INSTRUCTIONS FOR PERFORMING RADIO EXPERIMENTS 1 TO 10

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NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

A COURSE IN PRACTICAL DEMONSTRATIONS OF RADIO FUNDAMENTALS

A PLAN FOR STUDYING THE EXPERIMENTS

As you know, these Experimental Kits will come to you on a definite schedule. When you have completed a certain number of Lessons (and have submitted reports on any previous experiments), the next Kit will be sent to you.

This arrangement is such that you will study the necessary theory in your regular Lessons *before* you carry out any corresponding experiments. This permits you to adopt either of the following plans of study:

1. You may wish to complete one or two experiments in a Kit, then do a Lesson, and then return to the Kit for one or two more experiments. This plan permits the experiments in one Kit to be finished about the time the next Kit is due. Thus, the Lessons and experiments run along together, and provide you with a varied program of study.

2. You may prefer to break away from your Lessons and to complete all the experiments in a Kit at one time, before going back to your Lessons. This plan has the advantage that you do not waste any time getting out and putting away materials, but it can be followed only if you can leave your equipment set up long enough to finish.

Whichever plan you follow, you can begin NOW with the experiments in this Kit. Be sure to read the preliminary information on pages one through ten *before* you begin, however, so you will know just how the experiments are to be carried out. In a similar manner, begin on future Kits as soon as you receive them.

J. A. Dowie.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

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Instructions for Performing Radio Experiments 1 to 10

Bringing Lecture Room Demonstrations to Your Home

MASTERY of an important radio or electrical principle which you study in your NRI Course becomes much easier if you can actually demonstrate that principle for yourself. Seeing is believing; when you carry out an experiment, you impress indelibly upon your mind the principle involved.

The NRI Course of training in radio is a well-balanced combination of radio theory and practical instruction, *supplemented by the practical demonstrations* given in this and the following experimental Manuals. By doing these experiments yourself, you get actual experience in handling radio parts and making radio measurements, and you acquire the ability to understand explanations of more advanced circuit actions. This experience *is even more valuable to you* than demonstrations by an instructor in a lecture room.

These practical NRI radio experiments will develop confidence in your own ability, and will provide exactly what you need to develop yourself into a practical radio technician—a real *Radiotrician and Teletrician.* You will encounter and master technical problems, one by one. You will learn to connect radio parts together in a professional manner. You will see for yourself what happens when a particular part in a radio circuit is removed or made defective. You will learn how to detect and correct errors in connecting parts together, and how to adjust and align practical radio circuits.

Every single experiment is important, so do not pass over any one of them hurriedly even though you may already know what the results will be.

Importance of Mastering the Art of Soldering

If you examine the chassis of any modern radio receiver or public address amplifier, you will find that the parts are connected together by means of soldered connections. These are the most reliable connections it is possible to make in commercial production; a good soldered connection will not deteriorate appreciably during the entire life of a piece of radio equipment.

When repairing a defective receiver, you must first locate the defective part. But the ability to determine what is wrong with a radio device is of little value unless you also know how to remove the defective part and how to solder the connections for the new part. Furthermore, it will often be necessary to *unsolder* one or more connections in order to make tests which will reveal the defective part.

This first Manual in your Practical Demonstration Course is devoted entirely to soldering. You study the fundamentals of radio soldering, then learn how to make each of the common types of soldered connections used in radio work. The soldering iron, solder, hook-up wire, and radio parts included with this Radio Kit for these first ten experiments are all standard, just like those you would work with when servicing.

Contents of This Radio Kit

The parts included in your first Radio Kit are illustrated in Fig. *1*

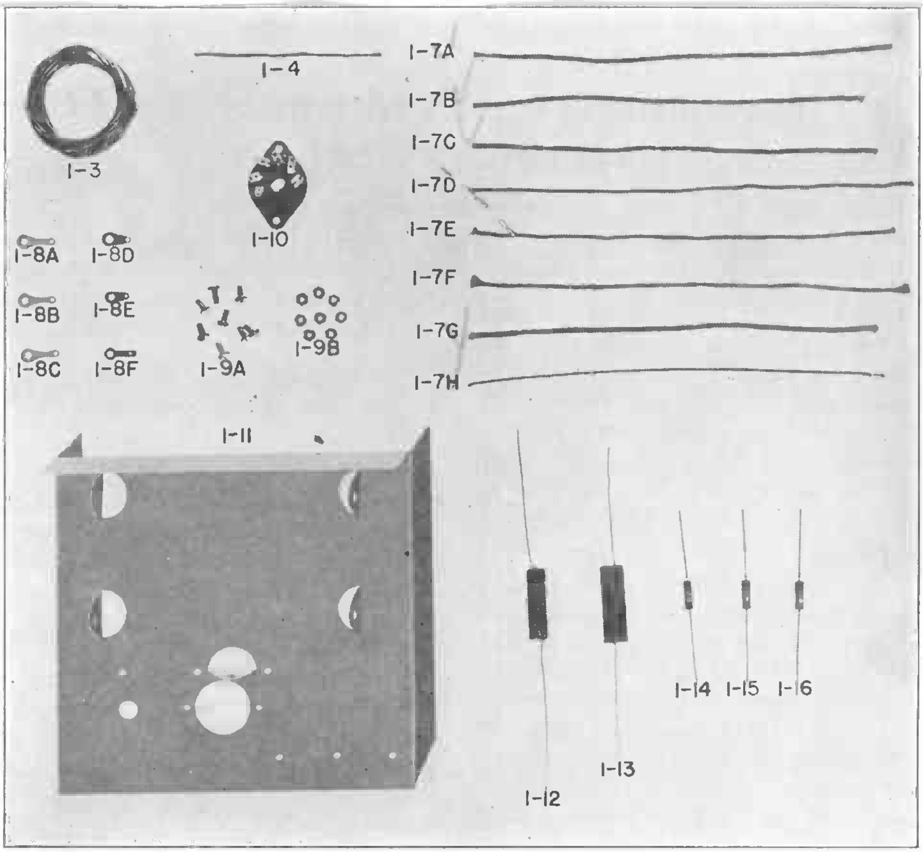

FIG. 1. The parts included in this Radio Kit are pictured above, and identified in the list below. The first numeral in a part number is that of the Kit in which the part is supplied; thus, parts supplied in the second Radio Kit will be numbered *2-1, 2-2,* etc., and parts supplied in the third Kit will be numbered *3-1, 3-2,* etc. With this system, you can tell at a glance the number of the Kit in which a particular part was supplied.

PART NO.	DESCRIPTION
1-1	One electric soldering iron (not shown above).*
1-3	One roll of rosin-core solder.
1-4	One 3-inch length of plain solder.
1-7A	One 8-inch length of No. 20 *solid* tinned push-back wire.
1-7B	One 8-inch length of No. 20 *solid* tinned push-back wire.
1-7C	One 8-inch length of No. 20 *solid* tinned push-back wire. (Parts *1-7A, 1-7B, and 1-7C* are identical, and are numbered differently merely for convenience.)
1-7D	One 8-inch length of No. 20 *stranded* tinned push-back wire.
1-7E	One 8-inch length of No. 18 solid *untinned* insulated wire.
1-7F	One 8-inch length of No. 20 stranded tinned wire with glazed insulation.
1-7G	One 8-inch length of No. 18 stranded untinned lamp cord.
1-7H	One 8-inch length of 7-strand No. 26 enameled aerial wire.
1-8A	One 13/16-inch tinned soldering lug.
1-8B	One 13/16-inch tinned soldering lug.
1-8C	One 13/16-inch tinned soldering lug. (Parts *1-8A, 1-8B, and 1-8C* are identical, and are numbered differently merely for convenience.)
1-8D	One 5/8-inch untinned soldering lug.
1-8E	One 1/2-inch untinned soldering lug.
1-8F	One 11/16-inch untinned soldering lug.
1-9A	Eight ¼-inch long, 6-32 cadmium-plated binder-head machine screws.
1-9B	Eight cadmium-plated hexagonal nuts for 6-32 screws.
1-10	One octal-type tube socket with six terminal lugs. (Slots 2, 3, 4, 5, 6, and 7 should have lugs, as shown in Figs. *39* and *40*. Some lugs may seem loose, but they will tighten automatically when a tube is plugged into the socket.)
1-11	One metal chassis bent to shape, with all holes already punched out for future use.
1-12	One .03-mfd., 400-volt tubular paper condenser.
1-13	One .05-mfd., 400-volt tubular paper condenser.
1-14	One .24-megohm, 1/2-watt resistor with 5% tolerance (color-coded red, yellow, yellow gold).
1-15	One .1-megohm, ½-watt resistor with 5% tolerance (color-coded brown, black, yellow, gold).
1-16	One 18,000-ohm, ½-watt resistor with 10% tolerance (color-coded brown, gray, orange, silver).
1-17	One metal-marking crayon (not shown above).

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* If you have previously notified the Institute that you do not have 115-volt power available, Part *1-1* will be missing. In its place you will receive Part *1-1A*, a plain soldering iron of the same general construction as the one illustrated in Fig *6*.

and listed in the caption underneath. Check off on this list the parts which you received, to be sure you have all of them. Do not destroy any of these parts until you have completed your NRI Course, for many of the parts will be used over and over again in later experiments.

IMPORTANT: If any part in this Radio Kit is obviously defective or has been damaged during shipment, please return *the defective part* to the Institute *immediately* for replacement.

Tools Needed

For the experiments in your Practical Demonstration Course, you will need the tools which are shown in Fig. *2* and listed in the caption underneath. These tools are *not* supplied in this Radio Kit. You undoubtedly have at least some of them already since they are common home tools. Those which you do not have are readily obtainable at local hardware stores, dime stores, mail-order firms, or radio-supply firms. All of the tools will be needed for radio servicing work and for later experiments in your Practical Demonstration Course, so they are a really worthwhile investment.

Theory of Soldering

Any art or technique is easier to master if you first study the fundamental principles and theories which are involved. For this reason, we will consider now what solder actually is, why it adheres to certain metals under certain conditions, and why solder is so essential for permanent connections in radio circuits.

Molecular Attraction. When two ordinary solid objects are pressed together, nothing happens. Thus, we cannot make a block of solder stick to a block of copper merely by pressing the two blocks together.

It is possible to grind two metal surfaces so perfectly flat and smooth that they will adhere to each other when pressed together with a twisting force. The Johansson gage blocks used by machinists for precision measurements are an example of this phenomenon. When these blocks are pressed together hard enough to force air out from between the adjoining surfaces, the molecules of steel get close enough to attract each other with tremendous force. *Molecular attraction* thus explains why Johansson gage blocks stick together.

Why Solder Adheres. In soldering, it is unnecessary to have perfectly flat surfaces on the objects which are to be joined together. When both metal objects, even though irregular, are made perfectly clean (free of foreign materials such as chemical oxides, grease, and dirt) and are heated to the proper temperature, molten solder will adhere to the two cleaned surfaces and will bridge the gaps between them. Now, when the solder has cooled and hardened, its surface molecules will be just as close to the molecules in the adjoining cleaned but irregular surfaces as are the molecules in gage blocks. *Molecular attraction* thus makes solder adhere to certain metals.

Once a metallic surface has been *tinned* by making a layer of solder adhere to it, additional solder can very easily be *fused* to that already on the metal. (Two pieces of solder can be combined or fused simply by placing one in contact with the other and applying heat.)

What Solder Is. Solder is a *fusible metal or alloy of metals which is used to provide a good bond between two or more metal objects.* Solder used for radio work contains only

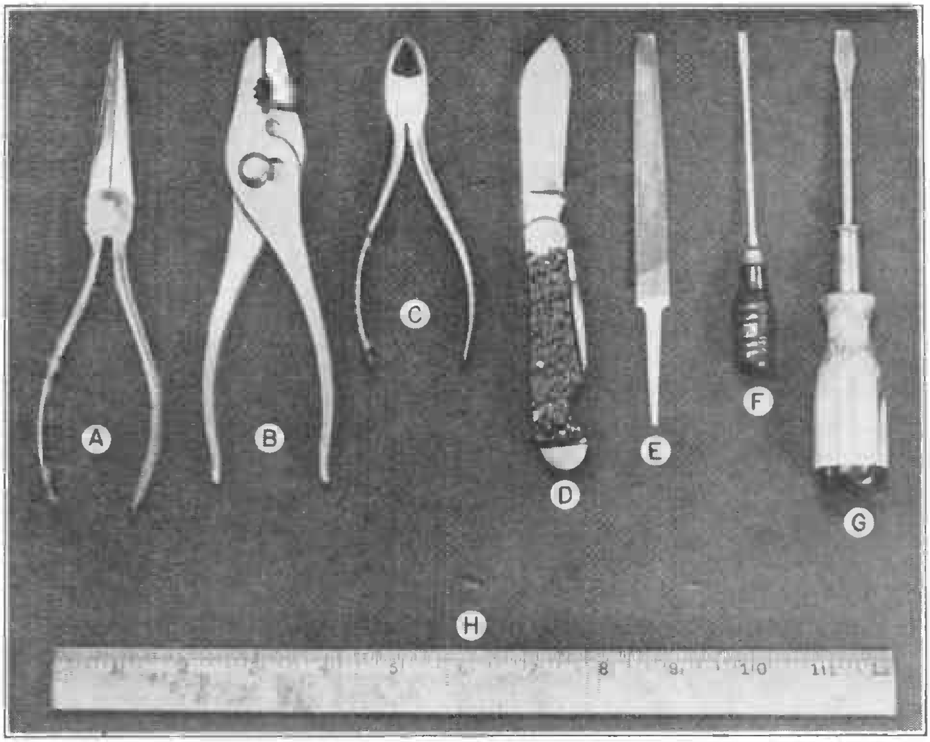

FIG. 2. The essential tools which you will need for the experiments in your Practical Demonstration Course are pictured here and identified below. Get the best side-cutting pliers and long-nose pliers you can afford, for you will use these tools continually throughout your Practical Demonstration Course and in actual radio work of all kinds.

A—One pair long-nose pliers (5 to 7 inches long). These may have wire-cutting jaws, but this feature is not essential.
B—One pair ordinary all-purpose pliers (6 to 7 inches long); the thin type is handiest for radio work.
C—One pair side-cutting pliers (5 to 6 inches long).
D—One ordinary pocket knife (jack-knife).
E—One medium-size flat metal-cutting file (about 7 inches long).
F—One small screwdriver (about 5 inches long).
G—One medium-size screwdriver (about 7 inches long).
H—One 12-inch ruler of any type.

lead and tin. The ratio of lead to tin determines the hardness, strength, and melting point of the solder.

Radio solder will adhere to iron, steel, brass, copper, cadmium, and phosphor bronze when these metals are properly cleaned. Radio men have no need for soldering to aluminum, which requires a special aluminum solder.

Importance of Heating the Work. Solder will *not* adhere to a metal surface unless that metal surface is perfectly clean. Furthermore, *molten solder will not adhere to a cold surface.* To solder successfully, you must *heat the work to a temperature that will melt the solder into a smooth flowing liquid when it is applied directly to the work.* If you fail to melt the solder to a liquid, you will get a "cold" joint that will be no good at all.

It is also essential that you apply the heat for a sufficient length of time to burn *all* the rosin flux out of the joint. If you fail to do this, you will get what radio men call a "rosin joint" which introduces unnecessary resistance into the circuit.

Soldering Irons

All types of soldering irons have a pointed tip made of copper or some suitable alloy of copper, a handle (usually made of wood), and a hollow metal tube, or some other suitable means of joining the handle and tip. The pointed tip is heated and applied to the work. Heat is transferred from the tip to the work, which quickly becomes hot enough to melt the solder. Soldering irons differ principally in the methods used to heat the pointed tip—some having the tip heated continuously by an electric current, others requiring an open flame.

Electric Soldering Irons. Electrically heated soldering irons like those shown in Fig. *3* are used more than any other type by the radio industry. The various makes differ in size and shape, but their essential construction is the same. Some have the pointed rod completely surrounded by the heating element; others have the heating element fitted inside the soldering tip.

At the other end of the hollow metal tube is a wooden handle. The line cord passes through the wooden handle and the hollow metal tube, and connects to the terminals of the heating element. The heating element itself consists of nichrome resistance wire (like that used in electric stoves) wound into a coil and covered by a heat-resistant insulating material.

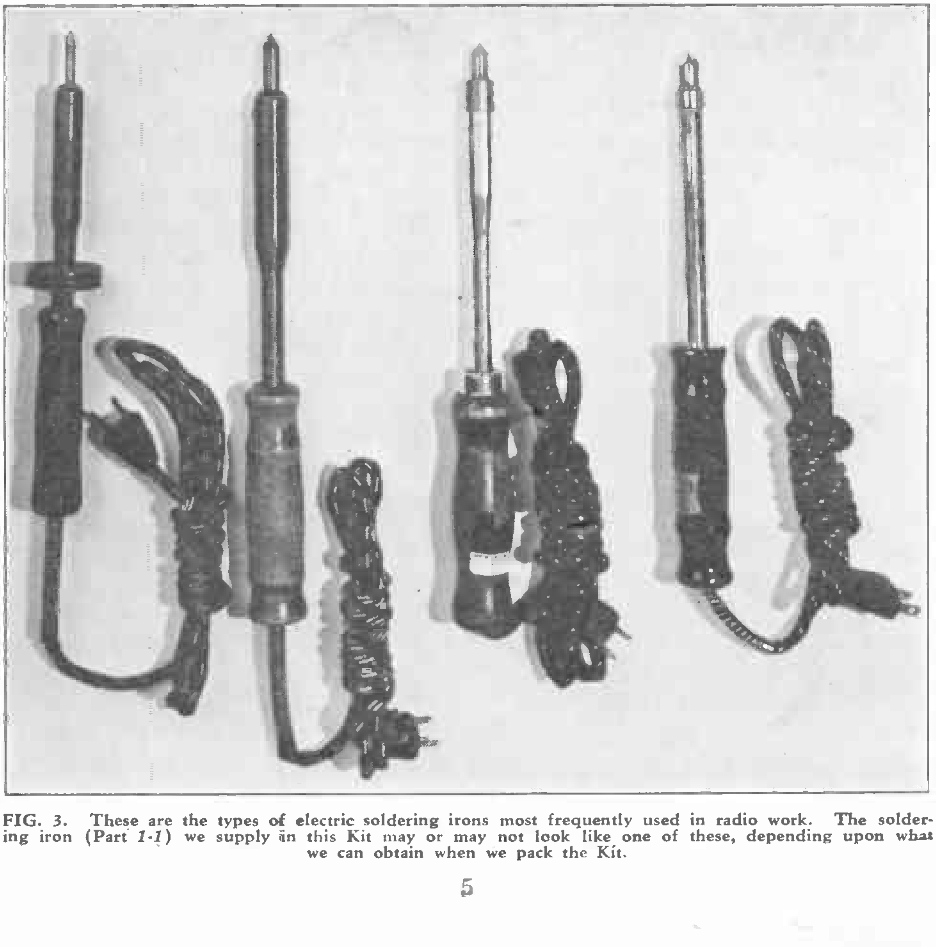

FIG. 3. These are the types of electric soldering irons most frequently used in radio work. The soldering iron (Part *1-1*) we supply in this Kit may or may not look like one of these, depending upon what we can obtain when we pack the Kit.

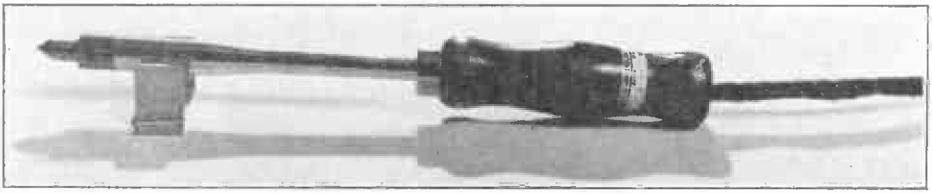

FIG. 4. This shows how to place your soldering iron on a metal holder. Note that the working tip is placed beyond the holder, so that it does not become cooler through contact with the metal which would carry off some of its heat.

Never unscrew the copper tip of the NRI electric soldering iron; the heating element inside is fragile, and is easily damaged when exposed. If the copper tip becomes loose during normal use, tighten it while the iron is cold. Do not drop your soldering iron or swing it carelessly against a hard object; more important yet, *never use your soldering iron as a hammer,* for that will surely damage the heating element.

Electric soldering irons are usually built for 115-volt operation,* and can be used with either a.c. or d.c. power. For ordinary radio servicing work, the heating element should have a wattage rating of from 50 to 60 watts. Allow about three minutes for the NRI iron to heat up after plugging it into a power source.

Purpose of Soldering Iron Holder. A heated soldering iron should always be returned to its metal holder when not in use. Fig. *4* shows a convenient holder and how to place the soldering iron on it. It is best not to let the hot copper portion touch the holder. The tip end of the barrel is the hottest part of the iron; heat conducted from the barrel through the metal holder may scorch the workbench or other surface on which the holder is resting, and heat conducted away from the barrel by the holder will tend to cool the tip.

The soldering iron holder should be kept conveniently close to your work, but never in a position where you might accidentally knock the iron out of the holder. A heated soldering iron is hot enough to do considerable damage to your hands, to your clothes, or to wooden table tops, so be careful.

Heat Controls. If the full rated voltage is applied to an electric soldering iron for long periods of time during which the iron is not used, the tip will become covered by a hard black substance (copper oxide) that will make it useless for soldering. The reason for this is that copper is a metal that oxidizes rapidly, especially when heated to the high temperatures required for good soldering. If you wish to plug your soldering iron in when you start your experimental work, and leave the iron plugged in until you are through for the day, you should form the habit of wiping the tip frequently with a cloth or piece of steel wool, to keep the oxide from forming.

You may, however, find it more convenient to use one of the heat controls shown in Fig. *5*. The control shown at *A* in Fig. *5* is a commercially manufactured unit having a thermostat that can be adjusted for any desired temperature. As long as the soldering iron is kept on this special stand, the thermostat in the base of

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*Power-line voltages may vary between 110 volts and 120 volts. Up to a few years ago, line voltages at homes were around 110 volts, but today most homes have voltages approaching 120 volts. An electric soldering iron built for 115-volt operation can be used on any voltage between 110 volts and 125 volts.

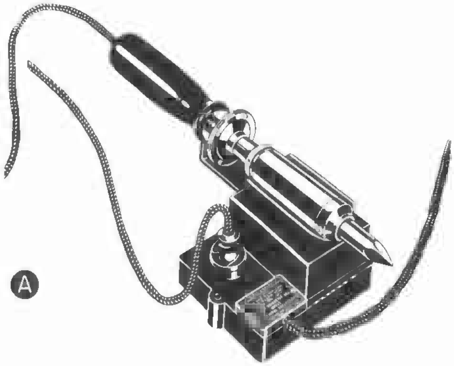
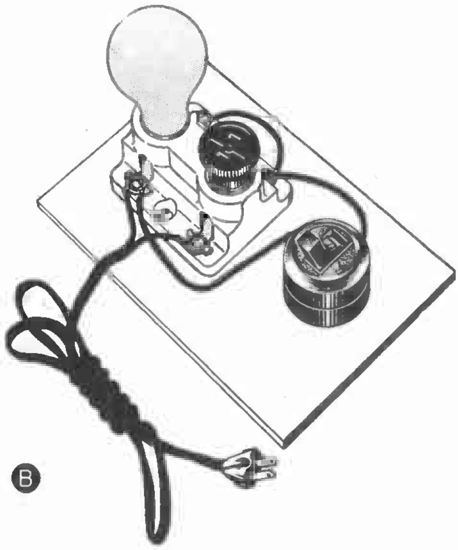


FIG. 5. A commercially manufactured heat control of the thermostat type is shown at A; one you can build yourself is shown at B.

the stand maintains the tip of the iron at the desired temperature. As soon as the iron is removed from the stand, full rated voltage is applied to the heating element, and the tip quickly reaches operating temperature.

The device shown at *B* in Fig. *5* is a thoroughly practical heat control, which you can build yourself. The wattage rating of the lamp bulb depends on the wattage rating of the iron, and should be chosen so that when the switch is *open*, the voltage applied to the iron will be between 80 and 90 volts. When the switch is open, the lamp and heating element of the iron are in series, and the iron operates at reduced voltage. This will keep the tip from oxidizing so quickly. Shortly before the iron is to be used, the switch is closed, and full voltage is applied to the iron, bringing the tip to operating temperature. Note that the switch is connected *in parallel*



with the lamp; not in series with the supply line.

Plain Soldering Iron. When electric power is not available, a plain soldering iron similar to the one shown in Fig. *6* may be used. This type of soldering iron is heated by placing the copper tip in the flame of an alcohol burner or gasoline blow torch. Once heated to the proper temperature, a plain soldering iron holds its heat long enough to make a number of soldered joints. It is then reheated for additional work.

In an emergency, you can heat the copper tip of any electric soldering iron in the flame of an alcohol burner. Radiotricians who get occasional calls from suburban or rural homes not equipped with electricity often carry

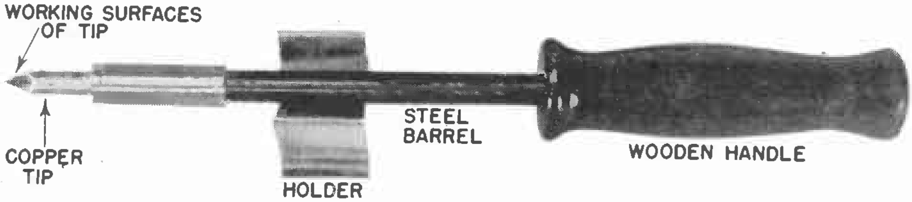


FIG. 6. This is called a plain soldering iron, as its working tip is heated in a flame. It is used where no electric power is available. A suitable heating device is described in the text.

along in their tool kit a can of special heating fuel called "canned heat," or an alcohol burner like that described later in this Manual.

Soldering Flux

When plain solder is applied to a heated piece of uncleaned brass or copper, the solder melts but rolls off immediately, without adhering. This is to be expected, for ordinary uncleaned metal is covered with a film of grease, dirt, and metal oxides which prevent the molecules of solder from getting sufficiently close to the molecules of brass or copper. Filing the surface of the brass or copper makes it appear clean, but ordinarily does little good because oxides form very rapidly on a heated metal surface. The oxygen in the air combines with the metal to form the oxide film, and heat accelerates this combining action.

If solder is to be applied successfully to a metal, the oxides must be removed from the heated metal surface as fast as they form. This can be accomplished by applying, along with the solder, an additional material called *flux*. For good radio work, this flux is always rosin (an amber-colored substance which remains after oil of turpentine is distilled out of crude turpentine). Sheet metal workers generally use an acid flux (usually some form of hydrochloric acid); this is more effective than rosin, but it *has a corrosive action which makes it unsuitable for radio work*.

Flux can be applied either in the form of a liquid or a paste, but it is more convenient to use a special radio solder having a core of the desired flux. In this way, both the solder and the flux are applied at the same time.

How Fluxes Work. Acid and rosin fluxes act in the same manner in making a lead-tin mixture (solder) adhere to another metal. These fluxes dissolve some of the oxides which are always present on a metal surface. The oxides then flow off the metal in liquid form, carrying along dirt, grease, and other oxides so as to leave a clean metal surface to which solder can adhere.

Disadvantages of Acid Flux. Although it is a well-known fact that acid flux or acid-core solder is easy to use, it is unfortunate that some of the acid *always* remains on the work and creeps over to unsoldered portions. In time, this acid will eat away the copper or brass around the joint, causing failure of the joint. The slightest presence of moisture in the air will speed up the creeping movement of acid flux. The acid may travel through the insulation between radio parts, thereby forming leakage paths for electric currents and impairing the efficiency of the circuit.

Because of its strongly corrosive action, acid flux should never be used for radio work.

Rosin Flux. Rosin is a solidified material when at normal room temperatures, but becomes liquid when heated by a soldering iron. Rosin is a fairly good insulator and has no corrosive action on metals. Rosin flux is considerably harder to use successfully than acid flux, but because of its superior insulating and non-corrosive qualities, rosin is by far the best flux for radio connections. It is generally used in the form of rosin-core solder.

Paste Fluxes. Both rosin and acid fluxes are available in the form of pastes which can be applied to the joint with a knife or a wooden splinter. A paste flux is fairly easy to use, but it is difficult to determine whether a particular paste includes corrosive ingredients which can ruin a radio connection. Even pastes which are advertised as being non-corrosive will sometimes cause enough corrosion to ruin a delicate radio joint. For this reason *the use of paste flux should be avoided in radio work.*

Making an Alcohol Burner for Heating a Plain Soldering Iron

If you have a plain soldering iron (Part *1-1A)* in place of the electric soldering iron (Part *1-1)*, you will need a convenient source of heat. A small alcohol burner is ideal for this purpose, as it is easy to make and safe to use. Furthermore, this burner provides an alcohol flame which is ideal for removing enamel insulation from wires.

Parts Needed. The only parts needed for the alcohol burner are a plain medium-sized oil can of the type sold for about ten cents in most dime stores and hardware stores, a lamp wick of the type used in kerosene lamps, and about a pint of denatured alcohol, wood alcohol, grain alcohol, Paco Solvent, or an equivalent alcohol product. These parts are pictured in Fig. 7.

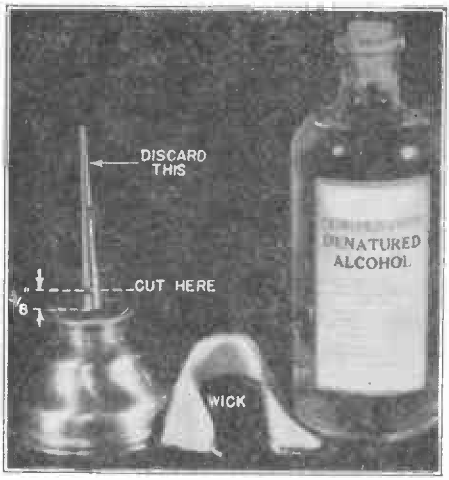


FIG. 7. Parts needed for making an alcohol lamp, which can be used for heating a plain soldering iron, for removing enamel from wires, and for heating an electric soldering iron in locations where power is not available.

Unscrew the spout of the oil can. With a hacksaw, cut off the spout about ⅜ inch above the base, as indicated by the dotted line in Fig. 7. You can clamp the small end of the spout in a vise while sawing, for this end will be discarded. Use a fine-tooth hacksaw blade and take light strokes to prevent excessive chattering. Smooth the saw cut with your file, and scrape off all metal burrs.

Roll the lamp wick together lengthwise at one end, and push it through the stub of the spout from the bottom. Let the wick project about ½ inch above the top of the spout.

Fill the can about half full of alcohol, then replace the spout and tighten it. Tip the can upside down for a few seconds so the entire wick becomes saturated with alcohol, then set the can upright and apply a lighted match to the wick. The flame should extend 2 to 4 inches above the wick. The color of the flame depends upon the type of alcohol used; pure grain alcohol will give an almost invisible blue flame, commercial alcohols give a predominantly yellow flame, with only a small blue portion.

The height and size of the flame can be adjusted by pushing the wick in or out of the spout. The more wick there is exposed and the more the wick ends are spread out, the larger will be the flame. If the flame decreases gradually in size, or flickers excessively when the burner is used for some time, loosen the cap about half a turn so that air can get in around its threads. Even a slight breeze or draft in a room will make the flame flicker; if the draft cannot be conveniently eliminated by closing windows and doors, set up boxes or boards around the burner to shield it from the air currents.

The flame can be extinguished simply by blowing it out, or by placing a thimble or small tin can momentarily over the flame to cut off its air supply.

Alcohol evaporates rapidly, so if a considerable amount is left in the can after work is finished, you can pour it back into the bottle or can in which the alcohol was sold. Keep your supply of alcohol tightly capped or corked to minimize evaporation. As an alternative to emptying the burner, you can place a small thimble over the wick.

Holder for Plain Soldering Iron. The soldering iron should always be placed so that the copper barrel is in the upper third portion of the flame. Soot will sometimes be deposited by the flame, so do not allow the flame to touch the copper tip of the iron. The iron should be in a horizontal position, or the handle should be lower than the tip during heating. Heat always travels upward; if the handle were higher than the tip, heat would travel up to the handle and make it uncomfortably hot.

A suitable holder in which the plain soldering iron can be placed *while heating* is illustrated in Fig. *8*. (This holder is used only for heating the iron; the ordinary metal holder shown in Fig. *6* is used to support the heated iron when wires or lugs are being tinned.) You can make this yourself very easily, using a large tin can, a scrap piece of wood, and a few nails, or you can design an equivalent holder from other materials which you may have at hand. Keep in mind that the two purposes of the holder are to prevent the alcohol burner from tipping and to hold the copper barrel of the soldering iron in the upper third portion of the flame.

How to Tell When the Iron Is Heated Sufficiently. An alcohol burner like that described here will ordinarily bring your soldering iron to the correct working temperature in from three to five minutes. After heating for three minutes, apply solder momentarily to a flat surface of the tip; if the solder melts readily, the iron is ready for use. If the solder melts slowly, continue heating for a while and then repeat the test. Ordinarily, it is best to heat the iron for about one minute after solder first begins to melt on the tip; extra heat is then stored in the copper barrel and tip, and a number of joints can be soldered before the iron needs reheating.

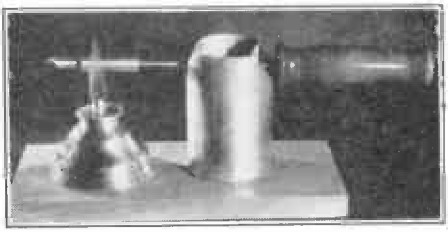


FIG. 8. Completed alcohol burner in use. The base is a wooden board of any convenient size. Three finishing nails hold the oil can in position on the base and prevent accidental tipping. A large empty tin can with notches cut in opposite sides can be used as a holder for the soldering iron, or you can cut a holder out of sheet metal for this purpose. The holder can be fastened to the base with two wood screws, in a position such that the copper barrel will be in the upper third portion of the flame.

Do not overheat the iron; above all, never allow a soldering iron to become red hot. *Too hot* an iron is just as bad as *too cold* an iron insofar as good soldering is concerned, and an excessively hot iron quickly becomes corroded.

Starting the Experiments

Choosing a Place to Work. The experiments in your Practical Demonstration Course can be performed on almost any type of table or workbench which does *not* have a metal top. Students living in city apart-ments will find that an ordinary folding card table serves nicely. If you will be using the plain soldering iron and alcohol burner, choose a location well away from curtains and other highly inflammable materials. If you will be using the electric soldering iron, you can either place the table near a wall electric outlet, or use an extension cord to bring electric power to your table.

Performing the Experiments. Develop the correct experimental habits right from the start by following a logical procedure for each experiment. Whenever you start a new Manual, always study first the introductory discussions at the beginning of the book. After this, perform the experiments *one at a time*, in the correct order, by observing the following procedures:

1. Read through the instructions and discussions for the entire experiment once very slowly, and study any parts which are not immediately clear to you. Do not touch a single tool or radio part until you make this preliminary study.

2. Lay out on your work table the parts and tools needed for the experiment which is to be performed.

3. Carry out the experiment, one step at a time. Record your results whenever spaces are provided in the Manual for this purpose. Additional observations and comments can be written in the margins of the pages, for future reference.

4. Study the discussion at the end of the experiment very carefully, and analyze your results. After finishing an experiment, you should be able to tell in your own words exactly what you proved and how you did it.

5. Fill out the Report Statement for the experiment just completed. This statement is given at the end of each experiment, and repeated on the inside of the back cover of the Manual, and will be numbered the same as the experiment. Check the statement that completes the question correctly, and copy your answer on the last page of the Manual.

6. When you have completed all ten experiments in a Manual and have answered all of the Report Statements, cut off the last page of the Manual on the dotted line according to the instructions on that page, and mail the Report Statement to NRI for grading. *Do not send in the entire Manual.*

IMPORTANT NOTICE: In order to build the NRI Tester with the parts furnished in the first two Radio Kits, it is absolutely necessary that you perform every step in each of the ten soldering experiments in this Manual. There are about twenty-five soldered joints in the NRI Tester, and these must be made exactly in accordance with the professional soldering techniques presented in this Manual. Furthermore, the ability to make good soldered joints is required in all later experiments as well as in practical radio work. In checking student troubles, NRI has found that poor soldering is more frequently the cause of failure to get proper results than all the other causes combined.

DO NOT SKIP ANY STEPS.

EXPERIMENT 1

***Purpose:* To tin the working tip of your soldering iron.**

Step 1. To determine if plain solder alone (without flux) can be used for tinning a soldering iron, hold the heated iron horizontally in one hand, and melt a small amount (about ½ inch) of plain solder (Part *1-4)* by rubbing it lightly over the flat surface of the tip in the manner shown in Fig. *9*. Wipe off the heated solder with quick strokes of a piece of cloth, and note whether any of the solder clings to the tip. Use several thicknesses of cloth so as not to burn your fingers. If you prefer, you can tack this cloth to a small board and use it like a brush for wiping the iron.

Now file this heated flat surface until it is uniformly clean, using for this purpose the flat file specified in Fig. *2*. Usually the Radiotrician will rest the tip of the soldering iron against a non-inflammable solid object such as a brick or a stove while filing. *Never squeeze an electric soldering iron tightly in a vise.* Note how the heated copper surface changes color soon after being filed. Apply plain solder to the freshly filed surface, wipe off with the cloth, and note how much solder adheres to the tip.

In the case of a plain soldering iron, reheat the soldering iron just before filing, and file rapidly so that the iron will still be hot enough to melt solder after you have finished filing one surface.

Step 2. To determine if rosin-core solder can be used for tinning a soldering iron, file a different surface from that used in Step 1, then rub a small amount (about ½ inch) of rosin-core solder (Part *1-3*, marked with printed letters) lightly over this entire surface. Wipe off surplus solder with the piece of cloth to see if any solder remains on the tip.

Step 3. To complete the tinning of your soldering iron, file the remaining flat surfaces of the heated soldering iron tip until bright. Rub rosin-core solder (Part *1-3*) over the surfaces. Wipe off surplus solder with a cloth, then apply additional rosin-core solder to those parts of the surfaces where solder did not adhere. Repeat until these surfaces are completely tinned, then do the same for any other surfaces which are not completely tinned. Your soldering iron should now be completely tinned on all four surfaces as shown in Fig. *10*.

Step 4. To learn the radio expert's technique for shaking surplus solder off the tip of a soldering iron, apply a small extra amount (about ¼ inch) of rosin-core solder to the heated tip. Now hold the iron firmly by its handle and shake it downward over a box, a board, or newspapers. Practice this several times, until you can flip off surplus solder without getting it on your clothes or scattering it all over the room. Apply more rosin-core solder to the heated tip, but this time wipe it off with quick strokes of a cloth.

Discussion: Plain solder without flux will not ordinarily adhere to a copper surface. You proved this in Step 1 by applying the solder to the heated tip of the soldering iron both before and after filing the tip. You would secure the same results with

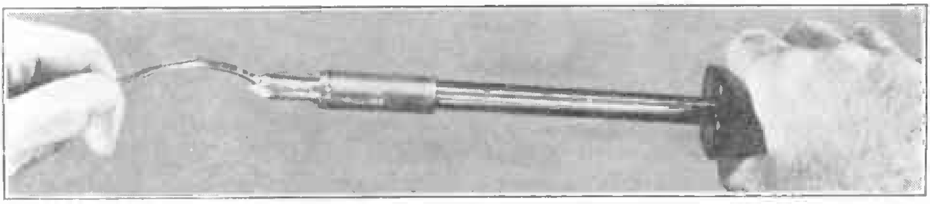


FIG. 9. Correct way to hold the soldering iron while applying solder to one flat surface of the tip for tinning purposes. By keeping the flat surface approximately level, the tendency of the molten solder to roll off the tip is minimized.

copper wire or any other heated copper surface.

The change in the color of the copper surface soon after filing was due to the formation of oxides of copper on the surface. These oxides, along with any other foreign matter which may be on the tip, prevent you from tinning the soldering iron with plain solder. There is no danger of destroying the temper of the file, for an electric soldering iron never gets hot enough to affect the hardness of steel.

In Step 2, you proved that rosin-core solder will adhere to a properly cleaned and properly heated copper surface. Only the surplus solder can be removed with the cloth; the bright silvery surface layer of solder adheres to the clean copper, and cannot be wiped off. In this step, therefore, you tinned one of the four working surfaces of the tip.

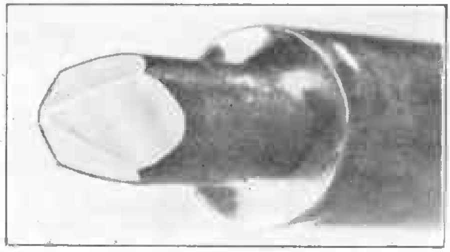


FIG. 10. Close-up photograph showing a properly tinned soldering iron tip. Note that only the flat surfaces of the copper tip are tinned.

Because of its highly corrosive action, *acid-core solder should never be used on the joints in radio and television equipment*. Paste fluxes should also be avoided, even though they are less corrosive than acid fluxes. If you need additional flux, dissolve some powdered rosin in a little alcohol.

Surplus solder often accumulates on a soldering iron during radio work. Rosin flux evaporates quickly from hot solder, so it is usually best to discard this solder. When radio men are in a hurry, they just give the iron an expert flip as described in Step 4, so as to shake off the solder. When the iron is also a bit corroded, however, wiping off the surplus solder with a cloth will usually remove the oxides too, leaving a clean tinned tip.

