,500	54,550	8.519	9,900	30,310	27.59
5,600	53,570	8.836	10,000	30,000	28.16
5,700	52,630	9.139	10,500	28,570	31.05
5,800	51,720	9.467	11,000	27,270	34.04
5,900	50,850	9.801	11,500	26,090	37.21
6,000	50,000	10.14	12,000	25,000	40.52
6,100	49,180	10.47	12,500	24,000	43.97
6,200	48,550	10.82	13,000	23,080	47.57
6,300	47,620	11.17	13,500	22,220	51.30
6,400	46,870	11.54	14,000	21,440	55.18
6,500	46,150	11.88	14,500	20,690	59.19
6,600	45,450	12.25	15,000	20,000	63.35
6,700	44,780	12.63	15,500	19,350	67.60
6,800	44,120	13.02	16,000	18,750	72.04
6,900	43,480	13.41	16,500	18,180	76.62
7,000	42,860	13.78	17,000	17,650	81.34
7,100	42,250	14.19	17,500	17,140	86.20
7,200	41,670	14.59	18,000	16,670	91.20
7,300	41,100	15.01	18,500	16,220	96.34
7,400	40,540	15.40	19,000	15,790	101.64
7,500	40,000	15.83	19,500	15,380	107.06
7,600	39,470	16.26	20,000	15,000	112.56
7,700	38,960	16.68	21,000	14,290	124.12
7,800	38,460	17.14	22,000	13,640	136.24
7,900	37,980	17.56	23,000	13,040	148.93
8,000	37,500	18.01	24,000	12,500	162.18
8,100	37,040	18.47	25,000	12,000	175.97
8,200	36,590	18.93	26,000	11,540	190.26
8,300	36,140	19.41	27,000	11,110	205.20
8,400	35,710	19.85	28,000	10,710	220.70
8,500	35,290	20.34	29,000	10,350	236.63
8,600	34,880	20.82	30,000	10,000	253.32
8,700	34,480	21.32			

be indicated by a higher deflection on the indicating device *c*. The indicating device is usually a thermo-galvanometer, which gives readings indicative of the strength of the local oscillating current.

The preceding type of wavemeter is used chiefly with a transmitting set where fairly large currents may be secured. For relatively weak signals the type of wavemeter shown in Fig. 5, will be more suitable. The main inductance coil *a* is tuned in the usual manner by the variable condenser *b*. The crystal detector *c* and the phones *d* are connected in series across the tuned circuit. If necessary, the crystal detector may be shunted by a small fixed condenser. If the incoming signal is too strong the lower

FIG. 4

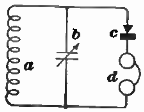


FIG. 5

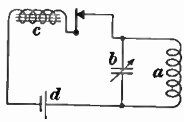


FIG. 6

phone connection to the variable condenser may be removed. This will give a weaker signal for more accurate wavelength settings. For this circuit the test signal must be modulated so as to be audible in the head phones. For tests on receiving sets the wavemeter should be connected with a source of supply so it may radiate a signal on a known wavelength for test purposes. In Fig. 6, the main coil *a* and the condenser *b* receive the current pulses from the buzzer *c*, which is operated by the dry cell at *d*. These pulsations cause an oscillating current to be established in the wavemeter circuit at a wavelength determined by the inductance and capacity in use. The receiving set may be tuned to the radio-frequency signal radiated from coil *a* for calibration purposes. With the set adjusted to an oscillating condition, a distinctive click will be heard in the phones, Fig. 5, when the circuit gets in resonance with the wavemeter. The set may be calibrated for several such points in succession over its tuning range.

CALIBRATION OF WAVEMETERS

Wavemeters are chiefly used for the measurement of wavelength, but the instrument must first be calibrated. This may be done by comparison with a previously calibrated wavemeter or it may be compared with an oscillating tube or oscillating crystal. When a wavemeter is calibrated by comparison, its readings are directly compared with those of another wavemeter whose settings are accurately known.

The wavemeter may also be calibrated by reference to a tube oscillator so adjusted as to give a number of harmonics in its oscillating current. The oscillator is first set to some reference standard frequency such as that from a 1,000-cycle tuning fork or a crystal of known frequency. The wavemeter tuning is started at this point and progresses upwards in frequency with definite reference points at the harmonic frequencies. These frequencies are integral multiples of the fundamental frequency. For example, the frequencies 2,000, 3,000, 7,000, 15,000, etc., are 2, 3, 7, and 15 times the main frequency of 1,000 cycles. By making use of these multiple frequencies the wavemeter may be calibrated over a wide wavelength range. Various types of piezo-electric crystals possess the faculty of governing oscillating circuits to a remarkable degree of constancy, and may be employed in the production of accurate reference frequencies. These crystals give three possible fundamental frequencies, which, with the harmonics of a crystal-controlled tube oscillator will give enough reference points to permit of calibration over a wide range of wavelengths.

WAVEMETERS IN USE

The natural wavelength of an antenna may be obtained by the aid of a radio transmitter and wavemeter. The transmitter should be coupled loosely with the antenna, that is, with one turn of wire in the antenna circuit. Care should be taken to couple the wavemeter with a turn in the antenna circuit not close enough to the transmitter for the wavemeter to be directly affected thereby.

The tuning of the transmitter condenser is varied until the largest possible reading is obtained on an ammeter connected directly in the antenna circuit. This maximum current reading indicates resonance between the antenna

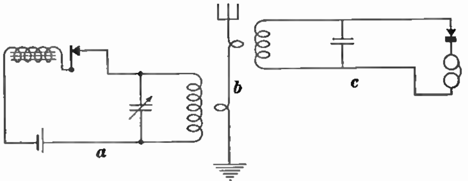


FIG. 7

and transmitter circuits. The wavelength may now be secured by reading the calibrated scale on the wavemeter. If greater accuracy is required, the coil with which the wavemeter was coupled could be eliminated, and coupling effected directly with the antenna lead.

Another convenient method of wavelength measurement employs an oscillating wavemeter as shown at *a*, in Fig. 7, connected with an antenna *b*. The antenna is also coupled with the detector circuit *c* by another single-turn coil. The receiver circuit is aperiodic, or sensitive to signals over a wide range of wavelengths by using a small amount of inductance and a relatively large capacity. A radio tube detector could be used in place of the crystal detector.

While listening with the head phones, the tuning of the oscillating wavemeter is varied until the loudest signal is received. The wavemeter scale reading is the wavelength of the antenna. It is generally advisable to check the settings with reduced coupling between the various circuits. Here, as elsewhere, the single-turn coils added to the antenna affect its wavelength to a slight degree.

The wavelength or the frequency of a transmitter may be obtained from a set of readings secured on a wavemeter. The wavemeter coil should be coupled loosely with the oscillating circuit and the condenser varied until a maximum deflection is obtained on the ammeter. The condenser tuning should be made slowly so that the resonance point is not passed over unintentionally. The reading of the wavemeter is the wavelength of the radio-frequency current under measurement. If the energy picked up by the wavemeter is too weak to operate the ammeter, the condenser may be shunted by a crystal detector and telephone receivers.

The condenser setting that gives a maximum signal strength is the one corresponding with the desired wavelength. The wavemeter should be calibrated with the detector and phones connected if accuracy is desired.

WAVEMETER CALCULATIONS

A wavemeter is ordinarily designed to operate over a limited range of wavelength adjustments with one condenser and coil. The wavelength tuning range may be increased by the use of additional coils with the proper number of turns on each. The inductance of each coil to cover the proper wavelength range may be calculated for a certain given variable condenser as shown with coil calculations, which follow. A good low-loss condenser should be used so it will not introduce any variable factors into the measurements. The resistance of the tuned circuit should be kept low so that the resonance readings will be sharp.

COIL CALCULATIONS

A radio circuit is usually tuned with a variable condenser. The coil has a fixed value of inductance. However, there is an appreciable capacity effect between the individual turns of wire in the coil. The minimum wavelength to which the circuit can be tuned depends on this inherent coil capacity and the minimum condenser capacity. The inductance of the coil should be such that it will permit of tuning over the desired wavelength range as the condenser is varied from its minimum to its maximum capacity setting.

The table of wavelength, frequency, and oscillation constant gives values of *LC*, which are merely the product of the inductance and capacity that will give the corresponding wavelength. The wavelength is given by

$$\lambda = 1885\sqrt{LC}$$

which is the expression whereby these data were secured. However, the complete formula need not be used each time. For instance, the *LC* factor of a coil and condenser to tune to 220 meters is .01362. If the distributed coil capacity and the minimum condenser capacity total .00005 microfarad, the inductance necessary is

$$L = \frac{.01362}{.00005} = 272 \text{ microhenrys}$$

If the maximum capacity of the condenser, including the distributed capacity of the coil, is .00035 microfarad the *LC* value will be $272 \times .0035 = .0952$.

This value for *LC* is not given in the table but would come just above 580 meters. That is, a coil and condenser as specified would tune over the range of wavelengths from 220 to just over 580 meters.

At the 220-meter wavelength, it would be possible to get several coils that would give the required wavelength with a condenser of proper capacity. If another coil is desired which will tune in stations below 220 meters, with this condenser of .00035 microfarad, the preceding formula will prove useful. The values become

$$L=\frac{.01362}{.00035}$$

or $L=39$ microhenrys, nearly.

This coil would permit of tuning to a station operating on 220 meters with the condenser set at its maximum capacity. The wavelength would be reduced, as the condenser was reduced to a new minimum of

$$LC=39\times.00005=.00195$$

From the table the corresponding wavelength is nearly 83 meters, which is the shortest wavelength to which this coil and condenser may be tuned. It was assumed that the total condenser and coil distributed capacity were the same for this case as for the longer wavelength coil.

ELECTRICAL AND RADIO FORMULAS

ANTENNA CALCULATIONS

Fundamental wavelength:

$$\lambda=1885\sqrt{LC}$$

where λ = wavelength, in meters; L = inductance, in microhenries; and C = capacity, in microfarads.

Loaded-Antenna Wavelength:

$$\lambda=1885\sqrt{C\left(L_1+\frac{L}{3}\right)}$$

where in addition to the preceding symbols, L_1 = inductance of the loading coil, in microhenries.

Capacity of one wire to ground:

$$C = .5562 \frac{l}{l_n \frac{2h}{r}}$$

where C = capacity of wire, in micro-microfarads; l = length of wire, in centimeters; l_n = symbol for logarithm of $\frac{2h}{r}$ to the natural base; h = height of wire, in centimeters; and r = radius of wire in centimeters.

Inductance of one wire to ground:

$$L = .002l\left(l_n \frac{2h}{r} + \frac{1}{4}\right)$$

where the symbols are as given previously with the same units.

Austin's formula for the capacity of a flat-top antenna:

$$C = 1.1124\left(36\sqrt{A} + 7.97\frac{A}{h_a}\right)$$

where in addition A = area of flat-top section, in square meters; and h_a = average or mean height of the antenna, in meters.

Radiation resistance:

$$Rr = 1580\left(\frac{h_s}{\lambda}\right)^2$$

where Rr = radiation resistance, in ohms; and h_s = effective antenna height, in meters.

This formula is only approximate and then only when the wavelength is considerably greater than the fundamental wavelength of the antenna.

Decrement of antenna or circuit:

$$\delta = .00167\frac{R\lambda}{L}$$

where δ = logarithmic decrement of the antenna or circuit; R = radio-frequency resistance of the antenna or circuit, in ohms; and the other factors are as already specified.

The decrement may also be expressed by the formula

$$\delta = 3.1416R\sqrt{\frac{C}{L}}$$

Effective height of loop antenna:

$$h_e = \frac{2\pi lhn}{\lambda}$$

where h_e = effective height, in meters; l = length, in meters; h = vertical height of loop, in meters; and n = number of turns in the loop.

CONDENSER FORMULAS

Two-plate condenser capacity:

$$C = .0885\frac{SA}{t}$$

where C = capacity, in micro-microfarads; S = specific inductive capacity for the dielectric material as given in the table of properties of electrical insulator materials. A = area of one side of one condenser plate, in square centimeters, and t = thickness of the dielectric material, in centimeters.

Capacity of multiplate condenser:

$$C = .0885\frac{S(n-1)A}{t}$$

where n = total number of plates, which are connected in alternate groups; and the other factors are as just specified.

Capacity of condenser with semicircular plate:

$$C=.139\frac{S(n-1)(r^2_1-r^2_2)}{t}$$

where the values remain as before with r_1=outside radius of the plates, in centimeters; and r_2=inside radius of the plates, in centimeters.

Voltage across a condenser:

$$V_e=\frac{I_e}{\omega C}$$

where V_e=effective voltage across the condenser; I_e =effective current in the condenser circuit; $\omega=2_n f$ or 6.2832 times the frequency, in cycles per second; and C=capacity, in farads.

Power input to a condenser:

$$P=.5\times10^{-6}NCV^2$$

where P=power input, in watts; N=number of charges or discharges per second; C=capacity, in microfarads; and V=applied potential, in volts.

Power loss in condenser:

$$P=\omega CE^2 \sin \psi$$

where P=power loss, in watts; $\omega=2\pi f$; C=capacity, in farads; and ψ=phase difference, in radians.

Condenser phase difference:

$$\psi=r\omega C$$

where ψ=phase difference, in radians; r=resistance, in ohms; $\omega=2\pi f$; and C=capacity, in farads.

$$\psi=.1079\frac{rC}{\lambda}$$

where ψ=phase difference, in degrees; r=resistance, in ohms; C=capacity, in farads; and λ=wavelength, in meters.

$$\psi=389\frac{rC}{\lambda}$$

where ψ=phase difference, in seconds.

INDUCTANCE-COIL FORMULAS

Inductance of a single circular turn of wound wire:

$$L = .01257 r_c \left[\left(1 + \frac{r_w^2}{8 r_c} \right) l_n \frac{8 r_c}{r_w} + \frac{r_w^2}{14 r_c^2} - 1.75 \right]$$

where L = inductance, in microhenrys; r_c = radius of coil, in centimeters; r_w = radius of wire, in centimeters; and l_n = natural logarithm of the expression immediately following.

Inductance of a single-layer closely-wound coil:

$$L = \frac{.03948 r_c^2 n^2}{l} K$$

where, in addition, n = number of turns in the winding; l = length of coil along winding, in centimeters; and K = value that is dependent on $\frac{2r_c}{l}$ and which may be obtained from the table for values of K.

Inductive reactance: $X_L = 2\pi f L$

where X_L = inductive reactance, in ohms; f = frequency, in cycles per second; and L = inductance, in henrys.

Energy associated with an inductance:

$$W = \tfrac{1}{2} L I^2$$

where W = energy, in joules; L = inductance, in henrys, and I = current, in amperes.

CIRCUIT FORMULAS

Resonance wavelength of a coil and condenser circuit:

$$\lambda = 1885 \sqrt{LC}$$

where λ = wavelength, in meters; L = value of inductance, in microhenrys; and C = capacity, in microfarads.

NOTE.—The inductance and capacity values must include all the inductance and capacity effects in the circuit; the distributed capacity of the coil must be added to the condenser capacity to give the total capacity value.

Impedance of an inductive circuit:

$$Z=\sqrt{R^2+(2\pi fL)^2}$$

where Z = inductive impedance effect, in ohms; R = resistance, in ohms; $\pi=3.1416$; f = frequency, in cycles per second; and L = inductance, in henrys.

Impedance of a capacitative circuit:

$$Z_c=\sqrt{R^2+\left(\frac{1}{2\pi FC}\right)^2}$$

where Z_c = capacitative impedance effect, in ohms; and C = condenser capacity, in farads.

Impedance of a circuit containing resistance, inductance, and capacity:

$$Z_a=\sqrt{R^2+\left(2\pi fL-\frac{1}{2\pi fC}\right)^2}$$

where Z_a = total impedance effect, in ohms; and the other terms are as previously given.

Natural frequency of a series circuit:

$$f=\frac{1}{2\pi}\sqrt{\frac{1}{CL}-\frac{R^2}{4L}}$$

where f = frequency, in cycles per second; $\pi=3.1416$; C = capacity, in microfarads; L = inductance, in microhenrys; and R = total resistance, in ohms.

Current in simple series circuit:

$$I=\frac{E}{\sqrt{R^2+\left(2\pi fL-\frac{1}{2\pi fC}\right)^2}}$$

where I = current, in amperes; E = electromotive force or potential, in volts; R = resistance, in ohms; L = inductance, in henrys; C = capacity, in farads; and $\pi=3.1416$.

Time constant of circuit:

$$T=\frac{2\times 3.1416}{\sqrt{\frac{1}{LC}-\frac{R^2}{4L^2}}}$$

where T = time of one oscillation or cycle, in seconds; L = inductance, in henrys; C = capacity, in farads; and R = resistance, in ohms.