Tinning serves the dual purpose of *keeping the tip of your soldering iron clean and aiding in the transfer of heat* from the iron to the work. The solder fills small irregularities in the tip and in the work, thus increasing the area of contact between the tip and the work.

A soldering iron which is untinned or only partially tinned on its flat working surfaces quickly becomes pitted and covered with crusts of copper oxide. An iron in this condition is difficult to use, for the oxide has heat-insulating characteristics and thus hinders the transfer of heat.

A certain amount of copper oxide will form even on a properly tinned iron which is used continuously for several hours. This can usually be removed by wiping the tip frequently with a cloth or steel wool as previously explained. The tip should be filed only when a considerable quantity of oxide has formed and cannot be removed by wiping or retinning.

In filing the tip of your soldering iron, always hold the file flat against the surface so as not to change the angle of the tip too much. The tip of your iron has been cut at the angle which has proved most satisfactory for radio work.

Instructions for Report Statement No. 1. The report question which checks your work on this experiment is given below, and repeated on the last page of this Manual. After you have completed the experiment and studied the discussion, read Report Statement No. 1 carefully. Check the correct answer, then copy your results on the report statement page at the end of this Manual. You are asked to specify *the type of solder* (plain or rosin-core) *with which it was the most difficult to tin your soldering iron.* Either the observations which you made during this experiment or the analysis of results in the discussion will give you the answer.

Report Statement No. 1: My untinned soldering iron was *most difficult* to tin with: *plain solder* ☑; *rosin-core solder* ☐.

EXPERIMENT 2

Purpose: **To recognize when solder has hardened, and to see what happens when a joint is moved before the solder has hardened.**

Step 1. To demonstrate how solder changes color as it hardens, hold your heated and tinned soldering iron over a scrap piece of wood with the tip downward, and apply rosin-core solder just above the point of the tip until a solder globule about ⅛ inch in diameter drips down onto the board (the drop is shown in actual size in Fig. *11*). Watch this globule for about a minute, noting the change in color as it hardens.

Drop another globule of solder on the board in this same way, then apply the tip of the iron to the globule and apply additional solder to the tip until this second globule is about twice the size of the first. In the same way, place on the board a third globule which is about three times the size of the first one. As each globule cools, study the changing colors.

Step 2. To find whether larger amounts of molten solder take longer to cool, reheat all three globules of solder on the board one after another as quickly as you can, by applying the heated tip of your soldering iron first to the largest globule, then to the medium-sized one, and finally to the smallest one. Jerk the tip of the iron away from each globule as soon as the solder takes on a silvery molten appearance. While the three globules are cooling together, watch them carefully to see which ones harden first.

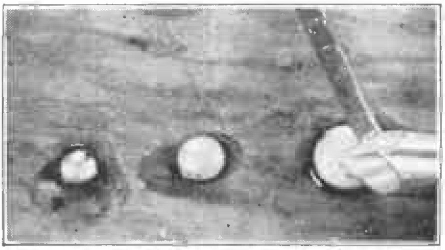


FIG. 11. Method of increasing the size of a molten globule of solder by feeding rosin-core solder to the soldering iron tip while it is in contact with the globule. The three globules used in Experiment 2 are shown clearly in this view. The darker rings on the board around each globule are formed by the surplus rosin flux, which is a yellowish liquid when heated. If you look closely, you will see your own image in the surface of a molten solder globule, just as if it were a tiny curved mirror. The image vanishes gradually as the solder hardens.

Step 3. To determine by actual test the instant when solder hardens, reheat the largest globule with the soldering iron, then remove the iron, and allow the globule to cool. Take the length of stranded enameled aerial wire (Part *1-7H)* and occasionally touch the *top* of the globule gently with it to determine when the solder hardens, while watching the changes in color. Repeat this test a few times if necessary, until you are familiar with the color corresponding to complete hardening of the solder.

Step 4. To see what happens to solder which is disturbed while it is *cooling,* reheat the largest globule with the soldering iron, and hold the wire in the center of the globule while it cools. *Just before the globule turns white,* tilt the wire sideways and twist it slightly so as to crack the globule.

Discussion: Step 1 showed you that solder has a bright, silvery color (much like mercury) when in a molten condition, and changes gradually in color as it hardens. This change in color serves as a "thermometer" to the Radiotrician, for it tells him when the solder has melted on a joint being unsoldered, and tells him when the solder has hardened sufficiently on a joint being soldered.

Step 2 showed clearly that a large globule of molten solder takes longer to cool than does a small globule. Likewise, you found that the larger globules took longer to heat up.

In the first two steps, we assumed that the solder was hard when it stopped changing color. In Step 3, you probe the solder with the wire, and you prove for yourself that a globule of solder has completely hardened when it changes all over to the characteristic color of hardened solder.

Step 4 demonstrates conclusively a highly important requirement of good soldering: *A soldered joint should not be moved until the solder has completely hardened.* Premature movement cracks the solder, for it is very brittle at the instant of hardening. Solder which is cracked gives very poor electrical contact between the parts of a joint. Provision for holding wires rigid while solder cools is an important part of the procedure.

Instructions for Report Statement No. 2. The test question for this experiment is a simple check of your ability to observe how solder changes in color as it hardens. A correct answer means that you have mastered one important requirement of good soldering, for these color changes tell you when solder has hardened enough to withstand movement.

After you have completed this experiment and studied the discussion, read Report Statement No. 2 carefully, place a check mark in the box which follows the answer you consider correct and copy your answer on the report statement page at the end of the Manual.

Report Statement No. 2: As molten solder becomes hard, it changes from its bright silvery color to: *a bright red color* ☐; *a dull black color* ☐; *a copper color* ☐; *a dull white color* ☑

EXPERIMENT 3

Purpose: **To remove insulation from wires and clean the wires preparatory to soldering.**

Preliminary Discussion. Although there is a great variety in the size and general appearance of the conductors used to interconnect (hook up) the various parts (tube sockets, switches, transformers, condensers, etc.) of radio and television receivers and transmitters, there are only two really basic types of conductors. One is the single strand of solid metal wire familiar to everyone. Copper, because of its high conductivity and good mechanical qualities, is the metal from which the wire is drawn. The other type, known as *stranded* wire, consists of several strands of copper wire twisted together to form a single conductor.

The principal difference between the many varieties of solid hook-up wire lies in the diameter of the wire and the kind of insulation surrounding it. The insulation may be any suitable non-conducting material such as silk, cotton, rubber, or enamel. Various plastics also have suitable insulating qualities. The chief purpose of the insulation is to prevent the conducting wire from touching anything that might cause undesirable grounds or short circuits.

Solid wire having no insulation at all is also available. Running the wire through molten solder during manufacture gives it a bright, shiny appearance. Such wire is generally known as tinned bus wire. The coating of solder protects the wire from oxidization and aids in soldering. Tinned, insulated wire is the most widely used hook-up wire for interconnecting the various parts of radio and television equipment.

Stranded wire is almost always insulated, the insulation forming a convenient means of holding the strands together. The individual strands may or may not be tinned, depending on the particular type of wire. Stranded aerial wire, a sample of which is included in this first Radio Kit, does not have insulation over the entire group of wire strands. Instead, each individual strand has a coating of a protective enamel.

Insulated wire, both solid and stranded, is available in a wide variety of colors. The color is used solely for the purpose of tracing and identifying various wires and circuits. This is especially helpful when a number of wires are bound together to form a cable. The color of the insulation has nothing whatsoever to do with the characteristics of the insulation, or the current rating of the wire itself.

In radio work, so-called "push-back" wire is widely used. This is tinned, stranded, or solid wire enclosed in a simple cotton wrap, over which is the regular insulation. The insulation can be slid back when a solder connection is to be made, and then slid toward the connection to form a complete protection.

The wire supplied in your first Radio Kit is typical of the wire you will encounter in radio service work. Stranded and solid wire, tinned and untinned, are included in the Kit to give you experience with the types in general use.

Step 1. To identify the various wires supplied in this Kit, first set aside the three wires which are identical in appearance and construction. These are given the identifying part numbers *1-7A*, *1-7B*, and *1-7C*, in the parts list on page 2. They are 8-inch lengths of No. 20, solid tinned push-back hook-up wire.

The length of aerial wire, Part *1-7H*, is readily identified, since it is the only one that does not have cloth-like insulation. Each of the seven strands of this wire is covered with enamel insulation.

Now identify the lamp cord, Part *1-7G*. This is the length of wire having the thickest insulation. The wire itself is made up of untinned strands; the insulation consists of a cotton braid over rubber.

Part *1-7F* is the stranded tinned wire with the glazed insulation; and Part *1-7D* is the stranded tinned wire with plain cloth insulation. Part *1-7E* is the solid untinned insulated wire. It may be necessary to cut away about ⅛-inch of the insulation on these wires to identify them positively.

When you have identified the wires according to the part numbers and descriptions given above, and in the parts list on page 2, place a small piece of ordinary adhesive tape around each wire, and mark its part number on the tape for easy future identification.

Step 2. To remove insulation from push-back insulated hook-up wire, grasp in one hand a length of the *solid* tinned push-back insulated wire (Part *1-7A*), and push the insulation back from the end with the thumb and first finger of your other hand, as shown in the upper view in Fig. *12*. Push the insulation back far enough to expose about ¾ inch of wire. To show that the insulation can be pushed forward again after a joint is made if too much wire was originally exposed, push the insulation forward until only about ¼ inch of wire is exposed. Push back again until the full ¾ inch is exposed. Now push back the insulation on the other end of this wire the same amount (¾ inch); use long-nose pliers this time to hold the end of the wire, as illustrated in the lower view in Fig. *12*.

Also, push back the insulation for ¾ inch from both ends of the *stranded,* tinned, push-back insulated wire (Part *1-7D*). Use long-nose pliers to hold the wire, as illustrated in Fig. *12*.

Step 3. To remove insulation from ordinary insulated hook-up wire by squeezing with long-nose pliers, grasp in one hand the length of solid, untinned, insulated wire (Part *1-7E*), and use your long-nose pliers to squeeze the insulation for a distance of ¾ inch from one end. Figure *13* illustrates how this is done. You will have to apply enough pressure with the long-nose pliers to split the insulation lengthwise, so that you can pull off the strips of insulation with the pliers. The closer you get to the hinge of the pliers, the easier this will be. Loose threads of insulation can then be clipped off with side-cutting pliers or a pocket knife. Remove ¾ inch of insulation from the other end of the wire in the same way. Scrape the exposed copper wire lightly with the blade of a pocket knife as shown in Fig. *15*, to remove oxides and dirt.

In this same manner, remove ¾ inch of insulation from each end of the length of stranded, tinned, No. 20 wire, insulated with rubber and cotton braid (Part *1-7F*).

If you are unable to break the insulation by squeezing, omit this step and apply to this same wire one of the alternative methods given in the next step.

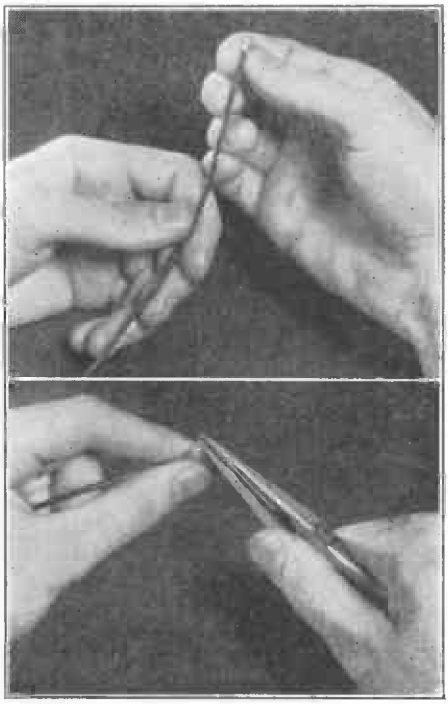


FIG. 12. The correct method of pushing back the insulation of solid push-back insulated wire with the fingers preparatory to soldering is shown in the upper view. The same method is used for stranded wire of this type. When the insulation cannot readily be pushed back far enough with the fingers, it will be easier to grasp the bare end of the wire with your long-nose pliers, as illustrated in the lower view. When holding the wire with pliers in this manner, it is a simple matter to push the insulation back with the fingers as much as desired.

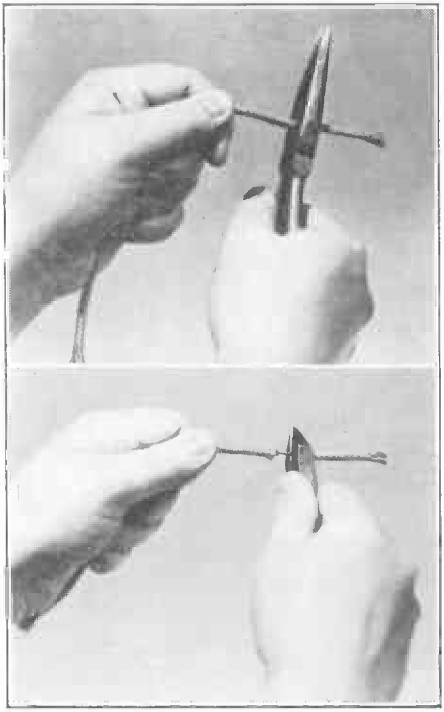


FIG. 13. This shows how to use a pair of long-nose pliers to squeeze the insulation on a piece of ordinary insulated wire so it can be removed more easily. If your pliers have wire-cutting jaws near the pivot, you will have to place the wire closer to the end of the pliers. Sometimes it is convenient to use a pair of sidecutters to remove insulation. This is done by *carefully cutting only the insulation*, and then pulling the insulation free by moving the sidecutters toward the end of the wire.

Step 4. To remove insulation from ordinary insulated wire with a pocket knife, hold the length of No. 18 stranded lamp cord (Part *1-7G*), flat upon your workbench or on a block of wood. Cut through the insulation all around the wire at a point ¾ inch from one end by moving the blade of a sharp pocket knife across the insulation with a sawing motion while rotating the wire slowly with your fingers. This is illustrated in Fig. *16*. Continue until the outer covering of woven cotton thread has been cut through all around, then slide this covering off over the end of the wire with your fingers or by pulling with long-nose pliers. Be careful not to cut through the inner rubber layer to the copper strands. Once the inner rubber insulation is partly cut through, peel it off with your fingers or a knife.

Scrape the exposed wire lightly with your knife blade if the copper appears corroded or dirty; do this several times, spreading out the strands each time so as to expose a different part of each strand to the knife.

Now take the other end of the lamp cord wire, hold it in your hands as shown in Fig. *17*, and slice off the outer braided cotton covering for a distance of ¾ inch from the end. Peel away the remaining rubber insulation with your knife and fingers,

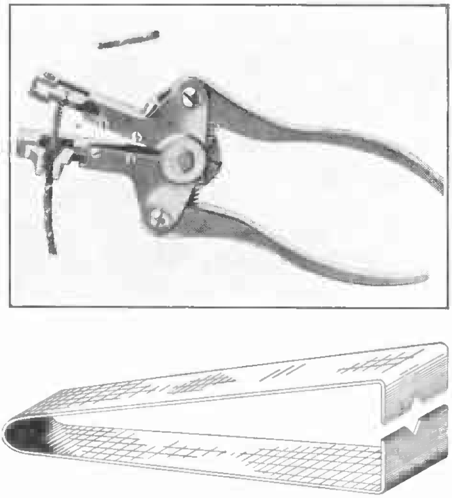


FIG. 14. These instruments are often used to remove insulation from various types of wire used in radio work. The wire strippers shown at A are generally used in production work. The bent strip of metal shown at B is a very convenient wire stripper for general radio service work.

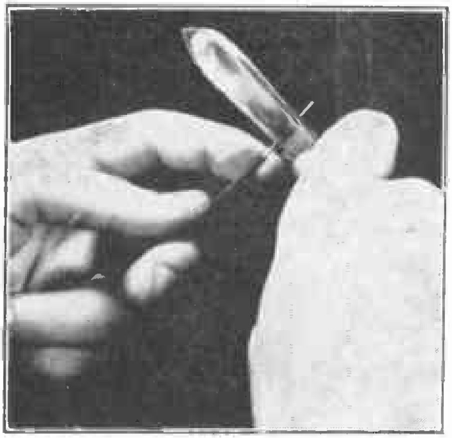


FIG 15. Always use the portion of your pocket knife blade closest to the handle for scraping oxides and dirt from exposed copper wire preparatory to soldering. This preserves the main part of the blade for purposes where sharpness is required, such as when cutting through braided cotton insulation.

and trim off loose threads. Be careful not to cut or nick any of the copper strands. Scrape the strands with the knife blade until all are clean and shiny.

Step 5. To remove enamel insulation from a wire, take the length of enameled aerial wire (Part *1-7H)* and untwist the wires for about 1½ inches at one end. Using your knife blade, scrape off the enamel from each of the seven strands of wire, one at a time, for a distance of ¾ inch from the end. Do this carefully and thoroughly, to give clean copper surfaces without nicking any of the wires. Leave the wires like this for a future experiment.

If you have an alcohol burner, use it to burn off the enamel at the other end of the aerial wire. Untwist the strands for about 1½ inches, and spread them out just enough so that none touch each other. Light the alcohol burner, and hold the spread-out strands just within the tip of the inner cone of flame, as shown in Fig. *18,* until the wires are red hot for about ¾ inch from the end. Now immerse the heated wires quickly in a little pan of alcohol. Repeat if any enamel remains on the ends of the wires and can't be rubbed off with a cloth. If you do not have an alcohol burner, use the scraping technique for both ends of this wire.

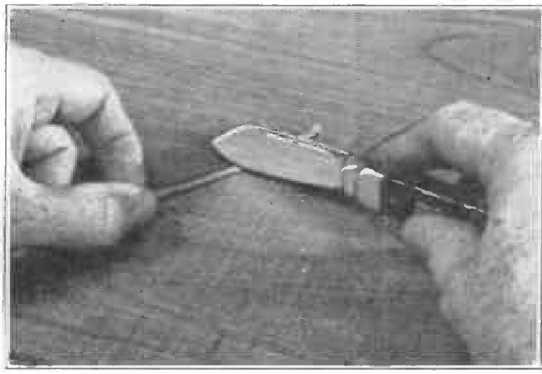


FIG. 16. When the insulation on a wire is too tough to be broken by squeezing with pliers, the pocket knife technique illustrated here is employed by some radio men for cutting through the outer braided covering on the wire. *The knife must be sharp,* and must be held lightly so as to avoid cutting too far and nicking or breaking the copper wire.

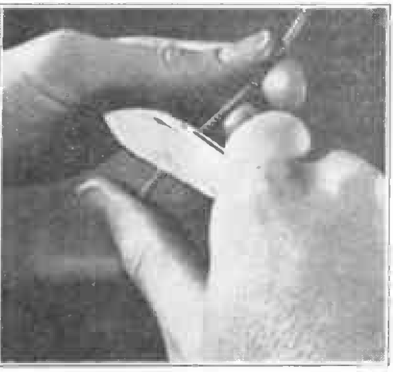


FIG. 17. This method is employed by radio men for cutting away the insulation from a wire which is anchored at its other end. The knife must be sharp, and extreme care must be used to avoid nicking solid copper wire or cutting strands in the case of stranded wire.

Discussion: Tinned push-back insulated hook-up wire, either solid or stranded, is the type of wire most commonly used by radio men. The copper wire is tinned during manufacture so that insulation slides along it readily, and the insulating cotton covering has a special weave which permits compressing the insulation. Solid push-back hook-up wire is supplied in your next radio Kit for use in hooking up practical radio circuits for demonstration purposes, so you will get plenty of experience with this type of wire.

Ordinary insulated wire (not of the push-back type) is used for the power line cords of radio receivers, and is occasionally used for receiver wiring as well. A highly convenient way to remove insulation from wire of this type is by squeezing with pliers as explained in Step 3, but there will be times when you will have to cut away the insulation with a pocket knife as explained in Step 4. Whenever you use a knife for removing insulation or scraping wire, however, *try to avoid cutting or nicking the wire.* Even the slightest nick will weaken the wire enough to cause a break eventually at that point, if the wire is subject to considerable bending or vibration.

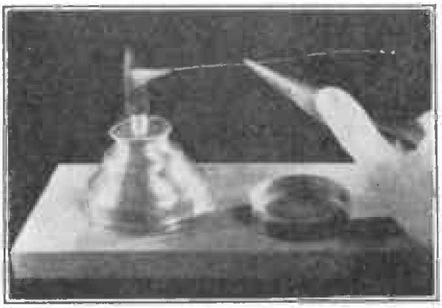


FIG 18. If enamel-covered wire is held just inside the tip of the *inner cone* of an alcohol burner flame as illustrated here, the wire will become red hot and the enamel will burn off. The inner cone appears darker in color than the outer cone. If the room is drafty due to air currents, the flame will flicker and make heating difficult; a few boxes or boards set up around the flame will prevent this flickering. Some experimentation may be necessary to find the portion of the inner cone which will heat the wires red hot, for other portions of the flame will not remove the enamel and oxides.

Scraping with a knife blade as described in Step 5 is the method used most often by radio men for removing enamel insulation from a wire. Use only a small portion of the knife blade near the handle for scraping wires, as this dulls the blade quickly. The main part of the blade should be kept as sharp as possible, for cutting purposes.

A small piece of fine sandpaper can be used for removing enamel insulation with no danger of nicking the wire. Simply fold the sandpaper over the wire, then pull the wire out from the sandpaper. Repeat as many times as necessary to remove all enamel. A few trials will tell you how hard to press the sandpaper between your fingers while drawing out the wire. Stranded enameled wire can be cleaned in this same way if the wires are spread out and are turned a little each time so as to expose all of their surfaces to the sandpaper; this is illustrated in Fig. *19*.

Burning off enamel with an alcohol burner gives a better job than scraping, and eliminates the possibility of damaging the copper wire. The tip of the inner cone in the flame is hot enough to make the wire red hot and remove the enamel and oxides. Plunging the hot wire quickly into alcohol prevents the cleaned wire from tarnishing while cooling. The same alcohol used for the burner can serve for this purpose; the alcohol can be poured back in the bottle after you have finished with it.

FIG. 19. Method of using fine sandpaper (about Number 00) to remove enamel insulation from stranded wire. Press the folded sandpaper (a piece about one inch wide and two inches long) together with the wire in between as indicated, then draw the wire out. Repeat this procedure until all the enamel has been removed from each strand of the portion of the wire which is to be tinned or soldered.

The samples of wire supplied you for the experiments in this Manual are long enough so that you can cut off an inch or so of wire from an end and repeat the experiment in case you accidentally damage the wire. Do not cut the wires any shorter than 5 inches, however, for you will need these wires later for practicing actual radio connections.

Instructions for Report Statement No. 3. After completing this experiment and studying the discussion, read Report Statement No. 3 carefully. Place a check mark in the box following *the type of wire which you found easiest to prepare for soldering.* Then copy your answer on the last page of this Manual.

Report Statement No. 3: The wire which I found *easiest* to prepare for soldering by pushing back or removing insulation was: solid tinned *push-back wire* ☒; *solid untinned insulated wire* ☐; *stranded untinned lamp cord* ☐.

EXPERIMENT 4

***Purpose:* To tin hook-up wire.**

NOT DONE

Step 1. To learn how to tin solid wire properly, practice by using the *solid* untinned wire (Part *1-7E)* from which you have already removed the insulation at the ends and cleaned the exposed copper. Leave the heated soldering iron in its holder with the tip facing you. Hold the wire in one hand with one end resting on a flat surface of the soldering iron tip, then apply solder to the *wire* with the other hand, as illustrated in Fig. *20*. Slide and rotate the wire slowly between the iron and the solder until the wire is completely tinned. Shake off surplus solder from the wire. Tin the other end of this wire in the same way.

Step 2. To learn how to tin stranded wire properly, untwist the exposed and cleaned strands at one end of the lamp cord wire (Part *1-7G)* so that the strands are separated from each other for a distance of about ½ inch from

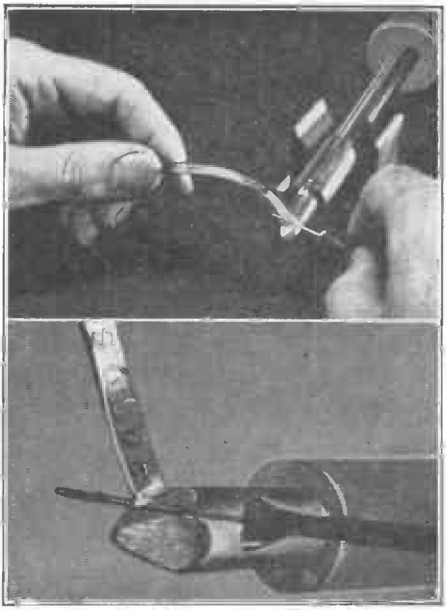


FIG. 20. Method of holding the solder and wire when tinning either solid or stranded wire. The heated soldering iron is left in its holder. The close-up photo shows a partly tinned wire. Slide the wire back and forth between the soldering iron tip and the solder until it is completely tinned for about half an inch from the end.

the end, as shown in Fig. *21*. Tin this wire by applying solder to one side of the strands while heating them from the other side with the soldering iron, just as you did in Step 1. When all strands have been tinned for ½ inch from the ends, shake off surplus solder from the strands while the solder is still in molten form, or simply tap the strands with the heated soldering iron. After the wire has cooled, twist the strands together again. If you have difficulty in getting the strands twisted tightly (see Fig. *21G*), heat them a little with the soldering iron. Stranded wire at various stages of this tinning process is illustrated in Fig. *21*. Tin one end of the 7-strand enameled aerial wire (Part *1-7H*) in this same manner.

Now tin the untinned end of the lamp cord wire (Part *1-7G*) with the strands twisted together, by following the tinning procedure given in Step 1. Tin the untinned end of the enameled aerial wire (Part *1-7H*) in this same way (with the strands twisted together).

Discussion: Solid wire is remarkably easy to tin if clean. New wire can usually be tinned without cleaning, but old wire should be scraped clean first. It is usually sufficient to tin the wire up to about ¼ inch from the insulation; if you go much closer than this with the soldering iron, there is danger of burning the insulation.

Untinned stranded wire is often difficult to tin properly unless the strands are individually cleaned and the procedure given in Step 2 is followed completely. If properly done, the tinned wire can be twisted together again. Difficulty in tinning stranded wire means that additional careful scraping is necessary.

With new and fairly clean stranded wire, it is possible to tin the wire without untwisting, just as if it were a solid wire. There are two drawbacks to this short-cut method. First and most important, *the inside strands may not be thoroughly tinned.* Second, after tinning, the wire will be so stiff that bending it to form a joint may be quite difficult.

Instructions for Report Statement No. 4 After completing this experiment and studying the discussion, read Report Statement No. 4 carefully, then place a check mark in the box following the answer which you believe tells when you will get *more thorough tinning of stranded wire.* Then copy your answer on the last page of this Manual.

Report Statement No. 4: Stranded wire can be tinned *more thoroughly: while the strands are twisted together* ☐; *while the strands are untwisted and spread out for individual tinning* ☑.

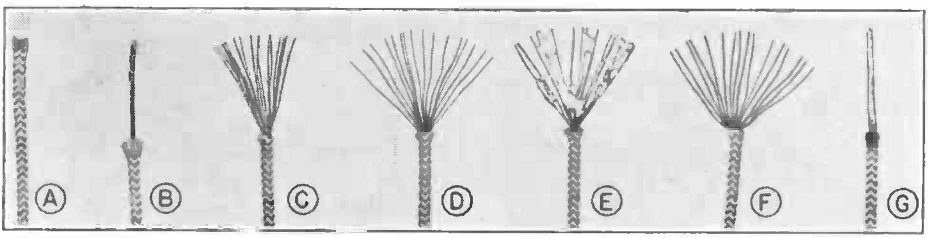


FIG. 21. Steps in preparing one end of the lamp cord (Part *1-7G*) which has rubber insulation covered with cotton braid. *A*—Original wire; *B*—Wire with insulation removed from end; *C*—Strands spread out for cleaning; *D*—Cleaned strands ready to be tinned; *E*—Completely tinned strands; *F*—Tinned strands after surplus solder has been removed; *G*—Tinned strands twisted together again.

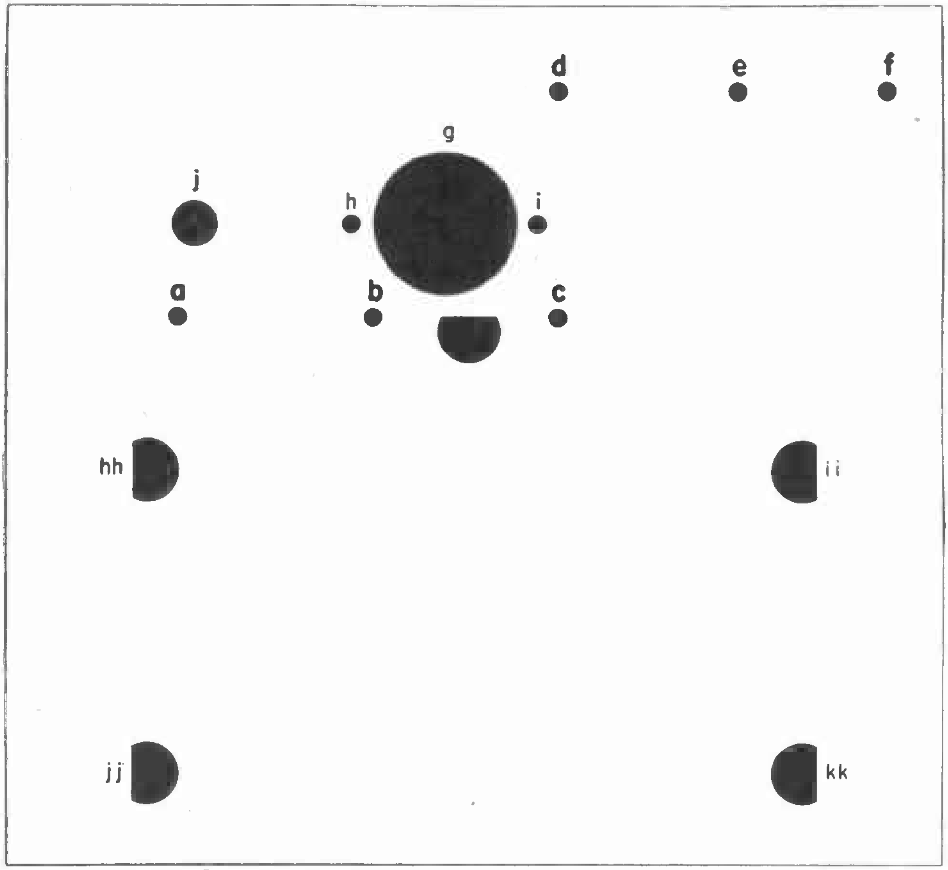


FIG. 22. Bottom view of the metal chassis, Part *1-11*. The front edge of the chassis has three holes and is bent in the same direction as the sides. The back edge of the chassis has no holes, and is bent in the opposite direction from the other three edges. The large letters *a, b, c, d, e,* and *f* can be placed alongside the holes with a metal-marking crayon, ordinary soft lead pencil, or with pen and ink.

EXPERIMENT 5

Purpose: **To mount soldering lugs on a metal chassis and prepare them for soldering.**

Step 1. Mount the three tinned soldering lugs (Parts *1-8A, 1-8B,* and *1-8C) in holes d, e, and f respectively on the bottom of the metal chassis* (Part *1-11),* in the following manner. Place the chassis on your table, bottom up, locate the six holes which are to be used for lugs in this experiment, and mark them with a metal-marking crayon as indicated in Fig. *22*.

Now bend a tinned lug *(1-8A)* at an angle of about 45°, using long-nose pliers as shown in Fig. *23*. Insert a machine screw (Part *1-9A)* in hole *d* from the top of the chassis, and hold the head of the screw in place with a finger. Place lug *1-8A* over the screw from the bottom of the chassis, with the bent part of the lug away from the chassis, then place a nut (Part *1-9B)* on the screw and tighten it with your fingers.

Hold the nut and lug with ordinary all-purpose pliers in the manner shown in Fig. *24A*, so that the lug points

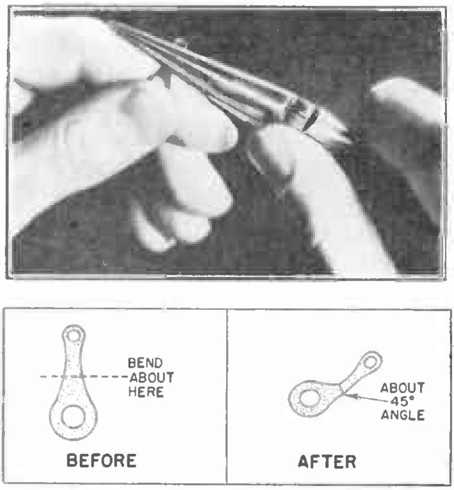


FIG. 23. Method of bending a soldering lug with long-nose pliers. Bending should be done *before* the lug is bolted to the chassis; once a flat lug is bolted to a chassis, it is difficult to pry the lug upward to a convenient soldering position.

toward the back of the chassis, and tighten the bolt head from the top of the chassis with a medium-sized screwdriver as shown in Fig. *24B*. Now bend the other two tinned lugs *(1-8B* and *1-8C)*, and fasten them in holes *e* and *f* respectively, with screws and nuts in exactly the same way. These three tinned lugs are now ready for use.

Step 2. To get experience in tinning untinned lugs before they are mounted, take untinned lug *1-8D* and file both sides of the lug at the end having the smaller hole, until the copper shows clean and bright at this end of the lug. Scraping the lug with your pocket knife blade is an alternative cleaning method. Now hold the cleaned part of the lug against a flat face of the heated soldering iron tip with long-nose pliers, and rub *a small amount* (less than ¼ inch) of rosin-core solder over the uppermost cleaned surface as shown in Fig. *25*. Turn the lug over and apply solder to the other side. Rub the lug back and forth over the iron to spread the solder and make it adhere to the cleaned surfaces.

To remove surplus solder after tinning, hold the lug with the pliers in one hand, heat the lug with the soldering iron held in the other hand, then tap the lug gently against the tip of

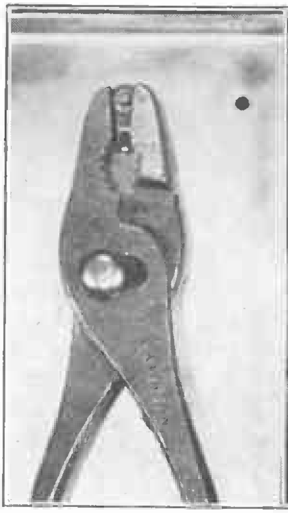


FIG. 24A. One method of using ordinary all-purpose pliers to prevent the soldering nut and lug from turning as screw is tightened.

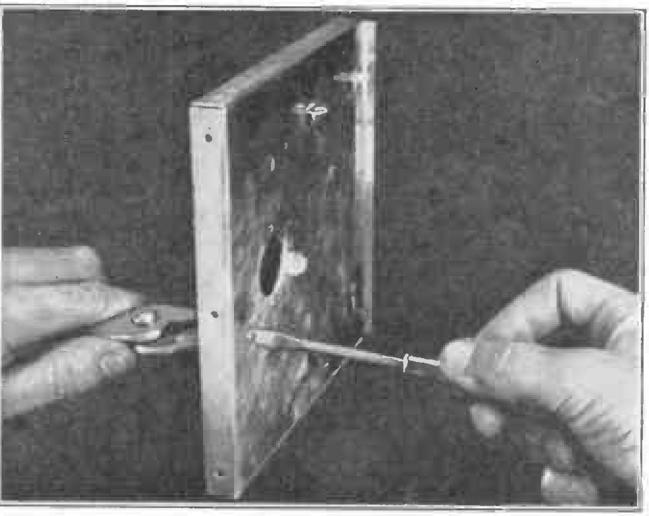


FIG. 24B. Another method of holding a nut with ordinary pliers while tightening a machine screw which is being used for mounting a soldering lug underneath the chassis. The screw should be tightened enough so that the lug cannot readily be moved with the fingers.

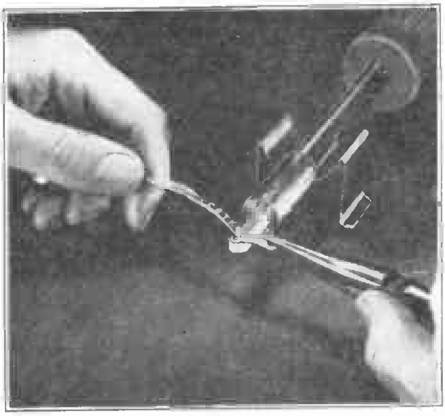


FIG. 25. Method of tinning a lug prior to mounting it on a chassis. This technique is used only for untinned lugs, or for tinned lugs which have become coated with oxides and dirt.

the iron to shake off surplus molten solder. (Sometimes it is more convenient to wipe off the surplus molten solder from the lug with a cloth.) Bend the lug approximately at its center, using pliers and fingers as shown in Fig. *23*, then mount this lug in hole *a* on the bottom of the chassis as shown in Fig. *26*.

Using the same methods, clean lug *1-8E* by filing or scraping, then proceed to tin the lug and remove surplus solder. Bend the lug at a 45° angle just as you did for the other lugs, then mount this lug in hole *b* on the chassis.

Step 3. To get experience in tinning an untinned lug which is already mounted on a chassis, bend lug *1-8F* in its center about half as much as you bent the other lugs, then mount this lug in hole *c* on the bottom of the chassis. Scrape the exposed upper half of the lug with the knife blade until clean, then hold the heated soldering iron against the top of the lug for a few seconds. Now slide the soldering iron down along the lug far enough so you can apply rosin-core solder directly to the top of the lug, and rub the solder over the lug by sliding the iron back and forth. Apply additional solder if some parts of the lug near the small hole are untinned, but use as little solder as possible in order to avoid having surplus solder roll down the lug to the nut.

Step 4. To practice removing surplus solder from a mounted soldering lug, use a cloth to wipe as much surplus solder as possible from the tip of

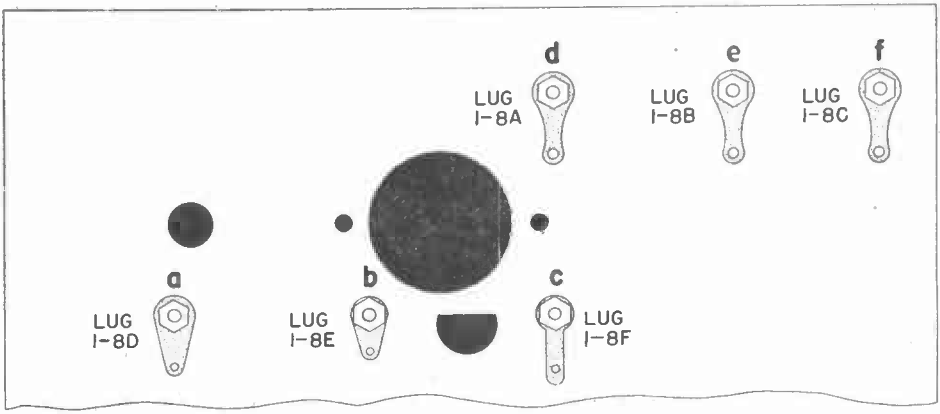


FIG. 26. Upon completion of Experiment 5, you should have six soldering lugs, all tinned, mounted on the chassis exactly as shown here, and with the ends of the lugs bent upward as shown in Fig. 23. Note that the letters in the part numbers identifying the various lugs do *not* correspond to the letters identifying the chassis holes in which the lugs have been mounted.

the heated soldering iron, then apply the iron to lug *1-8F* so as to pick up some of the surplus solder on the lug. Wipe this solder from the iron, then repeat the process as many times as are necessary to get the solder out of the small hole in the lug. Sometimes solder can be poked out of the hole by inserting the cleaned tip of the soldering iron in the hole. The six lugs should now appear as shown in Fig. *26*.

Discussion: Separate soldering lugs like those supplied in this Radio Kit are used chiefly for making connections to a metal chassis. Wire could be soldered directly to the chassis in some cases, but chassis metals are usually difficult to tin, and require more heat than can be supplied by the average radio soldering iron. Furthermore, a soldered connection to a flat metal surface is usually messy in appearance. Remember that tinned soldering lugs similar to those you mounted in Step 1, or lugs which you have previously tinned, should be used for making soldered connections to a chassis or any other large metal surface.

It is generally easier to bend soldering lugs before they are mounted. Bending a lug away from the chassis makes it easier for you to attach wires to the lug. As a general rule, bend a lug approximately in its center. Hold the small end of the lug with the pliers, for you can bend the large end more readily with your fingers.

When using a soldering lug, you ordinarily apply solder only to the bent-up half of the lug, hence only this portion need be cleaned and tinned. When the lug is unmounted, it is best to clean and tin both sides in the vicinity of the smaller hole. When a lug is mounted on a chassis, only the uppermost surface is cleaned and tinned, for it is difficult to work on the underneath surface.

Some soldering lugs which appear to be tinned are actually coated with nickel, a metal to which rosin-core solder does not readily adhere. With lugs like this, scrape or file away the nickel surface so as to expose the brass or copper underneath.