The resistance R must be numerically less than the value of the term $2\sqrt{\frac{L}{C}}$ in order that the current in the circuit may oscillate.

High-pass filter circuit:

$$f_c=\frac{1}{4\pi\sqrt{LC}}$$

where f_c = frequency, in cycles per second, below which other frequencies will be cut off or greatly reduced; π = 3.1416; L = inductance of coil across the line, in henrys; and C = capacity of condenser in the line, in farads.

Low-pass filter circuit:

$$f_c=\frac{1}{\pi\sqrt{LC}}$$

where f_c = frequency, in cycles per second, above which all frequencies will be cut off, or greatly reduced; and the other factors remain the same, except that now the inductance coil is placed in series in the line, and the condenser connects across the line.

RADIO-TUBE FORMULAS

Emission current:

$$I_s = aT^{\frac{1}{2}} \epsilon^{-\frac{b}{T}}$$

where I_s = emission current per unit of filament area with plate voltage high enough to draw all the available electrons to the plate; a and b = constants whose values depend on the filament material and surface; T = temperature of filament, in absolute Kelvin degrees; and ϵ = base of natural system of logarithms.

Plate current:

$$I_p = A(E_p + \mu E_g)^{\frac{3}{2}}$$

where I_p = plate current, in amperes; A = factor depending on the filament electrons; E_p = plate potential, in volts; μ = amplification constant; and E_g = grid bias, in volts.

Amplification constant:

$$\mu = \frac{2\pi d}{a \log_\epsilon \frac{a}{2\pi r}}$$

where μ = amplification constant; d = distance between grid and plate, in centimeters; a = space between adjacent grid wires, in centimeters; and r = radius of grid wire, in centimeters. The grid wire should be small compared with the distance between adjacent grid wires.

Mutual conductance:

$$g_m = \frac{\mu}{r_p}$$

where g_m = mutual conductance, in mhos; μ = amplification constant; r_p = plate impedance in ohms.

MISCELLANEOUS FORMULAS

Power, in watts:

$$W = EI$$

where W = power, in watts; E = potential, in volts; and I = current, in amperes.

Energy, in joules:

$$W = I^2Rt$$

where W = energy, in joules; I = current, in amperes; R = resistance, in ohms; and t = time, in seconds.

Transformer ratio:

$$\frac{E_s}{E_p} = \frac{N_s}{N_p} \text{ or } E_s = \frac{N_s E_p}{N_p}$$

where E_s = secondary potential, in volts; E_p = primary potential, in volts; N_s = number of turns of wire in secondary winding and N_p = number of turns of wire in primary winding.

DEFINITIONS OF RADIO TERMS

Air Condenser.—An air condenser is a condenser that has air as its dielectric material.

Alternating Current.—An electric current that periodically reverses in direction, such as that from an alternator.

Alternation.—An alternation of current is one-half cycle, or the rise and fall of a current in one direction.

Alternator.—An electric generator that produces alternating currents.

Ammeter.—An instrument for measuring electric current intensity in a circuit when connected in series in that circuit.

Ampere.—The standard electric unit of current is called the ampere.

Amplification Factor.—The value expressing the effectiveness of the grid control as compared with the plate-potential influence over the plate current.

Amplifier.—An amplifier is a device or an arrangement that strengthens feeble energy pulsations to increase their indications or amplitudes.

Amplitude.—The amplitude of a wave is a measure of the maximum deviation from its zero or normal axis.

Anode.—The electrode from which the current flows through the vacuous space. See *Plate.*

Antenna.—An antenna consists of a conductor system arranged to radiate or absorb the energy of radio waves, depending on whether the station is transmitting or receiving, respectively.

Antenna Resistance.—The antenna resistance is the opposition offered to the radio-frequency current by all the electrical properties of the antenna.

Antenna Switch.—A switch connected in the antenna lead-in circuit to open and close the connection to the set.

Aperiodic Circuit.—An aperiodic circuit is a circuit that has such electrical properties or adjustments that it does not sustain electrical oscillations.

Arc.—An arc is formed by the passage of an electric current through a gas or vapor, the conductivity of which is mainly due to the ionization of that gas or vapor.

Atmospheric Absorption.—Atmospheric absorption is that dissipation of signal energy which, owing to the atmospheric conductivity, increases as the distance increases.

Attenuation.—Attenuation is the decrease, with increase of distance from the source, of the magnitude or amplitude of an electric or a magnetic wave.

Audio Frequency.—An audio-frequency wave is one capable of producing sound in the human ear, and, in radio practice, is considered to be all frequencies from about 20 cycles per second to some over 10,000 cycles per second.

Battery.—A battery is a combination of two or more electric cells.

Battery Charger.—A battery charger is a device, usually of a rectifier type, for charging a storage battery.

Broadcasting.—Broadcasting is the promiscuous transmission of radio information and entertainment.

Buzzer.—A buzzer is an electromagnetic device that has a vibrating member for opening and closing its own electrical circuit to produce a distinctive buzzing sound.

By-Pass Condenser.—A by-pass condenser is a fixed condenser used to provide a path of low opposition to radio or audio-frequency currents around devices which would have a serious impeding effect.

Capacity.—The capacity of a condenser, or, better, its *capacitance*, is a measure of the amount of electrical energy which the condenser can store up.

Capacity Reactance.—Capacity reactance is the opposition offered by a condenser to an alternating current.

Carrier Current.—A carrier current is the fundamental transmitted current that is modulated by the desired signal.

Cathode.—The cathode is the element which produces the electrons; a more common name in radio tube practice is the *filament.*

Choke Coil.—A choke coil is a coil so wound and used as to present a large choking, or self-inductive, effect to the passage or change of an alternating current.

Chopper.—A chopper is a device for rapidly opening and closing a circuit.

Circuit.—A circuit consists of any path through which an electric current is or may be established.

Circuit-Breaker.—A circuit-breaker is a special type of protective switch so arranged as to open a circuit rapidly and without injury to itself.

Clip.—A clip is a form of snap fastener for making electrical connections that must be changed frequently.

Close Coupling.—Close coupling means the condition in which two circuits are placed in close electrically coupled proximity to each other.

Coil Antenna.—A coil antenna is one in which the wires of the antenna are in the form of a coil or loop.

Condenser.—A condenser is an electrical device for storing up electrical energy. It usually consists of two conducting surfaces separated by an insulating medium, called the dielectric.

Conductivity.—The conductivity of a substance is a measure of its current-carrying power.

Conductor.—A conductor is a substance that offers a relatively small opposition to the passage of an electric current; that is, one which has low resistance.

Continuous Wave.—Continuous waves are a series of waves all of which have a constant or unvarying amplitude and frequency. Sometimes abbreviated cw.

Conventional Symbols.—Conventional symbols are sets of easily drawn representations adopted to indicate various pieces of apparatus.

Coulomb.—The coulomb is the quantity of electricity or the charge transmitted in one second by a current of one ampere.

Counterpoise.—A counterpoise is a system of electrical conductors used to complete the antenna capacity effect in place of the usual ground connection.

Coupler.—A coupler is a device for the transfer of the energy of radio oscillation from one circuit to another by associating portions of these circuits.

Coupling.—Coupling refers to the amount of flux linkage of one coil with another for the transfer of energy.

Crystal Detector.—A crystal detector is a form of rectifier making use of the contact between a metal point and any one of certain metallic crystals, for the detector action.

Cycle.—A cycle of current is one complete set of one positive and one negative alternation of current.

Damped Waves.—Damped waves are electromagnetic wave trains each of which consists of a series of oscillations or cycles of current of gradually decreasing amplitude.

Decremeter.—A decremeter is an instrument for measuring directly the logarithmic decrement of a circuit or of a train of electromagnetic waves.

Detector.—A detector is any device that converts or rectifies high-frequency oscillations into a pulsating direct current with the aid of a suitable electrical circuit.

Dielectric.—A dielectric is an insulating substance that allows electrostatic induction to act across it, as the insulating medium between the plates of a condenser.

Diode.—A two-element radio tube, usually employed as a rectifier.

Direct Current.—A direct current is a current that does not reverse; that is, the flow of electricity is always in one direction

Dry Cell.—A dry cell is a type of primary electric cell in which the eletrolyte is in the form of a paste.

Electrical Oscillation.—An electrical oscillation is a complete cycle of alternating current.

Electromagnetic Lines of Force.—Electromagnetic lines of force are the lines of force existing about a current-carrying conductor and an electromagnet.

Electrolytic Detector.—An electrolytic detector is a type of rectifier consisting of a fine platinum wire projecting a very short distance into an electrolyte.

Electron.—An electron is the smallest known part of matter and is an extremely minute but very active particle or charge of negative electricity.

Electron Tube.—An electron tube is a special radio device consisting of electrodes in a highly evacuated chamber and whose operation depends primarily on a controlled flow of electrons between the elements.

Electromotive Force.—An electromotive force is the voltage or electrical pressure that causes electricity to flow in a circuit.

Emission Current.—The emission current is the total electron current liberated by the cathode under the influence of a voltage sufficient to attract all of the available electrons.

Ether.—The ether is a name given to a medium that is supposed to permeate all space and matter and to be the medium for the transmission of heat, light, and radio waves.

Expansion-Type Ammeter.—An ammeter that depends for its operation on the expansion of a piece of metal when it is heated by the electric current.

Fading.—Fading is the more or less periodic change in radio-signal strength caused by variable intervening conditions.

Farad.—The farad is the unit of capacity and represents the charge in a condenser when an electromotive force of one volt has given it an electric charge of one coulomb.

Filament.—A filament is an electrically heated fine wire sealed in a glass bulb, and it forms one element, the cathode, of most types of electron tubes.

Filament Battery.—The filament or *A* battery is a low-voltage battery used to send a heating current through the filament of an electron tube. It may be either a storage battery or a primary battery.

Filter.—A filter is an inductance coil and condenser combination introduced into a circuit so as to reject or greatly attenuate alternating currents of only certain frequencies.

Fixed Condenser.—One whose plates and dielectric are stationary and whose capacity cannot be readily changed.

Flux.—By the flux of a coil is meant the electromagnetic lines of force produced by a current in that coil.

Frequency.—The frequency of a current is the number of complete cycles of current occurring in one second.

Frequency Meter.—A frequency meter is an instrument designed to indicate directly the frequency of an alternating current.

Fuse.—A fuse is a protective element of a circuit designed to melt or dissipate and to open the circuit at a predetermined unsafe value of current.

Galena.—Galena is a natural crystalline structure of lead sulphide which makes one of the most sensitive crystal detectors.

Generator.—A generator is an electrical machine for converting mechanical energy into electrical energy.

Grid.—The grid of a radio tube is the element that controls the flow of electrons from the filament to the plate.

Grid Battery.—The grid or *C* battery is the battery that is often used in the grid circuit of a three-element radio tube.

Grid Condenser.—The grid condenser is one connected so as to give its charge to the grid of a radio tube to assist in its detector action.

Grid Leak.—Grid leak is the name applied to a very high resistance when connected so as to permit negative charges that accumulate on the grid to leak off to the filament.

Grid Potential.—The electric potential of the grid relative to the filament.

Grid to Plate Capacity.—The capacity effect between the grid and plate elements of a tube with the filament element not connected.

Ground.—A ground is an electrical connection and system, such as the earth, which acts with the antenna to form a condenser effect for transmission and reception.

Ground Switch.—A ground switch is a switch so connected that it can connect the antenna direct to ground for protection in lightning storms.

Ground Wire.—A ground wire is the wire connecting the radio set or ground switch to ground.

Harmonic.—A harmonic is an alternating current whose frequency is an integral number of times greater than the frequency of its fundamental wave.

Henry.—A henry is the unit of inductance, and a coil has an inductance of one henry when a current changing at the rate of one ampere per second produces a back electromotive force of one volt.

Honeycomb Coil.—A honeycomb coil is an inductance coil so wound that it appears to have a cellular or honeycomb construction.

Hydrometer.—A hydrometer is a device for conveniently measuring the specific gravity of the electrolyte in a storage cell, which reading gives an indication of the state of charge of the battery.

Impedance.—Impedance is the total opposition of a circuit to the passage of an alternating current.

Inductance.—The inductance of a coil or circuit is that property which allows it to store up electrical energy in electromagnetic form.

Interrupted Continuous Wave.—This term is applied to a continuous wave that is broken, as by a chopper, at periodic intervals. It consists of a series of wave trains, each cycle, however, having the same current amplitude. It may be abbreviated to icw.

Insulator.—An insulator is any material that presents such a high opposition to an electric potential that there is no perceptible flow of electricity through that material.

Ion.—An ion is an atom that has more or less than its required number of electrons.

Key.—A key is a special form of switch arranged for rapid operation to form dots and dashes of the telegraph codes.

Kilocycle.—A kilocycle is equal to 1,000 cycles.

Lead-In.—The lead-in is the electrical conductor which forms the electrical connection between the antenna proper and the station apparatus.

Lightning.—Lightning is a violent electrical discharge between clouds or a cloud and the earth, caused by an enormous accumulation of static charges.

Lightning Arrester.—A lightning arrester is a device for protecting apparatus from lightning and other dangerously high voltages.

Loading Coil.—A loading coil is a coil possessing inductance connected in a circuit to increase its wavelength.

Logarithmic Decrement.—The logarithmic decrement of a damped wave is expressed mathematically by the natural logarithm of the ratio of the amplitude of one oscillation to that of the next one in the same direction.

Loose Coupling.—Two coils possess loose coupling when only a small part of the flux set up by one coil links the other.

Loud Speaker.—A loud speaker is a special type of telephone receiver capable of giving very loud signals or sounds.

Megohm.—A megohm is a resistance of 1,000,000 ohms.

Meter.—The meter is the unit of length in the metric system, largely used in European countries, and corresponds with a length of 39.37 inches. Also, an instrument or means for measuring some quantity, as a voltmeter.

Microfarad.—A microfarad is a capacity of $\frac{1}{1,000,000}$ of a farad, and is a very useful division or part of the basic unit.

Microphone.—A device for converting sound energy into electric energy. Such a device is also called a telephone transmitter.

Milliampere.—A current strength of $\frac{1}{1,000}$ of an ampere.

Motor.—A motor is an electrical machine for converting electrical energy into useful mechanical energy.

Mutual Conductance.—Mutual conductance of a tube is the amplification factor divided by the plate impedance.

Mutual Inductance.—Mutual inductance is the inductance produced by a current change in one of two independent circuits which react upon each other.

Ohm.—An ohm is the unit of resistance, and is the resistance that allows one ampere of current to pass under the pressure of one volt.

Oscillation Transformer.—A special open type of transformer primarily used for transferring fairly large amounts of oscillating energy from one circuit to another.

Oscillatory Circuit.—An oscillatory circuit is one that offers very little opposition to the establishment of an oscillating current of the frequency to which it is tuned.

Panel.—A panel is a sheet of insulating material on which electrical apparatus is mounted.

Parallel Connection.—A connection of electrical devices or circuits in which the current divides, only a part of the total current passing through each device.

Period.—The period of an alternating current is the time required for one cycle to pass through a complete set of positive and negative values.

Plate.—The plate, or anode, of an electron tube is the positively charged plate-like element that collects the eletrons emitted by the filament.

Plate Battery.—The plate, or *B* battery, is a battery connected in the plate circuit of a radio tube to give the plate element its high positive charge.

Plate Circuit.—The plate circuit of a radio tube includes all the devices connected directly in the external circuit between the filament and the plate.

Plate Impedance.—The plate impedance is the internal impedance of the tube between the filament and the plate.

Potentiometer.—A potentiometer is an arrangement for securing any desired voltage by utilizing the voltage drop across the required portion of a current-carrying resistance.

Primary Cell.—A primary cell is a type of electric cell whose voltage is directly due to the chemical decomposition of matter contained in the cell.

Primary Coil.—The primary coil is the input winding of a transformer.

Quenched Spark Gap.—A quenched spark gap is one arranged and designed so as to put out, or quench, the spark very quickly.

Radiation.—Radiation means the sending of energy from a source; and is considered in radio as the transmitting or radiating of energy from an antenna in the form of electromagnetic waves.

Radio Beacon.—Radio beacon is a fixed station transmitting special signals for bearing or navigation readings.

Radio Communication.—The science of transmitting and receiving messages by electromagnetic or radio waves.

Radio Compass.—The name radio compass or direction finder is applied to a small coil antenna and receiving set when this arrangement is used for taking direction bearings.

Radio Frequency.—Alternating currents of a frequency above 10,000 cycles per second are said to have a radio frequency, as currents of this frequency and higher are easily radiated by an antenna.

Radio Tube.—An electron tube or a vacuum tube are other names often used for a radio tube.

Receiving Station.—A receiving station is a radio receiver equipped with suitable apparatus and capable of converting radio waves into intelligible signals.

Rectifier.—A rectifier is a device for converting an alternating current into a more or less pulsating direct current.

Reflex Circuit.—A circuit arrangement in which one or more tubes amplify the signal at both radio and audio frequencies.

Regenerative Circuit.—A radio-tube circuit in which increased amplification is produced by the intentional feed-back of some of the energy from the plate circuit into the grid circuit.

Resistance.—Resistance is the opposition to the passage of a current by any substance or material, exclusive of any additional effect caused if the current is alternating.

Resonance.—Two circuits are in resonance if they are in tune with each other; that is, if the product of the inductance and capacity of one is equal to that of the other.

Rheostat.—A rheostat is a variable resistance device.

Secondary.—The secondary of a transformer is the output winding or coil.

Self-Inductance.—Self-inductance is the property of a coil which tends to prevent any current change therein.

Sending Station.—A radio station equipped with apparatus for producing and transmitting radio signals.

Series Connection.—In a series connection of electrical apparatus or circuits all the current passes through each of the devices in succession or through one after the other.

Side Bands.—Side bands are the accessory frequencies above and below the fundamental, present in a modulated radio wave.

Socket.—A socket is a receptacle, or support, into which some piece of apparatus may be inserted for convenient connection to a circuit or circuits.

Solder.—Solder is a mixture of lead and tin, which has a low melting point, and which is widely used in making permanent metallic connections.

Soldering Flux.—A special chemical preparation used to clean the surface so the solder may stick properly.

Spark.—A spark is an arc of very short duration.

Spark Gap.—A spark gap consists of special terminals or electrodes with an intervening air space across which spark discharges may pass without injury to the electrodes.

Specific Inductive Capacity.—The specific inductive capacity of a substance is a measure of its ability, referred to air as unity, to store up electrical energy when used as a dielectric material in a condenser.

Specific Gravity.—The specific gravity of any substance is its weight in proportion to that of an equal volume of water.

Static.—Static is an electrical disturbance caused by atmospheric charges collecting on or affecting the antenna.

Storage Cell.—An electric cell in which the chemical changes of discharge may be reversed by an electric current to recharge the cell to its original condition.

Switch.—A switch is a device for opening and closing or changing the connections in an electric circuit.

Synchronous Spark Gap.—A synchronous spark gap is one that is operated so as always to open the circuit at the same portion of the current wave.

Telegraph Code.—A telegraph code is a system of dot and dash combinations arranged to form letters, figures, and other symbols for rapid telegraphic communication.

Telephone Jack and Plug.—A telephone jack is a special type of connection device into which a telephone plug may be inserted to make a convenient electrical connection.

Telephone Receivers.—Telephone receivers are sound-reproducing devices capable of transforming current variations into sound impulses of like variations.

Telephone Transmitters.—A device for converting sound pulsations into similar electric-current variations.

Thermo-Ammeter.—A thermo-ammeter is an ammeter operated by the thermoelectric effect caused by the current under observation.

Thermoelectric Effect.—The thermoelectric effect is the voltage effect generated at the heated junction of two dissimilar metals.

Tickler.—A tickler is the name applied to the coil in the plate circuit used to feed some of the energy back into the grid circuit to produce regeneration.

Transformer.—A transformer is a device for transferring energy from one circuit to another, usually with an increase or decrease in the voltage.

Triode.—A three-element radio tube.

Tuned Circuit.—A circuit is said to be tuned when its natural period of oscillation is the same as that of some other circuit to which it is coupled.

Tuning.—Tuning is the operation of adjusting a circuit to electrical resonance with another circuit or an alternating current.

Vacuum Tube.—See electron tube.

Variable Condenser.—A variable condenser is one whose electrical capacity may be readily changed or varied.

Variocoupler.—A variocoupler is composed of a set of coils so arranged as to make it possible to vary the coupling between different circuits.

Variometer.—A variometer consists of two coils relatively so arranged that their inductive effects may be made to assist or practically neutralize each other.

Volt.—A volt is the unit of electromotive force and is the electrical pressure required to send 1 ampere of current through a resistance of 1 ohm.

Voltmeter.—A voltmeter is a device for measuring the electromotive force in volts.

Watt.—A watt is the unit of electrical power, and represents the product of the electromotive force and current.

Wave.—A wave is a periodic disturbance which travels through some medium.

Wave Changer.—A wave changer is a device for rapidly and positively changing the radiated wavelength.

Wavelength.—The wavelength is the distance between two corresponding points on succeeding waves.

Wavemeter.—A wavemeter is a device arranged and calibrated to read the length of a wave directly in meters.

Wave Train.—A wave train is a short series of cycles of alternating-current waves with successive trains separated by inactive periods.

Wire.—A wire is a slender rod or filament of drawn metal.

Wire Gauge.—A wire gauge is a system of wire sizes arranged for the convenient designation of wires of different diameters.

Wiring Diagram.—A wiring diagram is a sketch or figure showing where the apparatus and connections are to be placed in a circuit.

CONVENTIONAL SYMBOLS FOR RADIO DEVICES

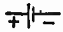
The conventional symbols which follow are convenient representations of the more common devices used in radio work. Their adoption simplifies the drawing of circuits and illustrations and tends to promote uniformity.

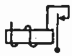
Alternator . . . . 

Ammeter . . . . 

Antenna . . . . 

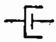
Arc . . . . 

Battery (polarity indicated) . . . . 

Buzzer . . . . 

Coil, or loop antenna . . . . 

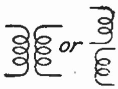
Condenser, fixed . . . . 

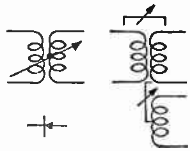
Condenser, shielded . . . . 

Condenser, variable . . . . 

Condenser, variable (with moving plate indicated) . . . . 

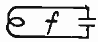
Counterpoise . . . . 

Coupler, inductive . . . . 

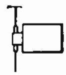
Coupler, inductive, variable .... 

Crystal detector ....

Enclosed fuse .... 

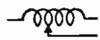
Frequency meter (wavemeter) .... 

Galvanometer .... 

Generator, direct current .... 

Ground .... 

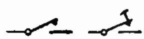
Inductor .... 

Inductor, adjustable .... 

Inductor, iron core .... 

Inductor, variable .... 

Jack .... 

Key, signaling .... 

Lightning arrester .... 

Loud speaker .... 

Piezoelectric crystal .... 

Plug .... 

Resistor .... 

Resistor, variable .... 

Spark gap, plain .... 

Spark gap, non-synchronous .... 

Spark gap, quenched .... 

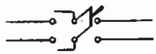
Spark gap, synchronous .... 

Switches:

Single-pole, single-throw .... 

Single-pole, double-throw .... 

Double-pole, single-throw .... 

Double-pole, double-throw .... 

Reversing .... 

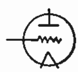
Telephone receiver .... 

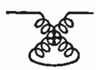
Telephone transmitter (microphone) .... 

Thermoelement .... 

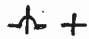
Transformer .... 

Vacuum tube, diode .... 

Vacuum tube, triode .... 

Variometer .... 

Voltmeter .... 

Wires, crossed not joined .... 

Wires, joined .... 

CONVERSION FACTORS

The following table of conversion factors may be used in converting values in one unit to equivalent values in some other unit. For instance, to convert 10 meters to feet would give 10× the conversion factor, or 10×3.2808 =32.808 feet. To change back, that conversion factor may be used as a divisor, or to convert 10 feet to meters would give $\frac{10}{3.2808}=3.048$ meters. Also, the direct conversion factor will give for this case 10×.3048=3.048 meters. Two or more conversion factors may be used to convert 10 meters to inches and would give 10×3.2808×12 =393.696 inches.

Ampere-hours×3,600=coulombs
British thermal units $\times 10{,}551 \times 10^{6}$=ergs
British thermal units×778.3=foot-pounds
British thermal units×1,055=joules
British thermal units×.2931=watt-hours
British thermal units per minute×17.57=watts
Bushels×1.244=cubic feet
(Centigrade degrees×1.8)+32°=Fahrenheit temperature
Centimeters×.3937=inches
Centimeters of inductance $\times 10^{-9}$=henrys
Centimeters (capacity)$\times 1.1 \times 10^{-12}$=farads
Centimeters×1.1=micro-microfarads
Centimeters per second×1.969=feet per minute
Circular mils×.7854=square mils

Cubic centimeters $\times$ .061 = cubic inches
Cubic feet $\times$ .02832 = cubic meters
Cubic feet $\times$ 7.481 = gallons
Cubic inches $\times 5.787 \times 10^{-4}$ = cubic feet
Cubic meters $\times$ 35.314 = cubic feet
Cubic meters $\times$ 1,000 = liters
Cubic yards $\times$ 27 = cubic feet
Cubic yards $\times$ .765 = cubic meters
Degrees (angular) $\times$ .01745 = radians
Ergs $\times 9.486 \times 10^{-11}$ = British thermal units
Ergs $\times 10^{-7}$ = joules
(Fahrenheit degrees $-32) \times \frac{5}{9}$ = Centigrade temperature
Farads $\times 10^{6}$ = microfarads
Farads $\times .9 \times 10^{12}$ = centimeters of capacity.
Farads $\times 10^{12}$ = micro-microfarads
Fathoms $\times$ 6 = feet
Feet $\times$ 12 = inches
Feet $\times$ .3048 = meters
Feet $\times$ .3333 = yards
Feet per minute $\times$ .508 = centimeters per second
Foot-pounds $\times$ .1383 = kilogram-meters
Foot-pounds per minute $\times 3.03 \times 10^{-5}$ = horsepower
Foot pounds per minute $\times$ .0226 = watts
Gallons $\times$ .1337 = cubic feet
Gallons (U. S.) $\times$ 3.785 = liters
Gallons (British) $\times$ 4.543 = liters
Grains (troy) $\times$ 1 = grains (avoirdupois)
Grains (troy) $\times$ .0648 = grams
Grams $\times$ 980.7 = dynes
Grams $\times 2.205 \times 10^{-3}$ = pounds (avoirdupois)
Gram-calories $\times$ 4.184 = joules
Grams per cubic centimeter $\times$ .03613 = pounds per cubic inch
Henrys $\times 10^{9}$ = centimeters of inductance

Henrys $\times 10^6$ = microhenrys
Horsepower $\times$ .7457 = kilowatts
Horsepower $\times$ 33,000 = foot-pounds per minute
Horsepower-hours $\times 2.684 \times 10^6$ = joules
Inches $\times$ 2.54 = centimeters
Inches $\times$ 1,000 = mils
Joules $\times 9.476 \times 10^{-4}$ = British thermal units
Joules $\times 10^7$ = ergs
Joules $\times$ .7376 = foot-pounds
Joules $\times 2.778 \times 10^{-4}$ = watt-hours
Kilogram-meters $\times$ 7.233 = foot-pounds
Kilograms $\times$ 2.2046 = pounds (avoirdupois)
Kilometers $\times$ 1,000 = meters
Kilometers $\times$ .62137 = miles
Kilowatts $\times$ 1.341 = horsepower
Knots $\times$ 1.152 = miles
Knots per hour $\times$ 1.152 = miles per hour
Liters $\times$ 1,000 = cubic centimeters
Liters $\times$ .03531 = cubic feet
Liters $\times$ .2642 = gallons (U. S.)
Log $_n$, or l_ε, of a number $\times$ .4343 = log $_{10}$ of that number
Log $_{10}$ of a number $\times$ 2.303 = log $_n$, or the natural logarithm
Megohms $\times 10^6$ = ohms
Meters $\times$ 100 = centimeters
Meters $\times$ 39.37 = inches
Meter $\times$ 3.2808 = feet
Meters $\times$ 1.0936 = yards
Microfarads $\times 10^{-6}$ = farads
Microhenrys $\times 10^{-6}$ = henrys
Micro-microfarads $\times 10^{-12}$ = farads
Micro-microfarads $\times$ .9 = centimeters of capacity
Miles (statute) $\times$ 5,280 = feet
Miles (nautical) $\times$ 6,080 = feet

Miles × 1.60934 = kilometers
Miles × .8684 = knots
Milliampere × 10^{-3} = amperes
Millimeters × .1 = centimeters
Millimeters × 39.37 = mils
Mils × .001 = inches
Ohms × 10^{-6} = megohms
Ounces (avoirdupois) × 28.35 = grams
Ounces (troy) × 31.103 = grams
Ounces (avoirdupois) × .0625 = pounds
Pounds × .4536 = kilograms
Pounds of water × .1198 = gallons
Pounds per cubic foot × 16.02 = kilograms per cubic meter
Pounds per square foot × 4.883 = kilograms per square meter
Quarts (liquid) × .9463 = liters
Radians × 57.3 = degrees (angular)
Square centimeters × .155 = square inches
Square feet × 144 = square inches
Square inches × 6.4516 = square centimeters
Square meters × 1.196 = square yards
Square mils × 1.273 = circular mils
Square yards × 9 = square feet
Square yards × .8361 = square meters
Watts × .05692 = British thermal units per minute
Watts × 44.26 = foot pounds per minute
Watts × .001341 = horsepower
Watts × 10^{-3} = kilowatts
Watt-hours × 3.411 = British thermal units
Yards × .9144 = meters.

PROPERTIES OF ELECTRICAL CONDUCTORS

Material	Component Materials	Specific Resistance Microhms per Cubic Centimeter at 20° C.	Temperature Coefficient at 20°C.	Specific Gravity (Referred to Water)	Tensile Strength Pounds per Square Inch	Melting Point Degrees C.
Aluminum, commercial...	97.5% Pure	2.828	.0039	2.70	30,000	659
Brass....................	66% Cu+34%Zn	7.0	.002	8.6	70,000	900
Carbon....................	Lamp filament	4000	−.0003			
Constantan, or Advance...	60%Cu+40%Ni	49	.00001	8.9	120,000	1,190
Copper....................	Annealed	1.724	.00393	8.89	30,000	1,083
Copper....................	Hard-drawn	1.771	.00382	8.89	60,000	1,083
German silver.............	18%Ni+Cu+Zn	33	.0004	8.4	150,000	1,100
Gold......................	99.9% Pure	2.44	.00342	19.3	20,000	1,063
Ideal, or Eureka..........	Resistance wire, Cu+Ni	49	.00001	8.9	120,000	1,190
Iron......................	99.98% Pure	10	.005	7.8		1,530
Lead......................	Pure	22	.0039	11.4	3,000	327
Mercury...................	Pure	95.78	.00089	13.546	0	−38.9
Molybdenum................	Drawn	5.7	.0033	9.0		2,535
Nichrome, or Calido.......	Resistance wire	100.	.0004	8.2	150,000	1,500
Nickel....................	Electrolytic	7.8	.006	8.9	120,000	1,452
Phosphor-bronze...........		7.8	.0018	8.9	25,000	750
Platinum..................	Pure	10.	.003	21.4	50,000	1,755
Silver....................	99.98% pure	1.629	.0038	10.5	42,000	960
Steel.....................	E. B. B.	10.4	.005	7.7	53,000	1,510
Steel.....................	Manganese	70	.001	7.5	230,000	1,260
Tantalum..................		15.5	.0031	16.6		2,900
Tin.......................		11.5	.0042	7.3	4,000	232
Tungsten..................	Drawn	5.51	.0045	19.0	500,000	3,400
Zinc......................		5.8	.0037	7.1	10,000	419

ELECTRICAL PROPERTIES OF MATERIALS

The main electrical properties of the more common conductor and insulator materials are given in the following tables. The figures in the table of conductor materials are quite accurate as these materials lend themselves to

PROPERTIES OF INSULATORS

Material	Megohms per Centimeter Cube	Specific Inductive Capacity	Dielectric Strength A.-C. Volts per Mil
Air, atmospheric pressure		1.00	10—75
Air, pressure 100 atmospheres		1.05	higher
Air, vacuum .001 mm. pressure		.94	lower
Asbestos	.16	2.5–3.0	60—100
Bakelite		4.0–8.8	200–1,100
Celluloid	2×10^4	4.2–16.	400–900
Enamel	1×10^8	2–4	300–1,100
Fiber, treated	1.1×10^6	5–8	700–1,100
Glass	2×10^8	3.5–10	150–300
Ice	72	86.4	20
Marble		8–9	50–100
Mica	2×10^{11}	2.5–7.5	700–1,500
Oils	1×10^8	2.0–4.5	150–500
Paper, dry	1×10^8	1.5–4.6	100–450
Paraffin	1×10^{10}	1.7–2.5	200–300
Phenolic molded materials	2×10^6	3–8.5	50–1,000
Porcelain, unglazed	3×10^8	4.4–6.5	40–200
Quartz		2–4	250–500
Rubber, India		2–4	250–500
Rubber, hard	1×10^{12}	2–3.5	500–1,500
Shellac	5×10^9	3–4	
Silk		4.5–5	75–150
Varnished cambric	1×10^8	3.5–5.5	500–1,300
Water (18° C.)	7×10^6	81.07	
Wood, dried	1×10^9	2.5–7.5	10–50

close readings and possess these characteristics very uniformly.