The secret of tinning a soldering lug properly lies in applying the rosin-core solder directly to the lug, a small distance away from the soldering iron tip. The rosin flux can then act on the lug. If the solder rolls off, the lug is too hot and should be allowed to cool for a few seconds. Insufficient cleaning and tinning is indicated when you can wipe off solder completely from parts of the lug. Rubbing the soldering iron tip back and forth over the top of the lug helps to make the solder adhere.

When a soldering lug is being tinned, the hole in its small end usually fills with solder. This hole must be opened to permit looping the connecting wire through the hole. Brushing out the solder is bad practice, for it scatters molten solder in all directions and may result in short circuits. One technique for getting out this solder is given in Step 4; practice this several times by filling the holes again with solder after you have cleaned them out, and you will soon find yourself lifting off surplus solder just as speedily as does an experienced serviceman. Incidentally, some servicemen do not bother to remove surplus solder from the hole; when ready to make a connection, they simply apply the soldering iron to melt the solder, then poke the wire through the hole. Shake surplus solder from the iron whenever necessary, and wipe the soldering iron frequently with a cloth. The less solder on the iron, the more solder you can pick up.

Instructions for Report Statement No. 5. After completing this experiment and studying the discussion, read Report Statement No. 5 carefully, place a check mark in the box following *the correct method of connecting a hook-up wire to the metal chassis of a radio receiver.* Then copy your answer onto the last page.

Report Statement No. 5: When a wire is to be connected to the chassis of a radio receiver, the wire should be: *soldered directly to the chassis* ☐; *soldered to a tinned lug which has been bolted to the chassis* ☒; *pushed into any convenient hole in the chassis and soldered* ☐.

EXPERIMENT 6

***Purpose:* To secure practical experience in making temporary and permanent soldered connections to lugs.**

Step 1. To make a temporary hook joint to a soldering lug with solid wire, bend one end of a length of the solid, tinned push-back wire (we will designate this as Part *1-7A)* into a hook by using long-nose pliers, as illustrated in Fig. *27*. Insert this hook in the hole in *lug 1-8D*, starting from the bottom of the lug as shown in Fig. *28A*. Bend the hook a little more after inserting, if there is any tendency for the wire to fall out, but do not pinch the hook together for this temporary joint.

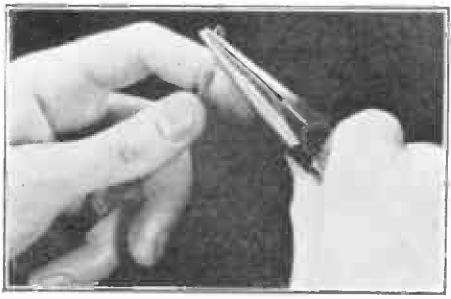


FIG. 27. Forming a hook on solid wire with long-nose pliers, preparatory to making a soldered hook joint.

Now apply your heated soldering iron to the under side of the lug, and apply rosin-core solder directly to the wire and to the lug, as in Fig. *28B*. Apply just enough solder to fill the gap between the lug and the upper part of the hooked wire, then remove the soldering iron. Do not move the wire until the solder has hardened. The finished temporary hook joint is shown in Fig. *28C*.

IMPORTANT. The soldering tip must make good contact with both the lug and the wire, so as to heat and solder both parts of the joint.

Step 2. To make a temporary hook joint to a soldering lug with stranded wire, take the stranded push-back wire (Part *1-7D)*, twist the strands

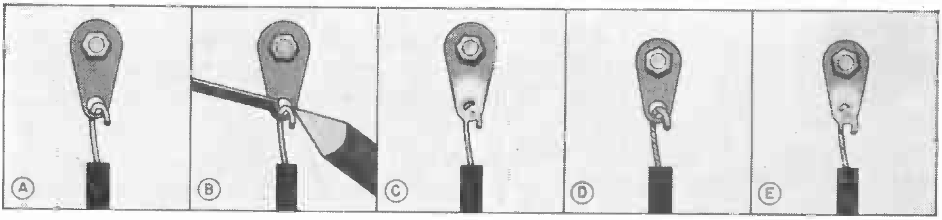


FIG. 28. Temporary connections to soldering lugs. *A*—Temporary hook joint to a soldering lug with solid wire, before soldering; *B*—Method of soldering a hook joint on a soldering lug. Note that the soldering iron is held on top of the lug, on one side of the wire, and solder is applied to the other side of the wire; *C*—Your temporary hook joint with solid wire should appear like this after soldering; *D*—Temporary hook joint with stranded wire, before soldering; *E*—Temporary hook joint with stranded wire, after soldering.

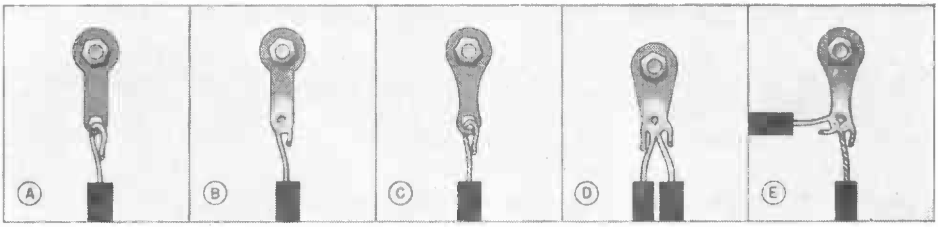


FIG. 29. These illustrations show essential features of various soldering lug connections. Note how the solder joins the wire and the lug into a single unit. This is possible only when the *work* is heated sufficiently to melt the solder into a liquid. *A*—Permanent hook joint with solid wire, before soldering; *B*—Permanent hook joint with solid wire, after soldering; *C*—Permanent hook joint with stranded wire, before soldering; *D*—Two temporary hook joints to a lug with solid wire, after soldering; *E*—Two permanent hook joints to a lug, after soldering.

together with your fingers if they have become unraveled, bend the end into a hook, insert the hook in *lug 1-8E* from underneath as shown in Fig. *28D,* and solder the joint exactly as instructed in Step 1. The soldered joint should appear as in Fig. *28E,*

Step 3. To make a permanent hook joint to a soldering lug with solid wire, take another length of solid push-back wire (we will designate this as Part *1-7C),* bend a hook in one end with long-nose pliers, and insert the hook in *lug 1-8F* from underneath just as you did in Step 1. Squeeze the hook together with long-nose pliers so that it resembles Fig. *29A,* then solder the joint according to the instructions in Step 1. The final soldered joint is shown in Fig. *29B.*

Step 4. To make a permanent hook joint to a soldering lug with stranded wire, take the stranded hook-up wire (Part *1-7F),* twist the strands together with the fingers if necessary, bend the end into a hook, insert the hook in *lug 1-8A* from underneath, squeeze the hook together tightly with long-nose pliers as illustrated in Fig. *29C,* and solder the joint as instructed in Step 1.

Now take the stranded lamp cord wire (Part *1-7G*) and make the same type of permanent hook joint to *lug 1-8B,* using that end of the wire which was tinned *without untwisting the strands.*

Finally, take the stranded enameled aerial wire (Part *1-7H)* and make a permanent hook joint with either end of it to *lug 1-8C,* then solder it.

Step 5. To make a temporary hook joint to a soldering lug which already has one connecting wire, take the remaining length of solid push-back wire (this will be designated as Part *1-7B)* and form a hook at one end with long-nose pliers. Apply the heated soldering iron to the solder at the top of *lug 1-8D* so as to melt the solder, then insert the hook of your wire in this hole from underneath while holding the soldering iron on the top or side of the lug so as to keep the solder in a molten state. When both wires are hooked through the hole in the lug as shown in Fig. *29D,* remove the soldering iron and allow the joint to cool.

Step 6. To make a permanent hook joint around a soldering lug instead of through the hole in the lug, take the length of solid untinned wire (Part *1-7E),* form a hook at one end with long-nose pliers, loop this hook around *lug 1-8A* just behind the existing connection to this lug, as shown in Fig. *29E,* squeeze the hook tightly over the lug with long-nose pliers, then apply rosin-core solder to one side of the hook and to the lug while holding the heated soldering iron on the other side of the hook.

Step 7. To secure practice in "dressing" wires neatly, first compare your work carefully with the illustration in Fig. *30* to make sure that your wires are on the correct lugs (again note that letters identifying the chassis holes and the solder lugs do not correspond), then straighten out each wire with you fingers and arrange them all neatly in the manner shown in Fig. *30* so they will be ready for the next experiment.

Now apply the heated soldering iron to lug *1-8A* so as to melt the solder on stranded wire *1-7F,* then grasp this wire with long-nose pliers and hold it rigidly in position at the angle shown in Fig. *30,* while the solder is hardening. Rest either your hand or the pliers on the chassis.

Discussion: Soldered connections to soldering lugs are among the most common which you will make in your radio work. In this experiment, you make such a wide variety of connections to soldering lugs that you are prepared for just about any type of soldering lug connection you may require in professional radio work.

A temporary connection is made only when you are reasonably sure that you will have to remove the wire in the near future. A permanent joint differs from a temporary joint only in the squeezing of the hook prior to soldering. A permanent connection is always more satisfactory, and should be used whenever there is any chance at all that the joint may be in use for some time. The permanent connection possesses mechanical strength as well as good electrical contact; thus, a good permanent connection will withstand pulling and will serve its electrical purpose even before it is soldered.

To avoid burning the insulation on a wire when soldering, it is best to bend the hook in such a way that all insulation will be at least 1/8 inch away from the lug when the wire is in soldering position. In the case of push-back wire, this insulation can be pushed right up to the lug after the joint is soldered; with other types of wire, the insulation cannot be moved.

Remember, *a joint must not be disturbed while the solder is hardening.* If the wire will not remain in position by itself during this time, hold it rigid with your hand. If you rest your hand on the chassis when doing this, you will have no difficulty in holding a wire without appreciable movement for the few seconds required for the solder to harden. Joints must often be remelted to change the positions of wires, so the experience you secure in Step 7 is particularly valuable.

Solder which is on a lug or wire hardens far more rapidly than a globule of solder on a board, because lugs and wires conduct heat away from the solder and speed up the cooling.

Instructions for Report Statement No. 6. After completing this experiment and studying the discussion, read Report Statement No. 6 carefully, then place a check mark in the box following *the correct method of making a temporary soldered connection to a soldering lug.* Copy your answer onto the last page of this Manual.

Report Statement No. 6: In a *temporary* soldered connection to a soldering lug, the wire is: *threaded twice through the hole in the lug* ☐; *hooked through the hole in the lug and squeezed before soldering* ☑; *hooked through the hole in the lug but not squeezed.*

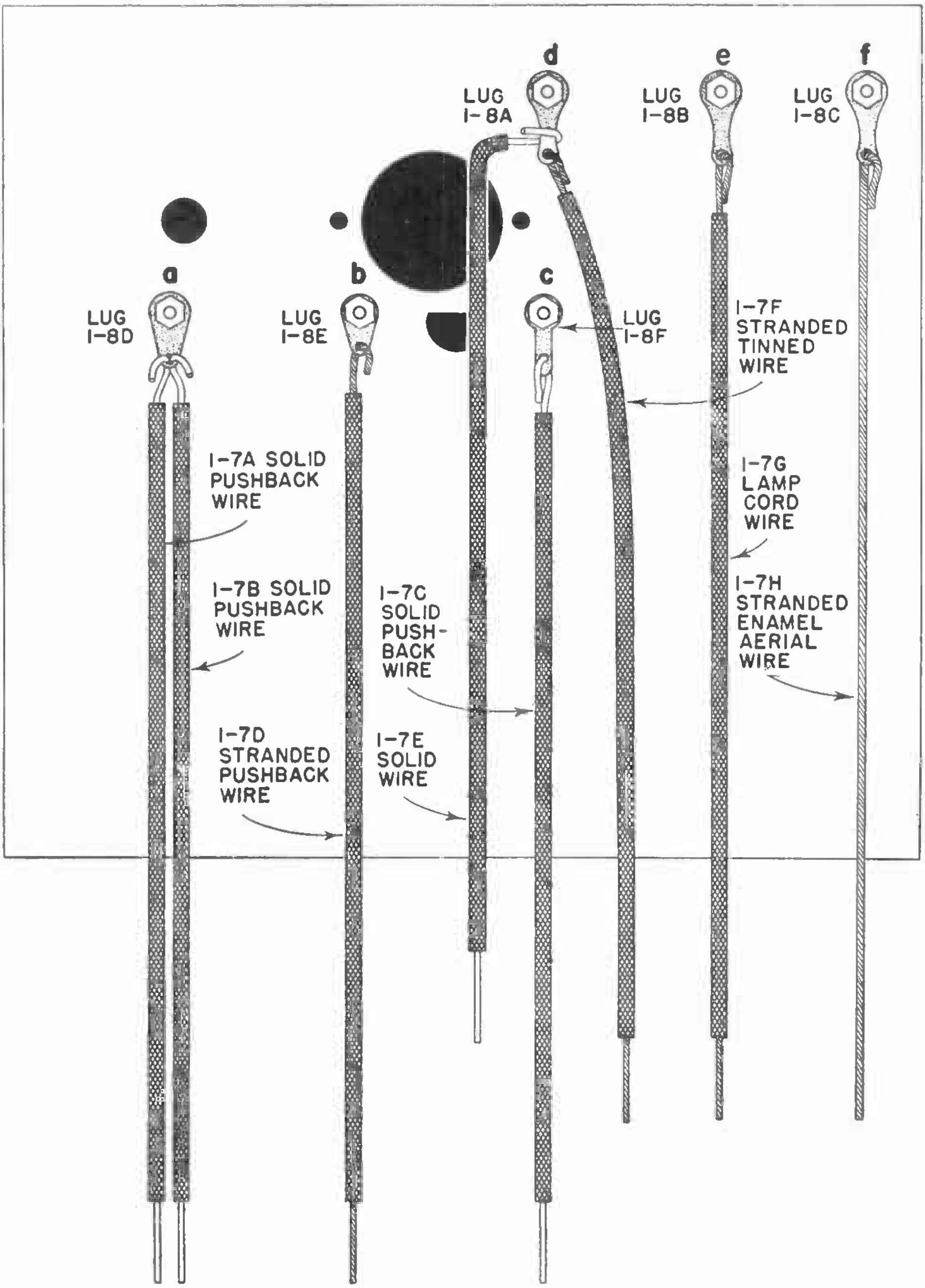


FIG. 30. Appearance of bottom of chassis after completion of Experiment 6. The actual soldering, of course, is not shown here. Each of the soldering lug connections commonly used by radio men is included in this experiment.

EXPERIMENT 7

Purpose: **To secure practical experience in soldering two wires together temporarily and permanently.**

Step 1. To make a temporary hook joint between two wires, locate wire 1-7B and wire 1-7E on the chassis (by referring to Fig. 30) and bend a hook in the free end of each with long-nose pliers. Hook together the free ends of the two wires as indicated in Fig. *31A*. If you first spread out the two wires, they will not fall apart when hooked together. Hold the heated soldering iron on one side of the joint for a few seconds, then apply rosin-core solder to the wires, starting at the soldering iron and then moving the solder away from it along the wires (see Fig. *31A)*. Remove the solder and the iron, and allow the joint to cool without disturbing it. The completed joint should resemble that shown in Figs. *31B* and *37*.

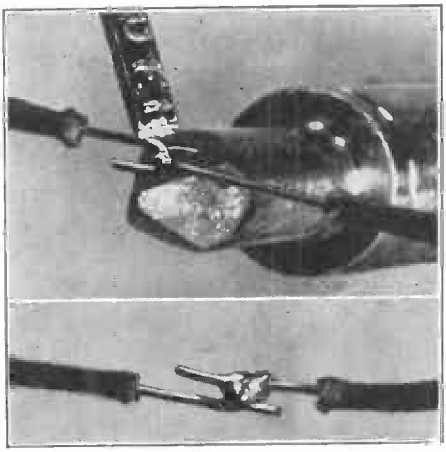


FIG. 31A (above). Correct way to solder a temporary hook joint. The tip of the iron is held under the joint, and the solder is applied to the wire from above.
FIG. 31B (below). Completely soldered temporary hook joint. Note that the hooks are *not* closed.

Step 2. To connect together two wires by means of a professional Western Union splice, locate wire *1-7A* and wire *1-7C*, and push back the insulation far enough to expose at least 1½ inches of wire at each free end (if the insulation cannot readily be pushed back this amount, remove the required amount of insulation by squeezing with pliers or by cutting with a pocket knife).

Grasp wire *1-7A* in your left hand, grasp wire *1-7C* in your right hand, and cross them in the manner shown in Fig. *32A*. The wires and the positions of the hands in this illustration are exactly as you would see them when looking at your work. Observe that wire *1-7A* is between you and wire *1-7C*.

Holding both wires between the thumb and forefinger of your right hand as shown in Fig. *32B*, twist the end of wire *1-7C* around the other wire with the thumb and forefinger of your left hand. Leave a little space between the turns so solder will flow readily between the wires. Continue twisting until only about ¼ inch of wire *1-7C* is left.

Now grasp the twisted part in your left hand and proceed to twist the free end of wire *1-7A* over the other wire in the *opposite* direction with your right hand, as illustrated in Fig. *32C*. Again allow about ¼ inch of wire to remain untwisted, so that the splice appears as shown in Fig. *32D*.

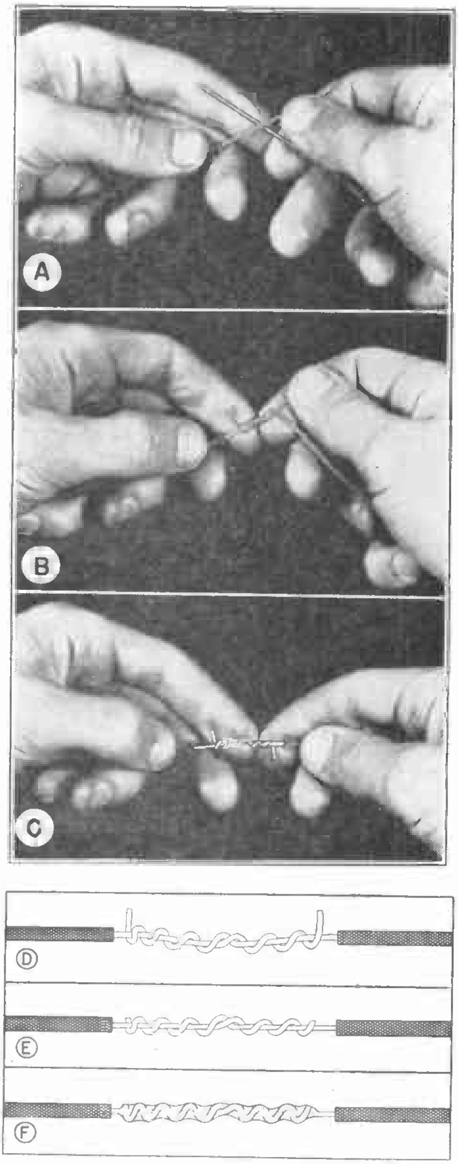


FIG. 32. Steps in connecting two wires together permanently by means of a Western Union soldered splice.

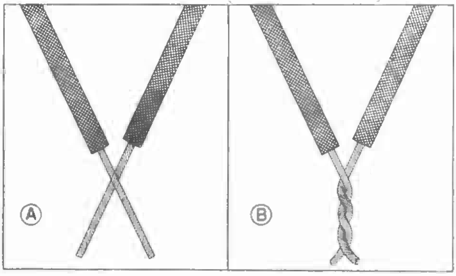


FIG. 33. Steps in making a common twist splice. This permanent joint is also known as a *Bell splice*, since it is used extensively by Bell Telephone linemen and switchboard men for connecting telephone wires together. When making this joint with solid wire, remove insulation for about 1½ inches from the end of each wire, twist up to about ¼ inch from the ends, solder the joint securely, then cut off the surplus wire with your side-cutting pliers.

Cut off the projecting ends of the wires with your side-cutting pliers, and straighten up the splice with the fingers so that it appears as shown in Fig. *32E*. Now hold the heated soldering iron alongside the splice just as you did in Step 1, and apply rosin-core solder first between the splice and the tip of the iron, then over all parts of the splice. Slide both the solder and the soldering iron along the splice to speed up the process, until the entire twisted portion of the splice is covered with solder. The completed splice should appear as shown in Fig. *32F*.

Step 3. To connect two wires together by means of a permanent Bell splice, locate stranded wire *1-7F* and the stranded lamp cord wire *1-7G* on the chassis, cross the bare end of the wires as shown in Fig. *33A*, then proceed to twist the wires together *with the fingers* so that the result appears as shown in Fig. *33B*. Cut off about 1/16 inch from the end of the splice with side-cutting pliers to give a neat joint, then solder the splice as instructed in Step 1.

Step 4. To make a permanent T type joint to some point on wire *1-7C*, take your pocket knife and cut through the insulation at a point near the center of this wire, being careful not to change the wire itself. Now push the insulation apart at this point so as to expose about 1 inch of wire. (Do not discard the wire if you accidentally nick it, for the soldered joint will bridge across the nick in the wire.) Take the stranded wire *1-7D*, shorten it as shown in Fig. *37* by winding the wire a few times around a pencil, then twist together the strands at its free end, and wind this end around wire *1-7C* with your fingers. Space the turns apart a small amount as shown in Fig. *34*. Trim off the ends of the strands with side-cutting pliers, then solder the joint as instructed in Step 1. Now push the insulation on wire *1-7C* up to this T joint on both sides.

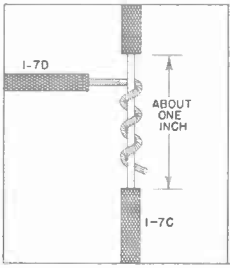


FIG. 34. Permanent T type joint between two insulated wires.

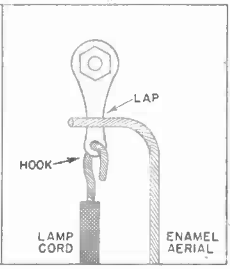


FIG. 35. Temporary lap joint on top of a soldering lug.

Step 5. To make a temporary lap joint between one wire and a lug or between two wires, take enameled wire *1-7H* and apply additional solder to its free end by employing the same technique used for tinning solid wires. Next, apply a small amount of solder to the top of lug *1-8B*, just behind the joint already on this lug. Now hold the free end of the wire over the lug just behind the joint, as shown in Fig. *35*, press your heated soldering iron over rosin-core solder so it will pick up some solder on its lower face, then apply the soldering iron to the top of wire *1-7H* so as to fuse together the solder on the wire and the solder on the lug. Remove the soldering iron when fusion occurs, but continue holding wire *1-7H* rigid until the solder has hardened. The completed joint is shown in Fig. *37*.

Discussion: Radio servicemen probably use the temporary hook joint more often than any other joint for connecting together two wires. The reason is simply that this joint can be unsoldered and separated very easily. The joint can be made more permanent, yet still be unsoldered fairly easily, by squeezing the two hooks together with long-nosed pliers just before soldering.

As a general rule, a joint between two wires should always be covered with friction tape when left permanently in a radio receiver. Radio men prefer to use a special narrow type of friction tape, obtainable in ⅜-inch wide rolls at radio supply houses, for the standard ¾-inch tape is awkward to use on small joints.

When a joint is taped, all exposed wires are covered with at least two thicknesses of the friction tape, and the surrounding insulation is also covered with friction tape for about ½ inch on each side of the joint. Typical taped joints are shown in Fig. *36*.

Figure *37* is presented for reference purposes, to show you how your chassis should look after completing this experiment. Whenever you are in doubt as to the position in which a particular joint is to be made, refer to this illustration.

The hook joint is not suitable for use where considerable force may be applied to the wires. The Western Union splice described in Step 2 is preferred by radio men when mechanical strength is required. Telegraph lines on poles are joined together by means of this splice.

The Bell splice described in Step 3 is usually easier to make in a crowded radio chassis than is the Western Union splice. When made with stranded wire, the Bell splice is readily formed with the fingers; with solid wire, it can either be twisted with the fingers up to about ¼ inch from the end, and the surplus wire then cut off, or the twisting can be completed with long-nosed pliers. Study the illustrations carefully, to determine just how much of a twist each type of splice should have.

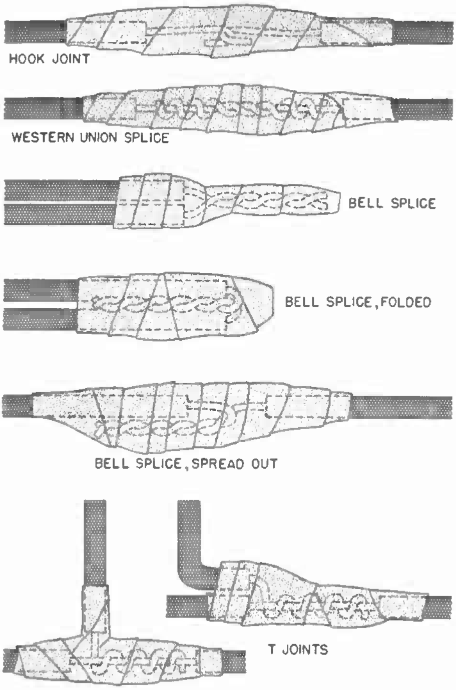


FIG. 36. Methods of taping the various types of soldered joints taken up in this manual. These diagrams are presented for future reference only, since you do not have to tape any of the joints used in your Practical Demonstration Course.

The permanent T joint described in Step 4 is occasionally required in radio work, for it permits connecting one wire to any point along another wire. The important factor in this joint is the removal of the insulation along the wire without damaging the wire itself. With push-back wire, only a single cut need be made, for the insulation can then be pushed apart. With other types of insulation, however, the insulation must be sliced off carefully with a knife, or squeezed with pliers and then trimmed off.

The temporary lap joint covered in Step 5 is widely used by radio men for test purposes. You will use it extensively in future experiments in your demonstration course. This joint can be made just as well to another soldered connection or to a wire; it was made to a soldering lug in this step merely for convenience. The secrets of a good lap joint are applying the solder to the individual parts *before* placing them together, and holding the wire perfectly rigid while the solder is hardening.

In soldering any joint, first make a secure mechanical connection, and then be sure that the solder flows in between the turns or twists of the wire. If the wire has previously been tinned properly, there should be no difficulty in accomplishing this.

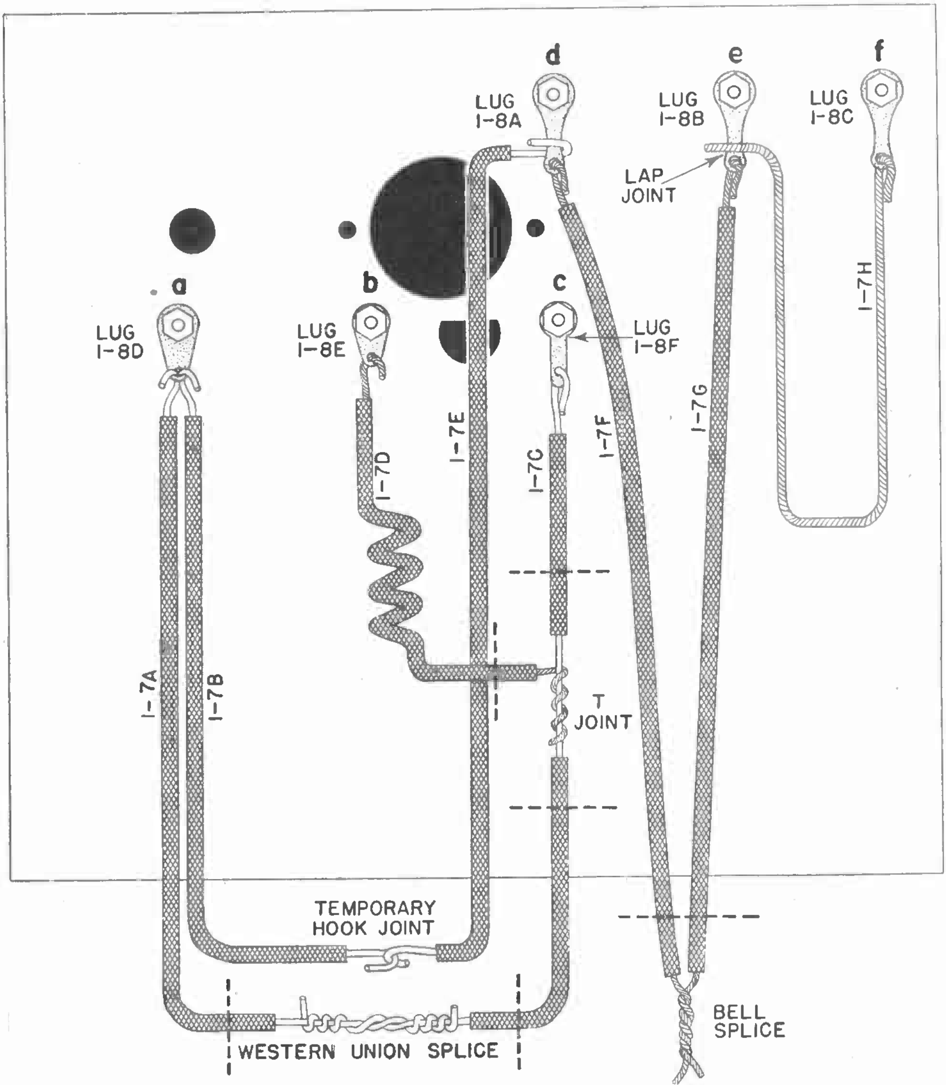


FIG. 37. Your chassis should appear like this after you have completed each of the joints called for in this experiment. The dotted lines indicate the approximate positions at which cuts should be made to remove the splices after completing the experiment.

Any connection which depends upon solder for adequate mechanical strength and electrical conductivity is known as a *joint*. A connection between two wires which gives adequate mechanical strength and electrical conductivity initially without solder is known as a *splice*. Solder is used on a true splice chiefly to prevent corrosion with age from affecting the original electrical conductivity.

The only two splices which are used to any extent in radio work are the Western Union splice and the Bell splice, both of which you made in this experiment. All other radio connections can be considered as joints. You thus see that the great majority of joints made by professional radio men require soldering for effectiveness.

Instructions for Report Statement No. 7. After completing this experiment and studying the discussion read Report Statement No. 7 carefully, then place a check mark in the box following the answer which you believe *will give the greatest mechanical strength,* when used to connect wires together end to end. Copy your answer onto the last page of the Manual.

Report Statement No. 7: When connecting two wires together where great mechanical strength is required, I would use a: *lap joint* ☐; *Bell splice* ☒; *Western Union splice* ☐; *hook joint* ☐.

EXPERIMENT 8

Purpose: **To secure experience in unsoldering the various types of temporary and permanent connections encountered in radio work.**

Step 1. To secure experience in disconnecting splices and permanent joints between two wires, try unsoldering the Western Union splice by any means you desire. Yes, this joint is very difficult to unsolder; in fact, radio men never bother unsoldering it. Therefore, proceed to cut out this joint with your side-cutting pliers as indicated by the dotted lines in Fig. *37.* Try also to unsolder the Bell splice. It, too, is difficult to unsolder. Cut it out of the lead as you did the Western Union splice. Finally, cut out the T joint by making three cuts with your side-cutting pliers as indicated by the dotted lines in Fig. *37.*

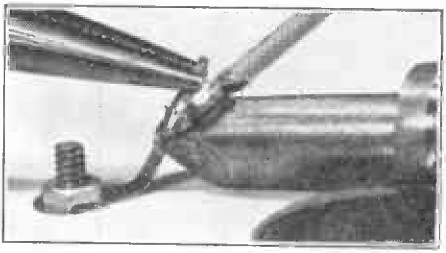


FIG. 38. Method of unsoldering a permanent hook joint on a soldered lug. Spread open the hook with long-nose pliers while keeping the solder molten by holding the soldering iron under the lug.

Step 2. To secure experience in unsoldering temporary joints, unsolder the temporary hook joint between wire *1-7B* and wire *1-7E,* by applying the heated soldering iron to the joint and unhooking the wires as soon as the solder has melted. Using this same procedure of holding the soldering iron against a joint to melt the solder, proceed to unhook the wires from *lugs 1-8D* and *1-8E.* Next, unsolder the lap joint on *lug 1-8B.*

Step 3. To secure experience in unsoldering permanent joints, hold your heated soldering iron in one hand and apply it to lug *1-8A* while pulling open the hook at the end of wire *1-7E* with your long-nose pliers. Slide the wire off the lug as soon as the hook has opened sufficiently for this purpose.

Now open the hook in wire *1-7F* (on this same lug) with long-nose pliers while heating with the soldering iron, and unhook the wire. Be sure to save this wire, because it is a specially insulated wire which you will need later. This professional unsoldering procedure is illustrated in Fig. *38.*

To practice the technique employed by radio men for unsoldering wires which are difficult to bend open, melt the solder on lug *1-8B* with the soldering iron, then wiggle the *1-7G* lamp cord vigorously while the wire is cooling. Spread out the hook as much as possible with long-nose pliers after the joint has cooled, then repeat the heating and wiggling procedure until the wire is separated from the lug.

Use this same wiggling and unbending procedure for enamel wire *1-7H* on *lug 1-8C* and for wire *1-7C* on *lug 1-8F*.

Finally, lift off surplus solder from the lugs on the chassis with the cleaned, heated soldering iron, as instructed in Step 4 of Experiment 5. When there is a great deal of solder on a lug, you can speed up this step by holding the soldering iron tip alongside or under the lug so as to keep the solder molten, and wiping off this solder with quick strokes of a cloth.

Discussion: As you learned by actual trial in Step 1, it is very difficult to unsolder a properly formed splice. In an emergency, you could untwist the splice bit by bit with long-nose pliers while keeping the solder molten with the soldering iron, but this tedious procedure is required only when the wires must be used again and would be too short if cut off. The Radiotrician invariably snips off splices and T joints with the side-cutting pliers, just as you did in this step.

Step 2 demonstrated to you that a temporary soldered joint can be disconnected simply by applying the heated soldering iron to melt the solder, then unhooking the joint. Only when working in awkward and crowded positions is it necessary to spread apart the hook in a temporary joint. Lap joints are the easiest to unsolder of all joints.

When working on radio receivers, most of the joints which you unsolder will be of the type you practiced with in Step 3. These invariably must be spread apart with long-nose pliers before the wire can be unhooked from the lug. Sometimes it will be necessary to remove surplus solder from the joint before you can grip the end of the wire with long-nose pliers.

During unsoldering, surplus solder will accumulate on the soldering iron. Shake this off from time to time, but remember that a *little* extra solder on the iron will speed up transfer of heat to the joint being unsoldered. Sliding the soldering iron back and forth a bit over the joint also speeds up unsoldering, for this tends to break through the coating of oxide and dirt on old solder.

Instructions for Report Statement No. 8. After completing this experiment and studying the discussion, read Report Statement No. 8 carefully, then place a check mark in the box following *the type of joint which you found easiest to unsolder* when you unsoldered these *three* joints in Steps 2 and 3. Copy your answer onto the last page.

Report Statement No. 8: I found it easiest to unsolder a: *lap joint* ☒; *Bell splice* ☐; *Western Union splice* ☐; *hook joint* ☐.

EXPERIMENT 9

Purpose: **To secure practical experience in connecting actual radio parts to soldering lugs by means of temporary and permanent soldered connections just as you would do when servicing radio receivers.**

Step 1. To mount the tube socket (Part *1-10) on the chassis* in preparation for this experiment, take one machine screw (Part *1-9A)* and insert it in hole *h* (Fig *39) from the top* of the chassis. Holding one finger on the head of this screw to keep it in the hole, turn the chassis over and place the tube socket in position in the manner illustrated in Fig. *39,* so that the aligning slot in the center hole of the socket is next to this screw. After pushing the metal mounting flange of the socket over the screw, place a hexagonal nut (Part *1-9B*) on the screw and tighten partially with the fingers. Now take another machine screw, insert it through hole *i* from the top of the chassis and through the other mounting hole of the tube socket, then place a hexagonal nut on this screw. Hold this nut with long-nose pliers, then tighten the screw from the other side of the chassis with a medium-sized screwdriver. Tighten the other socket mounting screw in the same manner.

The tube socket has six terminal lugs, each identified by a number molded into the Bakelite base alongside the lug. The numbers are *2, 3, 4, 5, 6,* and *7*. To speed up future work on this socket, take a crayon or pencil and mark the number of each lug clearly, directly alongside the lug on the bottom of the chassis. The portion of the chassis on which you will work in this experiment should now appear as shown in Fig. *40*.

Step 2. To connect a condenser temporarily between two soldering lugs, take the .05-mfd. condenser (Part *1-13)* and bend an open hook in the end of each lead with long-nose pliers. Bend the condenser leads with your fingers approximately to the shape shown for Part *1-13* in Fig. *41*. Now hook the condenser leads into the holes in lugs *1-8C* and *1-8E* from the bottom and allow the condenser to rest on the chassis, as in Fig. *41*.

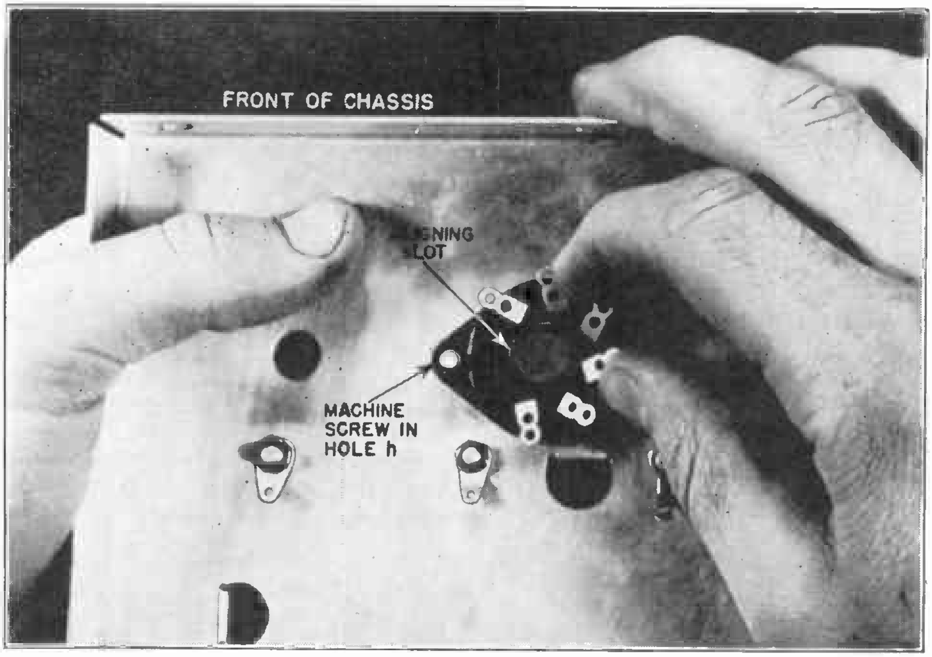


FIG. 39. Method of mounting the tube socket on the chassis. The terminal lugs of the socket should be underneath the chassis, and the aligning slot should be at the left (near hole *h*) when the chassis is held as shown in this illustration. Hold the machine screw in position with a finger of your left hand.

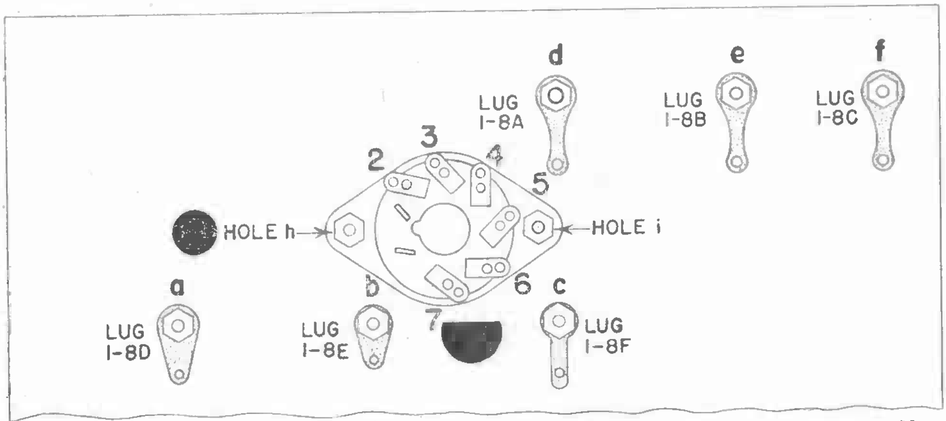


FIG. 40. Your chassis should appear exactly like this after you complete Step 1 in Experiment 9. Note that the socket has been fastened to the *under* side of the chassis.

Solder each condenser lead by applying the heated soldering iron to the top of the lug on one side of the wire, and applying rosin-core solder to the other side of the wire and to the lug.

IMPORTANT: The soldering iron tip must make good contact with both the lug and the wire, so as to heat and solder both parts of the joint.

Step 3. To connect a condenser permanently between two lugs of a tube socket, take the .03 mfd. condenser (Part *1-12),* bend an open hook in the end of each lead, then bend the leads themselves approximately to the shapes indicated for Part *1-12* in Fig. *41*. Hook the condenser leads through the outermost holes in lugs *2* and *7* of the tube socket, by inserting the ends of the leads through the holes in the lugs from underneath, and squeeze each hook together with long-nose pliers, as indicated in Fig. *41*.

Solder the condenser lead which is on lug *7* of the tube socket. Leave the lead on lug *2* unsoldered.

Step 4. To connect a resistor temporarily between two lugs, take the .1-megohm resistor (Part *1-15*) and bend a hook in the end of one lead with long-nose pliers. With your fingers, bend the leads for this resistor approximately as indicated for Part *1-15* in Fig. *41,* then insert the hook into the outermost hole in socket lug *4* from underneath. Push the other resistor lead into the hole in soldering lug *1-8B* from above, then bend the end of the lead up with long-nose pliers to form a hook, as shown on lug *1-8B* in Fig. *41*. Now solder both of the joints for resistor *1-15*.

In the same manner, bend one lead of 18,000-ohm resistor *1-16* into a hook and insert it in lug *1-8D* from underneath as indicated in Fig. *41,* then bend the other lead (as shown in the illustration), push it through the outermost hole in tube socket lug *6* from underneath, then bend the end of the lead back with long-nose pliers to form a hook. Solder both of the joints now for resistor *1-16*.

Step 5. To connect a resistor permanently between two tube socket lugs, take .24-megohm resistor *1-14,* bend its leads approximately as shown in Fig. *41,* form a hook in the end of each lead, then hook the leads through the holes in tube socket lugs *2* and *3* from underneath. This places two leads in lug *2*. If you have difficulty

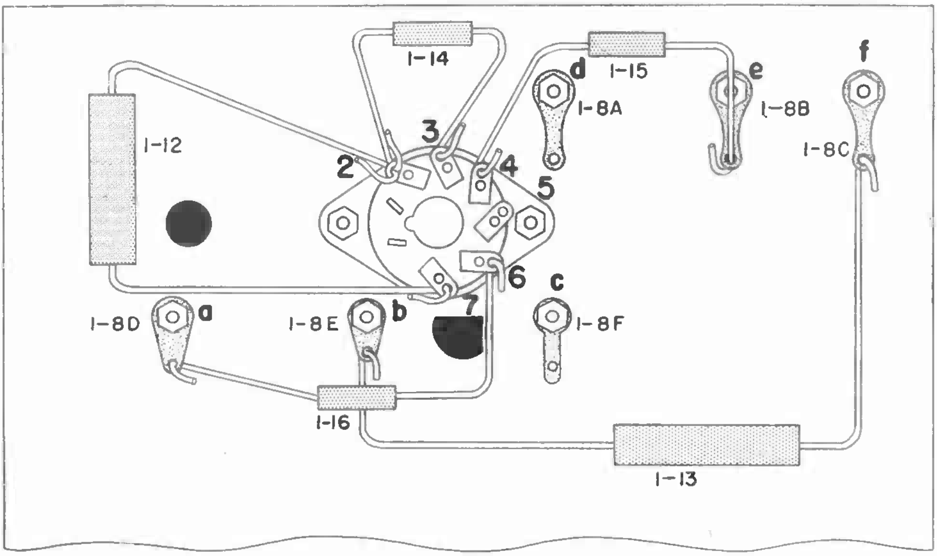


FIG. 41. The five radio parts which you connect to lugs in Experiment 9 are shown here ready for soldering. If you prefer, you can prepare all the parts in this manner, and then solder all the joints at once instead of soldering each part separately as called for in the experiment. WARNING: Bends in resistor and condenser leads should be *gradual* (not sharp), and should begin at least one-quarter inch away from the body of the part; otherwise, the leads will break off.

in inserting the lead in the outermost hole of tube socket lug *2* even though this lug has not yet been soldered, use the other hole in this lug. Squeeze the hooks together tightly with long-nose pliers, then proceed to solder lugs *2* and *3*.

Discussion: With radio parts like the condensers and resistors included in this radio Kit, the bending of the leads to their proper shapes is an important part of the connecting process. Do not intentionally make sharp-cornered bends in leads by means of pliers, however, for this may weaken the wire. Make the bends with your fingers, and use pliers only when forming hooks in the ends of wires. Bends in leads should always start at least ¼ inch away from a resistor or condenser for the same reason.

Bend each lead carefully, checking your work continually by fitting the leads to the correct lugs on the chassis. Additional bending may be done after the leads have been soldered; in fact, the leads should always be bent away from the chassis after this is done, to minimize the possibility of bare wires shorting to the chassis. The leads to these condensers and resistors are stiff enough to support the parts in air.

A permanent joint differs from a temporary joint only in the squeezing of the hook with long-nose pliers prior to soldering. The ends of permanent hook joints should be cut off after the joint has been soldered and allowed to cool, so that accidental short-circuits and grounds cannot occur. You will find that this little extra step makes a great deal of difference as regards the ease with which a joint can be unsoldered.

In this experiment, you have connected radio parts exactly as they would be connected by professional radio servicemen. With the repeated practice in soldering which you will secure in future experiments, you will soon find yourself able to make soldered connections with professional skill, speed, and efficiency.

Instructions for Report Statement No. 9. After completing this experiment and studying the discussion, read Report Statement No. 9 carefully, then place a check mark in the box following *the splice or joint which is most often used in radio work for connecting the leads or radio parts to soldering lugs.* Then copy your answer onto the last page of the Manual.

Report Statement No. 9: The leads of radio parts are usually connected to soldering lugs by means of: *Western Union splices* ☐; *Bell splices* ☐; *hook joints* ☒.

EXPERIMENT 10

Purpose: **To secure experience in unsoldering connections like those encountered in radio receivers, just as you would do when removing a defective part from a receiver.**

Step 1. To remove .1-megohm resistor 1-15 from your chassis, apply the heated soldering iron to one side of lug *1-8B,* unbend the hook with long-nose pliers while the solder is molten, then pull this lead out of the lug by pulling on the lead with long-nose pliers. Now apply the soldering iron to tube socket lug *4,* and unhook the other resistor lead from this lug.

Step 2. To remove 18,000-ohm resistor 1-16 from your chassis, use your long-nose pliers to open up the hook in lug *1-8D* while applying the soldering iron to this lug so as to melt the solder. When the end of the lead is straight up and down, pull the wire out of the hole in the lug with your long-nose pliers while keeping the solder molten with the soldering iron. Now apply the soldering iron to lug *6,* and unhook the resistor lead going to this lug.

Step 3. To remove .05-mfd. condenser 1-13 from your chassis, apply the soldering iron to lug *1-8E* while grasping with long-nose pliers the lead going to this lug. Unhook the lead from this lug. This will undoubtedly cause bends in both condenser leads, but you can readily straighten these out after the part has been removed. Now melt the solder on lug *1-8C,* and unhook the lead from this lug in the same manner.

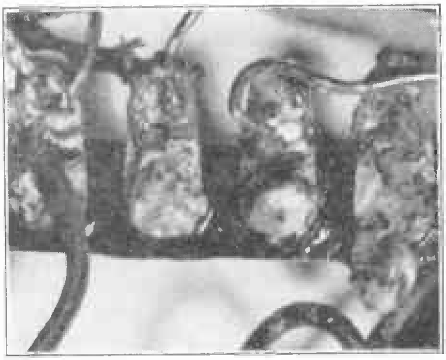
Step 4. To remove .03-mfd. condenser 1-12 and .24-megohm resistor 1-14 from your chassis, first apply the heated soldering iron to lug *7,* and pry open the hook in the condenser lead going to this lug. Do not expect to do this in one trial, for it is usually quite difficult to get a good grip upon the end of the wire with pliers. Continue unbending the hook until you can push the wire out of the lug. The other lead of this condenser will be somewhat more difficult to unsolder, since it goes to a lug *(2)* which has two connections; use exactly the same technique, however.

Part *1-14* also has permanent connections, so unsolder its leads from lugs *2* and *3* in the same manner.

Step 5. Remove surplus solder from all six soldering lugs and from the lugs on the tube socket, either by wiping off the molten solder with a cloth or by lifting it off with the clean soldering iron. Melt and shake off surplus solder from the leads of the five radio parts used in this experiment, then straighten out the leads with your fingers as well as you can. If the ends of any leads have been damaged by the long-nose pliers, cut off about 1/4 inch from each end.

Simply straighten out the hooks in the remaining leads if the wires themselves are in good condition, so that all parts are clean and ready for use again in future experiments. Now remove the six soldering lugs *(1-8A, 1-8B, 1-8C, 1-8D, 1-8E,* and *1-8F)* and the six screws and nuts from the chassis with your screwdriver and long-nose pliers, then set aside the lugs, screws, and nuts for future use. Leave the tube socket on the chassis.

Discussion: In this experiment, you demonstrated for yourself the fact that hook joints which are not squeezed prior to soldering are fairly easy to unsolder. You found that sometimes the leads can be removed from a lug without unbending the hook, while in other cases it was necessary to unbend the hook somewhat with long-nose pliers before the lead could be pulled away from the lug.



An example of poor soldering. The lumpy, cracked appearance shows too much solder was used and the joints were not heated enough.

You also found that permanent soldered connections can be unsoldered fairly easily once you get the knack of prying open the hook with long-nose pliers. As you undoubtedly realize now, it is quite a trick to hold a heated soldering iron against one part of a lug while prying open a wire on that lug with long-nose pliers. You will become quite proficient in this work, however, by the time you have completed your home demonstration course.

Whenever a permanent hook joint has been squeezed so tightly that it is very difficult to get a grip on the end of the wire with long-nose pliers, servicemen will usually snip off the wire as close as possible to the soldering lug with side-cutting pliers. The portion of the wire remaining in the lug can either be pushed out with the tip of the soldering iron after this is done, or can be cut again with side-cutting pliers so it will fall out when the soldering iron is applied. You may use this procedure if you have difficulty in unsoldering any of the joints.

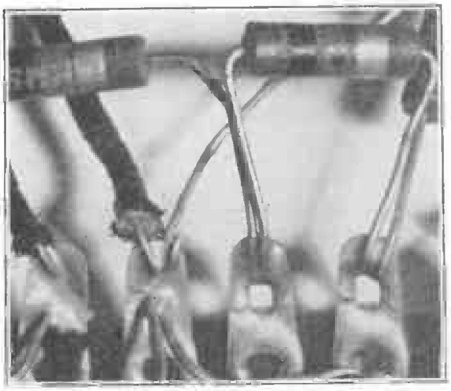
Sometimes the wire will come out after only a part of the hook is cut off. Then again, it may be possible to spread the hook apart with a small screwdriver or with the blade of a pocket knife.

Instructions for Report Statement No. 10. After completing this experiment and studying the discussion, read Report Statement No. 10 carefully. Place a check mark in the box following the statement that describes the condition of the solder which makes it easier to disconnect a permanent hook joint. Then copy your answer onto the last page of the Manual.

Report Statement No. 10: When disconnecting a permanent soldered hook joint, the hook is easier to pry open with long-nose pliers while the solder is: *hard* ☐; *molten* ☒.

Requirements of a Good Soldered Joint

The seven important requirements of a good soldered radio joint are reviewed in convenient reference form in Fig. 42. If you understand and follow each of these requirements, you should have no difficulty in making professional soldered joints once you have practiced as instructed in your home demonstration course.



Good soldering produces a smooth, even coating of solder. The joints have been heated sufficiently to melt the solder and just enough solder has been used to coat the joint thinly.

In the case of plain soldering irons, which must be heated by an alcohol burner, we have the additional requirement that the soldering iron be at the correct temperature. (This requirement is taken care of automatically in an electric soldering iron by the original design of the heating element.) If the soldering iron is too cold, a joint made with it may look good but be mechanically and electrically weak because hardened rosin is the chief bonding material. The resulting "rosin" joint (one in which there is little or no solder connecting the two parts together) is unsatisfactory and can actually be an open connection. In any event, a rosin joint will eventually break apart and cause trouble.

Too hot a soldering iron is equally unsatisfactory, for excessive heat will evaporate the rosin flux before it has a chance to act upon the work, and will make the solder flow too rapidly away from the joint. Furthermore, excessive heat will travel around the joint through the copper wire and burn insulation or loosen adjacent soldered joints.

Looking Forward

Having mastered professional soldering techniques, you are ready to set up real radio circuits with soldered joints, and demonstrate basic radio principles for yourself. In your next radio Kit will be another fascinating collection of actual radio parts, including a milliammeter and a vacuum tube. With these additional parts you will assemble simple electrical and radio circuits and trace electron flow through them. You will make measurements of current and voltage in these circuits, and see for yourself that current, voltage, and resistance in a circuit always have values which agree with Ohm's Law.

Finally, after completing Experiment 20, you will assemble the NRI Tester on its attractively designed panel and chassis. This is a specially designed measuring instrument which is equivalent to eighteen separate ordinary meters. You will use the NRI Tester a great deal in future experiments.

REQUIREMENTS OF A GOOD SOLDERED JOINT

1. KEEP YOUR SOLDERING IRON CLEAN AND WELL TINNED
2. REMOVE INSULATION FROM WIRES, AND SCRAPE OFF EXCESSIVE DIRT. AVOID NICKING THE WIRE WITH THE SCRAPING TOOL
3. USE ONLY ROSIN-CORE SOLDER FOR RADIO WORK.
4. TIN EACH PART SEPARATELY IF ORIGINALLY UNTINNED.
5. MAKE GOOD MECHANICAL CONTACT BETWEEN THE PARTS BEING SOLDERED
6. APPLY THE SOLDER TO THE LUG OR WIRE, NOT TO THE SOLDERING IRON.
7. DO NOT MOVE THE JOINT UNTIL THE SOLDER HARDENS.

FIG. 42. Observance of these seven basic requirements is the secret of making professional soldered joints for radio equipment.

IMPORTANT

Be sure to save ALL PARTS from this Radio Kit, including the soldering lugs, screws, and nuts, because you will need them later. Keep small parts in individual envelopes or boxes.

RADIO COILS AND HOW THEY WORK

6FR-3

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

STUDY SCHEDULE NO. 6

This schedule will help you to master the sixth part of your N.R.I. Course. For each step, read the specified pages first at your usual reading speed, then reread slowly one or more times. Finish with one quick reading, then answer the Lesson Questions specified for that step.

☑ 1. **Quickly Review Pages 12 to 18 of Lesson 1FR-3.**
Start with "Radio Uses for Magnetism" on page 12, and read to the bottom of page 18 just once.

☑ 2. **Coil Fundamentals .... Pages 1-6 of this Lesson**
You learn basic facts about magnetic circuits of coils, and find out what determines the amount of magnetic flux a coil will produce. Answer Lesson Questions 1 and 2.

☑ 3. **Using Coils to Produce Motion .... Pages 6-8**
Three different ways to explain the operation of motion-producing coils are studied. You can use them to explain the operation of radio parts like relays, headphones, magnetic loudspeakers, electrodynamic loudspeakers, p.m. dynamic loudspeakers, and moving-coil meters. Answer Lesson Question 3.

☑ 4. **Using Coils to Produce Voltage .... Pages 8-14**
Step by step you learn the meaning of the basic coil rule that the induced voltage depends upon how fast the flux linkages are changing. Finally, you fix this knowledge in your mind by considering three examples of voltage-producing coils: Dynamic microphone, magnetic phono pick-up and transformer. Answer Lesson Questions 4, 5, 6, and 7.

☐ 5. **Basic Idea of Inductance .... Pages 15-23**
Important principles which govern the behavior of coils in a.c. circuits are taken up one by one. You also learn about combinations of coils and about variable inductances. Answer Lesson Questions 8 and 9.

☐ 6. **Simple Coil-Resistor Circuit .... Pages 24-28**
Here's where you learn how to combine voltages correctly in a.c. circuits containing a coil. Phase relationships and uses for vectors are explained simply from a practical standpoint. Answer Lesson Question 10.

☐ 7. **Mail Your Answers for Lesson 6FR-3 to N.R.I. for Grading.**

☐ 8. **How To Test and Replace Resistors and Volume Controls .... RSM Booklet No. 6**
This is another of the series of Booklets that are to give you practical, how-to-do-it training in fixing radios. Read this Booklet now, then keep it handy for future reference. The "shop training" you get from these RSM Booklets is going to prove valuable to you throughout your service career, so you will want to read and review these Booklets many times. NOTE: Some of the Study Schedules in future Lessons may refer to "Job Sheets" instead of RSM Booklets. Read the correspondingly numbered RSM Booklet in such cases. These Booklets are an improved and enlarged version of the older Job Sheets, and are replacing them.

☐ 9. **Start Studying the Next Lesson, on Condensers.**

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RADIO COILS AND HOW THEY WORK

Coil Fundamentals

Radio Uses for Coils. Coils have many important jobs in radio receivers and transmitters. Working alone or in partnership with condensers and resistors, coils make it possible to tune in stations, to remove hum from power supply circuits, to keep signals in proper paths, to change a.c. voltages to higher or lower values, to transfer signals from one circuit to another without wire connections, and to do a host of other equally important jobs, all of which we will take up in this Course.

Definition of a Coil. In its simplest form, a *coil* is nothing more than one or more turns or loops of wire, usually wound in a circular or helical shape. More often, however, a radio coil also has certain accessories, such as a coil form, an iron core, or a metal housing or shield.

Basic Action. Coils produce magnetic lines of force, known also as *magnetic flux.* No matter what kind of coil we have—large or small, thick or thin, wound around air or iron—it produces magnetic flux whenever we send current through the coil.

Many different types and sizes of coils are used in radio, in order to get a particular desired amount of this

Courtesy Western Electric Co.

In this Western Electric magnetic-tape sound recorder, coils have many important jobs. A coil in the dynamic microphone produces the audio signal. An a. f. input transformer inside the cabinet transfers the signal to the first a.f. amplifier stage. Other transformers transfer the signal to succeeding amplifier stages to boost its strength, then feed it to a coil which magnetizes a moving steel tape. Sounds are thus recorded on the long tape. A flip of a switch reverses the process, enabling the speaker to hear her own voice from the loudspeaker, which has two more coils. Still another coil demagnetizes the tape to erase previous recordings.

magnetic flux in a particular and definite location inside or near the coil. This flux makes it possible for a coil to offer more opposition to the flow of alternating current than direct current, to transfer energy to another circuit without connecting wires, to produce mechanical motion, to convert mechanical motion into a correspondingly varying voltage, and do all the other jobs which are described in connection with coils in this and later lessons.

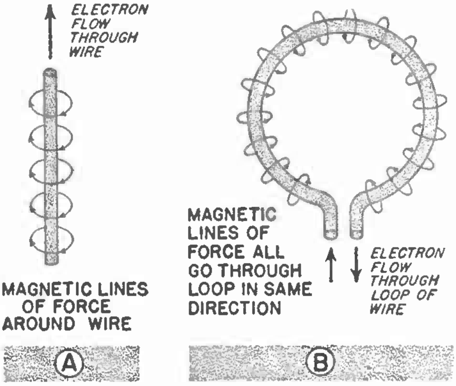


FIG. 1. Review of the basic principle applying to coils—that magnetic lines of force are produced whenever electrons flow through a wire or other object.

Fundamental Facts About Coils. You have already learned that whenever we send current through a straight piece of wire, magnetic lines of force are produced around the wire. These lines of force encircle the wire in much the manner shown in Fig. *1A*. They are distributed along the entire length of the wire, because the electrons are distributed throughout the wire and each electron has its own circular magnetic field. The larger the current (the greater the number of electrons) we send through the wire, the more lines of force there will be—just as we might naturally expect. Furthermore, reversing the direction of the current will reverse the direction of the magnetic lines of force.

If we bend the wire into a loop or single-turn coil as shown in Fig. *1B*, the lines of force all pass through the center of the loop in the same direction and give a concentration of magnetic flux there. The greater the current, the more flux we have passing through the coil.

If we add more turns of wire as in Fig. *2*, still more flux is concentrated inside the coil. Each current-carrying turn of wire contributes its share of flux to the total amount, so the more turns of wire we have in a coil, the more flux we get from a given current.

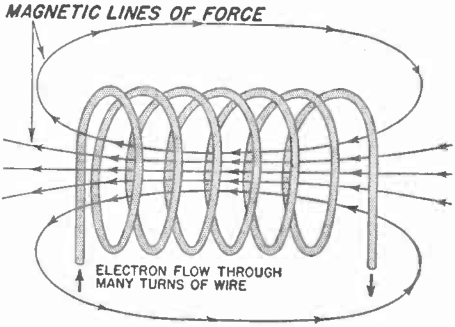


FIG. 2. A coil is simply a device which concentrates in a useful manner the magnetic lines of force produced by moving electrons.

The number of turns is, therefore, just as important a factor as current in determining how much flux a coil will produce. Many of these facts you will recognize as a review of what you have already studied about magnetic lines of force.

MAGNETIC CIRCUITS

The magnetic lines of force which are produced by a coil can exist *only as complete loops having no ends, passing through and around the coil turns which produced the lines*. Thus, the lines of force going out of the coil at the left and into it at the right in Fig. 2 are each portions of complete loops like those shown above and below the coil. In many cases, it would be impractical to show complete loops on diagrams, so for convenience we show only those portions of the loops in which we are most interested.

Each coil may have thousands of such loop paths, all passing through part or all of the coil and going out in all directions from the ends of the coil. Together, the paths of these magnetic lines of force make up the *magnetic circuit* of the coil.

The material inside a coil is called the *core* of the coil. Sometimes the core material is continued around the outside of the coil, and then forms the chief magnetic circuit of the coil.

When the path for the magnetic lines is entirely through air, as it is in Fig. 2, we have an *air-core coil.*

When a coil of wire is wound or placed around an iron or steel ring, as shown in Fig. 3, magnetic lines of force are produced in this core by the current flow in the coil turns. As we will shortly see, the iron core is a better magnetic circuit than air, and a greater number and concentration of flux lines exists. This is called an *iron-core coil,* and you will often meet it in radio work. The iron core will usually have some other shape than a ring, but there will usually be a continuous path through iron for the magnetic lines of force.

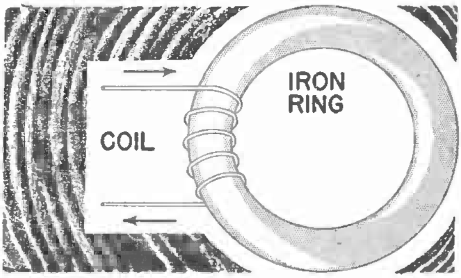


FIG. 3. A coil wound on an iron ring produces more flux and a greater concentration of flux than a similar coil having only air for a core.

Courtesy Western Electric Co.

The direction-finding loop antenna of this 30-ton Douglas DC-4 transport plane, being inspected here by a United Air Lines communication engineer, is nothing more than a coil enclosed in a tubular aluminum hoop. It is mounted inside the nose of the plane, but the magnetic fields of radio waves from beacon stations go right through the non-magnetic metal covering of the plane and through the loop housing.

Three Magnetic Terms. The magnetic circuit of a coil is just as important to us as the electric circuit in which the coil is connected. In fact, magnetic circuits are similar to electric circuits in many ways, and have terms which correspond to the voltage, resistance and current of an electric circuit. The terms are *magnetomotive force, reluctance* and *flux,* and they have the same relationship to each other as that expressed by Ohm's Law for voltage, resistance and current in an electric circuit.

1. Magnetomotive Force. Just as we have an electromotive force or voltage which forces current around an electric circuit, so do we have in every current-carrying coil a *magnetomotive force* which forces the flux around the magnetic circuit.

A true indication of the strength of the magnetomotive force of a coil can be obtained by multiplying the coil current in amperes by the number of coil turns, giving the number of *ampere-turns*. The greater the magnetomotive force (ampere-turns), the more flux it sends through the magnetic circuit, other things being equal. This corresponds to the Ohm's Law relationship that increasing the voltage will increase the current.

A clear understanding of ampere-turns can prevent plenty of headaches if you ever wind experimental coils for electromagnets or relays. For example, adding more turns of the same size wire doesn't do any good if you still use the same coil voltage, because it doesn't change the ampere-turns. Here is the explanation: The extra wire increases the coil resistance, and this reduces the current just enough to offset the increase in turns.

EXAMPLE: A 50-turn coil carrying 4 amperes gives 200 ampere-turns. Adding 50 more turns of the same wire gives 100 turns, but doubles the coil resistance. Therefore, if the coil voltage is the same as before, the extra turns just about cut the current in half, to 2 amperes. Multiplying 2 by 100 gives 200 ampere-turns, so the strength of the magnetic field stays the same even though the turns were doubled.

It should be pointed out that many radio coils are used in circuits where the resistance of the coil is negligibly small in comparison to the total resistance of the circuit. Here the coil current stays essentially the same even though we double the coil resistance, so increasing the number of turns increases the ampere-turns and gives a more powerful coil.

Remember, then, that the magnetomotive force (the force which sends magnetic flux around the magnetic circuit of a coil) depends upon the number of ampere-turns in the coil. The more ampere-turns we have, the more flux we get.

2. Reluctance. Just as resistance limits the amount of current flow in an electric circuit, so does the flux path of every magnetic circuit have *reluctance* which offers opposition to magnetic flux. This reluctance is distributed along the entire path taken by the flux, but for study purposes it can be considered as concentrated at one point like a resistor. The comparison between reluctance and resistance is shown in Fig. *4*. Here the magnetic path is through air.

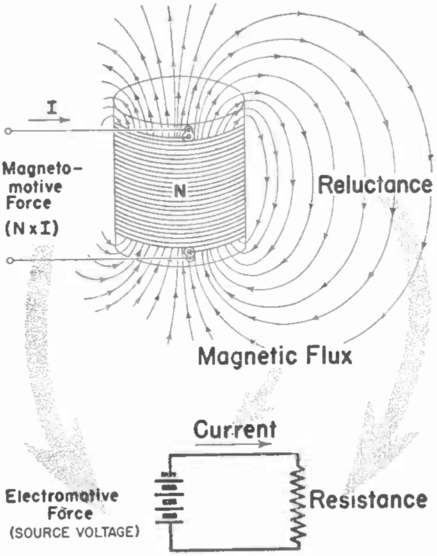


FIG. 4. Similarity between magnetic and electric circuits. The total reluctance is here the reluctance of the air through which the magnetic flux loops flow. Lines of force go out of the ends of the coil in all directions, but only a few of the lines can be shown in a diagram of this nature.

The lower we make the total reluctance of a magnetic circuit, the more flux we will get from a given magnetomotive force. This corresponds to the Ohm's Law relationship that lowering the resistance increases the current. On the other hand, increasing the reluctance cuts down the amount of flux.

From the standpoint of reluctance, all materials can be divided into two groups: 1. Non-magnetic materials; 2. Magnetic materials.

Non-Magnetic Materials. In this group, we have air and other non-magnetic materials, like paper, glass, bakelite, wood, brass, aluminum and copper. A coil having only non-magnetic materials in its core and in the form which supports the wire is an air-core coil, because the magnetic circuit has the high reluctance of air.

Magnetic Materials. This group includes iron, steel, ferrous (iron) alloys, and a few other metals and alloys which give magnetic circuits a lower reluctance than air.

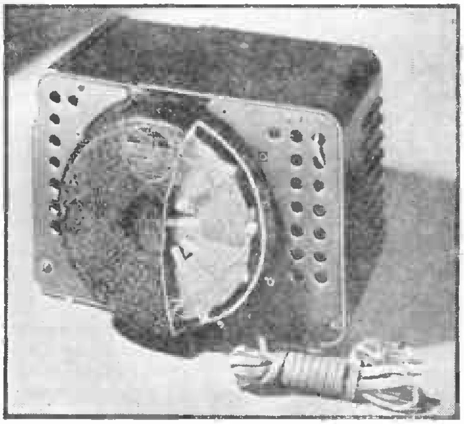
Magnetic materials make it possible to secure large amounts of flux with only moderate values of magnetomotive force. A coil having magnetic material in its magnetic circuit is known as an iron-core coil.

How Reluctance Affects Flux. You can think about reluctance much as you do about resistance. Thus, the longer the magnetic circuit, the higher is its reluctance. (Compare with an electric circuit, where increasing the length of a wire increases its total resistance.) Conversely, shortening the path for flux decreases the total length of the magnetic circuit and thereby decreases the total reluctance.

The greater the cross-sectional area of a magnetic circuit, the lower is its reluctance. (In electricity, the thicker a wire, the lower is its resistance for a given length.) Conversely, reducing the cross-sectional area of the magnetic path increases the reluctance.

The kind of magnetic material used has considerable bearing on the total circuit reluctance. Some materials are better magnetic conductors than others; the technician says the material has better *permeability,* just as copper has better conductivity than iron and therefore provides a lower-resistance path for current.

Permeability. The radio term which most conveniently expresses how much more flux we will obtain with a given magnetic material than with air is *permeability.* In a practical sense, permeability expresses how well a material can conduct magnetic flux. (*Permeability* comes from *permeate,* which means *to pass through.*)



Courtesy Continental Radio & Television Corp.

Coils are wound in many different shapes and sizes. In this cut-away view of the rear of a table-model Admiral receiver you see a basket-weave coil known by the trade name "Aeroscope," serving as a built-in loop antenna.

The permeability of a core material determines what the total reluctance of the core will be; when the permeability goes up, the reluctance goes down, and vice versa.

The permeability of air and all other non-magnetic materials is by agreement given the numerical value of 1. Magnetic materials all have higher permeability values than 1, with actual values ranging from about 50 all the way up to 10,000, or even higher for certain special alloys.

Air Gaps. In electrical circuits, we often find paths with different resistances in series. In magnetic circuits, we often find different magnetic materials in series, as shown in Fig. *5.* Here we have a magnetic circuit made chiefly of iron having low reluctance, but with a high-reluctance air gap at one point.

This is an actual case where most of the reluctance is concentrated at one point (in the air gap), with the rest of the circuit having such low reluctance that it is comparable to the conducting wires in the electric circuit of Fig. *4.*

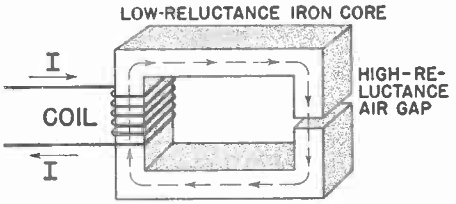


FIG. 5. The flux produced by this coil travels along a magnetic circuit consisting of an iron core and a short air gap. The total reluctance is but slightly higher than the air gap reluctance.

3. Magnetic Flux. Finally, corresponding to current in an electric circuit we have magnetic flux (magnetic lines of force) in a magnetic circuit. Just as current is equal to voltage divided by resistance, so is flux equal to magnetomotive force divided by reluctance.

Summary. The Ohm's Law relationships for these three magnetic characteristics can be summarized as follows:

You can INCREASE the amount of flux either by increasing the magnetomotive force or decreasing the reluctance.

You can DECREASE the amount of flux either by decreasing the magnetomotive force or increasing the reluctance.

Every change in flux is thus due to a change either in magnetomotive force or reluctance. This thought is well worth keeping in mind during the remainder of your study of coils.

Using Coils to Produce Motion

There are a great many radio devices in which we use flux to produce motion. Typical examples are meters, loudspeakers and automatic switches (called relays).

Three Explanations. There are three fundamental ways of explaining how current-carrying coils can produce motion. Once you clearly understand these fundamental explanations, you can choose whichever is the most convenient for explaining the action of any motion-producing coil you may encounter.

1. Attraction and Repulsion of Magnetic Poles. The basic law of magnetism which you took up in an earlier lesson (like poles repel, and unlike poles attract) is highly convenient for explaining the operation of many types of coil devices.

Whenever a magnetic circuit made of iron or other magnetic material is broken by an air gap, the ends of the iron core on each side of the air gap will have opposite magnetic polarity due to the flux which flows through the iron magnetic circuit. The end which magnetic lines of force enter will be the S pole, and the end which lines of force leave will be the N pole. In other words, flux mag-

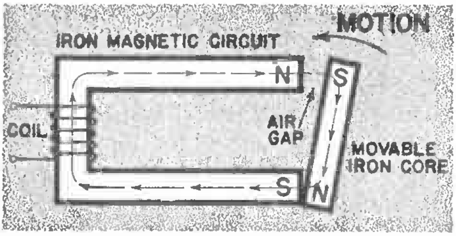


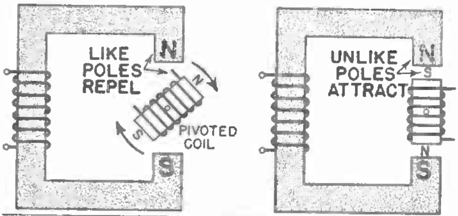
FIG. 6. Movement due to the attraction of unlike magnetic poles.

netizes any magnetic material through which it passes.

When you place a nail or other piece of iron on the pole of a permanent magnet, this nail acts like a magnet, and is capable of picking up small iron objects. The nail alone would not do this, so we say that the nail is *inductively magnetized* by the flux from the permanent magnet.

Since the core ends which are on opposite sides of an air gap have opposite polarity, they tend to attract each other in accordance with the law of magnetism. If a portion of the iron magnetic circuit of a coil is movable, as is the case in Fig. *6*, this attraction across the air gap will result in a motion which tends to bring the *N* and *S* poles closer together.

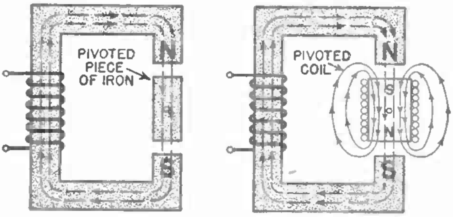
If an electromagnet is pivoted in the air gap between *N* and *S* poles in the manner shown in Fig. *7A*, the repelling action between like poles will cause rotation in a clockwise direction as indicated by the arrows. If there is no retarding force, this coil will finally come to rest at the position shown in Fig. *7B*, in which the unlike poles are as close as they can get to each other. Magnetic poles thus attract and repel in the same manner regardless of whether they are on permanent magnets, electromagnets or inductively magnetized pieces of iron.



Ⓐ ROTATION Ⓑ FINAL POSITION

FIG. 7. Rotation due to repulsion of like poles (A) and attraction of unlike poles (B).

2. Position of Maximum Flux. In some cases it is more convenient to explain the action of a coil device by means of the following basic rule: Whenever a movable magnetic object is in or near a magnetic circuit, this object will tend to move to the position which gives *maximum flux* in the magnetic circuit.



Ⓐ MINIMUM RELUCTANCE Ⓑ MAXIMUM FLUX

FIG. 8. Pivoted objects in magnetic circuits take the positions shown here.

In the case of a movable iron object, this rule means that it will move to a position wherein its longest dimension is parallel to the magnetic lines of force in its vicinity. The movable object is then placing as much as possible of its length in the magnetic circuit, thereby lowering the reluctance of the magnetic circuit and giving maximum flux.

In the case of a movable electromagnet, this coil will take a position wherein its flux acts in the same direction as the original flux. The two fluxes then add, so as to give maximum flux as specified by the rule.

Thus, an iron object pivoted in the air gap between *N* and *S* poles of a magnetic circuit will take the position shown in Fig. *8A*, with its longest dimension parallel to the lines of force in the air gap. You will shortly learn that in this position the magnetic circuit also has minimum reluctance.

A current-carrying coil freely pivoted in the air gap between the *N* and *S* poles of a magnetic circuit will take the position shown in Fig. *8B*. Its flux is then aiding the air-gap flux, thereby giving *maximum flux*.

3. Position of Minimum Reluctance. Last to consider, but equally as useful, is the rule which says: A movable magnetic object located in or near a magnetic circuit will tend to take a position which makes the reluctance of the magnetic circuit a *minimum*.

Minimum reluctance occurs when the greatest possible portion of the magnetic circuit is through iron or some other low-reluctance magnetic material.

The movable piece of iron in Fig. *6* is moving to the position of minimum reluctance, because the reluctance is a minimum here when the air gap is closed up. Likewise, the pivoted iron object in Fig. *8A* is in the position of minimum reluctance, because it is in the position which gives the shortest possible air gaps.

Since lowering of reluctance makes flux increase, the position of minimum reluctance is identical with the position of maximum flux. It is simply more convenient sometimes to think of reluctance rather than flux. Likewise, since opposite poles at an air gap attract each other and tend to close up the air gap, thereby lowering the reluctance and increasing the flux, the law of magnetic attraction expresses exactly the same result as the other two ways of explaining the motion produced by a current-carrying coil.

Using Coils to Produce Voltage

Some microphones and some phonograph pick-ups are coil devices which use changes in magnetic lines of force (flux) to produce a voltage. The basic rule is: *Whenever the flux linkages of a coil are changed, a voltage is induced in the coil.* Before going into the explanation of this rule, let us first see what flux linkages are.

FLUX LINKAGES

Let us imagine that we have four lines of flux (4 magnetic lines of force) passing through a 5-turn coil, as illustrated in Fig. *9A*. These lines of force can be produced by another coil or by a permanent magnet. (We will let straight lines represent flux, although we know that each of these straight lines is actually a portion of a complete loop of flux.) The electrical characteristics of this coil depend both on the number of turns in the coil and on the number of lines of flux passing through the coil. For convenience, radio men use the term *flux linkage* to describe this combination of flux and turns in a coil.

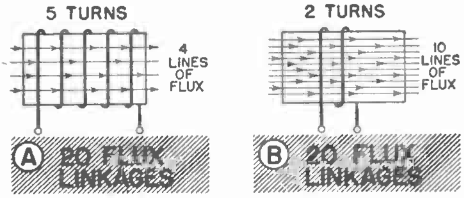
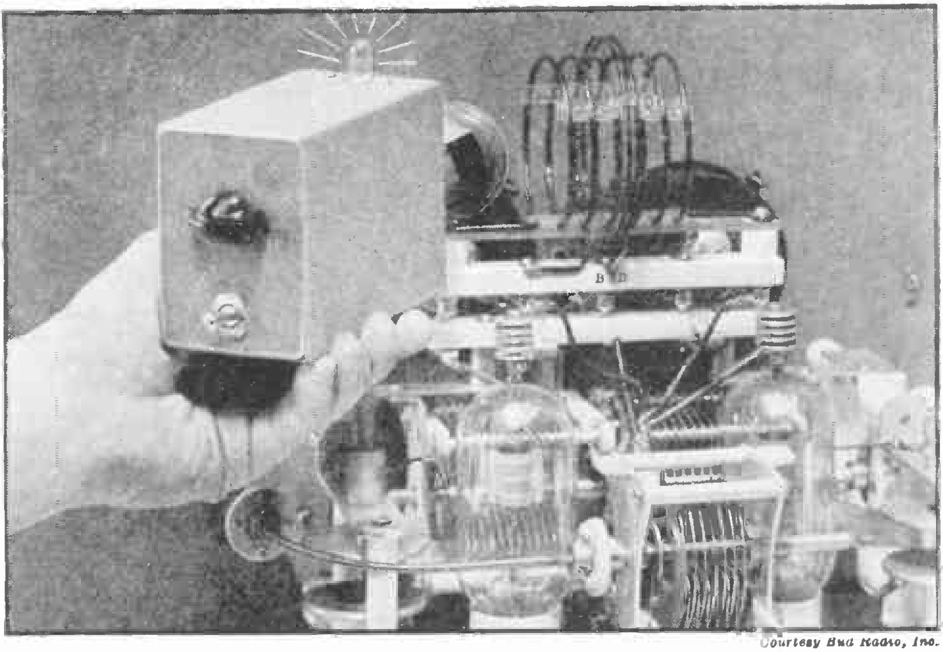


FIG. 9. Multiplying turns by lines gives flux linkages for a coil.



Courtesy Bud Radio, Inc.

There are plenty of coils in this interesting view of the r.f. section of a short-wave transmitter. The transmitter coils, without cores and with plastic spacer bars instead of forms, are prominent on top of the assembly. The box with a coil projecting from its back is a wavemeter, used to determine the approximate frequency at which the transmitter is operating. The bulb on top of the box lights up when the transmitter is properly adjusted.

Definition of Flux Linkage. One *flux linkage* is equal to *one* line of flux passing through (linking with) *one* turn of the coil. Thus, 1 line of flux passing through 10 turns gives 10 flux linkages.

When all the flux passes through all of the turns of a coil, the total flux linkage is obtained by multiplying the number of turns in the coil by the number of magnetic lines of flux passing through all of the turns of the coil.

As an example, with our 4 lines passing through the 5 turns, we would have 4 × 5, or 20 flux linkages. Clearly, it is much easier to say "20 flux linkages" than to say "4 lines of flux passing through 5 turns."

We can get the same number of flux linkages in a number of different ways, all of which will give exactly the same result. Thus, we can get 20 flux linkages by having 10 lines of force passing through 2 turns as in Fig. *9B*, because 2 × 10 is 20. We can have 5 lines of force passing through 4 turns, because 5 × 4 is also 20. The important thing for you to remember is that flux (lines) times turns is equal to flux linkages.

Changing Flux Linkages. Now imagine that we have the 5 turns shown in Fig. *9A, but we increase the* number of lines of flux from 4 to 8. This increases the flux linkages from 20 to 40, because 5 × 8 is 40. Whenever we increase the flux linkages of a coil in this manner, a voltage is induced in the coil, and this voltage is known as an *induced voltage*.

If we decrease the number of flux linkages in a coil, such as by changing them from 40 back to 20 or from 40 all the way down to 0, we will again have a voltage induced in the coil.

The strength of the induced voltage

depends not only upon *how much* we change the flux linkages, but also upon how long a time we take to make the change. If we change from 20 to 40 flux linkages in 1 second, we will get a certain voltage (the exact value of this voltage is not important to us in this explanation). If, however, we change from 20 to 40 flux linkages in only 1/1000 of a second, we will get exactly 1000 times as much voltage as before. The faster the rate of change in flux linkages, the greater will be the induced voltage.

There is no need to figure exact values of flux linkage in practical radio work, because we are concerned chiefly with the effects produced when flux linkages *change* from instant to instant. The one thing you *should* remember, however, is this simple induced voltage rule:

Whenever the flux linkages of a coil are *changing*, a voltage is induced in the coil.