The insulator materials are subject to considerable variation due to the different qualities and grades of both the manufactured and natural forms. These comprise imperfections and impurities in the natural state and difference in processes and grading of the manufactured product. Moisture and dampness also change the electrical properties of the insulator materials to a very marked degree.

COPPER WIRE TABLES

Sizes of Wire.—Unfortunately, various standards of wire gauges have been adopted by different manufacturers, with the result that there is a lack of uniformity in this direction, which frequently causes confusion. The standards by which the various sizes of wire are designated are usually termed *wire gauges*. In each gauge, a particular number refers to a wire having a certain diameter. The size of wire generally decreases as the gauge number increase, but the law by which this decrease occurs is not the same in the different gauges. In the United States, copper wire is usually designated by the Brown & Sharpe, or American, wire gauge, which is generally termed B. & S. G.

Circular Measure.—A method that is extensively used for designating the size of a wire is to express its diameter in *mils* and the square of its diameter in *circular mils.* A **mil** is a unit of length used in measuring the diameter of wires, and is equal to $\frac{1}{1000}$ inch; that is, 1 mil = .001 inch.

If the diameter of a wire is given in mils, the square of this number represents its circular mils. For instance, if a wire has a diameter of 80 mils, it will have $80 \times 80 = 6{,}400$ circular mils. It is quite common to state that the sectional area of a wire is a certain number of circular mils; this invariably means the square of the diameter expressed in circular mils.

The diameter multiplied by itself and by .7854 gives the area of a circular wire in square inches when its diameter is

STANDARD ANNEALED COPPER WIRE

Size of Wire B. & S. Gauge	Diameter of Wire Mils	Circular Mils	Ohms per 1,000 Feet at 77° F.	Pounds per 1,000 Feet
0000	460	212,000	.0500	641
000	410	168,000	.0630	508
00	365	133,000	.0795	403
0	325	106,000	.100	319
1	289	83,700	.126	253
2	258	66,400	.159	201
3	229	52,600	.201	159
4	204	41,700	.253	126
5	182	33,100	.319	100
6	162	26,300	.403	79.5
7	144	20,800	.508	63.0
8	128	16,500	.641	50.0
9	114	13,100	.808	39.6
10	102	10,400	1.02	31.4
11	91	8,230	1.28	24.9
12	81	6,530	1.62	19.8
13	72	5,180	2.04	15.7
14	64	4,110	2.58	12.4
15	57	3,260	3.25	9.86
16	51	2,580	4.09	7.82
17	45	2,050	5.16	6.20
18	40	1,620	6.51	4.92
19	36	1,290	8.21	3.90
20	32	1,020	10.4	3.09
21	28.5	810	13.1	2.45
22	25.3	642	16.5	1.94
23	22.6	509	20.8	1.54
24	20.1	404	26.2	1.22
25	17.9	320	33.0	.970
26	15.9	254	41.6	.769
27	14.2	202	52.5	.610
28	12.6	160	66.2	.484
29	11.3	127	83.4	.384
30	10.0	101	105	.304
31	8.9	79.7	133	.241
32	8.0	63.2	167	.191
33	7.1	50.1	211	.152
34	6.3	39.8	266	.120
35	5.6	31.5	335	.0954
36	5.0	25.0	423	.0757
37	4.5	19.8	533	.0600
38	4.0	15.7	673	.0476
39	3.5	12.5	848	.0377
40	3.1	9.9	1,070	.0299
41	2.8	7.84	1,348	.0237
42	2.5	6.22	1,700	.0188
43	2.2	4.93	2,145	.0150
44	2.0	3.91	2,707	.0118

expressed in inches. Multiplying .7854 by the number of circular mils and dividing the result by 1,000,000 gives the sectional area in square inches, when the number of circular mils in a wire are known.

Wire Table.—The size, resistance, and weight of average commercial copper for the commonly used sizes of wire are given in an accompanying table of Standard Annealed Copper Wire. The values are those given in a working table published by the United States Bureau of Standards, and have been commonly accepted in the United States. The values in this table are approximate, but are sufficiently accurate for practically all electrical calculations.

The ohms per 1,000 feet given in the table represent the resistance of 1,000 feet of wire at the temperature of 77° Fahrenheit. The resistance of 1 foot of conductor would be obtained by dividing the value as given by 1,000. Similarly, the weight of 1 foot of wire would be found by dividing the pounds per 1,000 feet by 1,000.

The values of circular mils given in the third column should be the square of the diameter of the wire in mils as given in the second column. Any instances where the value in the third column are not the exact squares are due to the fact that those in the third column are calculated from more nearly accurate data than those given in the second column.

ANTENNA WAVELENGTH TABLES

The accompanying table gives the approximate wavelength in meters for antennas of various heights and lengths. These data are not accurate enough for transmission work, but may be closely followed in general design and installation work. Numerous ground wires and other structures are apt to alter the wavelength considerably. An antenna of two, or even of one, wire will not be far different from the values given for the 4-wire antennas. For accurate work, the wavelength should be measured with a wavemeter.

APPROXIMATE NATURAL WAVELENGTHS OF FLAT-TOP ANTENNAS

INVERTED L-TYPE, 4-WIRE ANTENNAS

Horizontal Length Feet	Wavelengths in Meters for the Following Heights, in Feet, to the Flat-Top Portion				
	30	40	60	80	100
30	69	81	108	134	158
40	81	95	122	146	172
50	95	109	134	160	186
60	108	121	148	173	199
70	121	133	161	188	212
80	133	147	174	199	225
90	146	159	187	212	240
100	159	172	200	226	252
110	171	185	213	240	265
120	184	199	226	252	279

T-TYPE, 4-WIRE ANTENNAS

Horizontal Length Feet	Wavelengths in Meters for the Following Heights, in Feet, to the Flat-Top Portion				
	30	40	60	80	100
60	77	92	124	152	180
80	92	106	139	166	196
100	106	121	154	181	211
120	121	136	169	198	228
140	135	150	184	215	243
160	149	165	198	229	259
180	163	179	213	245	275
200	178	194	229	260	291
220	192	209	244	276	306
240	206	224	257	291	322

The loop, or coil, antenna data are likewise a useful guide to follow in the construction of such an antenna. The wavelength range is in most cases given with certain condensers, and in the others may be calculated by adding the coil capacity to that of the desired condenser.

CHARACTERISTICS OF COIL ANTENNAS

Length of Each Side Feet	Total Number of Turns	Spacing of Wires in Inches	Inductance, in Microhenrys	Capacity of Coil, in Microfarads	Fundamental Wavelength, in Meters
8	3	.50	96	.000075	160
6	4	.25	124	.000066	170
4	6	.25	154	.000055	174
3	8	.125	193	.000049	183

RANGES OF 5-FOOT COILS, WITH WIRES SPACED .5 INCH

Number of Turns on Loop	Wavelength Range Using Condensers of Following Ranges of Capacity, in Microfarads	
	.00065 to .00004	.0014 to .000045
4	200 to 400	380 to 650
8	350 to 700	400 to 950
16	500 to 1,000	675 to 2,300

RANGES OF 4-FOOT COILS, WITH WIRES SPACED 1 INCH

Number of Turns on Loop	Wavelength Range Using Condensers of the Following Ranges of Capacity, in Microfarads	
	.0006 to .00004	.0014 to .000045
4	150 to 300	180 to 500

APPROXIMATE WAVELENGTH OF 4-FOOT COIL ANTENNAS

Total Number of Turns	Number of Turns per Slot ½ Inch Apart	Tuning Condenser Capacity Values, in Microfarads					
		.00005	.0001	.0005	.001	.002	.003
1	1		65	128	178	250	310
3	1	130	155	290	400	550	675
6	1	230	280	500	710	1,000	1,200
12	1	430	490	920	1,250	1,700	2,050
24	1	760	880	1,600	2,100	3,000	3,600
48	2	1,550	1,775	3,150	4,300	6,000	7,000
72	3	2,200	2,650	4,800	6,400	8,800	11,000
120	5	3,930	4,500	7,900	10,000	14,700	17,700
240	10	7,600	9,000	15,650	20,500	27,200	32,900

TABLE FOR VALUES OF K

$\frac{2rc}{l}$	K	$\frac{2rc}{l}$	K
.00	1.000	0.95	.700
.05	.979	1.00	.688
.10	.959	1.10	.667
.15	.939	1.20	.648
.20	.920	1.40	.612
.25	.902	1.60	.580
.30	.884	1.80	.551
.35	.867	2.00	.526
.40	.850	2.50	.472
.45	.834	3.00	.429
.50	.818	3.50	.394
.55	.803	4.00	.365
.60	.789	4.50	.341
.65	.775	5.00	.320
.70	.761	6.00	.285
.75	.748	7.00	.258
.80	.735	8.00	.237
.85	.723	9.00	.219
.90	.711	10.00	.203

APPROXIMATE HONEYCOMB-COIL DATA

Number of Turns on Coil	Size of Wire. B. S. Gauge	Inductance in Millihenrys	Distributed Capacity in Micro-microfarads	Natural Wave-length in Meters	Wavelengths With the Following Shunt-Condenser Capacities Microfarads			
					.001	.0005	.00025	.0001
25	24	.038	26.8	60	372	267	193	131
35	24	.076	30.8	91	528	378	277	188
50	24	.150	36.4	139	743	534	391	270
75	24	.315	28.6	179	1,007	770	560	379
100	24	.585	36.1	274	1,470	1,055	771	532
150	24	1.29	21.3	313	2,160	1,546	1,110	746
200	25	2.27	18.9	391	2,870	2,050	1,470	980
250	25	4.20	22.9	585	3,910	2,800	2,020	1,355
300	25	6.60	19.0	669	4,900	3,490	2,510	1,670
400	25	10.5	17.4	806	6,160	4,400	3,160	2,095
500	25	18.0	17.3	1,052	8,070	5,750	4,140	2,740
600	28	37.5	19.2	1,600	11,600	8,300	5,980	3,980
750	28	49.0	18.3	1,785	13,300	9,500	6,830	4,540
1,000	28	85.3	16.8	2,260	17,600	12,500	9,000	5,950
1,250	28	112.0	15.5	2,490	20,100	14,300	10,250	6,780
1,500	28	161.5	15.8	3,000	24,200	17,200	12,350	8,150

TELEGRAPH CODE SYSTEMS

MORSE CODE

Telegraph codes consist of *characters* formed by combinations of dots, dashes, and spaces, which represent letters, numerals, and punctuation marks. These characters are sent by one operator to the other by means of electric impulses. With the aid of suitable apparatus, the receiving operator hears the incoming signals and is then able to reproduce the original message. The characters representing letters, figures, and punctuation marks for the International Morse code, the Morse code, and the Phillips punctuation code, which is used as a part of the Morse code, are to be found under the heading Code Charts.

The **Morse code** of characters came into general use in wire telegraphy shortly after the establishment of that means of communication. In this system, which is also called the *American Morse code*, some of the characters are made with so-called *spaces* that are a part of the group signal, and are essential in distinguishing those characters. The use of spaced letters in this system occasionally leads to errors in the transmission of messages, as the parts of those letters are apt to be divided into two letters, or two letters composed of a small number of signals may be combined unintentionally to form a single letter. This does not imply that no mistakes are made when other codes are used, but rather that they are apt to be more common in the Morse for the reason given. It is usually somewhat more difficult to learn a code with spaced letters than one which does not have any spaces as part of the letter characters. The *Phillips punctuation code* has superseded the punctuation characters of the Morse code, as it is much more complete and systematic.

INTERNATIONAL MORSE CODE

The **International Morse code** is a modified form of the Morse code in which no spaced characters are used, except in the character for the period. This alphabet is also commonly called the *Continental*, and the *Universal code*, and has come into extensive use in some fields.

The International Morse code is used all over the world for radio and submarine telegraphy, and for wire telegraphy in almost every country except the United States, Canada, and parts of Australia. It is superior for signaling through long submarine cables, as some of the recording devices used in that work do not give accurate signals when used with spaced letters.

The Morse code, owing to the fact that there are fewer dashes in its characters, is about 5 per cent. more rapid than the International Morse code. The latter, is, however, preferable for several reasons and would doubtless have been adopted in the United States if the Morse alphabet had not already obtained such extensive use among telegraph operators.

The only codes that are in general use are the Morse and the International Morse. Either of these codes may be used in wire or radio telegraphy, yet each has been adopted in certain particular fields. In some fields, such as railroad work where both wire and radio systems are employed and the Morse code is used in the wire system, it is sometimes convenient to use the Morse code also for the radio system.

CODE CHARTS

Code charts are introduced at this point in the text so that reference may be easily made to them in connection with the suggestions for sending the characters. The code charts include the characters and figures of the

International and the American Morse codes; the characters for punctuation marks of the International Morse

ALPHABETS

Letters	International Morse	Morse
A	· —	· —
B	— · · ·	— · · ·
C	— · — ·	· · ·
D	— · ·	— · ·
E	·	·
F	· · — ·	· — ·
G	— — ·	— — ·
H	· · · ·	· · · ·
I	· ·	· ·
J	· — — —	— · — ·
K	— · —	— · —
L	· — · ·	⸺
M	— —	— —
N	— ·	— ·
O	— — —	· ·
P	· — — ·	· · · · ·
Q	— — · —	· · — ·
R	· — ·	· · ·
S	· · ·	· · ·
T	—	—
U	· · —	· · —
V	· · · —	· · · —
W	· — —	· — —
X	— · · —	· — · ·
Y	— · — —	· · · ·
Z	— — · ·	· · · ·
&		· · · ·

NUMERALS

Figures	International Morse	Morse
1	· — — — —	· — — ·
2	· · — — —	· · — · ·
3	· · · — —	· · · — ·
4	· · · · —	· · · · —
5	· · · · ·	— — —
6	— · · · ·	· · · · · ·
7	— — · · ·	— — · ·
8	— — — · ·	— · · · ·
9	— — — — ·	— · · —
0	— — — — —	⸺

code, the Phillips code, and special International Morse code signals

PUNCTUATION MARKS, ETC.

Characters	International Morse	Phillips Punctuation Used With Morse Code	
. Period	· · · · · ·		· · — — · ·
: Colon	— — — · · ·	K O	— · — · ·
; Semicolon	— · — · — ·	S I	· · · · ·
, Comma	· — · — · —		· — · —
? Interrogation	· · — — · ·		— · · — ·
! Exclamation	— — · · — —		— — — ·
Fraction line	— · · — ·	{ E	·
		{ U T	· · — —
— Dash		D X	— · · · — · ·
- Hyphen	— · · · · —	H X	· · · · · — · ·
' Apostrophe	· — — — — ·	Q X	· · — · · — · ·
Underline (or Italics)	· · — — · —	U X	· · — · — · ·
End of underline	· · — — · —	U J	· · — — · — ·
(Parenthesis (start)	— · — — · —	P N	· · · · · — ·
) End of parenthesis	— · — — · —	P Y	· · · · · · · · ·
" Quotation marks (start)	· — · · — ·	Q N	· · — · — ·
" End of quotation	· — · · — ·	Q J	· · — · — · — ·
= Double dash (or break)	— · · · —	B K	— · · · — · —

SPECIAL INTERNATIONAL MORSE CODE SIGNALS

Conventional Signals

Attention call, to precede every transmission	-.-.-
Position report (to precede all position messages)	- .-.
General inquiry call	-.-. --.-
From (de)	-.. .
Invitation to transmit (go ahead)	-.-
Warning (high power)	--..--
Wait	.-...
Understand	...-.
Error (series of dots)	....
Received (O. K.)	.-.
Transmission finished (end of work)	...-.-
End of each message (cross)	.-.-.
Distress call	... --- ...

Special Letters

Ä (German)	.-.-
Á *or* Å (Spanish-Scandinavian)	.--.-
CH (German-Spanish)	----
É (French)	..-..
Ñ (Spanish)	--.--
Ö (German)	---.
Ü (German)	..--

LENGTH OF DOT, DASH, AND SPACE

In all codes, the dot is taken as the unit by which the lengths of the dashes and spaces are measured. The generally accepted relative lengths of the different dashes and spaces, some of which are used only in the Morse code, are as follows:

Signal		Duration of Signal
Dot	1	1 unit
The dash	3	3 units
The long dash (*l*)	6	6 units
The extra dash (naught)	9	9 units

Signal		Duration of Signal
Space between parts of a character..	▬ 1 ▬	1 unit
Space in spaced characters..........	▬ 2 ▬	2 units
Space between characters...........	▬ 3 ▬	3 units
Space between words...............	▬ 5 ▬	5 units

The dot, which also represents the character *e*, is made by a single instantaneous downward stroke of the key followed immediately by an upward stroke. The actual time required in making the dot will vary with the speed of signaling, but it is important that the relative lengths of the dots, dashes, and spaces should remain constant. There are four lengths of spaces and three of dashes, or, including the dot, four.

A dash, or the letter *t*, is made by holding the key down as long as it takes to make 3 dots. This should be timed so that the duration of the signal transmitted is actually 3 times as long as that sent as a dot. The space, or interval, of time between characters should equal 3 units. It will then be exactly like the dash in length of time. The space between words or groups of characters should be made equal to 5 units. This spacing is very distinct and enables the operator to separate the letter and number groups of characters very readily even when receiving code words such as are used often for secret communications.

Some characters which are used only in the Morse code have special lengths of dashes and spaces. A long dash is used to represent the letter *l*, and is made 6 units long. An extra long dash, normally 9 units in length, designates the figure *0* (naught). However, in practice, the *l* and the *0* are often made 5 and 7 units long, respectively. In many cases the *l* and the *0* (naught) are made the same; occurring alone, the long dash would be read as *l*, but when found among figures it would be translated as *0* (naught).

The space in the *spaced letters* of the Morse code, *Co, o, R, Y, Z, &*, is 2 units long, or just double that ordinarily used between the elements of a letter. In case the receiving is rather poor, it is sometimes difficult to distinguish the 2- and 3-unit spaces because of the relatively small difference between them.

RADIO DEVELOPMENTS

PICTURE TRANSMISSION

INTRODUCTION

The commercial application of picture transmission by radio, after many years of development work, has opened an important branch of the radio industry. Among the uses for this service may be mentioned the transmission of photographs of persons or of scenery, the exchange of facsimile legal and banking documents, engineering drawings, and sketches. Picture transmission is based on the same general operating principles as is communication by radio telegraph.

In the transmission of facsimiles of all types, it is necessary to prepare a suitable photographic film of the object selected and to translate the lights and shades of this film into photo-electric current impulses that will acutate standard high-power radio-telegraph circuits. At the receiving end the electric impulses are converted back into photographic gradations that will produce on a piece of paper the facsimile of the original picture.

PHOTO-ELECTRICITY

Photo-Cells.—To translate the lights and shades of the photographic film into high-frequency electrical impulses a *photo-cell* is employed. If the lining on the inside of the bulb of this cell is exposed to light rays of varying intensity a flow of electrons is established within the cell and the fluctuating current ensuing is applied, after certain modification, to the radio-telegraph apparatus. The type of photo-cell that meets the requirements of high-frequency work must be based on an electronic flow, and its inertia must be negligible. This is accomplished in the General Electric type PJ1, Westinghouse Zworykin, Western Electric, and Case photo-cells by the employment, as the active element, of potassium hydride, rubidium, or barium. All of these elements emit pure electronic discharges when exposed to light. The values of the electric discharges depend on the densities of the minute sections of the photographic film through which the light must pass before impinging on the active material of the photo-cell.

In Fig. 1 is shown one type of photo-cell. The glass shell is shown at *a*. Within the bulb of the shell is formed the platinum coating with the active element *b* of potassium hydride on its inner surface. This coating covers the whole of the inner surface of the bulb except for the cell window *c* of clear glass. The nib *d* is the negative terminal and is connected to the cathode or active element *b*. The anode *e*, at the center of the bulb, is connected through the long stem to the positive terminal *f*. The exhaustion nib for the photo-cell is shown at *g*. Highly attenuated argon gas is placed within the photo-cell. This gas increases the ionizing effect materially so that in combination with the action of the light on the potassium hydride a very minute current is established in the circuit including the photo-cell.

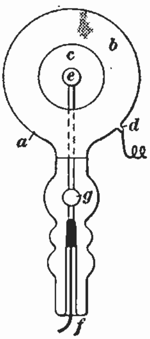


FIG. 1

Effects of Varying the Density of Film.—The conversion of light into electricity may be considered with reference to the elementary circuit diagram in Fig. 2. A source of light is indicated at *a*. Light rays pass through successive minute sections of a film photograph *b* and then through the window of a photo-cell *c*, where the rays impinge on the potassium hydride coating *d*. This action of the light rays establishes a flow of conducting electrons from the cathode *d* to the anode *e*. Actual current passes from the positive terminal of the battery *f*, through the anode *e*, the electron path, cathode *d*, and the resistance *g*, to the negative terminal of the battery *f*. The grid *h* of the amplifier tube is connected to the upper end of the resistance *g*, which is also connected to the negative terminal of the battery *f*. A negative potential is thus impressed on the grid *h* and the value of the negative grid biasing is

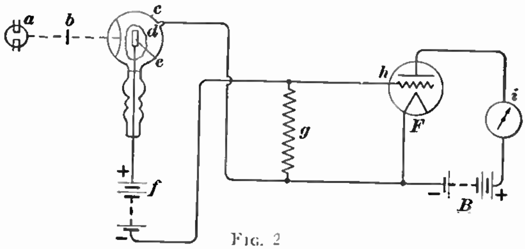


FIG. 2

varied in accordance with the fluctuations of the light passing from the lamp *a* through the sections of varying density of the film *b* to the active material *d*. The variations of the electronic discharge thus established control the activity of the grid *h*, and this in turn affects the current in the plate circuit. The indicating device *i* will give a response proportional to the density of the minute section of the film that is at any instant exposed to the light.

In radio circuits it is necessary to match the impedances of the various units of a set. It is equally important that the characteristics of the photo-cell be matched with the density of the photographic film. In Fig. 3 a characteristic curve of the potassium-hydride cell is shown. Current is plotted against light intensities. The rating from 0 to 25 of light intensity, which is also representative of the density of the film, is merely an arbitrary division. When the film is clear white the photo-cell will produce a maximum current output of approximately 15 microamperes. When the film is black no current is produced. When the light changes from maximum value to 20 per cent. less than maximum, the change in current is from maximum value to approximately 70 per cent. less than maximum. This shows that the greatest change in current is attained in a change of 20 per cent. of light from clear white. In order to work on this favorable portion of the characteristic curve it is necessary to so prepare the film that it ranges from clear white to a density a little deeper than that of light gray.

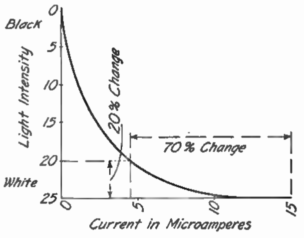


FIG. 3

COMMERCIAL PHOTO-RADIO-GRAM TRANSMITTER

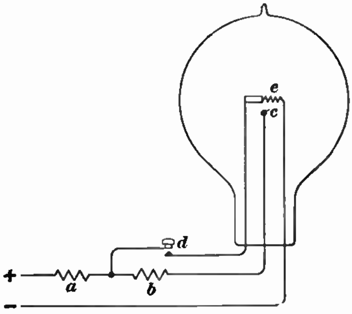


FIG. 4

Optical System.—The transmitter may properly be divided into the *optical system*, the *mechanical layout*, the *amplifier circuits*, and the *synchronizing equipment*. The source of light is an *incandescent arc*, Fig. 4, having an intrinsic candlepower of 12,000, rated at 100 watts, and a life of approximately 500 hours. Resistances *a* and *b* are in series and connected to the tungsten ball *c*. A push button *d*, when operated, connects the resistance *a* and the starting filament *e* across the circuit. This heats the filament and the gas within the bulb. When the push button *d* is released, current passes through the resistances *a* and *b*, the tungsten ball *c*, the gas, the filament *e*, and to the negative side of the circuit.

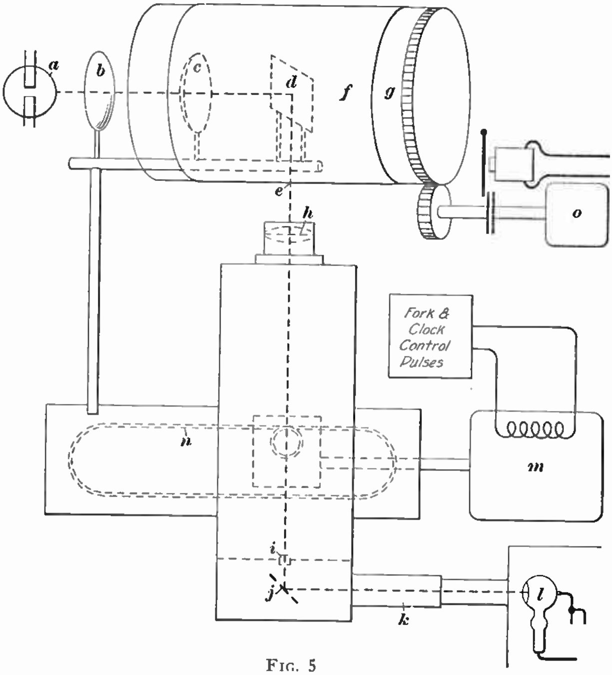


FIG. 5

In Fig. 5 are shown the elements of the optical system. The incandescent arc is represented at *a* and the light rays, first passing through the condensing lenses *b* and *c*, are then reflected by a mirror *d* to a focal point that at a given instant may be at *e* on the photographic film *f*. The film *f* is mounted on the glass cylinder *g*. After passing through the film the rays pass through a photo-lens at *h*. An inverted image of a minute section of the picture is produced upon a surface. This image is about twice the size of the part of the film that is exposed to the light rays at any given instant. A small adjustable slot is provided at *i* which may be used to regulate the amount of the picture that is, at a given time, to be photo-electrically converted. The standard machines take approximately 96 lines per inch of photograph so that the aperture must be set to take in a corresponding amount of the image, and no more, in order to avoid blurring of the received picture. After passing through the analyzing slot *i*, the light rays are reflected by a mirror *j* through the light tube *k* to the window of the photo-cell *l*, located in the stationary amplifier cabinet. Light shields are provided that prevent all light rays except the beam that passes through the film from entering the photo-cell.

Mechanical System.—In order that all portions of the film may be brought successively into the focus of the light beam from the incandescent arc *a*, Fig. 5, that passes through the lens *b* and *c* and is reflected by the mirror *d* to the focal point *e*, the film *f* and the glass cylinder *g* are rotated upwards approximately $\frac{1}{96}$ of an inch after the optical system has been moved one stroke laterally in either direction across the film. The traveling optical system consists of the lenses *b* and *c*, the mirror *d*, and the light-tight focusing box containing the photo-lens *h* and the mirror *j*. These are shown mechanically connected in Fig. 5. The paths of the lateral movement of the optical system and the rotary movement of the film are indicated in Fig. 6.

The lateral movement is imparted by the motor *m*, Fig. 5, which by means of gearing connected to its shaft drives the elliptical gear *n* and results in a back-and-forth motion of the optical system. The rotary movement or line feed of the film is imparted by the motor *o* acting through a friction clutch. When the optical system is making a stroke the clutch is open and there is no movement of the film. At each end of the stroke the clutch is closed and the film moves upwards a very short distance so that a new line across the film may be inspected by the beam of light as indicated in Fig. 6.

Electrical System.—The electrical system may be divided into two sections, the one relating to the control of the mechanical movements, and the other to the amplifier and relay system. The power-supply system being so closely allied with that of synchronism, this subject will be taken up with that of synchronism.

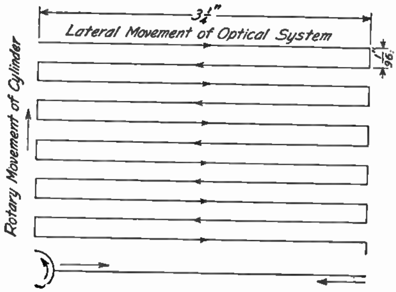


FIG. 6

In order to transmit a picture over a single communication channel it is necessary to explore the picture point by point on the transmitter, and then, at practically the same instant, to reproduce the picture point by point on the receiver; this finally results in a fascimile of the original photograph. The transmission of the picture impulses is by means of the trans-oceanic radio-telegraph system employing the Alexanderson high-frequency alternator and the multiple-tuned antenna. The picture impulses are essentially telegraphic in nature, and utilize either the full telegraphic current or nothing. The relays can therefore be set either electrically or mechanically so that their trigger action is above that of the static level, hence this form of disturbance is negligible.

It is necessary to translate the fluctuations in the electrical activity of the photo-cell, caused by the varying density of the film, into current impulses of such a nature that they may be sent over the radio-telegraph transmission system. This is accomplished by means of the apparatus indicated by Fig. 7. The photo-cell is connected with a direct-current amplifier that increases the output of the photo-cell to a value suitable for controlling a system of modulating tubes, which in turn modulate the output of an audio-frequency oscillator. An audio-frequency current is produced the amplitude of which is varied in accordance with the light modulation falling upon the photo-electric cell. The output of the oscillator is amplified, then rectified, and finally passed through a direct-current amplifier. The direct current is then of sufficient value to operate a Wheatstone relay. One contact of the Wheatstone relay is for *marking*, the other for *spacing*. Which of the two contacts is active depends on the effect of the output current of the direct-current amplifier on the relay. This relay delivers bi-directional current to the actual radio-telegraphic transmitter located many miles from the photo-transmitter terminal apparatus. Here the line current controls the station relay, which in turn controls the local potential of a magnetic amplifier. The latter device modulates the output of the radio-frequency alternator in accordance with the photo signals. With the contact of the station relay closed, the antenna circuit is out of resonance with the alternator and the energy set up in the antenna is a small per cent. of the normal amount of energy available when the contact of the station relay is closed and the antenna circuit and the alternator are in resonance. A series of current impulses are thus transmitted by radio in a manner similar to the transmission of telegraph code.

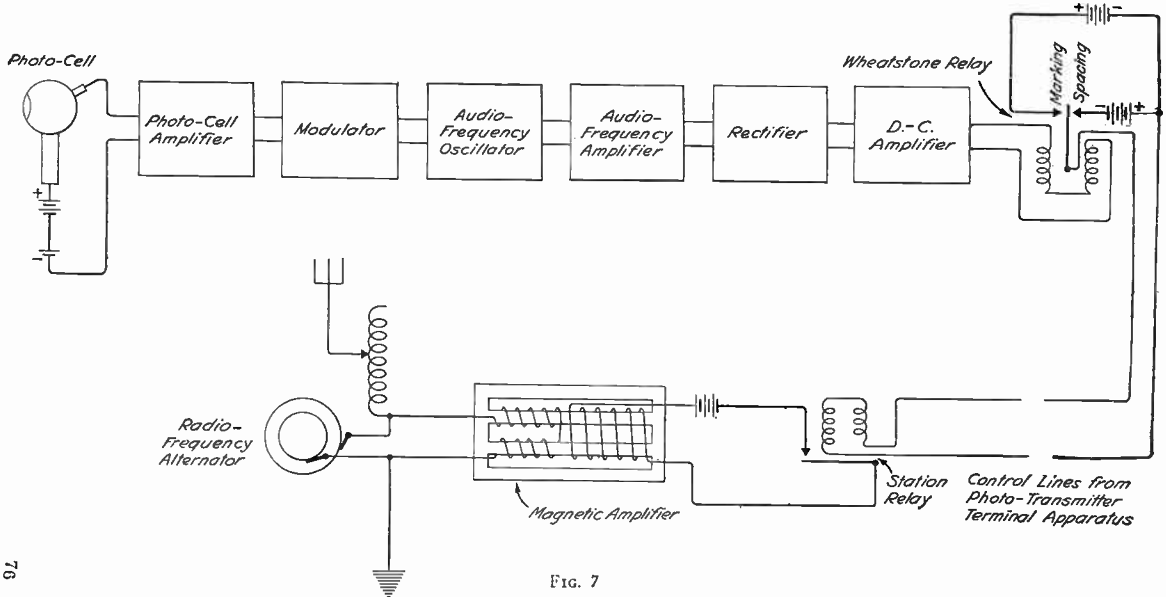


Photo-Cell
Photo-Cell Amplifier
Modulator
Audio-Frequency Oscillator
Audio-Frequency Amplifier
Rectifier
D.-C. Amplifier
Wheatstone Relay
Marking
Spacing
Radio-Frequency Alternator
Magnetic Amplifier
Station Relay
Control Lines from Photo-Transmitter Terminal Apparatus

Fig. 7

PICTURE RECEPTION

INCOMING SIGNAL

The incoming signal from the transmitting station is received at a remote receiving station usually on a wave, or Beverage, antenna. The signal passes through a long-wave tuner, Fig. 8, that contains selective circuits in both the radio- and audio-frequency circuits. The output is in the form of an alternating-current signal and passes into a line amplifier that contains circuits of the proper impedance for introducing the signal into the long-distance telephone lines.