Lenz's Law for Coils. The induced voltage in a coil always acts in a definite direction. This direction at any given instant depends on just two things—on the direction of the original flux, and on whether its flux linkages are increasing or decreasing.

The exact relationship between these things is expressed by a famous electrical law. It is known as Lenz's Law, because he was the first to realize that the direction in which an induced voltage acts can always be predicted beforehand. The law in its basic form is expressed as follows:

LENZ'S LAW FOR COILS

The induced voltage always acts in such a direction that it tends to *oppose* the original change in flux linkages.

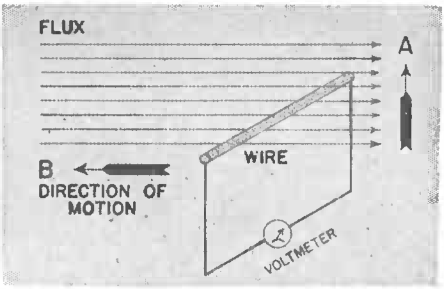


FIG. 10. Diagram illustrating how a conductor cutting across a magnetic field changes the flux linkages and gives an induced voltage.

If the flux linkages are *increasing*, the induced voltage will tend to prevent the flux from increasing. This means that the induced voltage will be in such a direction that it will tend to send through the coil a current which produces a magnetic flux which *opposes* the original coil flux. The induced voltage thus tends to prevent the increase in flux linkages.

On the other hand, if the flux linkages are *decreasing*, the induced voltage will be in such a direction that its current (when the coil circuit is complete) will produce a flux which *aids* the original flux, and thus tends to prevent the flux from *decreasing*.

METHODS OF PRODUCING CHANGES IN FLUX LINKAGES

The three basic methods of producing changes in the flux linkages of a coil are: 1. *Cutting lines of force;* 2. *Changing the reluctance;* 3. *Changing the coil current.* Each method will now be taken up in turn, after which actual radio devices using these methods will be studied.

1. Cutting Lines of Force. Imagine a steady magnetic field produced by a permanent magnet or electromagnet, with a conductor (wire) located in this field and connected to a voltmeter (*V*), as shown in Fig. *10.* When we move this conductor upward through the flux in direction *A*, we induce a voltage into the conductor, and the voltmeter will indicate the presence of the voltage.

We get this induced voltage because motion of the conductor changes the flux linkages of the single-turn coil formed by the conductor and the voltmeter circuit. Moving the conductor upward, for example, *increases* the number of flux lines which are passing through the loop, thus increasing the flux linkages.

Sometimes it is easier to visualize and explain the production of an induced voltage by thinking of cutting lines of force. Whenever the conductor is moved through a line of force, it is cutting that line of force momentarily, and this produces an induced voltage in the conductor.

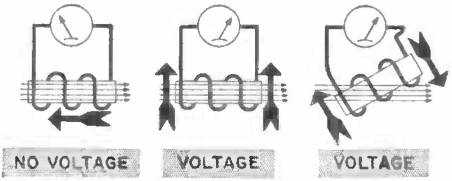


FIG. 11. FIG. 12. FIG. 13.

The large heavy arrows indicate the direction of coil motion.

If we move the conductor parallel to the lines of force, as indicated by direction arrow *B* in Fig. *10*, however, we do not get an induced voltage. We have neither cut lines of force nor changed the amount of flux passing through the coil, hence we have not changed the flux linkages of the coil.

Exactly the same explanation applies to Fig. *11*, where an entire coil is being moved parallel to lines of flux. There is no cutting of lines, no change in flux linkages, and hence no induced voltage.

When we move a coil across a magnetic field as in Fig. *12*, however, we are definitely cutting lines of force and changing the flux linkages of the coil, so we get an induced voltage.

Likewise, we cut lines of force and get an induced voltage when we rotate a coil in a magnetic field, as illustrated in Fig. *13*. Here we are changing the amount of flux which passes through the various turns of the coil.

The faster we cut across lines of force with a conductor or coil, the faster we will be *changing* the flux linkages and the higher will be the induced voltage.

2. Changing the Reluctance. Motion of a movable iron portion of the magnetic circuit of a coil will change the reluctance. Any change in the reluctance of the magnetic circuit will change the amount of flux which passes through the coil, thus changing the flux linkages of the coil and inducing a voltage. Remember, whenever there is a change in flux linkage, a voltage will be induced.

3. Changing the Coil Current. When two coils are arranged as shown in Fig. *14*, whereby the flux produced by current-carrying coil *L* passes through coil L_1, we can induce a voltage in coil L_1 simply by changing the current through coil *L*. By changing the current, we change the amount of flux produced by *L*. This changes the amount of flux passing through L_1, thereby changing its flux linkages and producing the induced voltage. The faster the current is changed, the faster the flux linkages will change and the greater will be the induced voltage.

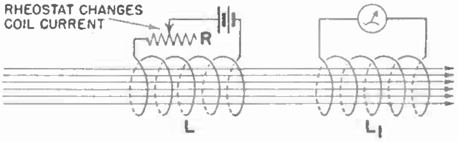


FIG. 14. This diagram shows how a change in current in one coil can induce a voltage in another coil.

Changes in current are usually secured in radio coil devices simply by sending alternating current through the flux-producing coil. An alternating current is varying continually in value from zero to maximum values in either direction, so it makes flux linkages change continually.

The higher the frequency, the more cycles of change there are per second and the faster is the current changing at all times. Therefore, increasing the frequency makes current, flux, and flux linkages all change faster, giving a higher induced voltage.

EXAMPLES

The best way to *understand* (not memorize) basic radio principles is by seeing how they are applied in actual radio parts. The following examples of voltage-producing devices will therefore familiarize you with these important principles and at the same time make you acquainted with the construction and operation of some highly important radio parts.

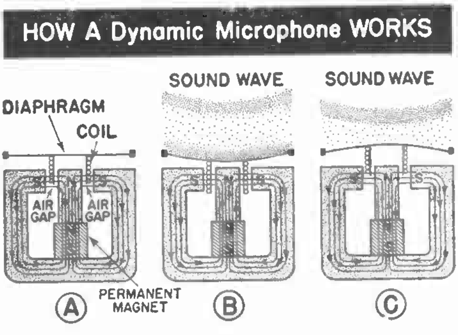

HOW A Dynamic Microphone WORKS

FIG. 15. Simplified cross-section views of a dynamic microphone.

Dynamic Microphone. This is an example of a voltage-producing radio device in which the changes in flux linkages are produced by making a coil cut magnetic lines of force.

The general construction of a dynamic microphone is shown in Fig. *15A*. A strong fixed magnetic field is produced by a permanent magnet inserted in the central soft iron core. Two return paths through iron, with an air gap in each one, are provided to complete the magnetic circuit of the permanent magnet from its lower end to its upper end.

Modern Dynamic Microphones

The voice coil is attached to a flexible metal diaphragm in such a way that this coil moves in and out of the flux in the air gap whenever the diaphragm is moved up and down by sound waves.

When the voice coil is at the normal at-rest position determined by the springiness of the diaphragm (Fig. *15A*), only a few turns of the voice coil are in the air gap. Only a part of the total air gap flux passes through these few turns, hence the number of flux linkages is quite small. These flux linkages are constant when the coil is at rest, hence no voltage is induced in the coil.

When sound waves push the diaphragm down, the coil moves farther into the air gap, as in Fig. *15B*, cutting magnetic lines of force and thus *increasing* the flux linkages of the voice coil. This induces a voltage in the voice coil.

When sound waves pull the diaphragm up, the coil moves out of the air gap as in Fig. *15C*, cutting those lines of force which formerly were passing through some of the coil turns. Now we are *reducing* the flux linkages, and again we have an induced voltage.

The voice coil thus cuts magnetic lines of force and changes its flux linkages whenever the coil is in motion. As a result, the voltage induced in the coil is an a.f. voltage corresponding to the sound wave which causes the movements of the diaphragm and voice coil.

Magnetic Phono Pick-up. Here is an example of a unit which depends for its action upon a *change in reluctance*. The series of diagrams in Fig. *16* will help you to understand the construction and operation of one of these units.

This phono pick-up unit is designed for lateral-cut phonograph records, where the groove is always the same depth but wiggles from side to side in accordance with the audio signal. In following the wavy path of a groove, the phonograph needle moves from side to side. This causes the pivoted iron armature to rock back and forth between the two U-shaped soft iron pieces, one of which is on the inside of each pole of the horseshoe-shaped permanent magnet.

When the groove in the phonograph record is straight, as during a moment of silence in a recording, the pivoted armature has the mid-position shown in Fig. *16A*. Flux now divides about equally over the two paths from the *N* poles to the *S* poles because both paths have about the same reluctance, and there is essentially no flux traveling vertically through the armature. As a result, there is no flux passing through the coil and no flux linkages in the coil.

When the needle tilts the armature to one side, as shown in Fig. *16B*, the lowest-reluctance path is that shown by the dotted arrows in this diagram. The farther the top of the armature tilts to the left, the lower becomes the reluctance and the more flux flows through the armature. This changing flux induces a voltage in the coil which surrounds the armature. The flux is changing continually because the phonograph needle is moving continually from side to side as it rides in the groove.

When the needle tilts the armature the other way, the flux will travel in the opposite direction through the armature, as indicated in Fig. *16C*.

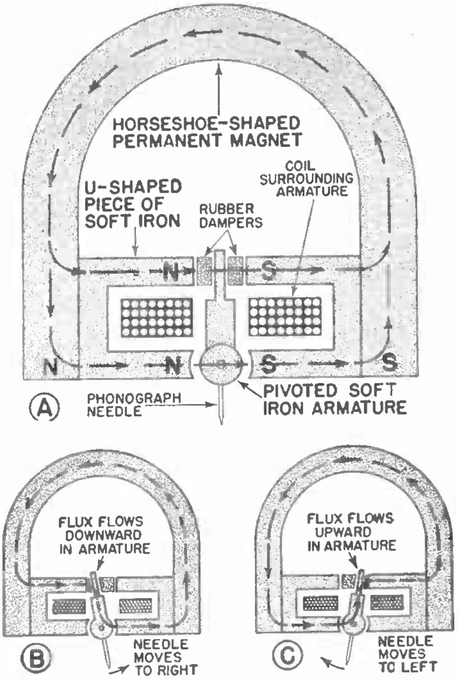
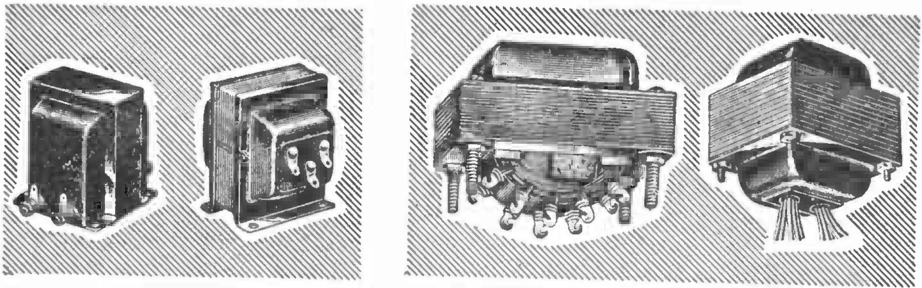


FIG. 16. Cross-section views illustrating the basic operating principles of a magnetic phono pick-up.

When the needle moves continually back and forth between the positions of Figs. *16B* and *16C* during the playing of a record, the continually varying and reversing flux in the armature and in the coil keeps the flux linkages of the coil changing continually, thereby inducing in the coil an a.f. voltage corresponding to the sounds recorded on the phonograph record.

Rubber dampers prevent the top of the armature from "sticking" in any



A.F. TRANSFORMERS POWER TRANSFORMERS

Examples of iron-core transformers you will encounter in radio receivers.

one position, and also prevent it from vibrating too greatly under certain conditions.

Transformer. The best-known example of a radio part in which changes in flux linkages are secured by changing the coil current is the *transformer*. The basic construction of one type of transformer, an iron-core unit, is shown in Fig. *17* to illustrate the basic principles involved.

Two coils are wound around the central part of the iron core. These coils could be placed side by side as shown in the diagram. In actual units, however, one is usually wound over the other, with insulating cloth between, because this gives lower manufacturing costs without affecting performance.

The winding through which we send the current from our voltage source is called the *primary winding*, and is usually marked PRI. or P. The other winding, in which the voltage is induced, is called the *secondary winding* and is usually marked SEC. or S. A transformer will have only one primary winding, but can have any number of secondary windings.

When steady direct current is sent through the primary winding, this current produces magnetic lines of force which take the paths shown in Fig. *17*. This flux passes through the secondary winding and gives it a definite number of flux linkages. With direct current, however, the number of flux linkages does not change, and hence no voltage is induced in the secondary winding.

Whenever we change the value of the primary current, the flux in the iron core changes accordingly, and hence the flux linkages of the secondary winding change. As a result, a voltage is induced in the secondary whenever the primary current changes.

When an alternating current is sent through the primary, we have a continually varying primary current and correspondingly varying flux linkages in the secondary winding. The voltage induced in the secondary under this condition is an a.c. voltage of the same frequency. A transformer thus transfers an a.c. voltage from one circuit to another without wire connections.

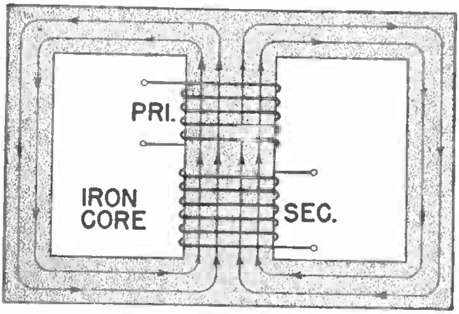


FIG. 17. This diagram illustrates the basic principles of an iron-core transformer. Arrow lines indicate paths taken by magnetic flux.

Basic Idea of Inductance

Self-Induced Voltage. Up to the present time, we have studied what happened when coils were placed in magnetic fields produced by other devices. However, a coil can be entirely by itself, far away from other magnetic fields, and still have an induced voltage. Here is how this "self-induced" voltage is produced.

When current is sent through a single coil, the coil produces its own magnetic field. And when this coil current changes, due to a change in the applied voltage, the magnetic field also changes in strength. Naturally, this magnetic field links with the coil, so we have changing flux linkages in the coil. This means that there is an induced voltage in the coil, produced by the coil itself and hence called a *self-induced voltage*. Lenz's Law says that this *self-induced voltage* must be in such a direction that it *opposes* the original change.

As an example, when we increase the coil current by boosting the applied voltage, we get an induced voltage which opposes the applied voltage and thus opposes the increase in applied voltage. The important thing for you to realize is that the induced voltage always *opposes* the *change* which is producing the induced voltage. If we didn't have this natural opposition to changes—if instead the induced voltage aided the change—then the induced voltage would build up to tremendously high values and destroy the coil.

Inductance. The characteristic which determines how much voltage will be induced in a coil by a given change in current is called inductance. Inductance is one factor which determines how much the self-induced voltage will be. More specifically, the electrical size or inductance of a coil determines how much *change* in flux linkages will be obtained with a given change in coil current. The higher the inductance, the greater will be the change in flux linkages for a given current change.

Units of Inductance. The basic unit of inductance is the *henry*. It is named after Professor Joseph Henry, an outstanding American scientist who announced the results of his coil experiments in 1832. The henry specifies the amount of flux linkages produced by an ampere of current. If one ampere produces 100,000,000 flux linkages in an air-core coil, the coil has an inductance of *one henry*.

All coils, including iron-core coils, are said to have an inductance of one henry when a current change of one

Courtesy General Electric Co.

Inside the cardboard housing of the "Beam-A-Scope" in this General Electric console receiver is a large coil which serves as a built-in loop antenna. The three cylindrical shield cans on top of the chassis contain r.f. and i.f. coils, and the two loudspeakers have iron-core coils.

ampere in one second produces a self-induced voltage of one volt.

Although some of the iron-core coils used in radio have inductance values ranging as high as 1000 henrys, air-core radio coils have inductance values of only a small fraction of a henry. For convenience in specifying inductance values of air-core coils and small iron-core coils, we frequently use another unit of inductance called the *millihenry*. One millihenry is equal to one-thousandth of a henry, hence there are 1000 millihenrys in one henry. Here are some examples: 500 millihenrys is equal to .5 henry; 9000 millihenrys is equal to 9 henrys.

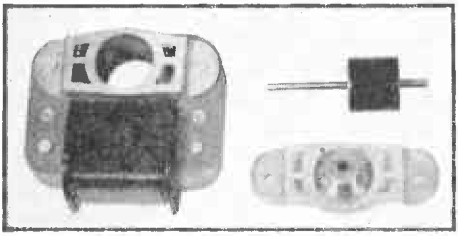
A still smaller unit of inductance occasionally encountered in radio is the *microhenry*. It is equal to one-millionth of a henry. It takes one thousand microhenrys to make one millihenry.

Factors Affecting Inductance. The inductance of a coil is determined by the number of turns in the coil, by the shape of the coil, and by the material used in the core of the coil. It is possible to calculate by means of formulas the inductance which will be obtained with any combination of these factors, but practical radio men do not particularly need to know such design procedures.

It is entirely sufficient to know that when you increase the number of turns in a coil, the inductance will increase likewise. If you reduce the number of turns, the inductance will go down. Furthermore, the change in inductance will be somewhat faster than the change in turns.

It should be pointed out that inductance is not necessarily limited to coils. Even a straight wire has inductance; in fact, straight wires or straight pipes are actually used as inductances in ultra-high-frequency equipment. The inductance value is too small for the type of radio receivers we use in our homes, but becomes effective and useful at ultra-high frequencies.

A. C. Voltage Drop of a Coil. We have learned that whenever the flux linkages of a coil are changed in any way, a voltage is induced in the coil. Therefore, if we send alternating current through a single coil, the continually changing flux linkages will cause an a.c. voltage to be induced in the coil itself.



Courtesy Barber-Colman Co.

A single coil wound on an iron core provides the varying magnetic field which operates this small a.c. motor, used to drive the magnetic tuning unit of a radio receiver. The "squirrel-cage" armature at the upper right fits into the hole above the coil, being supported there by two bearing assemblies like that shown at the lower right.

Since an induced voltage always opposes whatever force is producing it, a self-induced a.c. voltage in a coil opposes the a.c. source voltage. This is why a self-induced voltage is sometimes known as a *back e.m.f.* or *counter e.m.f.*

The back e.m.f. in a coil is the a.c. voltage drop appearing across the coil. Just as the voltage drop across a resistor is due to current flowing through the opposition in ohms of a resistor, so is the a.c. voltage drop (back e.m.f.) of a coil due to the opposition in ohms which the coil offers to alternating current. This coil opposition is known

Courtesy Henry L. Crowley & Co., Inc.

These two molded cup-shaped outer pieces and the cylindrical iron core of pulverized iron will, when assembled, form a complete magnetic core for the r.f. choke coil, greatly increasing its inductance.

as *inductive reactance,* and is well worth thorough study now because it determines how much alternating current will flow through a coil in a particular radio circuit.

Inductive Reactance. The opposition in ohms which a coil offers to the flow of alternating current varies with frequency. This explains why the frequency.value is included in the following rule for figuring the inductive reactance of a coil:

The inductive reactance in ohms of a coil is equal to the inductance of the coil in henrys multiplied by 6.28 times the frequency in cycles.

By using letter notations for some of these terms, we can express this relationship more conveniently by an equation or formula. The notation X_L is used to represent inductive reactance. The smaller letter f is used to represent frequency. The letter L is used in formulas to represent inductance. With these notations, the inductive reactance in ohms of a coil can be expressed by means of the following formula:

$$X_L = 6.28 \times f \times L$$

You will occasionally find this formula written as $X_L = 2\pi fL$; π is the Greek letter pi (pronounced *pie*) which is commonly used to represent the mathematical number 3.14, and 2π is 2 × 3.14, or 6.28, the number in our first formula.

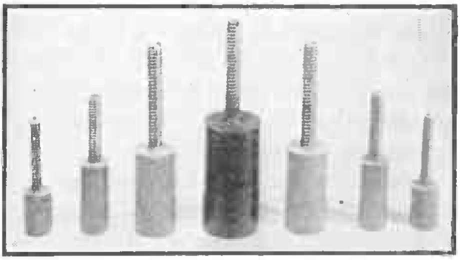
Example: Suppose we wanted to know the inductive reactance of a 30-henry choke coil at 120 cycles. The formula is:

$$X_L = 6.28 \times f \times L$$

Substituting 120 for f and 30 for L gives

$$X_L = 6.28 \times 120 \times 30$$

Multiplying these three numbers together gives 22,608 as the value of X_L. This coil would therefore have an opposition (inductive reactance) of about 22,600 ohms in a 120-cycle alternating current circuit.



Courtesy Henry L. Crowley & Co., Inc.

Examples of pulverized iron cores used in adjustable r.f. coils. Each screw is slotted at the end for adjusting purposes; rotating the screw with a screwdriver moves the core into or out of the coil, thereby changing the inductance. This method of changing the inductance of a coil is often called permeability tuning.

At 60 cycles, the inductive reactance of this coil would be 6.28 × 60 × 30, or 11,300 ohms, which is exactly half the reactance at 120 cycles. At 120,000 cycles, the inductive reactance would be 6.28 × 120,000 × 30, or 22,600,000 ohms. Inductive reactance thus varies directly with frequency. These examples are given not because you will solve such problems as a technician, but to show you how reactance varies with frequency, and to show that the reactance also varies with the inductance of a coil.

Just as a matter of comparison, we might point out that in a direct current circuit, the only opposition this 30-henry coil would offer to the flow of current would be that due to the resistance of the copper wire in the coil—about 400 ohms for a coil of this size. This d.c. resistance will also affect alternating current, and will produce an a.c. voltage drop. This resistance value is negligibly small in comparison to the 22,600-ohm inductive reactance at 120 cycles, so we normally neglect the a.c. voltage drop due to the resistance of the coil.

Ohm's Law for Coils. Ohm's Law tells us how much alternating current will flow through a particular coil under given conditions, just as it does for resistors in direct current circuits. We need to know only the inductive reactance of the coil in ohms and the effective value of the a.c. voltage applied to the coil. The effective alternating current value in amperes is then equal to the a.c. voltage in volts divided by the reactance in ohms. (This assumes that the d.c. resistance of the coil is negligibly small in comparison to its reactance.)

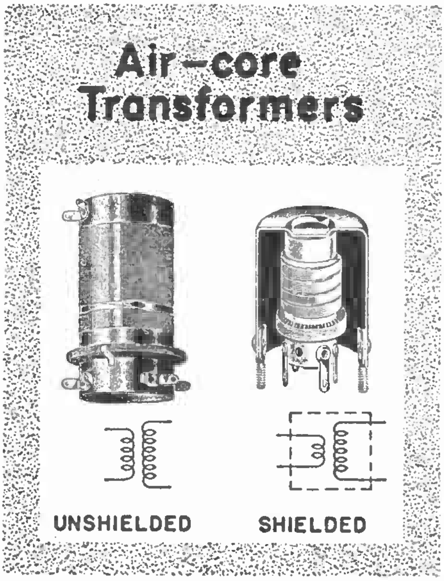
The simple formula is $I = E \div X_L$; you will recognize this as being very similar to $I = E \div R$, the d.c. version of this Ohm's Law formula.

Example: A coil having a reactance of 6000 ohms is to be connected across a 120-volt a.c. power line. What current will flow through the coil?

Since I is equal to $E \div X_L$, we divide 120 by 6000, and get .02 ampere as the a.c. coil current.

The other two Ohm's Law formulas for coils having negligibly small resistance are $E = I \times X_L$ (for use when you want to figure the a.c. voltage drop across a coil) and $X_L = E \div I$ (for use when you want to figure the inductive reactance of a coil).

Mutually Coupled Coils. When the two coils of a transformer are wound side by side or one over the other on a paper or fiber form, without any magnetic material in the core, we have an *air-core transformer*, and the two coils are mutually coupled through their magnetic fields. Air-core units are usually called *r.f. transformers* or *i.f. transformers*, because they are used chiefly in radio frequency (r. f.) and intermediate frequency (i.f.) circuits.



Radio men often speak of *r.f. coils* when they mean *r.f. transformers*. An r.f. transformer does consist of two or more r.f. coils, so there is some justification for this. Anyway, the terms are a part of the radio man's everyday language, so we might as well accept them.

In two coils which are mutually coupled, the voltage induced in the second coil depends on three things: 1. The *frequency* of the primary current; 2. The *effective value* of the primary current; 3. The *mutual inductance* of the two coils. Increasing any one of these three things will increase the induced voltage in the secondary, as explained later.

Effect of Frequency. The higher the frequency of the primary current, the faster will the flux be changing and the greater will be the induced voltage in the secondary.

Effect of Current. The higher the value of primary current, the more flux it will produce. Since this flux varies from a maximum value in one direction to zero and then to a maximum in the other direction, more flux means a greater change in flux per unit of time and a higher induced voltage in the secondary.

Mutual Inductance. This is a factor which expresses in a practical manner the amount of coupling (flux linkage) between the primary and secondary coils of an air-core transformer. The greater the mutual inductance value, the greater will be the voltage induced in the secondary of the transformer by a given change in primary current.

Mutual inductance depends upon the sizes of both air-core coils, the number of turns on each coil, their relative positions and their distances apart.

Mutual inductance is specified in henrys just like ordinary inductance, and is represented in formulas by the letter M. The higher the value of mutual inductance, the greater will be the induced voltage in the secondary coil.

Sometimes you will find mutual inductance defined as follows: When a change of one ampere per second in primary current produces one volt in the secondary, the mutual inductance is one henry. This applies to any mutually-coupled coil.

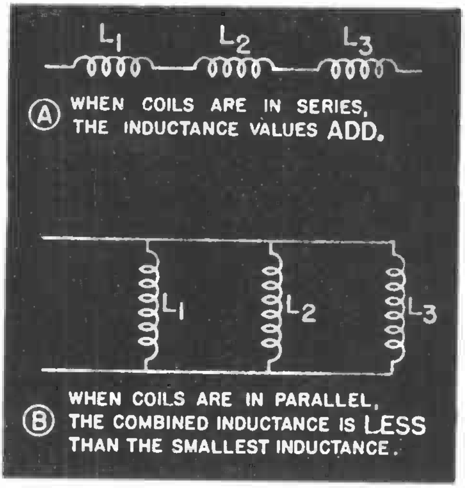


FIG. 18. Coils combine exactly like resistors

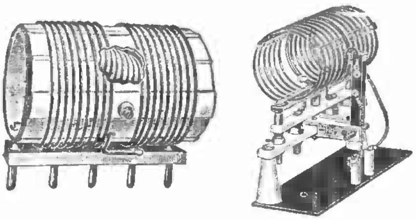
COILS IN SERIES AND PARALLEL

It is worth knowing in a general manner what happens when coils are combined in series or in parallel, the coils being far enough apart so that their magnetic fields do not affect each other, or shields being used to prevent interaction of the coils.

When coils are connected together in series, as shown in Fig. *18A*, the combined inductance is the *sum* of the individual inductances.

When coils are connected together in parallel, as shown in Fig. *18B*, the combined inductance is *less than* the smallest inductance in the group.

These rules for combinations of coils are exactly the same as for combina-



Air-core transformers for short-wave transmitters. The amount of coupling between the two coils is varied in the left-hand unit by rotating a small inner coil, and in the right-hand unit by moving a link (one or two-turn coil) between the two coils.

tions of resistors. This fact makes it easy for you to remember how coils combine.

Mutually-Coupled Coils in Series. When two coils are connected in series and are close enough together so that mutual inductance exists, we have interaction between the coils, and the combined inductance will be either increased or decreased by a factor equal to twice the value of the mutual inductance in henrys. Thus, if coil connections are such that the magnetic fields of the two coils aid each other, the combined inductance will be equal to $L_1 + L_2 + 2M$. If the connections are such that the magnetic fields of the two coils oppose each other, the combined inductance will be $L_1 + L_2 - 2M$. Reversing the connections to one of the coils will reverse the effect of the mutual inductance factor.

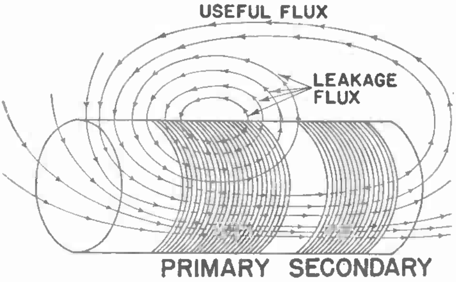


FIG. 19. Leakage flux. In the average coil, the leakage flux is only a small proportion of the total useful flux.

Leakage Flux. Flux which is produced by the primary winding of a transformer but does not produce the maximum possible number of flux linkages with the secondary winding is called *leakage flux*. Two mutually-coupled air-core coils do not give the maximum possible transfer of voltage from primary to secondary because of this leakage flux.

In a single coil by itself, the flux which is produced by some of the turns but does not link with all of the turns of the coil is called *leakage flux*. This is basically the reason why certain shapes and sizes of coils give greater inductance for a given length of wire.

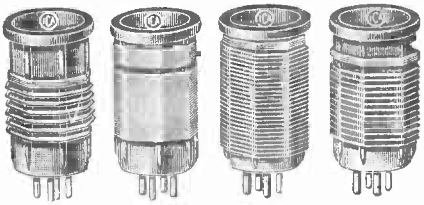
The name leakage flux is used because this flux "leaks" back around a path whereby it does not do its full quota of useful work. Examples of both types of flux are shown in Fig. *19*. You will frequently encounter the subject of leakage flux as you continue your study of radio.

VARIABLE INDUCTANCES

In some receiver and transmitter circuits, it is necessary to provide means for changing the inductance value of the coil in a radio circuit. Thus, in receivers having more than one band, different inductance values are needed for each band. This can be done in a number of different ways, which we will now consider, one at a time.

Changing Entire Coils. One way to change quickly from one inductance value to another is by means of plug-in coils, which fit into sockets in the chassis and can be changed just like tubes are changed. Plug-in coils are used today chiefly in experimental receivers, communications receivers and transmitters, for band-changing purposes so as to permit reception or transmitter operation in a particular band of frequencies.

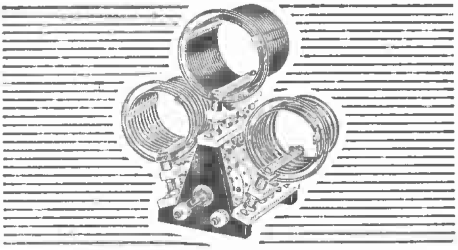
A more convenient way of changing coils, used in many modern all-wave



Examples of plug-in coils used in experimental short-wave receivers.

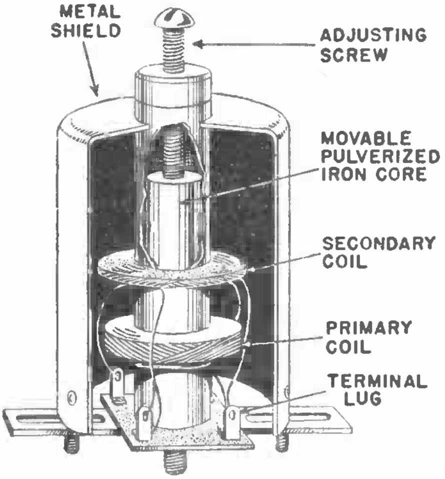
receivers and communication transmitters, is by means of a band-changing switch which disconnects one set of coils completely and connects another set in its place when the switch knob is rotated. Sometimes the coils are provided with taps, and the band-changing switch makes connections to the taps which place the desired numbers of turns in the circuits.

Variometers. The inductance of a coil can be varied gradually between two values with a *variometer*. This is simply a variable inductance in which one coil is rotated inside a larger coil. The two coils are connected in series. Rotation of the inside coil changes the amount of coupling between the two coils, changing the mutual inductance of the two coils and thus changing their combined inductance. Variometers were once widely used in receivers for tuning purposes, and are still to be found in some types of radio transmitters.



Transmitter band-switching arrangement which makes it possible to connect any one of three coils into the circuit merely by turning the switch. Many all-wave receivers have similar band-switching arrangements, using smaller coils and more compact switches.

Permeability Tuning. The inductance of a coil can be varied by moving a small cylindrical core of pulverized iron into or out of the coil. This varies the reluctance of the magnetic circuit of the coil, which changes the amount of flux the coil can produce, and thus varies the inductance.



R.F. transformer with adjustable pulverized iron core. Tightening the adjusting screw raises the core out of the primary coil, thereby reducing the amount of coupling between the two coils.

This method of varying inductance is usually known as *permeability tuning*, because as we include more of the iron in the magnetic path of the coil, we change the permeability of the magnetic path. Some modern receivers are now using variable inductances like this with fixed condensers for tuning purposes, in place of variable condensers with fixed inductances.

RESISTANCE OF A COIL

When a coil is connected to a d.c. voltage source, direct current flows through the coil. The value of this steady direct current depends only on the *d.c. resistance* of the coil, which is simply the resistance of the copper wire used in constructing the coil. (The inductive reactance of the coil has no effect whatsoever on the amount of direct current which flows through the coil, as reactance exists and offers opposition only in a.c. circuits.)

Although copper wire has a lower resistance per unit length and thickness than almost any other material you encounter in radio, coils are sometimes made with so much fine copper wire that they have d.c. resistance values even higher than 1000 ohms. On the other hand, some coils are made from only a few turns of large wire, so their d.c. resistance is considerably less than 1 ohm.

A knowledge of d.c. resistance values of coils is extremely useful when hunting for trouble in radio equipment. Just by comparing the measured d.c. resistance of a coil with the value specified on the circuit diagram, you may be able to tell whether or not a coil is defective.

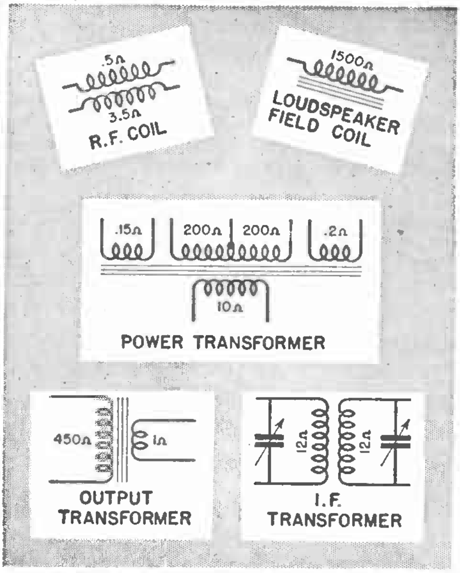


FIG. 20. The d.c. resistance values of coils are often given on circuit diagrams of radio receivers, much in the manner shown here.

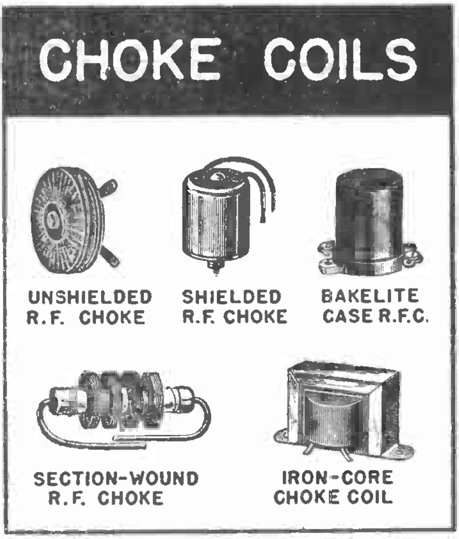
You will often find resistance values specified near the coil symbols on circuit diagrams, much in the manner shown in Fig. *20* for typical coils of different types. This information is particularly useful when checking resistance or continuity in a circuit with an ohmmeter in order to locate a defective part, as you will learn when you begin mastering radio servicing techniques.

Another practical use for d.c. resistance values of coils is in identifying the coils in the various bands of an all-wave receiver. Coils for short-wave bands always have less inductance than broadcast band coils. This means that short-wave coils have fewer turns, less wire and less resistance. The tuning coil having the lowest resistance can therefore be identified as belonging to the lowest short-wave band (the highest-frequency band). The tuning coil having the most resistance will belong to the broadcast band.

Using Ohm's Law. A coil in a direct current circuit acts exactly like a resistance insofar as the d.c. voltage source is concerned. This means you can use Ohm's Law to figure voltage, current and resistance values for coils in d.c. circuits, just as you do for resistors. For example, to figure the amount of direct current which will flow through a coil, you divide the d.c. voltage applied to the coil by the d.c. resistance of the coil ($I = E \div R$).

Coils Can Get Hot. In the previous lesson, you learned that whenever current flows through a resistance, heat is produced. The copper wire in a coil has resistance, and therefore heats up exactly like a resistor. If you overload a coil by sending too much direct current through it, the wire in the coil melts and burns out just like an overloaded wire-wound resistor. When coils are sealed with pitch, as is the case in some output transformers and filter chokes, overloading may melt the sealing compound, causing smoke and a characteristic burned odor.

Magnet Wire. Coils are usually wound with one or more layers of insulated copper wire. You will find three types of insulation in common use—enamel, cotton and silk, used singly or in combinations like silk



Examples of choke coils you will encounter in radio receivers and transmitters. Single coils by themselves are called choke coils by radio men, and are used individually in radio circuits to offer opposition to alternating current without appreciably hindering the flow of direct current. Basket-weave windings (like that of the unshielded r.f. choke) and criss-cross windings give low distributed capacity (explained later), thereby improving the effectiveness of the coil at high radio frequencies.

over enamel and cotton over enamel. Wire in the sizes and types used for coils is popularly known as *magnet wire,* because at one time such wire was used chiefly for electromagnets.

Coils are sometimes baked in a hot oven during manufacture to drive off moisture, then dipped in insulating varnish or molten wax to make them moisture-proof and to hold the turns of wire in position despite rough handling.

NON-INDUCTIVE RESISTORS

Wire-wound resistors made by winding nichrome resistance wire around an insulating form are really small coils having high resistance. Oftentimes, the coil characteristics of these wire-wound resistors are highly undesirable. This is particularly true in the high frequency radio circuits used in frequency modulation receivers and transmitters, in television receivers and transmitters, in ultra-high frequency police radio equipment, and in radio airplane locators. For these circuits we must use non-inductive resistors, which have no coil characteristics.

Carbon and metallized resistors are considered as non-inductive resistors, for each one is a single straight rod without any turns or coils, having negligible inductance.

Special windings are used on wire-wound resistors to get non-inductive characteristics. One example is the so-called "hairpin-type winding" shown in Fig. *21A*. In this winding, the electron flow is in opposite directions through any two adjacent wires, hence the magnetic fields produced by the adjacent wires are in opposite directions and cancel each other. The result is zero inductance.

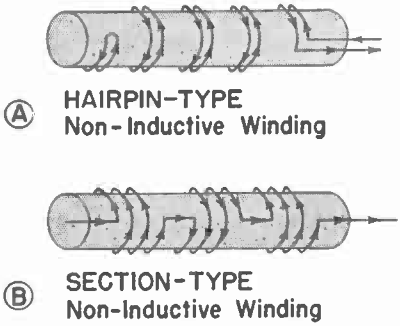


FIG. 21. Two ways of winding wire-wound resistors so they have practically no inductive characteristics. Arrows indicate directions of electron flow.

Another type of non-inductive winding is shown in Fig. *21B*. Here the resistor is made of an even number of sections, connected so current flows in opposite directions through adjacent sections. The magnetic fields of adjacent sections cancel each other, and again we have zero inductance.

Simple Coil-Resistor Circuit

We have already seen that when a coil alone is connected to an a.c. voltage source, its reactance determines what current will flow. We now come to a practical case where a coil is used in series with a resistor in an a.c. series circuit.

If we connect a coil and a lamp in series to a 115-volt d.c. source, as in Fig. *22A*, then connect d.c. voltmeters to measure the voltage drops across the coil and lamp, we will find that these voltages check with Kirchhoff's Voltage Law. In other words, the voltage drops will add up to 115 volts, the source voltage.

Suppose, however, that we change to a 115-volt a.c. source, as in Fig. *22B*. With a.c. voltmeters being used now to measure the voltage drops, we find that the two voltage drops add up to 154 volts, which is much higher than the source voltage. Clearly, we cannot apply Kirchhoff's Voltage Law directly to a.c. circuits.

We know this law must hold true because it is a fundamental radio law, so let us now see *why* it doesn't apply directly. Let us also investigate the special procedure a radio design engineer might have to use in order to make the law apply. This problem brings us for the first time to the subject of *phase*.

Phase. The voltage drops across the coil and lamp in Fig. *22B* do not add up to the a.c. source voltage because these a.c. voltage drops *do not reach corresponding peak values at the same instant of time in each cycle.* In other words, one a.c. voltage may be at the zero point in its cycle at the instant when the other a.c. voltage is at its maximum or peak value. We encounter this situation whenever we use coils or condensers along with resistors in radio circuits, and we say that there is a *phase difference* between these a.c. voltage drops.

The only time we can add directly the a.c. voltages which a.c. meters measure is when these voltages are in phase with each other (when all reach corresponding peak values in each cycle at the same instant of time, and all drop to zero together). This occurs only when all the parts in the circuit are identical (all are resistors, all are perfect coils or all are condensers). Let us see how phase enters into the picture when we use a coil in an a.c. circuit.