At the terminal apparatus this signal is slightly amplified, filtered, and then rectified. This direct-current output is increased by a suitable amplifier, which actuates the winding of a polarized relay of the Wheatstone type. This relay controls the local pen circuits and causes a deflection of the pens on the paper and consequent marking for each incoming signal.

REPRODUCING THE PICTURE

Pen Method of Reproduction.—As in the transmitter it is necessary to provide on the receiver a mechanical motion of a similar character and speed in order that an exact facsimile of the transmitted picture may be obtained. In Figs. 8 and 9 are indicated the more important features of the method for moving the pens and the paper on which the picture is reproduced. The receivers are built in a duplex manner in order to supply two copies of the incoming picture. This permits the retention of one copy for filing. A back-and-forth movement is imparted to the traveling carriage *a*, Fig. 9, by means of elliptical gearing driven by a motor as indicated in Fig. 8. This motor is shown at *b*, Fig. 9, and transmits its power through the gear box *c* to the elliptical gearing, Fig. 8. The carriage

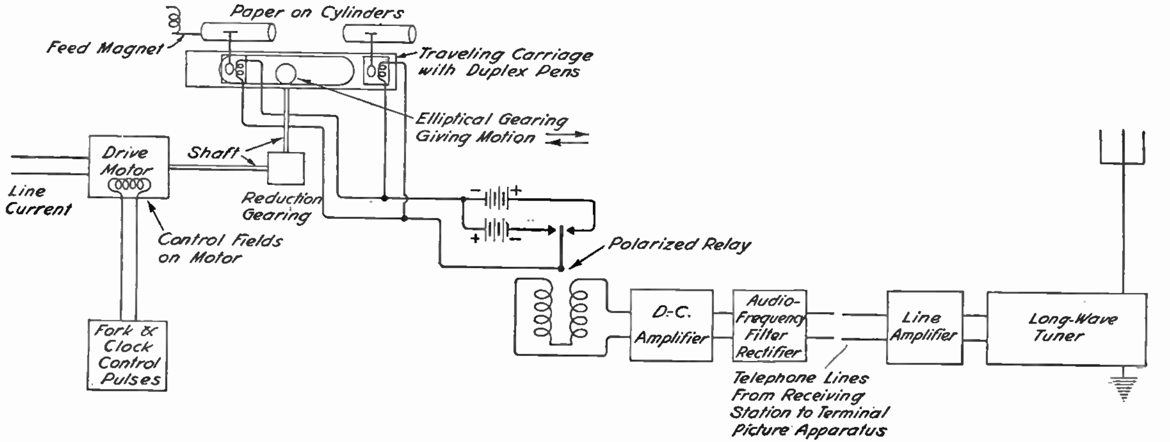

Paper on Cylinders
Feed Magnet
Traveling Carriage with Duplex Pens
Elliptical Gearing Giving Motion
Drive Motor
Shaft
Reduction Gearing
Line Current
Control Fields on Motor
Polarized Relay
Fork & Clock Control Pulses
D-C. Amplifier
Audio-Frequency Filter Rectifier
Line Amplifier
Long-Wave Tuner
Telephone Lines From Receiving Station to Terminal Picture Apparatus

FIG. 8

bears two pens *d*, Fig. 9, mounted on levers moved by the magnets *e*. These magnets receive current through the armature of the polarized relay, Fig. 8. The pens *d*, Fig. 9, are normally out of contact with the paper, but when a marking contact is made the pens are forced against the paper and leave a mark or a line during the duration of

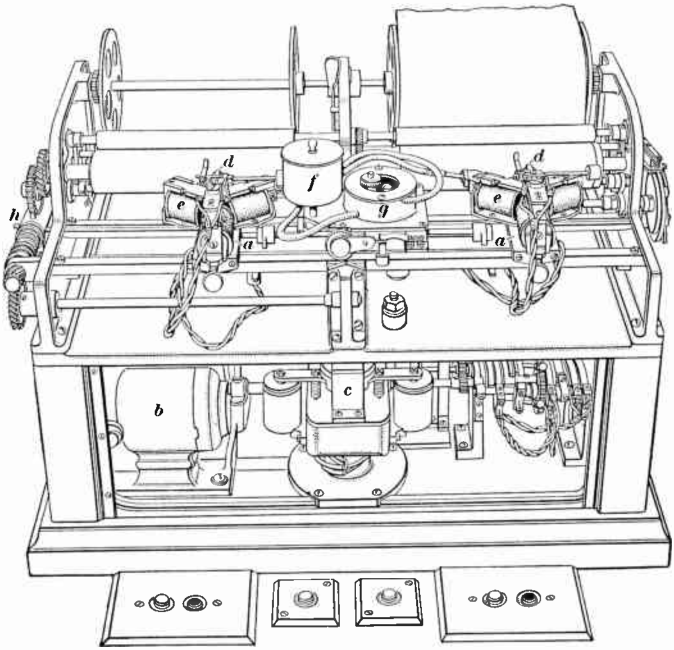


FIG. 9

this marking pulse. The marking fluid is placed in the reservoir *f* and air pressure is maintained by the pump *g*.

Paper is supplied in rolls. The feed mechanism is indicated at *h* near the left end of Fig. 9. As the carriage *a* reaches either end of its stroke an electromagnet actuates a friction clutch that disengages a holding pin and permits the feed roller for the paper to turn about $\frac{1}{96}$ of an inch. A complete picture is thus produced, section by section, by the action of the reproducing pens.

The movement of the carriage at the receiver compares with the movement of the optical system at the transmitter and the movement of the paper at the receiver compares with the movement of the film at the transmitter. A lower cabinet holds most of the control apparatus.

In Fig. 10 is a picture as reproduced by the pen method after transmission from England to the United States by radio.

Thermic Method of Reproduction.—It has been previously pointed out that the pictures sent over telegraphic systems are dependent on a varying frequency of solid color dots for the representation of halftones. That is, colors other than black and white are formed by the illusion of dotting. In order to overcome the loss of certain graduations in telegraphic transmission of pictures, the Radio Corporation of American have perfected a method which gives greater gradation, or halftones, when a picture is sent by their method.

This has been called the thermic method of reception, and, as its name implies, is a heat method. In ordinary photography the silver deposit in the emulsion of plate or film is affected to a varying depth corresponding to the intensity of light. This is accentuated by developing, so that after the proper treatment a picture composed of varying densities or opaqueness from clear white to black is produced. Early methods known as printing out gave a visual result without further development. This is still used; for instance, the proofs of photographs are made in this manner.

Engineers of the Radio Corporation of America, therefore, decided that a visual halftone method was the proper method to develop. A specially treated paper was made, which reacted under heat to form a deep black. A jet of air was heated by means of an electrical heater, and this

FIG. 10

heated air passed through a nozzle a few thousandths of an inch in diameter. A valve capable of working at several hundred cycles per second is controlled by the incoming signal.

As this valve is opened and closed for varying periods of time, more or less heated air reaches the sensitized paper, thereby causing different degrees of discoloration. This gives a result that is photographic in nature and as the various dots blend together the received photograph shows gradual gradations instead of a sharp black and white effect.

In Fig. 11, the air is supplied at *a*, under a pressure of a few pounds, and passes through the tube *b*. The air is heated by the heater coil *c*, which is supplied with current

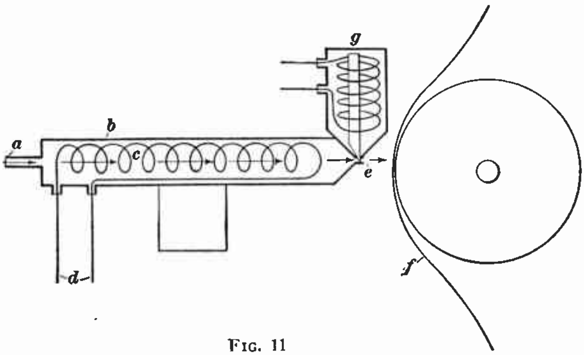


FIG. 11

from the supply lines *d*. There is a small valve *e* at the end of the tube *b* nearest to the treated paper *f*. An electromagnet *g* is operated by the current of the picture signals, opens the valve *e*, and allows a jet of hot air to strike the paper or closes the valve *e* and prevents the hot air from touching the paper in accordance with the picture pulses. While this obstruction is complete, no heat reaches the sensitized paper *f* and it remains white. As valve *e* is slowly opened an increasing amount of heated air reaches the paper, causing a proportionate discoloration. The full range of gradations capable in photographic methods are thereby obtained. The tube *b*, Fig. 11, is carried on the carriage a, Fig. 9, in the place of the pens. Flexible conductors are used to carry the photo signal to the electromagnet g as well as the heater current to the

FIG. 12

coil c. A flexible rubber hose establishes the air connection to the tube b. A picture reproduced by the thermic method is shown in Fig. 12.

SYNCHRONISM

By synchronizing is meant the ability to keep in step, and in this case it is necessary to control the movements of the traveling carriages on both transmitter and receiver so that their speed and phasing will be similar. In synchronizing, two methods are available as standards of time and speed; the tuning fork, and the chronometer. The electrically maintained tuning fork has a rate of vibration dependent largely on the length of the tynes. By the addition of weights certain vernier adjustments may be made. A sixty-cycle fork may be slowed down by the adjusting of the fork weights to fifty cycles and may be increased to as high as seventy cycles. By the addition of suitable contacts a pulsating current or commutation may be obtained that is practically unvarying in its frequency.

By the introduction of this pulsating current to the fields, through suitable commutators a motor, Fig. 5 or Fig. 8, such as is used in driving the transmitter or receiver may be maintained at a constant speed. Clocks may also be utilized to give correction impulses once every second or half-second. By a combination of the clock and the tuning fork it is possible to maintain a synchronizing system whereby the fork will constantly retard the speed of the drive motor, and the clock pulses will speed up the motor. An averaging of the two results will give a very uniform speed.

The term phasing is here used to describe the operation whereby the transmitter and receiver speeds, while synchronous, will allow movements of the carriage and of the optical system to differ in phase. This is shown in Fig. 13, where the transmitter is at a point on the picture *a*, and the receiver on the opposite side *b*. In this case a difference of 180° is the amount of displacement. With the backward and forward movement great care must be employed in phasing, otherwise a blurred and distorted picture will result. In order to accomplish phasing, means

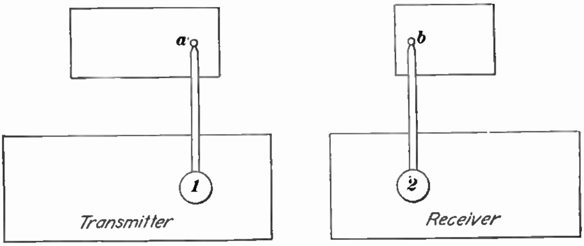


FIG. 13

are provided for releasing the drive gearing so that the carriage can be held until it is in phase with the transmitter again, when it is released and allowed to resume its speed.

PRINTING RADIO TELEGRAPHS

AMERICAN SYSTEM

Use.—Printing telegraphs have been used for several years over the land telegraphic circuits and it is only logical that attempts should be made to use them in conjunction with radio telegraph transmitters.

This field has especially appealed to the newspaper organizations, and a system of broadcast page printing receivers and transmitters has been tried out by one of the largest press organizations. The general plan is that a transmitter located in the news centers, such as New York, Chicago, and San Francisco, would broadcast to the hundreds of smaller cities within a five-hundred or thousand mile radius.

The present high cost of telegraph lines has compelled many small cities to forego printer service for their newspapers. In radio broadcast the expense of the one or two broadcasting stations would be borne by many papers. It is estimated that New York alone could serve over six hundred cities.

Perhaps the biggest problem of all in this work has been that of designing receiving equipment that would require little or no attention over long periods of time. When it is considered that in small cities there are no trained service men to look after the printers themselves the need is even more apparent.

Operation of Printer Over Land Lines.—In the operation of a page printer over land lines the following operations take place. The first operator takes the copy to be transmitted and by means of a keyboard perforator punches a tape. This perforator has a standard typewriter keyboard with the addition of keys for line feed, carriage return, spacing, in fact, all the operations required by hand to operate a typewriter.

This tape is punched in what is known as the Baudot code, and consists of combinations of perforated holes in conjunction with a feed hole. It is called a five-unit code because of the fact that as many as five current impulses are transmitted for the letters. Each letter is represented by the small feed hole, and one or more of the larger holes that are punched across the tape to form different combinations.

A section of this tape is shown in Fig. 14. It is seen that there is possible a total of 32 different combinations if one row of five blanks is considered as one combination. By using one combination for shifting the keyboard of the printer, both capital and lower case may be sent. On the standard machines today twenty-six combinations are used to represent the alphabet and the other six for carriage return, spacing, line feed, letter shift, figure shift, and blank.

This tape, after being punched, is delivered to the transmitter. This is a contact device operating from pins that are controlled by the punch marks on the paper. There are five pins arranged so that they are forced through the holes in the tape or do not change their position should there be no punching.

By means of relays, current of varying polarity is sent over the line for each of five impulses. A divided commutator is revolved at the same speed at the sending and the receiving station and is timed so that it will present five contact surfaces for each letter. Letter E, which is one dot, would consist of a positive and four negative pulses.

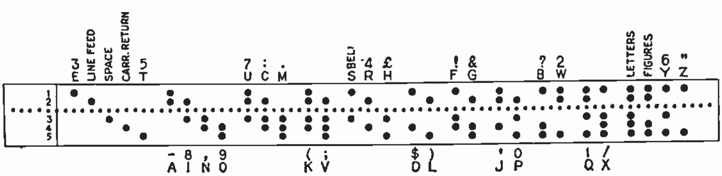


FIG. 14

Regardless of the number of holes punched in the tape, there are five pulses transmitted for each letter.

In some systems a sixth pulse is sent for resetting the selector circuits. A star wheel is used to engage the feed hole in the tape and feeds one letter through at a time.

At the receiver there is an electromagnetically operated typewriter that analyzes each set of pulses and prints the corresponding letter. It is motor driven, and power for the carriage return, line feed, and the other mechanical movements is supplied through clutches, which are released by the various impulses.

Operation of Printer by Radio.—In radio use it is, of course, impossible to send polarized pulses with the standard type of transmitter, and a spring-biased relay is used. Only the punch-hole pulses are transmitted by radio.

It was necessary to design high-speed heavy-duty relays for controlling the radio transmitters, and a speed of from forty to sixty words per minute has been accomplished over radio circuits several hundred miles long. A series of three relays are used when a high-power transmitter is to be controlled. An ordinary telegraphic Wheatstone relay controls a slightly larger relay, and this in turn controls the heavier contacts of the station relay. In a high-power transmitter several hundred amperes must be broken with the same speed and precision as on an ordinary telegraph line.

At the receiving end a multistage amplifier is connected to a tuning and detection circuit. The output is used to operate a telegraph relay that supplies the pulses to the typewriter. A very serious problem on the receiving end is the elimination of inductive kickback from the printing typewriter to the receiving set. This is overcome by thorough shielding.

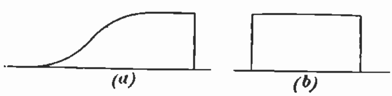


FIG. 15

In radio printing-telegraph systems the shape of the transmitted signal is of the utmost importance, owing to the necessity for positive relay action. For instance, the signal for carriage return is a single pulse. Should this signal be so distorted that the relay did not function properly, the result would be that an entire line would be wasted. In the case of the line-feed signal, which is also a single pulse, the printer would print one line on top of another, thereby ruining two lines.

In Fig. 15 are shown two different types of signal. In view (*a*) is shown the distorted signal, and in view (*b*) the type of signal known as a square-top signal, which gives reliable relay action. The distortion is largely the result of lag in the relay circuits.

CREED PRINTING RADIO-TELEGRAPH SYSTEM

Transmitter.—Creed and Co. of England developed the Creed Printing Radio-Telegraph system. It is different from the American method in that it uses the Continental Morse code instead of the five-unit system. On this account it is not as critical when distortion is encountered. It also has an advantage in synchronizing to the extent that errors as high as 30 per cent. in speed control will not affect its operation. In the five-unit methods there is only a tolerance of a few per cent.