First of all, we can definitely say that the same value of alternating current flows through both the coil and the lamp in our a.c. circuit of

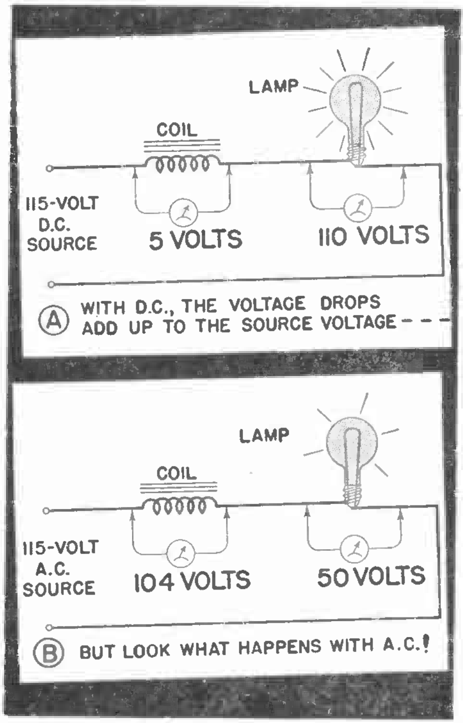


FIG. 22. Circuits illustrating the effects of phase in a.c. coil circuits.

Fig. *22B*, because these two parts are in series. The curve in Fig. *23A* shows how this current varies during each complete cycle. On diagrams of this type, time is always assumed to be zero at the extreme left of the curve, so the beginning of the cycle is at the left on the diagram. Time therefore increases *to the right*, and the end of the cycle is at the right.

A lamp is a resistance, so this current produces across the lamp an a.c. voltage drop which is *in phase* with the current. The resistor voltage curve is shown in Fig. *23B* for the same interval of time covered by the current curve in Fig. *23A*. Compare these two curves, and you will see that voltage and current values for a resistor reach corresponding peak values in each cycle at exactly the same instant of time.

The a.c. voltage across the coil is definitely not in phase with the circuit current. Technically speaking, the current in a perfect coil always *lags* the coil voltage by 90° (one-quarter cycle). The reason for this can be explained in a few sentences, with the aid of the circuit current curve in Fig. *24A*.

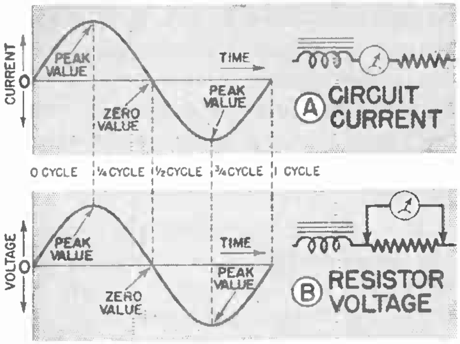


FIG. 23. These two curves show that voltage and current values for a resistor reach corresponding values at exactly the same instant of time. This means that voltage and current for a resistor are IN PHASE with each other.

First of all, we must remember that the a.c. voltage drop of a coil depends upon *how fast the coil current is changing*.

Examining the current curve in Fig. *24A*, we see that the current changes very little—hardly at all—during time interval *a*. The current on this diagram is represented by the distance a point on the curve is from the horizontal reference line. Since points *1* and *2* are both almost the same distance above this line, the current is essentially the same at *2*, the end of time interval *a*, as at the beginning (*1*). When the current doesn't change, the flux doesn't change, and hence the flux linkages do not change. No changes in flux linkages mean no induced voltage to act on an a.c. voltmeter connected across the coil, which explains why we find the coil voltage to be zero when we trace downward from point *2* to the coil voltage curve in Fig. *24B*.

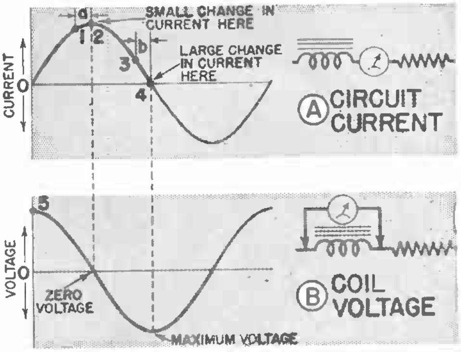


FIG. 24. The basic fact that a coil voltage is OUT OF PHASE with the coil current is shown by these two curves.

At time interval *b* (Fig. *24A*), however, the current is changing very rapidly (it drops from the value at point *3* all the way down to zero at point *4*).

The steeper (more vertical) the curve, the more change there is in current during a given interval of time. We therefore expect the a.c.

Courtesy Sensitive Research Instrument Co.

The number of magnetic lines of force passing through a given area can actually be measured with this special instrument known as a fluxmeter. When the exploring search coil (below the instrument) is rotated or moved in a magnetic field, the resulting change in the flux linkage of this coil produces an induced voltage which sends current through the meter. The meter scale is calibrated to indicate lines of force. (On this instrument, each small division on the scale represents a change of 10,000 lines of force in a single-turn exploring coil.)

coil voltage drop to be a maximum at the time of point *4*, where the curve is most nearly vertical, and we find this to be true when we trace downward to the coil voltage curve.

Continuing in this same way for other instants of time, we will find that when coil current is represented by the curve in Fig. *24A*, the coil voltage will vary as shown by the curve in Fig. *24B*.

If we carefully compare the two curves in Fig. *24*, we will find that the coil voltage curve reaches its peak value exactly one-quarter cycle *before* the current curve reaches a corresponding peak. For example, at zero current the coil voltage is at its upper peak (5), but the current does not reach its upper peak (2) until a quarter-cycle later. This is why we say that the coil voltage *leads* the current by one-quarter cycle, which is 90°. (One cycle is 360°, so one-quarter cycle is 90°, pronounced *ninety degrees.*) This holds true for all perfect coils.

Of course, we can express this relationship in another way if we prefer: The coil current *lags* 90° behind the coil voltage. Saying *current lags* voltage is exactly the same as saying *voltage leads current.*

Since the coil voltage is *out of phase* with the current, and the resistor voltage is *in phase* with the current, we arrive at the fact that the coil and resistor voltages are *out of phase* with each other. A.C. voltages as read by a meter can be added directly only when they are *in phase* with each other, and consequently we cannot add these two a.c. voltages directly.

Always remember that a.c. meters measure *effective* values of a current or voltage which is continually varying. The meters read the same even though the current through them is varying, because meter coils cannot respond to such fast variations in current.

If we had some means of measuring the exact values of our a.c. voltages all at the same instant, we would find that the instantaneous voltage drop values would add up to the exact value of the source voltage at that instant. We have no convenient meters for this, however, and there is no practical need for measurements of instantaneous a.c. values, so let us go on now and learn the correct way for combining out-of-phase a.c. voltages.

Vectors. We have found that the coil and resistor (lamp) voltages reach their peaks at different times in each cycle. The simplest way to show the phase relationships of all voltages and currents in an a.c. circuit is by means of a single diagram in which rotating arrows represent the a.c. voltages and currents. These arrows are called *vectors*.

The length of each vector indicates the *amount* of voltage or current, and the position of the vector with respect to the starting or reference line indicates the phase of the voltage or current with respect to the other voltages and currents.

Each complete revolution of a vector represents one a.c. cycle. By general agreement among radio and electrical men, vectors are always assumed to be rotating *counter-clockwise*, opposite to the direction in which the hands of a clock move. Furthermore, the starting or reference position for all vectors is the vector position shown in Fig. *25A*, which is a line going *to the right* horizontally from the center (*0*) of the vector diagram.

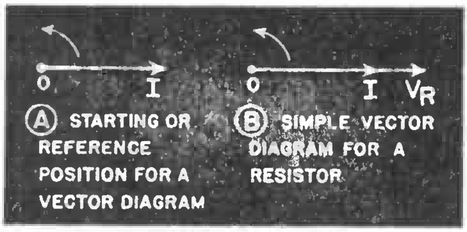


FIG. 25. Vector diagrams like these are easy ways of showing how continually varying currents and voltages in a.c. circuits are related to each other.

In a series circuit, we almost always use current for our reference vector. To make the vector in Fig. *25A* represent the circuit current, we make the length of the vector proportional to the effective current value which would be indicated by an a.c. ammeter. We then put on the arrow head, and label it with the capital letter *I* to indicate that it represents current.

The voltage drop across the lamp is *in phase* with the current, so the voltage drop vector V_R will have exactly the same position as the current vector. We therefore draw voltage drop vector V_R from *0* along the reference line, right over the current vector and in a length which is proportional to the effective a.c. value of the resistor voltage drop, just as in Fig. *25B*. Thus, we might let one inch of length along the vector line represent 5 volts, 20 volts or any other value which gives a convenient size of vector diagram. This simple diagram now tells us at a glance that the voltage and current for the lamp are in phase with each other. Incidentally, a vector diagram with overlapping vector arrows like this would be obtained for any resistor in any a.c. circuit.

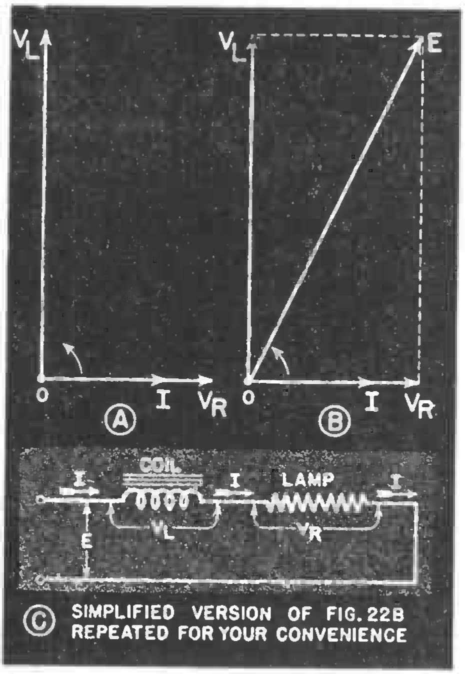


FIG. 26. These simple vector diagrams tell the entire story about how the current and voltage are related to each other in the a.c. coil resistance circuit of Fig. 22B.

Next comes the coil voltage vector, which we know must be 90° ahead of the current. One complete vector revolution is one cycle or 360°, so 90° will be one-quarter of a revolution. We must go one-quarter cycle counter-clockwise to get ahead 90°, so we draw coil voltage vector V_L straight up from *0*, as in Fig. *26A*. Coil voltage and current vectors 90° apart like this would be obtained for any perfect coil in any a.c. circuit.

Only one voltage remains to be placed on our vector diagram—the source voltage. And now we learn the secret of making Kirchhoff's Voltage Law apply to our a.c. circuit: If we take the *vector sum* of the voltage drops, they will add up to the source voltage *E*.

To get the vector sum of voltage drops V_L and V_R on our diagram in Fig. *26B*, we simply draw in dotted lines to complete a rectangle, then draw the diagonal of this rectangle from *0*. This diagonal line is the vector sum of the coil and resistor voltage drops, and is also equal to the source voltage, so we place an arrow on its other end and label it *E*. Since this vector is ahead of current vector *I* (remember that we have assumed counter-clockwise rotation), we say that source voltage *E leads* the circuit current. If we prefer to express it the other way, we would say that the current *I lags* the source voltage.

If we made the lengths of the voltage vectors in Fig. *26B* proportional to the actual effective a.c. voltage values (for instance, if we let each inch of length along the vector represent a definite amount of voltage), then measured the length of voltage vector *E* in Fig. *26B* and converted it back to volts, we would find that it was exactly equal to the source voltage value. Kirchhoff's Voltage Law holds true for all a.c. circuits if we apply it in this way so as to take phase into account.

The vector diagram in Fig. *26B* thus tells us the complete story about voltage and current relationships in our coil-resistor circuit shown in Figs. *22B* and *26B*.

Importance of Phase. A general knowledge of phase and vector diagrams will help you to understand the actions of coils and condensers in a.c. radio circuits, and will make you a better-than-average radio man. You will understand *why* you do certain things when making adjustments or repairs, instead of just blindly following instructions. It is the men who know *why* and *how* who command the highest salaries in the modern world of radio.

Later in your course, you will learn that the opposition of a coil can be balanced or cancelled by the opposition of a condenser because of *phase;* you will find that hum can be balanced out of a receiver because of *phase;* pictures are black when they should be white in television receivers because of *phase;* radio beacons guide aircraft in the skies because the designer took account of *phase* among other things; and so the examples pile up. Phase, however, is not a subject which you can grasp in one lesson; you will understand it better and better with each succeeding lesson.

LOOKING AHEAD

You have now finished your study of the basic facts about resistors and coils. When you complete a similar study of condensers in the next lesson, you will have secured a thorough basic knowledge of these three important radio parts.

Lesson Questions

Be sure to number your Answer Sheet 6FR-3.

Place your Student Number on *every* Answer Sheet.

***Send in your set of answers for this lesson immediately after you finish them,* as instructed in the Study Schedule. This will give you the greatest possible benefit from our speedy personal grading service.**

1. What effect does an increase in the number of ampere-turns have on the amount of magnetic flux produced by a coil?

2. Copy the following list on your Answer Sheet, and indicate after each material whether it is magnetic or non-magnetic.

   (a) Copper.
   (b) Sheet steel.
   (c) Plywood.
   (d) Aluminum.
   (e) Cast iron.

   Examples (do not copy these):

(x)	*Brass.*	*Non-magnetic.*
(y)	*Air.*	*Non-magnetic.*
(z)	*Alnico alloy.*	*Magnetic.*

3. When a pivoted iron object takes the position which gives minimum reluctance to the magnetic circuit of a coil, will we get *maximum flux* or *minimum flux?*

4. How many flux linkages do we have when 25,000 magnetic lines of force pass through a 3-turn coil?

5. Will we get an induced voltage if we suddenly reduce the number of flux linkages in a coil?

6. Is any voltage induced in a coil when the flux linkages are not changing?

7. Why do we get an induced voltage in a current-carrying coil when we change the reluctance of the magnetic circuit of the coil?

8. If a coil has an inductance of 2 henrys, what is its inductance in millihenrys?

9. Is the inductive reactance of a coil the same at all frequencies?

10. How many degrees out of phase with each other are the voltage and current in a perfect coil?

SINCERE APPRECIATION PAYS

Have you ever watched a dog respond to a friendly pat as a reward for obedience? Have you noticed how a child glows with joy when praised for good behavior? Have you ever felt your own brain cells respond with increased effort when you praise them by saying, *"That's a fine piece of work, even if I did do it myself!"*?

Yes, everyone responds to sincere and merited praise. It is a tonic to both giver and receiver. It brings greater praise and appreciation back to you. It costs nothing more than a smile and a few sincere words, but it can truly achieve miracles in happiness and success, and put real money in your pocket.

Here are a few ways in which praise can speed up your radio career. Tell the family how much you appreciate their thoughtfulness in being quiet and not interrupting while you study. Make your radio servicing customers feel that you appreciate their business. Find ways to praise sincerely the business men, club leaders and public officials in your community.

Time spent in figuring how to give sincere and deserved praise is well worth while. Let people know that you appreciate *their* fine work, and watch the breaks come *your way*.

J. E. SMITH

RADIO CONDENSERS AND HOW THEY WORK

7FR-3

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

STUDY SCHEDULE NO. 7

For each study step, read the assigned pages first at your usual speed. Reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind, then answer the Lesson Questions for that step. Study each other step in this same way.

☑ 1. How a Condenser Stores a Charge .... Pages 1-8

Here is the fascinating story of how it is possible to cause electrons to redistribute themselves on the plates of a condenser and thus make this important part store a charge. The voltage applied and the capacity determine the amount of charge. The capacity in turn depends on the physical dimensions of the condenser. Answer Lesson Questions 1 and 2.

☑ 2. Typical Radio Condensers .... Pages 8-18

This section is crammed full of practical information. You study the difference between types, learn to recognize them and see how the way they are made causes them to have certain defects. You'll find plenty of use for this information in your radio work. Answer Lesson Question 3.

☑ 3. Connecting Condensers Together .... Pages 18-21

Condensers are frequently connected in series or in parallel to get the proper capacity. The effects are exactly opposite to those obtained with coils or resistors. Also, you are introduced to leakage and its effects on voltage distribution. Answer Lesson Question 4.

☑ 4. How a Condenser Works with A. C. .... Pages 21-24

This short section describes an important but little understood action—how a. c. can "flow" through a condenser. Read this several times carefully. Answer Lesson Questions 5 and 6.

☑ 5. A Simple Condenser-Resistor Circuit .... Pages 24-30

When a condenser and resistor are connected together, several important actions occur. The condenser takes longer to charge and, with a. c., a phase shift occurs. Here is more about vectors. Answer Lesson Question 7.

☐ 6. Voltage Division with R, L and C .... Pages 30-36

Here is the "heart" of the lesson. You are introduced to some of the basic circuits you will find in every radio device and find out how condenser defects upset them. You will get more details later, but you should study and restudy this section. Answer Lesson Questions 8, 9, and 10.

☐ 7. Mail your Answers for this Lesson to N. R. I. for Grading.

☐ 8. Start Studying the Next Lesson.

JD25M447 1947 Edition Printed in U.S.A.

RADIO CONDENSERS AND HOW THEY WORK

How a Condenser Stores a Charge

CONDENSERS are one of the four corner-stones of radio. Like coils, resistors and tubes, condensers are found in every radio—even the tiniest. In fact, there are usually more condensers than there are of any other type of part. These condensers (acting in combination with other parts) are used to tune the set, to furnish the right power for operating the various sections, to keep the currents in the proper paths, and to perform many other important tasks which must be done for the radio to operate properly. You'll be meeting these useful devices all through your N.R.I. Course, but we should first study the types and basic actions of condensers before we take up their uses in combination with other parts. You'll want to learn about the defects occurring in condensers, as they cause more radio breakdowns than any other part, except possibly tubes. Hence, this lesson gives practical facts about condensers and their troubles.

What a Condenser Is. A condenser* is a device for storing electricity. Any condenser, no matter what type it is, consists essentially of two or more conducting surfaces separated by an insulator. The conducting surfaces are usually called plates, and the insulator is known as a "dielectric" (pronounced die-eh-LECK-trick).

▶ As you'll learn in this lesson, there are a great many types of condensers. They differ in construction, in kinds and shapes of plates, and in the dielectrics used, but basically they all work the same way to store electricity. So before taking up the various types and their uses, let's see just how a condenser works.

CHARGING A CONDENSER

Let's first take the simple case of a condenser which has absolutely nothing—a perfect vacuum—between its plates. When such a condenser is connected to a battery, as in Fig. *1*, the battery voltage makes electrons rush from the negative terminal of the battery through wire *a* to plate *A*. *There the electrons stop, because they cannot flow through the vacuum which separates them from plate B.**

But although these electrons cannot move across the vacuum, their *effect* can. As you learned in an earlier lesson, electrons repel one another—that is, they try to drive one another away. This repelling action occurs even when the electrons are a considerable distance apart, and are separated by a perfect vacuum.

Thus, the electrons which have collected on plate *A* repel an equal number of electrons from plate *B*. The electrons from plate *B* then flow into

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* A *condenser* does not "condense" anything. This is just the popular name for the part, which is more correctly called a *capacitor* by radio engineers. Similarly, *capacitance* is more proper than *capacity*. However, radio men have used these terms so long that they are accepted as correct.

* The electrons normally do not have sufficient energy to escape from the plate and jump the gap. Later you will learn that if the voltage is too high, they can jump the gap between the plates.

wire *b,* and through the wire to the positive terminal of the battery.

We thus have an electron flow, or current, from the battery to plate *A*, and an equal current from plate *B* to the battery *but no flow between plates A and B*. The flow of electrons onto plate *A* makes it *negative*, because it has an excess of electrons. The flow of electrons away from plate *B* makes this plate *positive,* because it has a scarcity of electrons. Thus, a difference in potential, or a voltage, exists between plates *A* and *B*.

▶ The electron flow continues until plate *A* is just as negative as the negative battery terminal, and plate *B* is just as positive as the positive battery terminal. As electrons do not flow across the gap, there can be no continuous flow of current. The electrons just flow long enough to make the condenser charge up so the condenser voltage equals the battery voltage.

Notice the polarity of this voltage, shown in Fig. *2*. As you go around the circuit, you find the condenser voltage opposes (bucks) the battery voltage. Therefore, when the condenser voltage is equal to the battery voltage, it cancels the battery voltage and the flow of electrons stops. That is, after a condenser is charged, it does not act like a load—it resembles a source of voltage. Hence, we have the effect of two sources of voltage connected so as to buck each other out, leaving no voltage to maintain electron flow. When the condenser voltage is equal to the voltage of the battery, we say the condenser is fully charged.

The Charged Condenser. Many people believe that a charged condenser contains more electrons than an uncharged one. But what you have just learned shows that this idea is not accurate. It is true that the negative plate has many more electrons than normal on it; however, each of these extra electrons has forced another electron out of the positive plate, so the *total* number of electrons on the condenser plates is unchanged. In charging a condenser, we increase the number on one plate and decrease those on the other—the same as if we transferred some electrons from one plate to the other around the circuit. The number of electrons added to the negative plate (and, of course, subtracted from the positive plate) is called the "charge" on the condenser.

▶ You may wonder what good it does to charge a condenser, since we don't change the total number of electrons on it by so doing. Well—suppose we disconnect the condenser from the battery. The electrons on the negative plate must remain there, because they have no other place to go. Thus we have an unbalanced condition inside the condenser, with more electrons than normal on one plate and fewer than normal on the other.

As you know, nature always tries to correct an unbalance of this sort. If we provide a path, the extra electrons on the negative plate will rush to the positive plate. In other words, if we connect the plates of our charged condenser with a wire, a current will flow through the wire. (Of course, it will flow only for the time necessary for all the excess electrons to reach the positive plate).

Thus, you might consider a condenser to be a kind of storage battery, or an electrical reservoir. Within limits, we can put electricity into a condenser whenever we wish, and draw it out again whenever we wish. This makes a condenser a highly useful device in radio circuits.

Amount of Charge. The charge on any particular condenser—which, as you just saw, is the number of electrons moved around the circuit—depends on the voltage of the battery used to charge it. The higher the battery voltage, the more the charge will be. However, the voltage alone does not determine the amount of charge we can store in a condenser. The *capacity* of the condenser is just as important as the charging voltage. Let's see what is meant by this term "capacity."

CAPACITY

If we divide the amount of charge on any condenser by the voltage necessary to give it this charge, the result shows us the amount of charge that can be stored on that condenser by an applied voltage of one volt. This is called the "capacity" (sometimes "capacitance") of the condenser. We can express capacity by the equation $C = Q/V$, where C is the capacity of the condenser, Q is the charge it takes, and V the charging voltage.

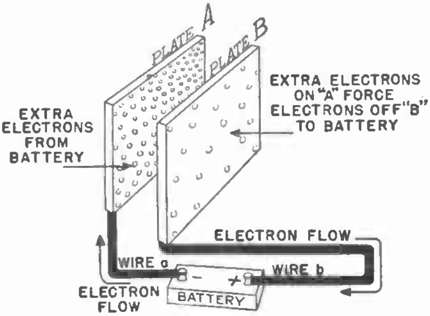

FIG. 1. When a condenser is connected to a battery, electrons collect on the negative plate, driving others off the positive plate as shown here.

The capacity of a condenser is really a measure of its ability to store electricity. A condenser with high capacity can store a great deal of electricity for a given voltage, while less can be stored in a condenser of lower capacity. For this reason, its capacity is usually the first thing a radio man wants to know about any condenser he uses.

Units of Capacity. Just as ohms are the units of resistance and henrys the units of inductance, so *farads* (pronounced FAIR-ads) are the units of capacity. A condenser which stores 6.3 million million million more electrons (which is called a "coulomb" of charge) on its negative plate than on the positive plate when one volt is applied to it has a capacity of one farad. Of course, a farad is a very large unit, so large in fact, that it is not practical for radio work. Instead, two smaller units are used:

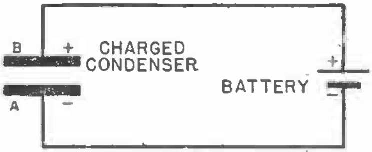

FIG. 2. No current flows when the condenser is charged to a voltage equal to the battery voltage. The condenser voltage then acts as a "bucking" voltage by being equal and opposite to the battery voltage as you progress around the circuit.

1. The microfarad, equal to one millionth of a farad. It is abbreviated *μf.*, *mf.*, or *mfd.*

2. The micro-microfarad, equal to one millionth of a microfarad. Its abbreviations are *μμf.*, *mmf.*, or *mmfd.*

All six abbreviations are frequently used in radio, so you should learn them all. The sign μ is the Greek letter "mu" (pronounced MEW).

Sometimes it will be necessary for you to change a value in microfarads to its equivalent value in micro-microfarads, and vice versa. Learn these two simple rules, and you'll find it easy to make the change:

Rule 1. To change mfd. to mmfd., move the decimal point six places to the right.

Rule 2. To change mmfd. to mfd., move the decimal point six places to the left.

For example, suppose we have a capacity of .001 mfd. and we want to know its value in micro-microfarads. We can write .001 as .001000. Then, moving the decimal point six places to the right (Rule 1) gives us 001000 mmfd., or 1000 mmfd. Similarly, to express 250 mmfd. in microfarads, we would first write 250 as 000250, then move the decimal point six places to the left (Rule 2). This gives us .000250, or .00025 mfd.

Incidentally, radio men usually pronounce .001 mfd. as *point double oh one* microfarad, or as *point zero zero one* microfarad. They would pronounce .00025 mfd. as *point triple oh two five* microfarad, or as *point triple zero two five* microfarad.

WHAT DETERMINES CAPACITY

Many times in your future radio work, you will use condensers whose capacities can be changed. So you will understand how and why such condensers work, let's now take up the important subject of what determines the capacity of a condenser.

The ability to store a charge depends on the amount of repelling effect we can develop between the condenser plates, so we must either increase the number of repelling electrons or increase the repelling effect of the electrons to store a greater charge. It has been found that the capacity of any condenser depends on just four things —the *area* of the plates, the *number* of plates, the *spacing* of (distance between) the plates, and the *dielectric* used. Let's see just how each factor affects capacity.

1. Area. Besides acting across space to repel electrons from the positive plate, the electrons collected on the negative plate repel each other. For a particular voltage, only a certain number can be made to collect on a plate of fixed size, because they refuse to crowd too closely together. Increasing the area of the plates allows more "standing room" for electrons on the negative plate, so a greater charge is stored for the same voltage. If we double the overlapping area of the plates of a condenser, we double its capacity; if we triple the overlapping area, we triple the capacity; and so on. Notice that it is the *overlapping* area which is important—any section of the negative plate of a condenser which is not directly over a section of the positive plate does not greatly affect the capacity. You will see the practical use of this fact when we come to variable condensers a little farther along in this lesson.

2. Number of Plates. Suppose we have three plates instead of two, arranged as shown in Fig. *3A*. There will be a certain capacity formed between plates A_1 and B, and another capacity between A_2 and the other side of B. As A_1 and A_2 are the same size and connected together, they act like a single plate twice the size of either alone. Since both sides of plate B are used, the effective area is also twice that of one side of B. We thus have twice the effective plate area by adding one more plate. As you just learned, doubling the area doubles the capacity.

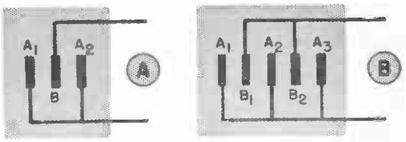

FIG. 3. Adding plates increases capacity.

The capacity can be further increased by adding more plates. In Fig. *3B*, we have capacities between A_1 and B_1, B_1 and A_2, A_2 and B_2, and B_2 and A_3. Here we have four times the capacity that would be formed by one pair of the same size plates.

Thus, the total capacity is equal to the capacity of one pair of plates, multiplied by a number which is *one* less than the number of plates. For example, if a condenser has a capacity of 10 mmfd. between each pair of plates and has 7 plates, the capacity will be 10 times 6 (7 plates minus one) or 60 mmfd.

3. Plate Spacing. The distance over which the repelling effect must work is important. The smaller the distance, the stronger the force between the plates. This makes it easier to overcome the desire of the electrons to remain on the positive plate, so more are forced away, permitting more to collect on the negative plate. Thus, varying the plate spacing will affect the amount of charge per volt, and so vary the capacity. If we make the distance between the plates of a condenser only half what it was, we double the capacity; if we make the distance a third, we triple the capacity; and so on. This fact, too, has a practical use, as you will find when we treat trimmer condensers in a later section of this lesson.

4. Dielectric. So far, we have been talking about a condenser which has a perfect vacuum between its plates—that is, a condenser which uses a vacuum as a dielectric. If, instead, we used mica as a dielectric between the plates, we would increase the capacity as much as 6 to 8 times. Other substances would give different capacity increases.

Since most condensers use some dielectric other than a vacuum, and since a great many of your service problems will be caused by dielectric failures, let's see just what effects dielectrics have on condensers.

EFFECTS OF A DIELECTRIC

You recall that electrons flowing onto the negative plate of our vacuum dielectric condenser repelled electrons from the positive plate and thus allowed the condenser to become charged. What happens to this repelling effect when we put a solid dielectric between the plates?

The two pictures in Fig. *4* show the answer. A dielectric, as you know, is an insulator. Like everything else in the world, it is made up of atoms, which consist of electrons whirling around positive charges. Fig. *4A* shows an atom which has a positive charge at its center and one electron revolving around it in a circle. (Actually, all but one of the 93 known atoms have more than one whirling electron, but for simplicity we'll assume we are dealing with an atom which has only one.)

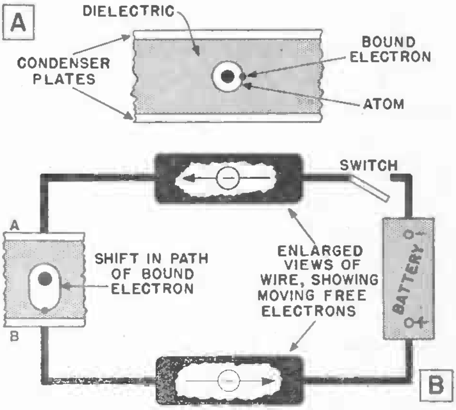

FIG. 4. Electrons in the dielectric are bound to their atoms. They do not "flow"; instead their paths are shifted so they come closer to the positive plate and thus transfer the effect of the extra electrons gathered on the negative plate.

As you learned in an earlier lesson, a *conductor* has a large number of free electrons, which can move easily when even a low voltage is impressed across the conductor. But this is not true of an *insulator*. When a voltage is impressed across an insulator, nearly all the electrons within the insulator tend to keep whirling around their central positive charges, because they are bound tightly within their atoms; normally, they will break away only when acted on by a very high voltage. For this reason, the electrons in an insulator are called "bound" electrons.

Now, let's close the switch in the circuit shown in Fig. *4B*. Electrons start to pile up on the negative plate of the condenser. These electrons repel the bound electrons of the dielectric. Unless this repelling force is extremely large, the bound electrons do not break away from their atoms; however, the force does change their paths within their atoms from the circle shown in Fig. *4A* to the oval shown in Fig. *4B*. This brings the bound electrons closer to the positive plate of the condenser; they then exert a repelling effect of their own on the free electrons of plate *B*, driving them out of the plate into the battery.

In this manner, the repelling effect of the electrons on the negative condenser plate is relayed right through the dielectric. Placing the dielectric material between the plates provides bound electrons within the space, and so provides a better transfer medium. This increases the capacity.

Dielectric Constant. You learned a moment ago that any other dielectric gives a condenser a higher capacity than does a vacuum. However, experiments show that the increase in capacity is very slight when air or any other gas under normal pressure is used as the dielectric. In fact, the difference can be detected only by the finest laboratory equipment, so for all practical purposes we can say that a condenser using air as a dielectric has the same capacity it would have with a vacuum dielectric.

If we divide the capacity of a condenser using any given dielectric by the capacity of the *same* condenser using air as a dielectric, we get a number which shows how much the dielectric increases capacity. This number is called the *dielectric constant* * of the dielectric material.

You can readily see that condensers using dielectrics which have a high dielectric constant have a higher capacity than condensers using materials with a low dielectric constant. The dielectric constants of various common materials used in condensers are: air = 1; paper = 1.5 to 3; paraffin = 2 to 3; mineral oil = 2.5; rubber = 2 to 4; mica = 4 to 8; glass = 4 to 10; castor oil = 4.7; porcelain = 5 to 7. Ceramic materials now coming into use have dielectric constants as high as 1500. Thus a condenser which has a capacity of 10 mmfd. using air as a dielectric would have a capacity between 40 and 80 mmfd. with a mica dielectric, and as much as 15,000 mmfd. with one of the new ceramic dielectrics.

VOLTAGE RATINGS

We have shown how increasing the voltage applied to a condenser will increase the charge stored on it. However, there are limits to the amount of voltage we can safely apply to the condenser. For example, when the voltage gets too high for the plate spacing of an air dielectric condenser, a spark will jump between the plates. Thus, the amount we can increase the capacity of an air condenser by decreasing the distance between its plates is limited by the voltage to be applied to the condenser.

The same thing is true for condensers using other dielectrics. If we apply too high a voltage, the bound electrons of the dielectric escape from

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* Scientists sometimes call the dielectric constant the "specific inductive capacity" of the material; both names mean the same thing. Don't confuse this term with inductance, a property of coils, as there is no relationship.

their atoms and start a flow of current through the condenser. This burns a hole right through the dielectric. When this happens, we say the condenser "breaks down"; the voltage which is just high enough to cause the condenser to break down is called the "breakdown voltage" rating of the condenser. The value of breakdown voltage for any given condenser depends on the dielectric used in it and the dielectric thickness.

Working Voltage. Condenser manufacturers almost always specify the *"working voltage"* of a condenser. This is the *maximum* voltage that can safely be applied to the condenser for long periods of time. Working voltage ratings for solid dielectric condensers, such as paper or mica, are always less than half the breakdown voltage. That is, over twice the working voltage can be applied to solid dielectric condensers before they will break down.

This rating does not mean you *have* to apply the working voltage to the condenser—this is just the *maximum* that *can* be applied safely. Thus, you can use a 400-volt condenser in a 10-volt circuit, or in any circuit having not more than 400 volts applied to it.

If a condenser is used in a d.c. circuit, we can put a voltmeter across it to make sure the working voltage is not being exceeded. But, as you have already learned, an a.c. voltmeter used on an a.c. circuit reads *effective* voltage; this meter reading must be multiplied by 1.4 (approximately) to get the actual peak voltage in the circuit. For example, if the meter shows that 110 volts a.c. is across the condenser, you would multiply this value by 1.4 to find the peak voltage. Since 1.4 times 110 equals 154 volts, the condenser would have to have a working voltage of at least 154 volts to be used in the circuit. Actually, a radio man would use at least a 200-volt condenser, and possibly a 400- or 600-volt type, as these are easily obtained standard sizes and allow an extra amount of safety factor.

▶ Some solid dielectric condensers also have a "peak voltage" rating. This is twice the working voltage; it is therefore just under the breakdown voltage, and represents the maximum voltage the condenser can stand for short periods of time.

Condenser Life. When the condenser has a solid dielectric, like paper or mica, a breakdown ruins the condenser, because a conductive "hole" has burned through the dielectric. Liquid dielectrics are not damaged unless the breakdown is too frequent, in which case the liquid may carbonize and become conductive.

Even when the safe working voltage limits are never exceeded, condensers using solid dielectrics will not last forever. The constant voltage stress on the bound electrons in the dielectric finally forces them out of their atoms and causes breakdown, just as constant bending of a bar of iron will eventually break the iron. Good solid dielectric condensers, used at or below their working voltage, should last from 10,000 to 20,000 working hours—usually much longer than a radio receiver will last.

Condensers must be kept cool to have such long service life. Exposing the condenser to heat speeds up the breakdown process, because bound electrons escape much more readily from their atoms when heated. For this reason, designers usually position condensers in radio equipment so they will not be exposed to too much heat. That brings up a practical hint for your service work—*if possible, always put a replacement condenser in the same place the designer put the* *original,* or in an equally cool place.

Air condensers will last almost indefinitely. Unlike condensers using solid dielectrics, air condensers are not particularly harmed by breakdown, because the air dielectric is "self-healing" (that is, more air immediately rushes in to replace the air broken down by the voltage). However, they should always be kept dry to minimize the number of breakdowns suffered because, although the condenser itself is usually not injured by breakdown, other parts in the circuit may be harmed by the sudden flow of excess current.

Typical Radio Condensers

So far, we have learned that the condenser is basically a means of storing electricity; that the condenser capacity depends on the area, number and spacing of the plates as well as the dielectric, and that a condenser can withstand just so much voltage before breaking down. Now let us learn something about the types of condensers used in radio, so you can recognize them when you meet them in receivers. Let's also study their weaknesses, so you can see just how and why they become defective, as they so often do.

▶ Condensers whose capacities cannot be changed are called "fixed" condensers. They are usually classified according to their dielectrics. Thus there are paper, mica, oil, gas-filled, cellulose acetate, polystyrene, electrolytic (in these a chemical deposit is the dielectric), ceramic, rubber and even glass fixed condensers. They are usually in some kind of case, which might be a metal, paper or cardboard box or cylinder, or a molded plastic covering.

▶ Radio men also use two types of condensers whose capacities can be changed — "variable" and "adjustable." Variable condensers—for example, the tuning condenser of a radio —almost always use air as a dielectric. Their name comes from the fact that their capacities can be varied easily, usually just by turning a control knob.

Adjustable condensers are usually used to make corrections or minor adjustments in the capacity of other condensers. For this reason, they are often called "trimmer" or "padder" condensers. They usually have air, or air and some other insulator, as their dielectrics. Their capacities are generally varied by changing the separation of the plates, usually by turning a screw. When they have been adjusted to the desired capacities, they are ordinarily left alone.

Let us now go on to some of the more common types, to see how they are put together and what they look like.

PAPER CONDENSERS

Fig. *5* shows you the important steps in making typical paper condensers. When the condenser is in the form shown in Fig. *5C*, it is thoroughly dried in a vacuum to remove air and moisture, then impregnated with wax to keep moisture and air out. Finally, the unit is housed in a cover of some kind—often a waxed cardboard cylinder. Condensers so housed are called "cartridge" condensers because of their appearance. Many paper condensers, especially the larger ones, are housed in metal cases.

If the condenser leads are merely clamped to the foils instead of being

HOW A CARTRIDGE TYPE PAPER CONDENSER IS MADE

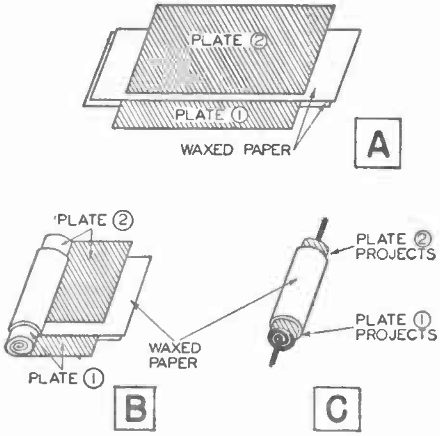


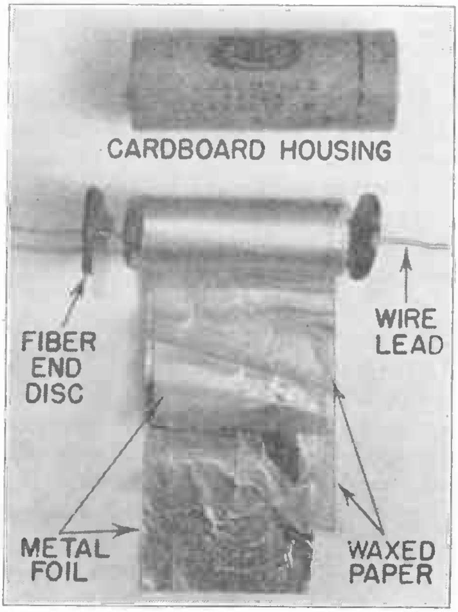
FIG. 5. How paper condensers are made. Waxed paper sheets separate the plates, which are tin or aluminum-foil sheets. After the condenser is rolled up, the projecting ends of the plates are crimped around the spirals formed by the connecting wires. The wires are soldered to tin-foil plates but cannot be soldered to aluminum-foil plates. Instead, the wire spiral is filled with solder and is pressed tightly into the foil. This mechanical joint is held only by wax and the container, so frequently comes apart.

soldered, heating of the condenser when in use may make one lead separate from its foil. This will, of course, disconnect the condenser from the circuit. Such an "open" may occur intermittently or permanently; either condition is something you will meet quite frequently in your servicing. If you service a radio which gives alternately good and bad reception, remember that an intermittent open in a condenser may be the cause.

Voltage Rating. The voltage a paper condenser can withstand depends on the thickness of the waxed paper between the foil sheets. Of course, a thicker dielectric gives a higher voltage rating but also separates the foil sheets more, giving less capacity per unit length of foil. A condenser with a higher voltage rating but the same capacity as another will be larger physically, as longer sheets of foil and paper are needed to give the same capacity because, for a fixed dielectric thickness, the capacity is determined by the plate area, which depends on the length and width of the foil sheets used.

Standard radio receiver condensers of the paper type have ratings of 200, 400, 600 and 1000 volts, with capacities between .0005 mfd. and 2 mfds. Transmitting condensers have much higher voltage ratings.

Inductive and Non-Inductive Types. The method of rolling up the condenser shown in Fig. *5*, with all of one edge of each foil sheet fastened to a lead, is known as a "non-inductive" winding. Electrons coming through each wire can move almost directly to any point on the corresponding foil sheet.



This picture shows the details of a paper condenser.

Fig. *6* shows an "inductive" winding. In this condenser, the leads are soft metal ribbons, projecting from each foil sheet. When electrons enter the condenser through a ribbon, they have to flow around and around inside the condenser to get to the other end of the plate. This makes the condenser have an inductive effect like a coil, which is often undesirable in high-frequency radio circuits. For this reason, these condensers are found only in power supply and audio circuits, and then only where the convenience of having both leads come from the same end of the condenser is an important factor.

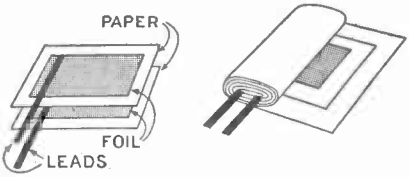


FIG. 6. The "inductive" winding shown here is rarely found in radio, as it can be used only in power packs and audio amplifiers. The non-inductive type shown in Fig. 5 can be used throughout radio receivers or transmitters, so is more commonly found.

Condenser Casings. Fig. *7A* shows the final appearance of the condenser constructed as in Fig. *5*. It is cased in a waxed cardboard tube, with the pigtail leads coming out each end through eyelets in a round cardboard or fiber disc (or through a plug of hard wax).

The condenser may also be cased in a square or rectangular metal box like those shown in Figs. *7B* and *7C*. The leads extend through the housing but are insulated from it. These condensers are usually provided with mounting brackets, so they can be bolted, riveted or soldered to the radio chassis.

High-voltage paper condensers which can stand 1000 to 2000 volts (and even 50,000 volts in some special types) are made by using several strips of high-grade waxed linen paper as a dielectric between strips of aluminum foil. The unit is mounted in a container filled with insulating oil. The terminal leads are brought out through porcelain stand-off insulators. Such a condenser is shown in Fig. *7D*.

MICA CONDENSERS

Mica is a far better dielectric than waxed paper where very high-frequency currents are involved, as in the r.f. signal circuits of receivers and transmitters. Mica condensers are considerably bigger than paper condensers of equal capacity, so are usually used only where low capacities are required. Mica condensers are generally made in capacities ranging from 10 to 10,000 mmfds. Larger units are available, but are quite expensive.

Fig. *8* shows how a fixed mica condenser is assembled. Thin, clear sheets of mica (only a few thousandths of an inch thick) are stacked in between sheets of copper, lead or aluminum foil. As in the paper condenser, these sheets of foil form the condenser plates. When the desired number of plates have been stacked up, a thicker piece of mica is placed at top and bottom for extra strength, the foil ends are bent over at each end, and a combination lug and clamp is squeezed over each end while the unit is held under pressure. Bakelite is then molded over the unit, leaving only the terminal lugs exposed, as shown in the bottom picture of Fig. *8*. This gives the condenser a neat, water-proof insulated housing. Frequently the condenser is then impregnated with wax to seal any tiny cracks which may have formed in the bakelite.

In this condenser the plate area is kept small, but a number of plates are used. This method of manufacture has the advantage of making all except the two outside plates do double duty.

What Practical Condensers Look Like

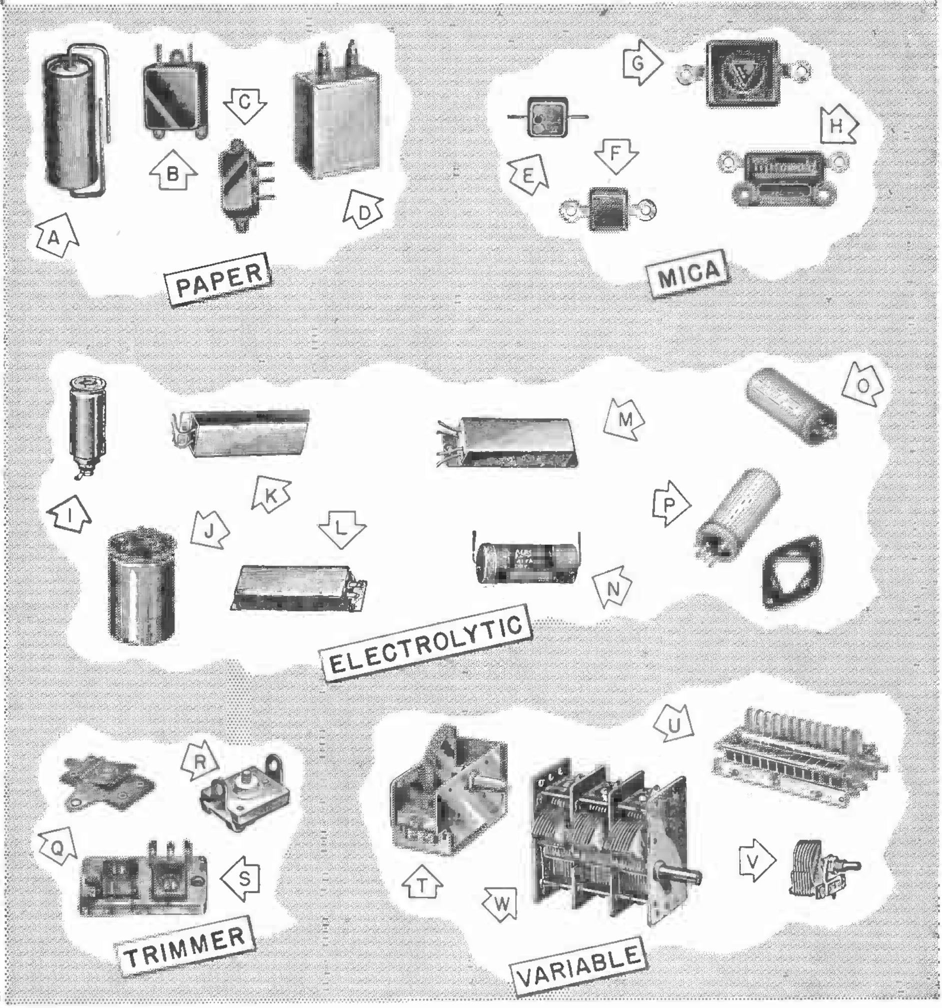


FIG. 7. Here are pictured some of the many condensers you will find in radio apparatus.

A = Tubular paper condenser.
B and C = Metal housing used for moisture and heat protection.
D = High-voltage type used in transmitters.
E and F = Postage-stamp size mica condensers.
G = Larger size having higher capacity.
H = Mounting holes are provided here so condenser can be rigidly fastened.
I and J = Wet electrolytics; single and triple units.
K, L, M, N = Typical dry electrolytics, differing only in the number of units and lead arrangement.
O and P = Plug-in dry electrolytics.
Q, R = Top and bottom views of a typical trimmer.
S = Dual trimmer unit.
T, U, V = Variable condensers differing in size and number of plates.
W = A three-gang variable condenser.

In the condenser shown in Fig. *8*, plates *2* and *1* are really one condenser, and plates *2* and *3* are another. Since plates *1* and *3* project out the same side and are connected by the lug clamp, this gives the whole condenser a capacity equal to twice the capacity of each individual condenser. Therefore, using only *three* plates, we have a capacity double what we would have by using *two* plates of the same size and separation.

When mica condensers are made with many plates, all the foils sticking out at each end are usually soldered together, instead of just being held with a clamp. This makes a better electrical connection.

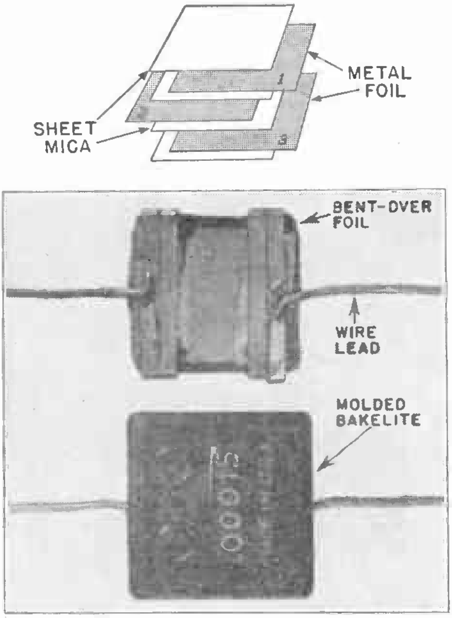


FIG. 8. Mica condensers are made of alternate layers of mica and metal plates, as shown at the top. The leads are clamped over the foil projections, then the unit is molded in a bakelite housing.

▶ Figs. *7E*, *F*. *G* and *H* show some typical fixed mica condensers in their bakelite housings. The terminals of these condensers are strong enough to support the condensers without need for other mounts. When the condenser is to be bolted to the chassis or when several condensers are to be bolted together, units like that in Fig. *7H*, with mounting holes molded in the bakelite housing, are used.

▶ Since mica is a very good insulator, mica condensers have amazingly high working voltages for their size. Receiver types are all 500 to 600 volts, while transmitters use slightly larger sizes rated as high as 2500 volts.

ELECTROLYTIC CONDENSERS

The electrolytic condenser shown in Fig. *9* consists of an aluminum rod placed in a metal container filled with a conductive chemical solution. The solution is called an "electrolyte" (pronounced *e-LECK-troh-light*). The rod is called the "anode," which is the general term for the positive part or terminal of any device.

To make the condenser, the positive terminal of a d.c. voltage source is connected to the anode, and the negative source terminal to the metal container. In a few hours, electrochemical action produces a thin, high-resistance film of aluminum oxide on the anode. The condenser is then said to be "formed," and is ready for use.

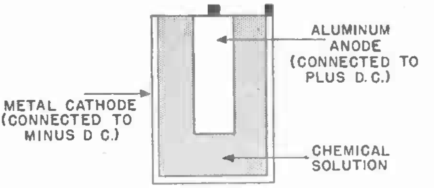


FIG. 9. Electrolytic condensers depend on the formation of an aluminum oxide film on the anode as the dielectric, then the anode rod and the electrolyte form the "plates" of the condenser. The can is called the cathode, as it is the means of making connection to the electrolyte which is the true negative plate.

The anode is one plate of the finished condenser, the aluminum oxide film is the dielectric, *and the surface of the electrolyte which is in contact with the dielectric film is the other* *plate*. The metal container acts only as a container and as a lead from the outside circuit to the electrolyte; it is *not* a plate of the condenser. (The container is usually called the "cathode," which is the general name for the negative part or terminal of an electrical device.)

▶ Using a rod as the anode limits the capacity, as the area of the rod surface is limited. More modern condensers obtain greater surface areas. A cross-section of a typical electrolytic condenser is shown in Fig. *10*. Here the anode is a sheet instead of a rod, and is folded back and forth within the container. This increases the surface area of the anode, and so gives higher capacity. In this particular condenser, the anode is "crimped" so it will take up as little space as possible; in other types, the anode is often wound in a spiral for the same reason. Frequently the anode is also chemically etched so that it has a rough surface, and therefore more surface area.

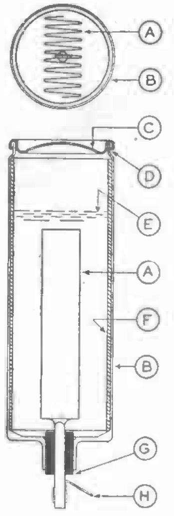


FIG. 10. Top and side views of a typical wet electrolytic condenser.
A = Anode, a plain or etched aluminum foil sheet folded in a zig-zag or crimped manner and riveted to a support rod.
B = Cathode, an aluminum can.
C = Aluminum cover.
D = Semi-porous gasket under cover, which prevents leakage of liquid electrolyte yet allows gases to escape.
E = Level of electrolyte.
F = Insulating material, which prevents short circuits between anode and cathode.
G = Insulating gasket which separates anode terminal from cathode and seals container at this point.
H = Connection to anode.

Courtesy Sprague Products Company

The thin dielectric and large plate area allow an electrolytic condenser to be physically rather small and yet have a very high capacity. In fact, electrolytics (as radio men call them) can have a much higher capacity for a given size than any other kind of condenser, with the possible exception of the new ceramic type. (As an example of comparative sizes, an electrolytic condenser of about the same dimensions as a 2-mfd. paper condenser might have a capacity of around 60 mfd.) This fact, and their relatively low cost, are the chief reasons electrolytics are used so much in radio circuits.

▶ Electrolytics which have a fluid electrolyte are often called "wet" electrolytics to distinguish them from two other types—semi-dry and dry electrolytics. Semi-dry electrolytics are like wet electrolytics except that a thickening material is added to the electrolyte, making it jelly-like and almost spill-proof.

The dry electrolytic condenser is today taking the place of the semi-dry type. Fig. *11* shows how dry electrolytics are made. Here the cathode is a sheet of pure aluminum, while the anode is a sheet of aluminum which has been "formed," so that it is covered with a thin dielectric film. The two electrodes are separated by strips of cheesecloth, paper or cellophane, which have been filled with an electrolyte in paste form. The four strips of material are rolled into a compact cylinder, flexible wire leads are attached to each electrode, the unit is mounted in

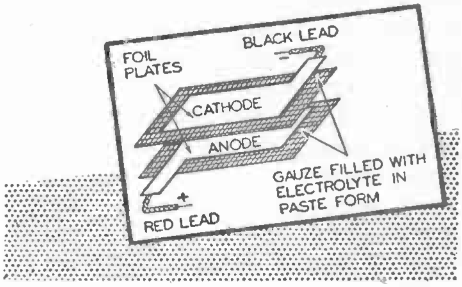


FIG. 11. How dry electrolytics are made.

a cardboard or other container, and the whole condenser is dipped in hot wax several times to make it air-tight. Sometimes dry electrolytics are sealed in metal cans similar to the containers for wet types.

Capacity of Electrolytics. The thickness of the dielectric film of an electrolytic depends on the voltage used to form it. High forming voltages give fairly thick dielectric films, while low voltages give thinner films. As you have already learned, the thinner the dielectric the closer the plate spacing and the higher the capacity will be. So, other things being equal, the electrolytic formed at a low voltage will have a higher capacity than one formed at a high voltage.

The forming voltage also determines the breakdown voltage of the condenser, since a voltage higher than that used to form the dielectric film cannot be applied to it without breaking the dielectric down. On the other hand, the ability of the condenser to maintain the dielectric film depends on the applied d.c. voltage. That is, the dielectric film becomes thinner as the applied voltage is decreased, so the capacity and working voltage ratings are not reliable unless the applied voltage is near the forming voltage. Hence, the working voltage rating of an electrolytic is usually about 90% of the forming voltage. Notice this means the breakdown voltage is only slightly higher than the working voltage. The electrolytic condenser thus differs from those using solid dielectrics in the relationship of its voltage ratings. These condensers should be used in circuits having voltages close to their working voltage ratings, although they can be used on lower voltages if the increased capacity will not matter.

The highest standard working voltage for electrolytic condensers is 450 to 475 volts. These condensers will break down if the applied voltage exceeds about 525 volts. (One manufacturer has produced a condenser with a breakdown rating of about 600 volts.) Capacities up to 60 mfds. are available in the 450-volt electrolytics, and capacities as large as 125 mfds. may be found in condensers with working voltages around 50 volts.

Service Notes on Electrolytics. Unlike all other common forms of condensers, *electrolytics must always be connected into a circuit with the proper polarity.* The anode must always be connected to the positive terminal of the circuit, and the cathode must be connected to the negative terminal. Now you see why the terminals are so named. Condensers with solid dielectrics do not have polarity so the leads can be interchanged at will.

Dry electrolytic condenser leads are labeled or colored, so the proper connections can be made. An identifying code or table is stamped on the case of most replacement types. Thus, you may find a red lead is the anode (+) and a black lead is the cathode (—) connection for a single-section dry condenser. When in a cylindrical container, the case may be marked (+) near the positive lead.

The metal container of wet and semi-dry electrolytics is the cathode, and so is connected to the negative terminal of the circuit. The other condenser terminal (usually in the center of the condenser) is the anode, and should go to the positive part of the circuit.

If you connect electrolytics into a circuit with the wrong polarity, the dielectric will break down almost at once. This is usually not too harmful with wet and semi-dry electrolytics, because they are self-healing—that is, the dielectric will repair itself within a short time after the connections are corrected. But dry electrolytics do not have this property; if broken down, they are ruined.

▶ The fact that electrolytics must be connected with proper polarity means they can be used only on d.c. or on d.c. mixed with a.c. In the latter case, the d.c. part of the voltage must be larger than the a.c. part, so that the polarity of the applied voltage will never be reversed by the a.c. variations. For example, it is all right to connect an electrolytic with a suitable working voltage to a circuit which furnishes 110 volts d.c. and 40 volts (peak) a.c., provided the positive terminal of the condenser is connected to the positive terminal of the d.c. voltage. Then the voltage applied to the positive terminal of the condenser will vary from 110 minus 40 to 110 plus 40, or from plus 70 to plus 150, but will always be positive, so the condenser will not break down. If the circuit furnishes 40 volts d.c. and 110 volts (peak) a.c., however, the voltage on the positive terminal of the condenser will vary from 40 plus 110 to 40 minus 110, or from plus 150 to *minus* 70, and the condenser will break down when the voltage reverses polarity.

▶ As you will learn a little later, electrolytics are often used in circuits where d.c. and a.c. are mixed. When you use one in such a circuit, you must be sure not only that the circuit does not reverse polarity, but that the peak value of the a.c. added to the value of the d.c. does not exceed the working voltage of your condenser. Electrolytics break down very quickly when the working voltage is exceeded. As with breakdowns caused by wrong polarity of connections, a voltage breakdown does not usually cause permanent harm to wet or semi-dry electrolytics, but ruins dry electrolytics. Servicemen usually play safe when replacing condensers by being sure the replacement has a working voltage rating equal to or greater than the original part.

▶ One disadvantage of electrolytics is that the aluminum oxide film which forms their dielectric is not a true insulator, so some electrons can flow through the condenser. This is called a *leakage current*, as it "leaks" through the dielectric. Since the electrolyte (through which the leakage current must flow) has some resistance, the flow of leakage current through it creates heat within the condenser. This heat drives gas out of the electrolyte. Normally, the vent on the top of wet and semi-dry electrolytics allows this gas to escape; if the vent becomes plugged for any reason, the condenser may blow up.

The escaping gas carries a certain amount of electrolyte with it. In time, this action disturbs the chemical balance within the condenser, increasing the resistance of the electrolyte; also, since the electrolyte forms one plate of the condenser, and lowering its level is the same thing as decreasing the plate area, lowering the electrolyte level reduces the condenser capacity. The added resistance of the electrolyte increases the heating effect of the flow of leakage current, thus speeding up the destructive process. Eventually, this combination of actions ruins the condenser. From 2000 to 10,000 hours of service can be expected from a good wet electrolytic.

▶ Much the same effect occurs in dry and semi-dry electrolytics, in which the heat caused by the flow of leakage current tends to dry out the paste electrolyte. In fact, these types will not usually last as long as wet electrolytics; dry electrolytics are used in preference to wet electrolytics in radio circuits only because they are usually much smaller in size, may be mounted in any position, and cost less.

Of course, heat from any source is as bad for electrolytics as the internal heat caused by leakage current. Keep electrolytics away from tubes, transformers and large resistors that may radiate considerable heat.

Identifying Electrolytics. Sometimes it is hard to tell just what type an electrolytic is by looking at it. If the condenser is in a metal can with water-tight gaskets around the terminals, and a rubber nipple through which gas can escape, you are usually safe in assuming it is a wet or semi-dry type. Pick such a condenser up and shake it—if you hear a swish, it is a wet electrolytic. Dry electrolytics usually have flexible leads and are cased in cardboard containers or in sealed metal cans which have no vent to permit gas to escape.

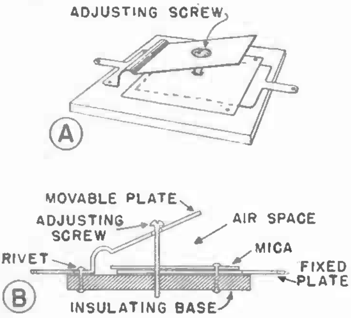


FIG. 12. Two views of a typical trimmer.

Figs. *7I* and *J* show two kinds of wet electrolytics. (Semi-dry would look exactly the same.) A single unit is shown in *I*. The triple unit in *J* has three terminals on the top of the can as the positive terminals, while the can is the common cathode.

Eight common types of dry electrolytics are shown in Figs. *7K* through *7P*. The terminals of condenser *7O* come out to a plug mounted on the end of the condenser. This condenser is connected into the circuit by being plugged into a receptacle. Type *7P* is also a plug-in condenser, with flat terminal pins which fit into the special wafer mounting shown beside it. These pins are twisted after the condenser is plugged in; this both makes a good electrical connection and holds the condenser firmly in place.

TRIMMER CONDENSERS

A trimmer condenser is used to make a small adjustment in the capacity of a circuit. A typical trimmer is shown in Fig. *12*.

Air and mica are used as dielectrics. One plate is riveted to the bakelite base of the unit, and the other plate, usually made of spring brass or phosphor bronze, is moved close to or away from the fixed plate by turning the adjusting screw. When the two plates are close together, the mica sheet is the dielectric, and the capacity is a maximum. When the two plates are farther apart, both air and mica are between them and the capacity is less. In some condensers, the adjusting screw makes electrical contact with the movable plate; in others it is insulated from the movable plate; it is always insulated from the fixed plate. When a trimmer with large capacity is wanted, several pairs of plates are used, with alternate plates connected together.

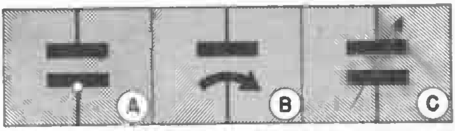


FIG. 13. Adjustable condenser symbols used in wiring diagrams. The one at A is used for trimmer condensers. The other two are used for variable tuning condensers usually, although sometimes they are used to indicate trimmers too.

▶ Trimmer condensers are also called "equalizing," "neutralizing," "aligning," "phasing" or "padding" condensers, depending on how they are used in the radio circuit. Fig. *13A* shows

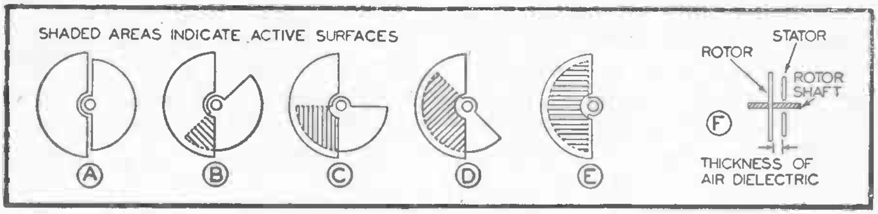


FIG. 14. How a variable air condenser works.

the symbol used in your N.R.I. Course and by many radio manufacturers to indicate a trimmer, while *13B* and *C* show the ordinary symbols for a variable condenser, which some authors and manufacturers also use for trimmers.

▶ Typical trimmers are shown in Figs. *7Q* through *7S*. Because these trimmers open like a book, they are often called "book type" trimmers.

VARIABLE CONDENSERS

The series of pictures in Fig. *14* show the working principle of the variable air condensers used to tune many modern radios. (For clearness, only one set of plates is illustrated, but most such condensers have several sets, as shown in Fig. *15*.) The plate at the left in *A*, *B*, *C*, *D* and *E* is a fixed plate, called the "stator." The smaller plate is pivoted on a shaft so that it may be rotated; this plate is called the "rotor."

When the plates are in the position shown in *A*, the condenser has a minimum capacity, because, as you learned earlier in this lesson, only the *overlapping* parts of plates have a capacity between them. As the rotor is turned past the stator, more and more of the plates overlap, as shown by the shaded areas, and the capacity of the condenser increases. When the plates reach position *E*, the capacity is a maximum. Relatively high-capacity variable condensers are made by using large plates or by adding additional rotors and stators. When this latter is done, the rotor plates are connected together electrically by the shaft to which they are attached, and the stators are electrically connected by a metal bar built into (but insulated from) the condenser frame.

▶ Several typical variable condensers are shown in Figs. *7T* through *7W*. Those pictured in *T*, *U* and *V* are similar, differing only in size. Unit *W* is really three separate condensers with the rotors mounted on the same shaft, so that the capacity of all three condensers is varied at the same time. Each condenser stator is insulated from the other two, and separate connections are made from each to the radio circuit it is used in. This kind of unit, in which the capacities of two or more condensers are varied by turning one shaft, is called a "gang" condenser. The one pictured in *W* is a three-gang condenser.

▶ Although the condensers in a gang

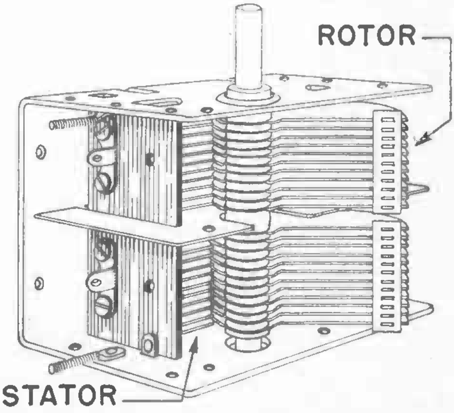


FIG. 15. What a variable condenser looks like.

are carefully made, manufacturing tolerances result in slight differences in capacity. To correct this and make the capacities of condensers in the gang "line up" with each other and with the circuits with which they are used, a trimmer condenser is usually connected to each condenser. The trimmer is adjusted to get exactly the right capacities in each section. Thus, the trimmer is a "corrector" and once adjusted is left alone until some change makes it necessary to repeat the adjustment.

Connecting Condensers Together

Now that you know what condensers are and how they work, let's consider a very practical point—what happens when condensers are connected together. Very frequently, you may need a certain capacity and find you do not have the right value, but have several condensers of other sizes to choose from. What is the effect on capacity when condensers are connected in parallel or in series?

CONDENSERS IN PARALLEL

Going back to Fig. *3A*, you will see that the condenser plates A_1 and A_2 are connected together so that the capacity A_1-B is in *parallel* with the capacity B-A_2. (There is a separate path from one terminal to the other through each condenser.) This parallel connection increases the capacity in this one condenser and would also increase the capacity if these were separate condensers. So if one condenser doesn't have enough capacity for the use to which you want to put it, you can connect another condenser to it *in parallel* to get a higher capacity. The capacity of a combination of two or more condensers connected in parallel is equal to the *sum* of the capacities of the individual condensers.

Fig. *16* shows why. Since they are connected in parallel, each condenser has the full line voltage across it. Each stores the amount of charge it usually does with such a voltage across it, so the amount of charge stored is the sum of that in all the condensers. As the capacity is equal to the charge divided by the voltage, this adding of charges means the capacity of the combination is equal to the capacity of all three condensers added together. Thus, the capacity of the combination in Fig. *16* is 33 mmfd. (10 mmfd. plus 11 mmfd. plus 12 mmfd. equals 33 mmfd.).

CONDENSERS IN SERIES

When condensers are connected in series, as in Fig. *17*, the capacity of the combination is *less* than the capacity of the smallest condenser in the group. Since plates *b* and *c* in Fig. *17A* are connected by a wire, the same charge must be on each of them; similarly plates *d* and *e* have equal charges. Hence, we can consider the series combination to be really one condenser with plates *a* and *f* and a dielectric equal in thickness to the sum of the thicknesses of the dielectrics of all three condensers (Fig. *17B*). Naturally, the greater dielectric thickness makes the capacity of the combination less than that of any one of the individual condensers.

From this you can readily see that if several condensers having equal capacities are connected in series, the total capacity of the group equals the capacity of one condenser divided by the number in the group. For example, if all three condensers in Fig. *17A* are identical, then the equivalent condenser shown in Fig. *17B* will have the same plate area as any one of the condensers and three times the dielectric thickness. Its capacity will therefore be one-third that of any one of the condensers (or C/3, where C is the capacity of one condenser). The total capacity of four identical condensers in series would be C/4, of five in series C/5, and so on.

▶ This method of finding the capacity of a series combination can be applied only to condensers of equal capacity. But there is a simple rule for finding the capacity of any two condensers connected in series, whether they have the same capacity or not; just divide the product of the two capacities by the sum of the two capacities. Using symbols:

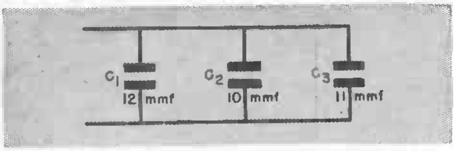


FIG. 16. Condensers in parallel give more capacity.

$$C = \frac{C_1 \times C_2}{C_1 + C_2}$$

where C is the capacity of the series combination, C_1 the capacity of one condenser, C_2 the capacity of the other condenser, with all capacities expressed in mfd. or all in mmfd.

▶ If you have more than two unequal condensers connected in series, find the combined capacity of two of them by this equation. Then treat this combined capacity as C_1 in the equation, take the third condenser as C_2, and again solve for C. You can keep this up for as many condensers as you have in the series circuit and your final answer will be the combined capacity of all of them. Notice—the combined capacity of condensers in *series* is found in exactly the same way that you learned to find the combined resistance of resistors in *parallel.*

VOLTAGE RATINGS FOR CONDENSER COMBINATIONS

When condensers are connected in parallel, each has the source voltage across it. Therefore, each condenser must have a working voltage *at least equal to the source voltage.*

While each condenser in a series combination has only part of the source voltage applied to it, still the safest thing is to make sure all of them can stand the full source voltage. But sometimes you won't be able to get condensers with high enough working voltages to observe this rule. Let's take a practical problem and see the simple trick you can use to solve it.

Suppose you have a d.c. source with a voltage of 1000 volts which must be used with a 2-mfd. capacity. (This is a problem which often comes up in transmitters and high-voltage power packs.) You have two 4-mfd. paper condensers, which will give the 2-mfd. you want if put in series. But suppose the working voltage rating of each condenser is only 500 volts.

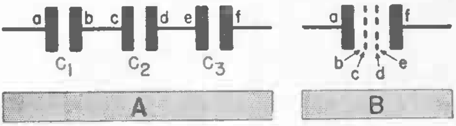


FIG. 17. Condensers in series give less capacity.

▶ If you can be sure each condenser will get no more than 500 volts across it, you'll be safe in using them in series. But how can you be sure?

Leakage Current. A perfect condenser (excluding electrolytics) will pass no d.c. However, no solid dielectric condenser is perfect; there are always some free electrons in even the best dielectric and, when a voltage is applied across the condenser, these electrons will flow through the dielectric. (Of course, this flow of current is much smaller than that necessary to cause breakdown.) Further, there is always some flow of current between the leads across the surface of the case of the condenser; in fact, this current is usually considerably higher than the current through the dielectric.

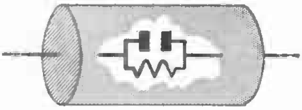


FIG. 18. A practical condenser acts like a perfect condenser in parallel with a high resistance.

The amount of current that flows from one terminal of the condenser to the other when a d.c. voltage is placed across the condenser is known as the "leakage current." Condensers having impurities in the dielectric, or so made that moisture can get in, will have much higher leakage currents than well-made ones. Condenser manufacturers always test the leakage of their solid dielectric condensers; those which pass too much current are rejected. For most purposes, the leakage current is so small it is ignored altogether.

▶ Where the leakage is important, we can take leakage current into account by considering a practical condenser to be a perfect condenser with a high resistance shunted across it, as shown in the cutaway section in Fig. *18*. This way of picturing a practical condenser is often very useful.

The high resistance shunting the condenser is called the "leakage resistance" of the condenser. Naturally, a condenser with a high leakage resistance will pass less d.c. than one with a lower leakage resistance.

▶ Since the perfect condenser won't pass d.c., it must be the current passing through the leakage resistance which determines the I × R drop (or voltage) across the condenser.

Now if one of the 4-mfd. condensers has a leakage of 50 megohms and the other has a leakage resistance of 200 megohms, as shown in Fig. *19A*, the total resistance is 250 megohms. Using Ohm's Law, you could figure the current flow and resulting voltage division. You would find that the line voltage will divide according to the ratio of the resistances. Thus, the condenser with 50 megohms will get 50/250 or ⅕ the source voltage. This puts 200 volts (⅕ of 1000) across this condenser and leaves 800 volts across the other condenser. Since the 800 volts across the latter condenser is considerably more than its safe working voltage rating of 500 volts, it will break down fairly soon. Then the full 1000 volts will be applied to the other condenser, breaking it down almost at once.

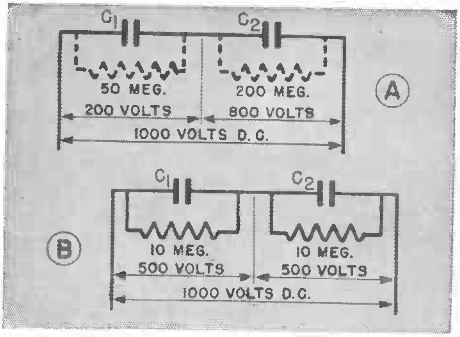


FIG. 19. Unequal leakage resistance values may cause an improper voltage division, as at A. By shunting the condensers with equal resistances which are much less than the leakage values, an equal drop can be obtained, as at B.

If the condensers are used in a circuit where a small current flow will not matter, you can solve this problem very easily by putting a 10-megohm resistor across each condenser. These added resistors are in parallel with, and considerably lower in ohmic value than the leakage resistances of the condensers. As you learned in your lesson on resistors, combining two resistors of widely different values in parallel gives a combined resistance just about equal to the smaller of the two. Therefore, the total resistance of each condenser-resistor combination will be about that of the added resistors, as shown in Fig. *19B*. Thus the resistances are made equal, so the voltage will divide about evenly across the combinations, and each condenser will be operating at its working voltage.

The same trick can be used if your condensers are electrolytics, but since electrolytics have much lower leakage resistances than paper condensers, you'll have to use lower shunting resistors. Between 10,000 ohms and 50,000 ohms will be satisfactory. (If you connect two electrolytics in series, remember that the *positive* terminal of one must connect to the *negative* terminal of the other.)

These extra resistors act as "bleeders," drawing or "bleeding" an extra current from the source of such value that they determine the voltage division. Naturally, this method of getting an even split of voltage across two condensers can be used only if this extra current is not objectionable in the circuit.

How a Condenser Works with A.C.

So far, we have dealt with the charging action of a condenser when a d.c. voltage is connected across it. You have learned that leakage current is the only current flow through a condenser when a d.c. source is used, and this flow can be ignored in most instances. Ordinarily, when a d.c. voltage is applied to a fixed condenser, the condenser charges up to the source voltage value, as long as the voltage does not exceed the safe working voltage rating of the condenser. When the charge on the condenser has reached its maximum, the movement of electrons in the circuit stops, so all current flow ceases until a different voltage is applied or until the condenser is discharged.

The nature of an alternating current provides a different action, however. As you will recall, electrons do not flow always in one direction when acted on by an a.c. voltage. Instead, they move a short distance in one direction in the wire; then, when the voltage reverses, they move in the other direction. This back-and-forth motion of the electrons in the circuit permits us to say that alternating current flows through a condenser. Let's examine this action more closely.

HOW ALTERNATING CURRENT FLOWS THROUGH A CONDENSER

When electrons are moving back and forth in the circuit due to an a.c. source, electrons must flow in and out of the plates of the condenser. When the electrons flow into one plate, the bound electrons in the dielectric are forced away from that plate and force electrons out of the other condenser plate.

When the a.c. voltage reverses, the electrons are forced back into the second plate of the condenser. And now the electrons on the second plate act just the way the electrons on the first plate did a moment before—they push the bound electrons in the dielectric away and the movement of the bound electrons now push the electrons out of the first plate.

This action is shown in Fig. *20*. At *A*, we start with the electrons at rest in the dielectric. Then, as electrons are forced into plate *1*, the path for the bound electrons in the dielectric shifts, forcing electrons out of plate *2* as shown at *B*.

This movement of electrons causes the condenser charge to reach a maximum when the a.c. voltage reaches a maximum on this half cycle. Then, as the a.c. voltage decreases, the electrons redistribute themselves about the circuit, allowing the electrons in the dielectric to return to their neutral position as shown in Fig. *20C*. As the cycle reverses, electrons begin to flow into plate *2*, forcing a movement in the dielectric in the opposite direction so that electrons are forced out of plate *1* as shown at *D*. This action reaches a maximum, charging the condenser in this reversed direction. Then the voltage decreases toward zero, allowing the bound electrons to return to the neutral position shown at *A*, after which the cycle is repeated over and over. Fig *21* shows the points on an a.c. cycle corresponding to this action. The condenser charges between *A* and *B*, discharges between *B* and *C*, charges with the opposite polarity between *C* and *D*, discharges again between *D* and *A*, and repeats the cycle over and over.

From the foregoing, you can see that there is a back-and-forth motion of the bound electron paths in the dielectric when acted on by a.c., just as there is a back-and-forth movement of free electrons in the conductor. Therefore, around the complete circuit there is a back-and-forth motion of electrons and we are perfectly justified in saying that an alternating current passes through a condenser. Scientists call this current within the dielectric a "displacement current." This new name is given the current flow because there is no actual electron movement from plate to dielectric or from dielectric to plate. Instead, there is a displacement of electrons within the dielectric which passes on the current flow action of the entire circuit.

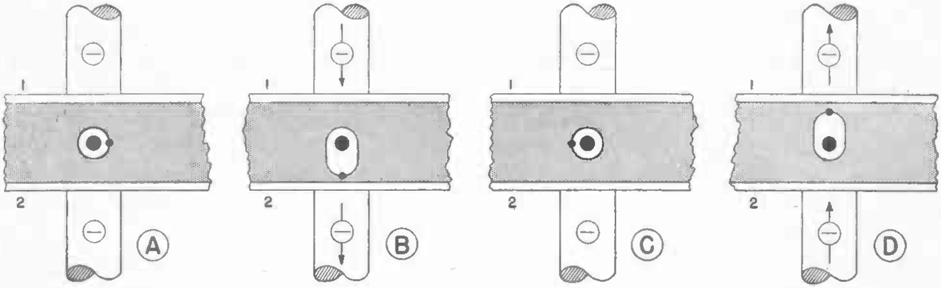


FIG. 20. When a.c. is applied, the bound electrons move first one way, then the other, so, in effect, an alternating current flows through the condenser.

It is important that you get the idea clearly that an alternating current is just a movement back and forth of electrons, and further, this actual amount of movement is over an astonishingly short distance. However, when electrons move in the circuit, it is not the distance they travel that is important, it is the number of electrons which actually do move within a given period of time which gives us a measure of current flow.

CAPACITIVE REACTANCE

Although a condenser permits a flow of alternating current through the circuit, it also restricts the current flow. Work must be done to move the bound electrons in the dielectric, so there is an opposition to the flow of current. Actually, the charge-storing ability will limit the current flow.

Now, the larger the condenser, the greater its ability to store a charge. As the current flow depends on the number of electrons in the charge, we see that the larger the capacity, the less the opposition to current flow.

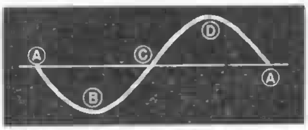


FIG. 21. The points on the cycle corresponding to the electron path shifts shown in Fig. 20.

The opposition of a condenser to an alternating current is called reactance, just as it is for a coil. This reactance, as is that of a coil, is measured in ohms. However, notice this important difference—for a condenser, *the larger the condenser the less the reactance*, while for coils, *the larger the inductance the greater the reactance.*

Furthermore, frequency changes also have an inverse effect upon condenser reactance. That is, the higher the frequency, the less the reactance of a condenser, whereas with a coil, the higher the frequency the greater the reactance. As you will soon see, these are very important differences.

You can figure out the reactance of a condenser by this simple method:

> *Multiply the frequency of the current in cycles per second by the capacity of the condenser in microfarads, then divide the number 159,000 by this result.*

The equation for this is:

$$X_C = \frac{159{,}000}{f \times C}$$

Where X_C is the capacitive reactance in ohms, f is the frequency in cycles per second, and C is the capacity in mfd.

Another way we might express this is:

$$X_C = \frac{1}{6.28 \times f \times C}$$

where C is in farads. (Compare this with the equation for inductive reactance you learned in your lesson on coils.)

▶ Let's take a few practical examples, to see just what these important equations mean. We will use only the first equation, since its units are more convenient. (The second equation, of course, is exactly the same as the first one; the difference in units is what makes them look different.)

Suppose we have a condenser of 10-mfd. capacity fed by a source supplying 100-cycle current. Then:

$$X_C = \frac{159{,}000}{f \times C} = \frac{159{,}000}{100 \times 10}$$

$$= \frac{159{,}000}{1{,}000} = 159 \text{ ohms}$$

so the a.c. reactance of our condenser is 159 ohms. (Remember, this a.c. reactance has nothing to do with the d.c. leakage resistance; a condenser has a reactance only when it is used in an a.c. circuit.)

Now if we supply the same condenser from a source which furnishes 1000-cycle current:

$$X_C = \frac{159{,}000}{f \times C} = \frac{159{,}000}{1000 \times 10}$$

$$= \frac{159{,}000}{10{,}000} = 15.9 \text{ ohms}$$

so *increasing* the frequency of the current *decreases* the reactance of our condenser. Notice that the increase in frequency causes a proportionately equal decrease in reactance; *increasing* the frequency 10 times *decreases* the reactance 10 times.

If we keep the frequency at 100 cycles and increase the capacity of the condenser to 100 mfd:

$$X_C = \frac{159{,}000}{f \times C} = \frac{159{,}000}{100 \times 100}$$

$$= \frac{159{,}000}{10{,}000} = 15.9 \text{ ohms}$$

so *increasing* the capacity of the condenser *decreases* its reactance. Just as the increase in frequency did in the previous example, the increase in capacity causes a proportionately equal decrease in reactance; increasing the capacity 10 times decreases the reactance 10 times.