For transmission this method employs a tape of the type employed by the cable companies. It is known as the Wheatstone tape and consists of a single perforation on each side of the guide hole.

These holes are grouped according to the Continental Morse code, and vary in number for the different letters. This tape is then passed on to a transmitter of the Wheatstone type and this instrument controls a small current from a direct-current source. This current controls the station relay controlling the radio transmitter proper.

A special type of station key has been devised, a schematic diagram of which is shown in Fig. 16. A polarized power relay *a* is operated by current controlled from the transmitter tape. This relay operates the valve of a pneumatic engine *b*. The control engine operates the rock shaft *c* in an oscillatory movement imparted through a suitable link motion. On this shaft are fitted the pieces *d* to which are connected links operating the slide valves of a number of pneumatic engines *e*. The piston rods of these engines have extensions of an insulating material, and on the ends are mounted contact disks *f*. The movement brings them against the other contact faces *g*. The number of contacts used is dependent on the current to be broken. As many as eight have been employed for transmitters of 500-kilowatts capacity. For the higher powers an air draft is forced on each set of contacts, which cools the gap.

This type of key is capable of extremely high speeds, and very little attention is necessary. It differs radically

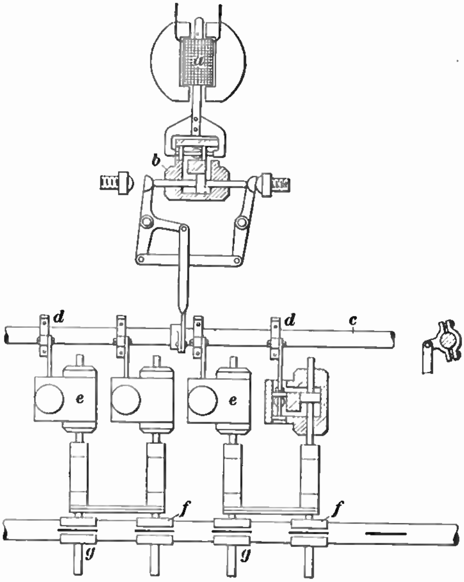


FIG. 16

from the usual American practice of electromagnetically operating relays in that one air engine controls several others. In Fig. 17 are shown the connections to a 300-kilowatt arc-type transmitter.

Receiver.—As in other methods, it is necessary to insert a control relay between the output of the audio-frequency amplifier and the printer itself. In Fig. 18 is shown a complete schematic diagram of a Creed transmitter and receiver. The pulse from the receiver relay is used to operate a reperforator, which is a machine similar to that used to punch the tape on the transmitting end. This machine delivers a tape identical to that used to transmit, and this is fed into the printer proper.

Printer.—This printer reproduces the message in type faces on a tape, which can be pasted on a blank form. By printing on a paper tape a large number of mechanical and electrical actions may be dispensed with and the result is

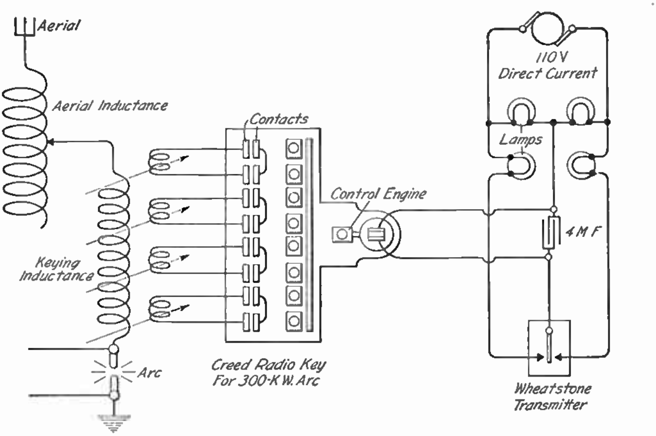


FIG. 17

a machine much simpler in operation. Characteristic of the other Creed apparatus, the printer is operated by air pressure with a small motor to operate the driving camshaft.

The punched tape is fed through guiding channels letter by letter. Ten selecting pins are operated by ten slide valves and are permitted to move forwards when there is a punch hole opposite the pin in question. The valve plates take either one or two positions, that of selected or non-selected. Different combinations can therefore be set up for each letter so that a different key can be engaged, and a final air blast working on a piston strikes the key and causes an impression to be printed.

A schematic diagram of the printer is shown in Fig. 19. The perforated tape *a* is fed by means of a sprocket wheel *b* between two vertical guide plates *c* and *d* that have ten pairs of holes so placed that any of the ten pairs *e* of selecting needles may enter the tape in case there are holes in the tape at that position. Certain combinations of tape holes permit only certain selecting pins to enter the tape, which permits the selection of the proper type bar.

The sprocket wheel *b* is mounted on the same shaft as the feed wheel *f*, and this shaft is actuated by the main-shaft cam (not shown) and the vertical feed rack *g*. In Fig. 20 is shown a section of Wheatstone tape and it will be observed that, between each combination of holes representing a letter by the Continental telegraph code, there is a blank space. This would not permit the entrance of one pair of selecting pins *e*, Fig. 19, in the same horizontal plane. It is upon this basic idea that the mechanical construction of this printer was evolved. If a space occurs in the tape neither of the pair of selecting pins *e*, Fig. 19, opposite this point can enter the tape, and the space lever *h*, which they control, will remain in a position whereby the downward movement of the feed rack *g* is blocked.

Should a spaced position occur opposite the sixth pair of pins, the feed back *g* will move down to that position, the feed wheel *f* turning freely but the sprocket wheel *b* not turning. On the upward movement of the feed rack *g*, the sprocket wheel *b* and the feed wheel *f* will both rotate and carry the tape upwards. If this space occurs opposite the second pair of selecting pins which represent the letter E (one dot) then the tape is fed up two spacing holes.

The valve selecting levers *i* are controlled by the selecting pins *e*, which enter the lower row of signal perforations,

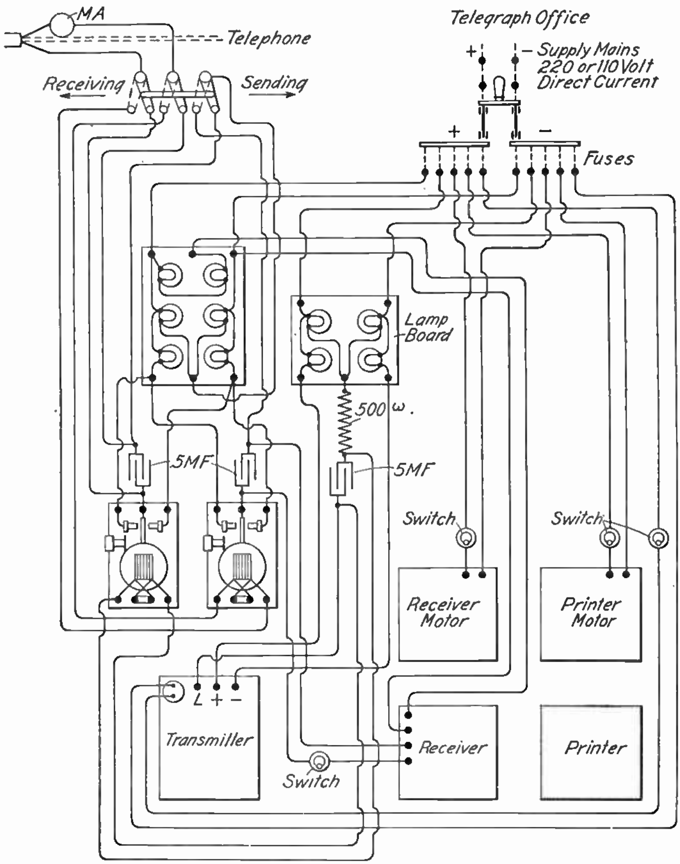


FIG. 18

Fig. 20, only. When one of these levers *i*, Fig. 19, is pushed forwards by a selecting pin *e*, it is in a position to be moved laterally by the rack whose lateral movement is

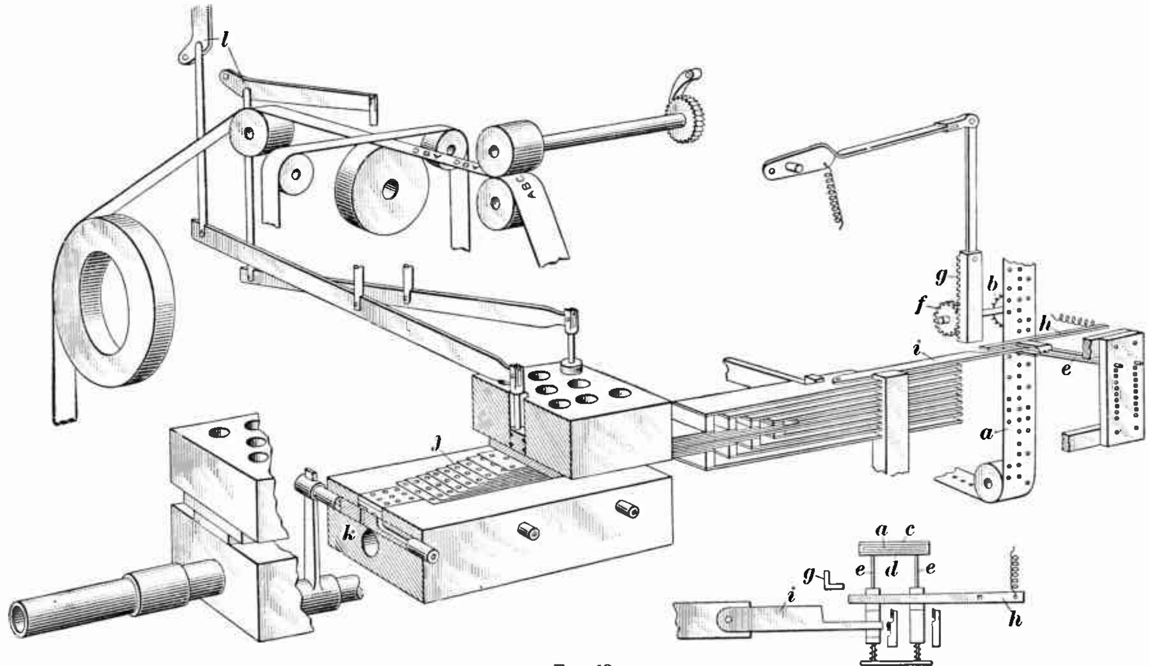


Fig. 19

supplied by a cam. The selecting pins below a spaced position enter the signal holes of the next letter combination on the tape, and carry simultaneously the valve selecting levers *i*. However, these levers *i* are not acted upon by the rack, owing to the fact that it does not drop that far down.

Only those levers *i* that are above the space position are moved to the left, and they carry with them the slide valves *j* to which they are fixed. When the slide-valve plates *j* have been moved they are compressed between two plates forming a slide-valve chamber. The main air

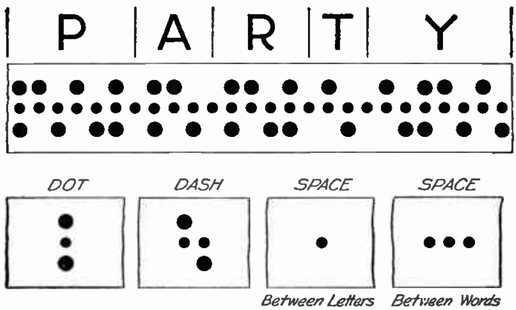


FIG. 20

valve *k* is then opened by a cam action, which releases compressed air to the slide-valve chamber. From this it escapes through the ten slide-valve plates *j* by the one hole made available by this particular valve setting, and causes a piston to move a type bar *l* which corresponds to this piston.

Upon the printing of the character a slide valve is opened and all valves return to a normal position. The paper-lifting rack *g* is drawn up by means of a cam action and engages the feed wheel *f* so that the tape is drawn up the proper distance for the selection of the next letter.

The main disadvantage of the Creed system for the purpose of broadcasting press by radio is in the production of tape instead of a printed page. It is necessary to gum the tape manually and paste it on a blank form. Very satisfactory speeds have been obtained, however, and further development may produce a printed page direct.

It is necessary in the Creed method, as in that previously described, to shield the receiver from the inductive effects of the relay that actuates the perforator.

PRINCIPLES OF TELEVISION

Television is the art of transmitting, electrically or by radio, complete images of actual scenes or events in such rapid succession that the actions appear continuous at the receiving end. In many respects television is similar to the transmission of still pictures. In television, however, quoting the Bell Laboratories Record, a series of essentially instantaneous views of a scene with action must be transmitted and reproduced at a rate of fifteen or more a second, such that an observer will detect no discontinuity of action. A photoelectric cell acting as an eye rapidly scans the scene, viewing in orderly succession each detail of it, and transmitting to the distant station a varying current, the variations of which correspond to the differences in light and shade of the successive details.

At the receiving station this current produces at each instant a spot of light of a brightness corresponding to that of the detail of the scene which the photoelectric eye was observing at the moment it originated that particular amount of current. At each instant the position of this spot of light is also caused to correspond to that of the detail of the scene. The entire scene, in successive details, is thus reproduced for an observer. The complete process of reproducing in proper order the light details of the scene occupies less than $\frac{1}{15}$ second. It is then automatically repeated and thus each detail is instantaneously viewed by the observer fifteen times a second. Because of physiological and psychological phenomena, however, the observer is unconscious of the series of details and apprehends the scene as a whole with continuous action.

REGULATIONS OF THE NATIONAL BOARD OF FIRE UNDERWRITERS FOR RADIO EQUIPMENT

GENERAL

a. The requirements of this article shall not apply to equipment installed on shipboard, but shall be deemed to be additional to, or amendatory of, those prescribed in Articles 1 to 19, inclusive, of this code.

b. Transformers, voltage reducers, keys, and other devices employed shall be of types expressly approved for radio operation.

FOR RECEIVING STATIONS ONLY

ANTENNA AND COUNTERPOISE

a. Antenna and counterpoise outside buildings shall be kept well away from all electric light or power wires of any circuit of more than 600 volts, and from railway, trolley or feeder wires, so as to avoid the possibility of contact between the antenna or counterpoise and such wires under accidental conditions.

b. Antenna and counterpoise where placed in proximity to electric light or power wires of less than 600 volts, or signal wires, shall be constructed and installed in a strong and durable manner, and shall be so located and provided with suitable clearances as to prevent accidental contact with such wires by sagging or swinging.

c. Splices and joints in the antenna span shall be soldered unless made with approved splicing devices.

d. The preceding paragraphs, *a*, *b*, and *c*, shall not apply to light and power circuits used as receiving antenna, but the devices that are used to connect the electric light and power wires to radio receiving sets shall be of approved type.

LEAD-IN CONDUCTOR

e. Lead-in conductors shall be of copper, approved copper-clad steel or other metal which will not corrode excessively, and in no case shall they be smaller than No. 14, except that bronze or copper-clad steel not less than No. 17 may be used.

f. Lead-in conductors on the outside of buildings shall not come nearer than 4 inches to electric light and power wires unless separated therefrom by a continuous and firmly fixed non-conductor which will maintain permanent separation. The non-conductor shall be in addition to any insulating covering on the wire.

g. Each lead-in conductor shall enter the building through a non-combustible, non-absorptive, insulating bushing slanting upwards toward the inside or by means of an approved device designed to give equivalent protection.

PROTECTIVE DEVICE

h. Each lead-in conductor shall be provided with an approved protective device (lightning arrester) which will operate at a voltage of 500 volts or less, properly connected and located either inside the building at some point between the entrance and the set which is convenient to a ground, or outside the building as near as practicable to the point of entrance. The protector shall not be placed in the immediate vicinity of easily ignitable stuff, or where exposed to inflammable gases or dust or flyings of combustible materials.

i. If an antenna grounding switch is employed, it shall in its closed position form a shunt around the protective device. Such a switch shall not be used as a substitute for the protective device.

> It is recommended that the antenna grounding switch be employed, and that in addition a switch rated at not less than 30 amperes, 250 volts, be located between the lead-in conductor and the receiver set.

j. If fuses are used, they shall not be placed in the circuit from the antenna through the protective device to ground.

PROTECTIVE GROUNDING AND OPERATING CONDUCTOR

k. The protective grounding conductor may be bare and shall be of copper, bronze or approved copper-clad steel. The protective grounding conductor shall be not smaller nor have less conductance per unit of length, than the lead-in conductor and in no case shall be smaller than No. 14 if copper nor smaller than No. 17 if of bronze or copper-clad steel. The protective grounding conductor shall be run in as straight a line as possible from the protective device to a good permanent ground. Preference shall be given to water piping. Other permissible grounds are grounded steel frames of buildings or other grounded metal work in the building, and artificial grounds such as driven rods, plates, cones, etc. Gas piping shall not be used for the ground.

l. The protective grounding conductor shall be guarded where exposed to mechanical injury. An approved ground clamp shall be used where the protective grounding conductor is connected to pipes or piping.

m. The protective grounding conductor may be run either inside or outside the building. The protective grounding conductor and ground, as prescribed in paragraphs *k* and *l*, may be used as the operating ground.

It is recommended that in this case the operating grounding conductor be connected to the ground terminal of the protective device.

If desired, a separate operating grounding connection and ground may be used, this operating grounding conductor being either bare or provided with an insulated covering.

CONDUCTORS INSIDE BUILDINGS

n. Wires inside buildings shall be securely fastened in a workmanlike manner and shall not come nearer than 2 inches to any electric light or power wire not in conduit unless separated therefrom by some continuous and firmly fixed non-conductor, such as porcelain tubes or approved flexible tubing, making a permanent separation. This non-conductor shall be in addition to any regular insulating covering on the wire.

o. Storage battery leads shall consist of conductors having approved rubber insulation. The circuits from storage batteries shall be properly protected by fuses or circuit breakers rated at not more than 15 amperes and located preferably at or near the battery.

PROPOSED SPECIFICATIONS FOR CONSTRUCTION AND TEST OF POWER-OPERATED RADIO RECEIVING SETS

General.—1. These requirements cover radio appliances for non-commercial use, designed to be operated from lighting or power circuits.

2. Under this classification are included battery substitutes or power-supply devices; battery chargers with or without batteries; battery units with switches and connections, designed particularly for radio use; and radio receiving devices incorporating any of the above-mentioned appliances.

3. Battery chargers, either portable or for permanent installation and not intended for use with radio appliances, are classed as rectifiers and are not covered by these requirements.

4. The following specifications apply to devices designed to be operated from alternating-current circuits.

5. Where not otherwise specified, voltages referred to are root-mean-square values.

General Design and Construction.—6. The devices throughout shall employ materials that are suitable for the particular use, and shall be made and finished with the degree of uniformity and grade of workmanship practicable in well-equipped factories, fabricating materials and devices similar to those employed in this product.

Enclosure.—7. The enclosing case or cabinet shall enclose all current-carrying parts of the device except primary leads and secondary terminals.

8. Current-carrying parts of the secondary, the voltage of which does not exceed 25 volts, may be exposed, provided the power input to the devices does not exceed 150 volts when such parts become short-circuited.

9. The device may be so designed that tubes may be replaced without opening the case; but the current-carrying parts of the sockets for such tubes shall be enclosed.

10. The enclosing case shall be of substantial construction and provide the necessary mechanical strength to protect the various parts from physical injury.

11. Cabinets of suitable non-metallic material are acceptable for power-supply devices or radio sets; but individual units such as transformers, inductances, and condensers which are conductively connected to a power circuit shall be enclosed in non-combustible material.

12. Metal enclosures shall be enameled or otherwise suitably protected against corrosion.

13. When the cabinet or enclosing case is ventilated, the opening shall be either not larger than $\frac{1}{4}$ inch in greatest dimension or so designed, located, or protected that the average small tool or the operator's hand can not be inserted and come in contact with current-carrying parts of the primary circuit or of a secondary circuit involving potentials exceeding 200 volts.

Supply Circuit.—14. Component parts of the device such as flexible cord, attachment plug, snap switch, lamp holder, attachment-plug receptacle or cut-out base shall be standard appliances.

15. Where a flexible cord passes into the enclosing case, it shall be protected by an insulating bushing with smoothly rounded edges. Suitable strain relief shall be provided in the flexible cord.

16. The type of flexible cord required shall depend upon the nature of the device with which it is supplied.

17. Materials for mounting the current-carrying parts shall be of standard phenolic composition, standard cold-molded material, or the equivalent.

18. Hard fibre may be used for insulating washers, separators, and barriers, but not as the sole support for current-carrying parts.

Transformers.—19. Transformers connected to the lighting or power circuit shall have the primary insulated from the core, case, and secondary winding.

20. All materials entering into the construction of transformers, except insulation, shall be non-combustible. The amount of combustible material employed for insulation shall be as small as consistent with the design of a device having high insulation.

21. Transformers shall be of thoroughly substantial design. The coils shall be wound in a workmanlike manner and impregnated or otherwise enclosed to exclude moisture.

22. Taps may be put on the primary winding for factory adjustment, but shall not be arranged to facilitate the user's varying the number of primary turns. If a primary control or multipoint switch is employed to regulate the secondary voltage, the complete device shall be capable of successfully withstanding the prescribed tests with the switch in any position, including the most severe conditions possible in actual operation.

Condensers.—23. Condensers shall employ such materials and shall be so constructed that they will not constitute an undue fire hazard. They shall not be injuriously affected by the temperature attained by the device under the most severe conditions of normal use. Paper condensers shall be impregnated or otherwise suitably enclosed to exclude moisture.

Interior Wiring.—24. All wires that are accessible when alive shall be insulated, and the insulation shall be suitable for the voltages involved and the temperatures attained under any conditions of actual use. Wires of special type (that is, other than standard, listed, insulated wire) shall be made the subject of a special investigation with respect to their intended use and shall be judged accordingly.

25. No terminals or other live parts shall come in contact with the enclosing case, unless the case is made of a suitable insulating material.

Voltage Limitations in Secondary Circuits.—26. No special protection against accidental contact need be provided for live parts in secondary or output circuits involving potentials not in excess of 200 volts.

27. Live parts in circuits involving potentials in excess of 200 volts shall be wholly inaccesible, or the opening of the enclosing case shall cut off this high voltage. The device or arrangement whereby this result is obtained shall

be positive in action and such as to defeat any attempt to manipulate it so as to nullify its purpose.

Spacings.—28. A spacing of not less than ½ inch over surface or through air shall be maintained between exposed live metal parts of the primary or supply circuit and the case, except where location and relative arrangement of the parts is such that permanent separation is assured.

Secondary Terminals.—29. Outside (exposed) secondary terminals involving potentials in excess of 25 volts shall be provided with insulated nuts.

30. The maximum open circuit voltage between any two outside (exposed) terminals shall not exceed 200 volts.

31. If permanent secondary leads are supplied, additional outside (exposed) terminals shall be eliminated. In such a case a suitable strain relief shall be provided and the cord or cords shall be properly bushed where they pass through the wall of the cabinet or enclosing case. This requirement shall limit a device to one set of exposed terminals.

Fuses.—32. A device including a storage battery shall be protected by a fuse or circuit breaker in the battery leads. Such fuse or circuit breaker shall be rated at not more than 15 amperes.

33. Fuses if used in primary circuits shall not be readily accessible.

34. Fuses wherever used shall be standard and suitable for the voltage involved.

Marking.—35. Secondary terminals shall be properly identified.

36. No terminal marking is required when a keyed plug and socket is used or when the form of connection is such that it cannot be put together incorrectly.

37. The device shall be plainly marked where it may be readily seen with the name of the manufacturer, and the rating of the primary supply or input in volts, frequency, and amperes or watts. The secondary output ratings shall be stated in the accompanying instructions or on the device.

38. An installation diagram or instructions shall accompany the device if the connections and method of operation are such that there may be any question regarding the same

SOCKET-POWER TESTS

Current Consumption.—39. Each device shall be tested to determine its current consumption on a supply circuit, the voltage and frequency of which correspond to the primary voltage rating.

40. The current-consumption test shall be made (1) with no load on the secondary output, (2) with full load on the secondary output.

Temperature.—41. Temperature tests shall be made at full load with the device connected to a supply circuit whose voltage corresponds to the primary rating of the device, and such tests shall be continued until constant temperatures are reached

42. When the cabinet or enclosing case is of non-combustible material, temperatures shall be noted at various points on the exterior surface of the device. When the cabinet or enclosing case is of combustible material, temperatures shall be noted at various points within the cabinet.

43. In this test, temperatures attained on the exterior surfaces of non-combustible cabinets or enclosing cases, or temperatures on the interior surfaces of combustible cabinets shall not exceed 90° Centigrade (194° Fahrenheit). Temperatures attained at any point on or within the

device shall not be sufficiently high so as to affect injuriously the material used in the construction of the device.

Voltages.—44. Each device shall be tested to determine the terminal output voltages and the highest obtainable secondary voltage. Limits for these potentials have already been given in paragraphs 26 and 27.

Dielectric Strength.—45. The insulation and spacing of the device shall be capable of withstanding the applied potentials specified below, for a period of 1 minute without breakdown. This shall not apply to standard appliances which are component parts of the device.

46. With the device still hot after the full-load temperature tests, a potential of 900 volts a. c. shall be applied between current-carrying parts of the primary circuit and the core of the transformer; between current-carrying parts of the primary circuit and the enclosing case; and between the current-carrying parts of the primary and secondary circuits.

47. With the device still hot after the full-load temperature test a potential of twice the highest (primary or secondary) open circuit voltage plus 1,000 volts a. c. shall be applied between the primary and secondary windings, with the transformer disconnected.

48. The insulation of all current-carrying parts of the secondary circuit, except condensers, operating at a difference of potential from the transformer core, case, or any other parts, shall be subjected to an a.-c. potential of a value three times the highest voltage to which the parts may be subjected without disturbing any permanent connections in any of the circuits, as measured by a d.-c. voltmeter or voltmeter-multiplier combination having a resistance of not less than 150,000 ohms for potentials not exceeding 500 volts, or a voltmeter or voltmeter-multiplier combination having a resistance of not less than 300,000

ohms for potentials greater than 500 volts but not exceeding 1,000 volts. Where such parts carry alternating current only, the a.-c. potential shall be three times the highest a.-c. potential to which the parts may be subjected without disturbing any permanent connection in any of the circuits.

49. Condensers connected to the primary, or supply, circuit, and not tested under the specifications in paragraph 46 shall be tested for breakdown by the application of 900 volts a. c. Condensers in secondary circuits shall be tested for breakdown by the application of a d.-c. potential of a value three times the highest voltages to which the condensers may be subjected without disturbing any permanent connections in any of the circuits, as measured by a d.-c. voltmeter or voltmeter-multiplier combination having a resistance of not less than 150,000 ohms for potentials not exceeding 500 volts, or by a voltmeter or voltmeter-multiplier combination having a resistance of not less than 300,000 ohms for potentials greater than 500 volts and not exceeding 1,000 volts. These requirements do not apply to electrolytic condensers.

50. Audio output transformers and condensers used for speaker coupling shall be tested for breakdown by the application of an a.-c. potential between primary and secondary windings in the case of transformers, and a d.-c. potential across the terminals of condensers. The test potential shall be of a value equal to four times the maximum d.-c. plate voltage used on the output tube, but shall in no case be less than 800 volts.

Maximum Input Test.—51. During this test there shall be no emission of flame or of molten metal from (1) the metal case enclosing a device as a whole or (2) the separate units within an enclosing case or cabinet of wood or other inflammable material.

52. Devices having secondary output terminals shall be tested with the input leads connected to a circuit of rated voltage and frequency with the secondary output terminals connected to give maximum primary input, and shall be operated until constant temperature is reached or until burnout occurs.

53. Where a device has exposed live parts of the secondary involving potentials not exceeding 25 volts, it shall be tested as specified in paragraph 52 with the exposed live parts connected to give maximum input.

54. When the enclosing case or cabinet is of non-combustible material, the temperatures reached in this test shall be such that cheese cloth placed in contact with the outside of the case will not be ignited. When the enclosing case or cabinet is of wood or other inflammable material, the temperatures reached shall be such that no charring of the case occurs.

FOR TRANSMITTING STATIONS ONLY

ANTENNA AND COUNTERPOISE

a. Antenna and counterpoise outside buildings shall be kept well away from all electric light or power wires of any circuit of more than 600 volts, and from railway trolley or feeder wires, so as to avoid the possibility of contact between the antenna or counterpoise and such wires under accidental conditions.

b. Antenna and counterpoise where placed in proximity to electric light or power wires of less than 600 volts, or signal wires, shall be constructed and installed in a strong and durable manner, and shall be so located and provided with suitable clearances as to prevent accidental contact with such wires by sagging or swinging of either the antenna or power wires.

c. Splices and joints in the antenna and counterpoise span shall be soldered unless made with approved splicing devices.

LEAD-IN CONDUCTOR

d. Lead-in conductors shall be of copper, bronze, approved copper-clad steel or other metal which will not corrode excessively and in no case shall be smaller than No. 14.

e. Antenna and counterpoise conductors and wires leading therefrom to ground switch, where attached to buildings, shall be firmly mounted 5 inches clear of the surface of the building, on non-absorptive insulating supports such as treated pins or brackets, equipped with insulators having not less than 5 inches creepage and air-gap distance to inflammable or conducting material, except that the creepage and air-gap distance for continuous-wave sets of 1,000 watts and less input to the transmitter, shall be not less than 3 inches.

f. In passing the antenna or counterpoise lead-in into the building a tube or bushing of non-absorptive, insulating material, slanting upwards toward the inside, shall be used and shall be so insulated as to have a creepage and air-gap distance of at least 5 inches to any extraneous body, except that the creepage and air-gap distance for continuous-wave sets of 1,000 watts and less input to the transmitter, shall be not less than 3 inches. If porcelain or other fragile material is used it shall be protected where exposed to mechanical injury. A drilled window pane may be used in place of a bushing, provided creepage and air-gap distance as specified above is maintained.

PROTECTIVE GROUNDING SWITCH

g. A double-throw knife switch having a break distance of at least 4 inches and a blade not less than $\frac{1}{8}$ inch by $\frac{1}{2}$ shall be used to join the antenna and counterpoise lead-in to the grounding conductor. The switch may be located inside or outside the building. The base of the switch shall be of non-absorptive insulating material. This switch shall be so mounted that its current-carrying parts will be at least 5 inches clear of the building wall or other conductors, except that for continuous-wave sets of 1,000 watts and less input to the transmitter, the clearance shall be not less than 3 inches. The conductor from grounding switch to ground shall be securely supported.

It is recommended that the switch be located in the most direct line between the lead-in conductors and the point where grounding connection is made.

PROTECTIVE GROUNDING CONDUCTOR

h. Antenna and counterpoise conductors shall be effectively and permanently grounded at all times when station is not in actual operation and unattended, by a conductor at least as large as the lead-in and in no case smaller than No. 14 copper, bronze, or approved copper-clad steel. This protective grounding conductor need not have an insulated covering or be mounted on insulating supports. The protective grounding conductor shall be run in as straight a line as possible to a good permanent ground. Preference shall be given to water piping. Other permissible protective grounds are the grounded steel frames of buildings and other grounded metal work in buildings and artificial grounding devices such as driven pipes, rods, plates, cones, etc. The protective grounding conductor shall be protected where exposed to mechanical injury. A suitable approved ground clamp shall be used where the protective grounding conductor is connected to pipes or piping. Gas piping shall not be used for the ground.

It is recommended that the protective grounding conductor be run outside the building.

OPERATING GROUNDING CONDUCTOR

i. The operating grounding conductor shall be of copper strip not less than $\frac{3}{8}$ inch wide by $\frac{1}{32}$ inch thick, or of copper, bronze, or approved copper-clad steel having a periphery, or girth, of at least $\frac{3}{4}$ inch, such as a No. 2 wire, and shall be firmly secured in place throughout its length.

OPERATING GROUND

j. The operating grounding conductor shall be connected to a good permanent ground. Preference shall be given to water piping. Other permissible grounds are grounded steel frames of buildings or other grounded metal work in the building, and artificial grounding devices such as driven pipes, rods, plates, cones, etc. Gas piping shall not be used for the ground.

POWER FROM STREET MAINS

k. Where the current supply is obtained directly from lighting or power circuits, the conductors, whether or not lead-covered, shall be installed in approved metal conduit, armored cable or metal raceways.

PROTECTION FROM SURGES, ETC.

l. When necessary to protect the supply system from high-potential surges and kick-backs there shall be installed in the supply line as near as possible to each radio-transformer, rotary spark gap, motor and generator in motor-generator sets, and other auxiliary apparatus one of the following:

1. Two condensers (each of not less than $\frac{1}{10}$ microfarad capacity and capable of withstanding 600 volt test) in series across the line with mid-point between condensers grounded; across (in parallel with) each of these condensers shall be connected a shunting fixed spark-gap capable of not more than $\frac{1}{32}$ inch separation.

2. Two vacuum-tube type protectors in series across the line with the mid-point grounded.

3. Resistors having practically zero inductance connected across the line with midpoint grounded.

It is recommended that this third method be not employed where there is a circulation of power current between the mid-point of the resistors and the protective ground of the power circuit.

4. Lightning arresters such as the aluminum-cell type.

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