▶ Let us sum up what we have just learned in one easily remembered rule:

An increase in frequency or an increase in capacity will cause a decrease in the reactance of a condenser.

Of course, the reverse effect is also true; *a decrease in frequency or capacity causes an increase in reactance.*

Since a drop in reactance means it is easier for a.c. current to pass through the condenser, you can readily see that high-frequency currents pass through a condenser much more easily than do low-frequency currents; also, that a current of any frequency flows more easily through a condenser of high capacity than through one of low capacity. You will see how extremely important these facts are a little later on in this lesson, when we discuss some practical condenser circuits.

A Simple Condenser-Resistor Circuit

Now we know that a condenser will store a charge when a d.c. voltage is applied, and that condensers permit a.c. current to flow in the circuit, limiting the current flow by their reactance. What happens when we connect other parts with condensers? Let's combine a resistance with a condenser and consider the action both for d.c. and a.c. sources. We'll start with a d.c. source.

TIME CONSTANT

With the resistor and condenser connected to a d.c. source, as shown in Fig. *22*, a very interesting action occurs. If the condenser were connected by itself directly to the source, the condenser would charge to the full source voltage almost immediately. However, when we put a resistor in the circuit, we find that it takes longer—the charging time increases to as much as several minutes, if the resistor and condenser are large enough. Let's learn more about this action.

The *effective* voltage in this circuit—that is, the voltage which acts to cause current flow—is equal at any time to the source voltage minus the back, or bucking, voltage of the condenser. When the circuit is first closed, there is no charge on the condenser and therefore no voltage across it, so the effective voltage is equal to the full source voltage. The current flow in the circuit is then equal to the source voltage divided by the value of resistor *R*. As this current flows through the circuit, however, the condenser begins to store a charge, and voltage builds up across it. This, of course, makes the effective (or current-moving) voltage less than the full source voltage, so the current through the resistor and circuit must drop. As the condenser continues to charge, the effective voltage becomes less and less, making the circuit current continually smaller. Eventually, when the condenser voltage equals the source voltage, there is no effective voltage and all current flow stops.

▶ The effect of the resistor is to increase the time necessary to charge the condenser. Even a very large condenser will charge almost at once if there is a sufficient current flow into it, but when, as in this circuit, the current flow is limited to a small initial value by the resistor, and then grows even smaller, it may take a considerable time for enough electrons to flow into the condenser to charge it completely.

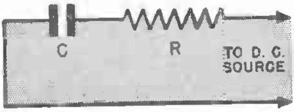


FIG. 22. The condenser charges through the resistor more slowly than it would if the resistor were not used.

The amount of time it takes for the condenser to charge up with a resistance in series with it is an important factor in the action of many radio circuits. It has been found that multiplying the capacity of the condenser in mfd. by the value of the resistor in megohms gives a figure equal to the time in seconds that it takes the condenser voltage to reach about 63% (actually 63.3%) of its final value. This time is called the "time constant" of the condenser-resistor combination. The time it takes a condenser to reach its full voltage is many times this special value, but comparing time constants directly is often a useful way to compare the action of one radio circuit with that of another.

Fig. *23* is a graph showing how the condenser voltage increases with time. Notice the rapid rise at first, followed by a gradual tapering off until the final condenser voltage is reached a relatively long time later on. As shown, the time constant is the amount of time it takes to reach about 63% of full charge.

You will meet time constants frequently in later lessons, for they have much to do with such important things as the ability of an amplifier to amplify signals without distortion. For the present, just remember that the time constant of a condenser-resistor combination is the time in seconds required to charge the condenser to about 63% of the charging voltage. Further, this time can be obtained directly from the condenser and resistor values by multiplying the capacity of the condenser in mfd. by the ohmic value of the resistor in megohms. Thus, a 10-mfd. condenser and a 5-megohm resistor have a time constant of 10 × 5 or 50 seconds, or almost a minute to charge to 63% of the source voltage, while a .05-mfd. condenser and a .1-meg (100,000 ohms) resistor will charge to this same value in .05×.1, or .005 second, thus, the larger the resistor or the condenser, the longer the time constant.

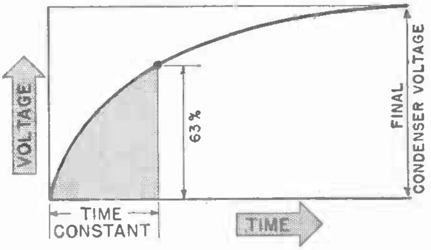


FIG. 23. This curve is more steep at the beginning and then gradually flattens out. This shows the condenser voltage builds up rapidly at first, then more slowly as time passes. The time in seconds required for the condenser to reach about 63% of its final charge is known as the time constant.

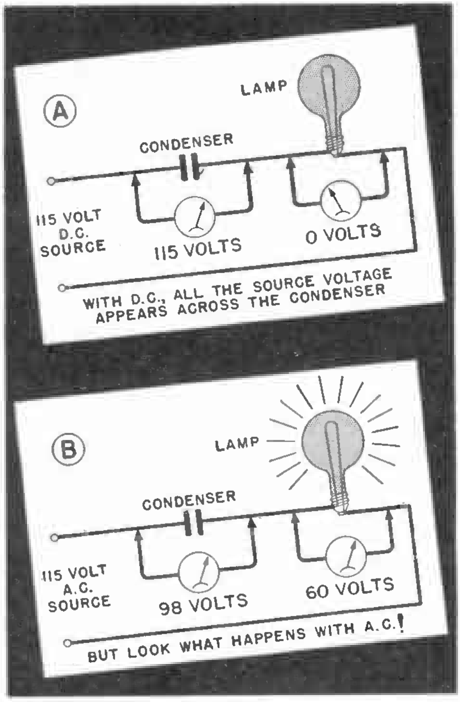


FIG. 24. How the voltages are divided when d.c. is applied at A. The division for a.c. is shown at B.

ACTION WITH A. C.

You recall that in the lesson on coils, we compared the action of a coil and a lamp in series on a.c. with their action on d.c. Let's make the comparison again, this time substituting a condenser for the coil. Of course, the lamp represents a resistor, so we have the same circuit as Fig. *22*. However, the lamp shows when current flows by lighting.

Starting first with a d.c. source, as shown in Fig. *24A*, we find that the lamp will not light. This indicates that no d.c. flows through the condenser. Actually, there is an initial flow of current when the circuit is first completed, but this current flows for too short a time to light the lamp even momentarily. When the condenser is charged, the entire d.c. voltage is across the condenser and none across the lamp. The d.c. voltage drops in the circuit check with Kirchhoff's Voltage Law, as 115 volts across the condenser added to zero lamp volts equal the 115-volt source voltage.

Suppose we now change to a 115-volt a.c. source, as in Fig. *24B*. With a.c. voltmeters being used now to measure the voltage drops, we find that the two voltage drops add up to 158 volts, which is much higher than the source voltage. Clearly, we cannot apply Kirchhoff's Voltage Law directly to this circuit. Once again we have met the subject of *phase.*

The voltage drops across the condenser and lamp in Fig. *24B* do not add up to the a.c. source voltage because these a.c. voltage drops *do not reach corresponding peak values at the same instant of time in each cycle.* In other words, one a.c. voltage may be at the zero point in its cycle at the instant when the other a.c. voltage is at its maximum or peak value. We encounter this situation whenever we use coils or condensers along with resistors in radio circuits, and radio men say that there is a *phase difference* between these a.c. voltage drops.

The only time we can add directly the a.c. voltages which a.c. meters measure is when these voltages are in phase with each other (when all reach corresponding peak values in each cycle at the same instant of time, and all drop to zero together). This occurs only when all the parts in the circuit are identical (all are perfect resistors, all are perfect coils or all are perfect condensers).

The a.c. meters do not show the *instantaneous* voltages; they show the *effective* values over a period of time. If they could show the instantaneous values, we would find they would add up properly at all times. Instead, we must combine the meter readings in a way which will take phase into account in order to see just what goes on. Let us now see how phase enters into the picture when the a.c. circuit has a condenser in it.

Phase. You remember that voltage and current are always in phase in a purely resistive a.c. circuit, and that they are always 90° out of phase in a purely inductive a.c. circuit, with the current lagging behind the voltage. In a capacitive a.c. circuit the current and voltage are again 90° out of phase, but here the voltage lags behind the current—or, to put it another way, the current leads the voltage.

The reason why is easy to see. You learned in your study of time constant that, when the circuit is closed, the maximum current flows at once and the voltage across the condenser is zero. As current continues to flow, the condenser voltage builds up and, at the same time, the current decreases. When the condenser is fully charged—the voltage across it is a maximum—the current is zero.

When a.c. is applied, this same action occurs during one quarter of the cycle. Then, as the voltage decreases, electrons begin to flow off the condenser plates. By the time the voltage across the condenser reaches zero again, the condenser is completely discharged, and again a maximum current flow is taking place, this time in the opposite direction from the original flow.

Thus the circuit current and the condenser voltage are 90° out of phase in a capacitive circuit fed by a.c.; the circuit current is always a maximum when the voltage across the condenser is zero, and vice versa. Since the current is maximum first, the current leads the voltage.

Vector Diagrams. You remember that we had to use voltage vectors to combine the voltages across a coil and a lamp, because the two voltages were out of phase. Since the voltages across the condenser and resistor in Fig. *24B* are also out of phase, we must also use voltage vectors and a vector diagram to combine these voltages.

First, we can see that the same alternating current flows through both the condenser and the lamp as these parts are in series, so we will use the current as a reference value. We start by drawing our current reference vector, as shown in Fig. *25A*. Remember—in a vector diagram the *length* of any vector is proportional to the *amount* of current or voltage the vector represents. Further, the *position* of any current or voltage vector with respect to the circuit current reference vector we have just drawn shows how much the current or voltage is out of phase with the circuit current.

FIG. 25. The starting or reference position is shown at A. Each complete revolution of a vector represents one a.c. cycle. By general agreement among radio and electrical men, vectors are always assumed to be rotating counterclockwise, opposite to the direction in which the hands of a clock move. Furthermore, the starting or reference position for all vectors is the vector position shown at A, which is a line going to the right horizontally from the center (O) of the vector diagram. In a series circuit, we almost always use current for our reference vector. To make the vector A represent the circuit current, we make the length of the vector proportional to the effective current value which would be indicated by an a.c. ammeter. We then put on the arrow head, and label it with the capital letter I to indicate that it represents current. As the resistor voltage drop is in phase with the current, its position will be the same as the reference line, so we draw it right on top of the current line, as at B.

Since the resistor voltage drop is in phase with the circuit current, we draw the resistance voltage vector V_R right over the current vector, as shown in Fig. *25B*.

We must now draw the vector for the condenser voltage drop. We just learned that voltage lags the current in a condenser by 90°, so we will have to draw the voltage vector V_C 90° *behind* our reference current vector, or straight *down* from the point of origin (O), as shown in Fig. *26A*. Then we complete the rectangle, as shown in Fig. *26B*, and draw a diagonal line from the point O to the opposite corner of our rectangle. This diagonal, vector E, then represents the source voltage. Since it is behind the circuit current vector I, we know that the source voltage lags behind the circuit current in a capacitive circuit.

If we draw V_R and V_C to scale so that every inch along them represents a certain number of volts, the length of line E will be equal to the source voltage figured on the same scale. Thus, Kirchhoff's Voltage Law applies to our capacitive a.c. circuit when we use a vector diagram to take phase into account.

Impedance. You have learned that resistors have resistance, while coils and condensers have reactance. Now reactance and resistance are somewhat alike, in that both act to oppose the flow of current. In other words, current flow through either of them produces a voltage drop equal to the product of the current multiplied by the resistance or reactance. However, as you know, the voltage drops produced differ in phase from one another.

Thus, the voltage drop produced by current flow through resistance is in phase with the current. The drop produced by current through an inductive reactance leads the current by 90°. The drop produced by current through a capacitive reactance lags the current by 90°.

You have already learned how to represent these phase differences in voltage drops by vector diagrams. In each diagram, a voltage vector represents the product of the circuit current multiplied by the resistance or reactance of the part concerned. Thus, V_R really equals $I \times R$, while V_C equals $I \times X_C$ and V_L equals $I \times X_L$. Now, since the *current is the same in each of these voltage drops* if the parts are in series (because the same current flows through each part of a series circuit), we might just as well ignore it, and draw our vector diagram to represent our resistance or reactances only.

How do we do this? First, we draw our resistance vector R horizontal, making its length in inches proportional to its value in ohms. Then we draw our capacitive reactance vector X_C straight down, also making its length in inches proportional, on the same scale, to the ohmic value of the capacitive reactance. If we have a coil in the circuit instead of the condenser, we draw its inductive reactance vector X_L straight up, again making the vector length proportional to the ohmic value of the reactance.

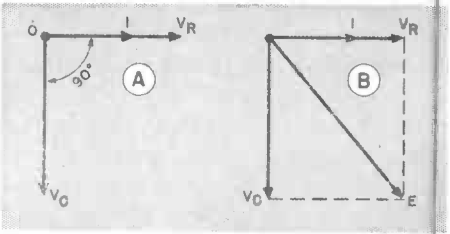


FIG. 26. The condenser voltage drop lags one-quarter of a cycle or 90° behind the current, so is drawn one-quarter of a revolution clockwise from the reference line, as at A. We can now complete the rectangle as at B and draw the diagonal E, which represents the source voltage. This tells the complete story of the voltage and current phase relationships in the circuit of Fig. 24B.

Figs. *27A* and *B* show how these vectors look when drawn this way. Notice—in each diagram, the rectangle has been completed and a diagonal vector Z drawn. What does this vector represent?

You know that, in the similar diagrams drawn for voltages, this diagonal vector represented the source voltage—the vectorial sum of all the voltage drops in the circuit. In these resistance-reactance diagrams, the diagonal vector similarly represents the vectorial sum of the reactance and the resistance in the circuit. It is called the "impedance" of the circuit; its symbol is "Z"; it is measured in ohms.

The impedance of a circuit represents the *combined opposition of all the parts of the circuit to the flow of a.c.* We can't add resistance to reactance directly, we must follow the same rules we do for their voltage drops. However, when we have the impedance, the product of the ohmic value of the impedance multiplied by the value of the circuit current in amperes equals the source voltage in volts.

Since this is true, we substitute impedance for resistance when we apply Ohm's Law to a.c. circuits. The three ways of writing the law then are:

OHM'S LAW FOR A. C.

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

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

$$E = IZ$$

As you will notice, they are exactly like the Ohm's Law forms for d.c., except that impedance is substituted for resistance.

Thus, if we know them, we can use impedance and the source voltage to figure the circuit current, and use this current with the resistance and reactance values to find the voltage drops across the parts. Or, if we already know the voltages across each part, we can add them vectorially to find the source voltage, as we did in Fig. *26*. Either method will give us the right answer, but one will usually be more convenient than the other, as we shall see later.

CONDENSER LOSSES

Losses in the dielectric of a condenser keep it from being 100% efficient. You have already learned that there's a certain amount of leakage through the dielectric. This leakage provides a discharge path which will allow the charge to "leak off" and prevents the condenser from keeping its charge forever. The better the condenser is, the lower *leakage loss* it has.

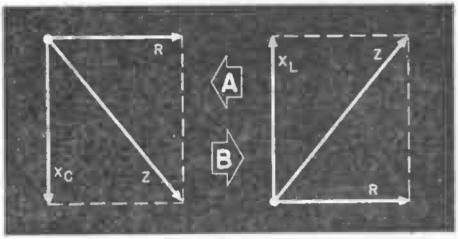


FIG. 27. Combining resistance with either inductive or capacitive reactance by means of vectors gives the impedance or total opposition to alternating current flow.

You can get some idea of how good a fairly large paper condenser is by connecting it to a 200- to 400-volt d.c. source long enough to charge it, breaking the connection, waiting two or three minutes, then shorting the condenser terminals with a screwdriver. If you get a strong spark, you know the condenser has low leakage and is therefore of good quality. (This test is useful only for paper condensers larger than .25 mfd.)

Another dielectric loss is caused by the fact that the dielectric absorbs some energy from the charging operation which it does not give back at once upon discharge. The reason is that when a condenser is charged, then discharged suddenly, all the bound electrons do not return at once to their normal orbits. If you wait a moment or two, then short the condenser again, there will be another (smaller) discharge. This effect is called "absorption." In an a.c. circuit, absorption is given the technical name of "dielectric hysteresis" (*di-eh-LECK-trick HISS-ter-E-sis*).

Both leakage loss and hysteresis loss can be lumped together and called the dielectric loss of the condenser. For simplicity, we can consider their combined effects as either a low resistance in *series* with a perfect condenser, or as a high resistance in parallel with a perfect condenser. Both ways of picturing losses are shown in Fig. *28*.

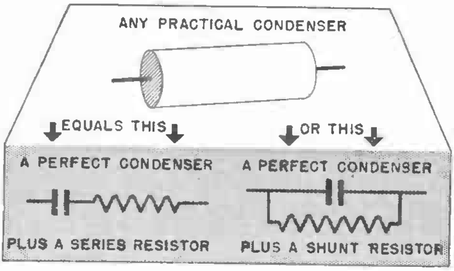


FIG. 28. Dielectric losses are in series with the condenser, while leakage losses are across the condenser. One or the other may be ignored, or both can be lumped together and shown by either of these methods.

The losses in a condenser go up as the frequency goes up, so condensers do not work as well at higher frequencies unless carefully made. Certain kinds of condensers cannot be used at high frequencies, particularly electrolytic condensers, due to the high amount of loss in these condensers.

Power Factor. Another way of expressing the losses in a condenser is in terms of "power factor." The power factor of a condenser shows the per cent of applied electrical power that is wasted by the resistance of the condenser. It is usually expressed in per cent. A perfect condenser would have a power factor of zero, while one with a high loss would have a fairly high power factor. As you can readily see, the lower the power factor of a condenser, the more efficient it is.

Test instruments are available that measure the power factor of condensers directly. Such instruments are used in radio service work, for they are very helpful in telling whether a condenser has such high resistance in series (high power factor) that it should be replaced. Usually such a test is necessary only on electrolytic condensers. You'll learn more about these instruments when you study service equipment in later lessons. For now, just remember power factor tells how much loss there is in a condenser.

Voltage Division with R, L and C

We have now reached the point where we can combine what we have learned about the action of resistors, coils and condensers into some of the basic circuits which you will meet time after time in radio receivers and other radio equipment. This section is a preview of circuits you will study again in later lessons. Several readings now, and later when you encounter similar circuits are recommended.

▶ In radio circuits we may have d.c. alone; we may have d.c. mixed with an alternating current; we may have d.c. with many different a.c. frequencies, or we may have different a.c. frequencies together. Regardless of what we have, we must have a means of combining and separating the different a.c. frequencies, as well as combining any or all frequencies with d.c., in order to obtain the radio actions we shall study later.

In addition to making the proper combination and separation, we must consider the necessity of supplying the right voltage for the particular reaction we want to occur.

▶ Right now, we are going to start off with some very simple circuits. However, complex radio circuits can be "boiled down" into simple circuits so that the actions in a radio receiver are easy to understand. We will leave the subject of complete radio circuits for later lessons, where you can pick them up one by one, analyze them into their basic elements, and thus reach a complete understanding of just what goes on in a radio. This thorough understanding of the actions which occur in a set will lead you directly into an understanding of what might go wrong, how it can go wrong, and what is necessary to clear up trouble when it arises.

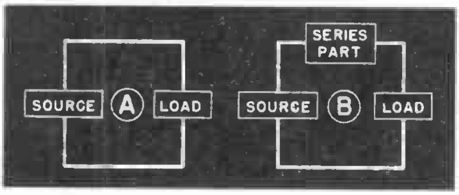


FIG. 29. When the source voltage is exactly correct for the load, they can be connected together as at A. However, a series part may be needed as at B, to lower the voltage, separate d.c. from a.c., or to separate different a.c. frequencies.

▶ Suppose we start with a source and "load" connected as shown in Fig. *29A*. (We call the device to which the source is connected a "load" because it uses the energy from the source.) For us to be able to connect a source of voltage directly to any radio part like this, the source must deliver voltage of exactly the right amount and right frequency for that radio part.

If the source furnishes too much voltage or voltages with the wrong frequency, this condition is often corrected by using the proper part in series with the load, as shown in Fig. *29B*. The exact size and kind of series part to use depends on the correction needed.

SERIES RESISTANCE

Let us assume that our load is a resistor R_L, as shown in Fig. *30*, and that the voltage source supplies more voltage than we want to apply to R_L. Now, suppose we put resistor R in series with R_L. As you have already learned, the source voltage will divide, part appearing across R, the rest across R_L. This same division will occur whether the source supplies a.c. or d.c., and the frequency of the source makes no difference. Thus, the effect of resistor R is to reduce the amount of voltage available for the load R_L. The amount of reduction depends on the relative resistance of R and R_L. *Therefore, by adjusting the value of resistor R, we can adjust the voltage across R_L to the desired value.* However, resistor R will affect only the *amount* of voltage. It has no effect on the frequency of the source voltage, and cannot separate frequencies, so the source must deliver the correct frequency.

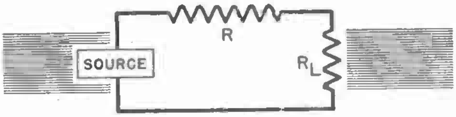


FIG. 30. The series resistor can reduce the voltage to the right amount for the load but cannot separate frequencies.

SERIES INDUCTANCE

Now, suppose we use an inductance L instead of resistor R, as shown in Fig. *31*. We have again made up a voltage-dividing circuit, but one which acts in an entirely different manner.

▶ Suppose the source produces d.c. The normal resistance of the coil is relatively low, so there will be very little d.c. voltage drop in coil L. Nearly all the d.c. voltage will appear across R_L. As far as d.c. is concerned, the coil L has practically no effect in this circuit.

▶ Now suppose the source furnishes a.c. of both low and high frequencies. The coil has a low reactance at low frequencies, so very little low-frequency voltage is dropped across it. But the reactance of coil L is very much greater at high frequencies, so most of the high-frequency voltage supplied by the source is dropped across the coil, and only a little appears across R_L. Thus, the series coil acts as a *frequency separator*. It passes d.c. and low-frequency a.c., but tends to exclude high frequencies from the load. The larger the reactance, compared to the value of R_L, the greater the tendency to exclude high frequencies.

As low frequencies find less opposition in the coil, this circuit might be called a low-pass filter, because it passes low frequencies but filters out the higher frequencies.

▶ Again, as in Fig. *30*, the division of voltage between the load and the series coil depends on the relative opposition each offers to current flow. If the ohmic value of the coil reactance is high compared with the ohmic value of load resistance, more voltage will be dropped across the coil than across the resistor. And remember, the reactance of the coil depends upon both its electrical size and the frequency of the source. It is quite possible for the reactance of the coil to be much smaller than the resistance of the resistor at low frequencies and much higher at high frequencies. The coil reactance may be large because of high inductance, high source frequency, or both.

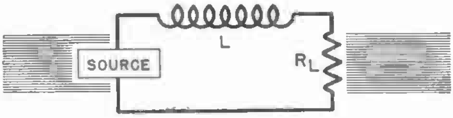


FIG. 31. The coil has greater reactance as frequency is increased, so higher-frequency voltages are divided so most of the drop is across the coil. The coil thus tends to separate frequencies, excluding the higher ones.

SERIES CAPACITY

Now let's change the circuit to that shown in Fig. *32*, with a condenser C as the series part.

We know that if the source is a d.c. voltage, there will be an initial charging current, the duration of which depends on the time constant of C and R_L. However, once the condenser is charged, there will be no further d.c. flow through the circuit (except for a tiny leakage current, which is so small that we can normally ignore it). Therefore, we can say that the condenser *blocks* the d.c. flow because, as soon as the condenser is charged, there is no current in the circuit and no d.c. voltage across R_L. All the voltage supplied by the source appears across condenser C.

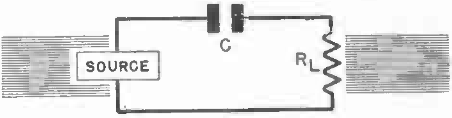


FIG. 32. The condenser blocks d.c. and, as its reactance decreases as the frequency is increased, it passes higher frequencies with less opposition, exactly opposite to the action of a coil.

▶ We have learned that a.c. does flow through a condenser, however. Further, we know that the higher the frequency, the *lower* the condenser opposition to a.c. flow.

Thus, the action of a series condenser is opposite to the action of a series coil. For low-frequency a.c., there is a large voltage drop across the condenser, leaving less voltage for the load resistance. At higher frequencies, less and less voltage is dropped across the condenser and more of the source voltage appears across the load resistance.

Again, the relative opposition of the condenser and the load to current flow determines the voltage division between them. The larger the capacity, or the higher the source frequency, the lower the condenser reactance—and the greater the voltage applied to the load.

Fig. *32* is one of the most common radio circuits you will meet later on. Condenser C is sometimes called a *blocking condenser,* because it prevents d.c. from flowing. As it will pass a.c. to the load, it is also called a *coupling condenser,* because it "couples" an a.c. voltage from one circuit to another. The name used depends upon which action is more important in the circuit.

A Typical Circuit. Fig. *33* is a typical radio circuit where a condenser is used both as a blocking and a coupling condenser. Battery B causes a d.c. flow through tube VT_1 and through resistor R_1. Condenser C prevents direct current flow from battery B through resistor R_2. However, a.c. signals in the circuit of tube VT_1 are passed on to R_2 through condenser C, where they operate tube VT_2.

Of course, we don't expect you at this point to understand all about how this circuit works. There are a few practical facts you can see, though. If condenser C becomes "open" (disconnected by a break where the lead is fastened to the foil), no signal energy will be passed on to the next tube, because the circuit is broken so the condenser is effectively not there. This may make the receiver dead.

On the other hand, if condenser C becomes leaky or short circuited, d.c. will flow through this condenser and through resistor R_2, where it is not wanted. As you will learn in a later lesson, this will cause distortion.

Thus, a properly operating condenser C blocks d.c. and couples the a.c. signal to the next tube. A defective condenser C may prevent the passage of signal energy, or may permit the passage of d.c.

Summary. Fig. *34* shows in chart form the action of a resistor, coil and condenser individually. You will find this chart helpful in summarizing the information given to you so far.

▶ Now, having learned how these parts will act when in series with the load, let us consider a few more basic circuits using condensers.

BY-PASSING AND FILTERING

Suppose we go back to our resistive circuit shown in Fig. *30* for a minute. You will recall that the voltage division depends on the relative resistance values, but the same division occurs regardless of frequency. This circuit cannot separate d.c. from a.c., nor can it separate alternating currents of different frequencies.

▶ There are plenty of cases where we want d.c. in the load without a.c., or want low-frequency a.c. and no high frequencies. We can add a condenser in parallel with the load, as in Fig. *35*, and will again have a frequency-separating circuit—one of the most useful in radio.

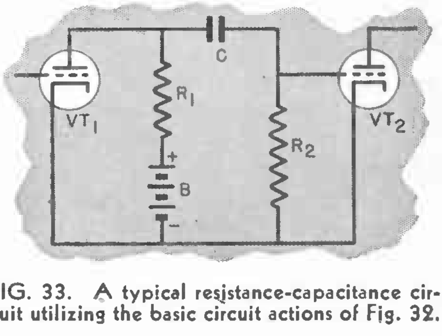
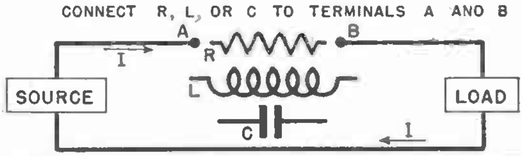


FIG. 33. A typical resistance-capacitance circuit utilizing the basic circuit actions of Fig. 32.

As you know, there is no d.c. path through the condenser. If we apply a



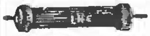
APPEARANCE	SYMBOL	DOES IT CONTROL D.C. CURRENT ?	DOES IT CONTROL A.C. CURRENT ?	WHAT HAPPENS WHEN THE ELECTRICAL SIZE IS INCREASED ?	WHAT HAPPENS WHEN FREQUENCY OF A. C. IS INCREASED ?
 RESISTOR		YES	YES	OPPOSITION INCREASES	NO CHANGE IN OPPOSITION
 COIL		NO (CURRENT PASSES)	YES	OPPOSITION INCREASES	OPPOSITION INCREASES
 CONDENSER		NO (NO CURRENT PASSES)	YES	OPPOSITION DECREASES	OPPOSITION DECREASES

FIG. 34. This chart summarizes the actions of a resistor, coil or condenser when used in the simple circuit shown above. (Because a condenser completely blocks the flow of d.c., some engineers say that it does control d.c. to this extent.)

d.c. source, condenser *C* charges through resistor *R*, after which there is no further direct current flow in the condenser section of the circuit. Of course, the load R_L provides a d.c. path, so a direct current flows through resistors *R* and R_L, and the condenser might as well not be there, so far as d.c. is concerned.

▶ When low-frequency a.c. is applied to this circuit, the capacitive reactance is high, and if it is much higher than the resistance of load R_L, very little a.c. flows through the condenser, most of it going through the load R_L.

As the frequency is increased, however, the reactance of the condenser decreases. Condenser *C* and resistor *R* begin to divide the source a.c. voltage, with a greater and greater drop occurring across resistor *R* as the frequency increases. Therefore, less and less a.c. voltage is available across *C* and the load R_L. This circuit can be considered a low-pass filter, because low-frequency currents flow through R_L, while higher frequencies do not.

Notice—this action is exactly opposite to that of the circuit in Fig. *32*. The circuit in Fig. *32* permitted only higher frequencies to pass, while that in Fig. *35* permits only lower frequencies to pass. Hence, Fig. *35* is acting much like the coil circuit of Fig. *31*.

▶ Sometimes we may use a coil as a filter, sometimes a condenser. By putting the coil or condenser in the proper place in the circuit, we can get either a low-pass or a high-pass action for a.c. The condenser has the advantage of blocking direct current flow when in series, and has no effect on d.c. when in parallel, so the condenser is often more desirable in circuits where d.c. is also present. You will usually find coils used more commonly in circuits containing only a.c. frequencies.

▶ Notice how the parts *work together* to give the desired actions. Without the series *R* in Fig. *35*, an entirely different action would occur. The condenser would then act just as it does alone and would serve only as an *additional load* on the source. It would not have any control over the R_L voltage unless the source contained enough impedance to replace the action of the series R. Of course, in practice, the source *will have appreciable impedance* so some a.c. drop will occur.

By-pass Action. The condenser connection shown in Fig. *35* is very frequently called a "by-pass" because it "by-passes" high-frequency currents so they do not flow through the resistor R_L. This action is also called "filtering," because the effect is one of "filtering out" certain frequencies. Which name we use depends upon the exact action required in the circuit, as you will learn later. Usually, the term "by-passing" is used whenever we want to provide an easy path for a.c. and at the same time keep this a.c. out of another circuit.

Fig. *36A* shows a typical by-passing circuit. Battery *B* causes d.c. to flow through the source, through R_L and through R_B. Condenser *C* has no effect on this action.

The source produces a.c., which we may want to keep out of battery *B*. This a.c. flows through R_L and condenser *C*, rather than through R_L, R_B and the battery, because the opposition to a.c. in the path through condenser *C* is very low, causing the a.c. voltage to divide between R_L and *C*. Since most of this voltage is across R_L there is little voltage across *C*, and as R_B and *B* are in parallel with *C*, they have the same low a.c. voltage across them.

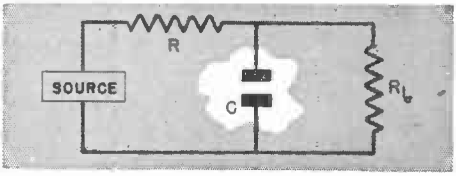


FIG. 35. Another important condenser circuit. Here, the condenser acts with resistor R to keep the higher frequencies from affecting the load R_L.

▶ The practical radio equivalent of this filter circuit is shown in Fig. *36B*, where the tube *VT* acts as the source of the a.c. signal. Again, we include this circuit just to show you a practical use for one of our simple circuits. Much more information will be found in later lessons on this subject.

▶ From what you've already learned, however, you can see that if condenser *C* in Fig. *36* becomes leaky, it provides a path for d.c. from battery *B* through R_B. As the leakage resistance becomes lower, there will be a greater drop across R_B and less voltage will be available for the tube and R_L. In other words, the d.c. path becomes R_B-*C*, rather than R_B-R_L-*VT*. Thus, a leaky condenser can stop the operation of the circuit. On the other hand, if the condenser becomes disconnected (open), the a.c. has no by-passing path and must flow through the battery, where it can produce undesirable effects, as we shall study later.

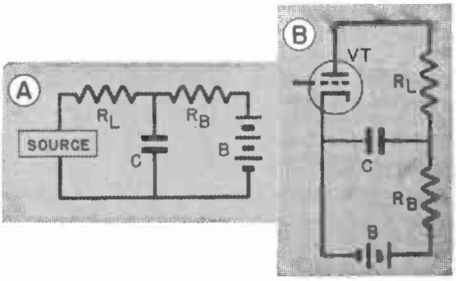


FIG. 36. This typical by-pass circuit uses the basic actions of Fig. 35.

COMBINING L AND C

So far, we have discussed using a coil or condenser with a resistor. What happens when we combine a coil and condenser?

Let us first consider the circuit shown in Fig. *37*. We know that the coil tries to exclude higher frequencies from R_L, because it offers a greater opposition to higher frequencies. We also know that condenser C has less reactance at higher frequencies, and so tends to "by-pass" the higher frequencies.

Thus, both elements of this combination try to exclude higher frequencies from the load, L by offering high reactance and C by offering low reactance to the high frequencies. The practical result of combining these two parts in this circuit is that the high frequencies are cut off quite abruptly, instead of dropping off gradually as they do when either the coil or the condenser is used alone. This is a low-pass circuit, since only low frequencies reach the load.

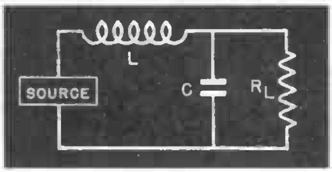


FIG. 37. Using a coil and condenser together this way gives a low-pass filter, which "passes" low frequencies to the load but sharply cuts off higher frequencies.

By interchanging the two parts as shown in Fig. 38, we produce the opposite condition. Condenser C offers greater opposition to low frequencies, and coil L acts as a "by-pass" element. Therefore, the circuit in Fig. 38 cuts off low frequencies, and is thus a high-pass circuit.

The actual frequency where this "cut-off" action occurs depends on the values chosen for L and C in both circuits. When you take up filtering later on, you will find that coil and condenser combinations of these types are quite commonly used where it is necessary to separate high and low frequencies abruptly.

Looking Ahead. In radio, we will find circuits which contain resistance only. Circuits of this type will act the same regardless of the frequency. In other circuits, we introduce a coil or condenser to discriminate against either low or high frequencies. Then there are other combinations of coils, condensers and resistors which pass some frequencies but reject those higher or lower. Another group will reject a band of frequencies but allows higher and lower frequencies to pass. Exactly when and how we do this will be the subject of many of your future lessons.

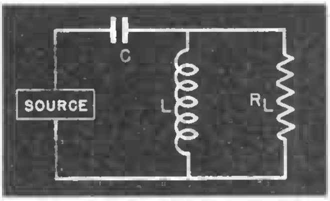


FIG. 38. Reversing the coil and condenser positions gives a high-pass filter which excludes low frequencies from the load.

▶ In your next lesson you will take up the interesting and important subject of vacuum tubes and how they operate. You will then be ready to put together resistors, coils, condensers and tubes to form actual radio circuits.

Lesson Questions

Be sure to number your Answer Sheet 7FR–3.

Place your Student Number on *every* Answer Sheet.

***Send in your set of answers for this lesson immediately after you finish them,* as instructed in the Study Schedule. This will give you the greatest possible benefit from our speedy personal grading service.**

1. Name the four factors that determine the capacity of a condenser.

2. What is meant by the "working voltage" of a condenser?

3. Is it necessary to consider polarity when connecting electrolytic condensers?

4. How would you connect two condensers together to get an increased capacity?

5. When the frequency is *decreased,* does the capacitive reactance: *1, increase; 2, decrease; or 3, remain the same?*

6. When the capacity is increased, does the capacitive reactance: *1, increase; 2, decrease; or 3, remain the same?*

7. When a resistor is connected in series with a condenser, does the charging time: *1, increase; 2, decrease; or 3, remain the same?*

8. Suppose you want to exclude d.c. from a load. What part would you use in series with the load to do this?

9. Suppose a condenser is in series with a resistive load, as shown in Fig. *32*. Will a larger-capacity condenser permit *more* or *less* a.c. voltage to be applied to the load?

10. Suppose distortion occurs due to a d.c. voltage across resistor R_2 of Fig. *33*. Choose the *two* following conditions of condenser C which could cause this: *1, leaky; 2, open; 3, short-circuited; 4, normal condition.*

SUCCESS AND HAPPINESS

I would like to have you feel, as you read these short personal messages, that you are seated right alongside my desk. Years of experience with thousands of ambitious men proved to me that a word of advice or cheer can go a long way toward speeding your progress. As I see it, my responsibility goes farther than just giving you the *very best* training in radio—my duty is to help you get the very most out of *life*—to attain *real happiness.*

You, in common with all other N.R.I. men, desire success. You think that success will bring happiness, but this is not necessarily true. I believe that a man must train himself for happiness, just as he must train himself for success! Many a successful man of today is not happy, just because he did not realize this important truth.

The first thing you must understand is this: *Happiness comes from within!* There is no guarantee that material things—money, success, friends and possessions—will make you happy, for happiness is a state of mind. You must learn to be happy within yourself.

In these one-minute chats, then, I am going to teach you how to get the most happiness out of the success which is in store for you.

J. E. SMITH.

HOW RADIO AND ELECTRONIC TUBES WORK

8FR-4

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

STUDY SCHEDULE NO. 8

For each study step, read the assigned pages first at your usual speed. Reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind, then answer the Lesson Questions for that step. Study each other step in this same way.

☑ 1. The Tube as an Electronic Switch.............................Pages 1-5

This section gives the ways in which electron emission can be produced, then describes thermionic emission in full. After learning this, you are shown how a diode tube can be used as a one-way device. This is the basic action of rectifiers and detectors—two important radio circuits. Answer Lesson Questions 1, 2, 3 and 4.

☑ 2. Basic Tube Construction....................................Pages 6-10

Here are the important facts about the kinds of materials used in making tube filaments, cathodes and plates. This is important information, because the materials used determine the conditions of tube operation. Answer Lesson Questions 5 and 6.

☑ 3. Basic Tube Characteristics..................................Pages 10-15

The voltages applied to a tube are limited to values within the operating range. Here you learn what limits there are.

☑ 4. The Triode Tube..Pages 15-25

This section should be read and studied over and over. The triode is the basis for all multi-element tubes and is the basic amplifier tube. Be sure you understand exactly how the signal on the grid is used as the "pattern" for the tube to reproduce another and larger voltage within its plate circuit. Answer Lesson Questions 7 and 8.

☑ 5. Multi-Element Tubes..Pages 25-28

A brief introduction to tubes having many elements. You will meet these tubes in later lessons. Answer Lesson Question 9.

☑ 6. Special Purpose Tubes Pages 29-30

Photoelectric cells, gas-filled tubes and cold-cathode types are explained.

☐ 7. Tube Classification Systems................................Pages 31-36

Practical information on the identification of tubes and their base pin connections. You will use this system constantly in your radio work. Answer Lesson Question 10.

☐ 8. Mail Your Answers for this Lesson to N. R. I. for Grading.

☐ 9. Start Studying the Next Lesson.

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HOW RADIO AND ELECTRONIC TUBES WORK

The Tube as an Electronic Switch

VACUUM TUBES are the heart of modern electronics. They are used not only in broadcasting and receiving radio entertainment, but also in commercial radio (aircraft, police, shipboard, and radio-telegraph systems), telephone repeater systems, diathermy equipment, and many other applications. In fact, tubes are used in devices which can see, hear, talk, feel, taste, smell, count, sort objects, keep time, control machinery, detect intruders, and cure diseases! And they range in size from tiny hearing-aid tubes scarcely larger than a thumbnail up to five-foot tall transmitter giants.

Let us now learn what kinds of tubes there are, how they operate, and what they can be made to do. These facts will apply to all tubes, whether they are used in broadcast, f.m., or television receivers or in transmitters. We must also learn something about tube weaknesses, since tubes are responsible for more radio breakdowns than any other part.

▶ When we have finished our study of tubes, we will be ready to put coils and condensers together in practical circuits, then to combine them with resistors and tubes to form actual radio circuits.

Electron Emission. In ordinary electrical circuits, electrons stay within the circuit wiring, and flow only over complete paths. However, in a tube, *electrons are forced out of the surface of a metal cathode, and are made to flow across a space*. Let's see how electrons are made to do these things.

▶ Electrons normally stay within a conductor, because an atomic force prevents even free electrons from escaping through the conductor surface. An ordinary current flow through a conductor is a result of an *exchange* of electrons from atom to atom. There is no *loss* of electrons, because others replace those which pass on. However, if an electron can gain enough energy, it can separate itself from the atoms of the conductor and become a "free agent" in space.

▶ There are four ways in which electrons can gain enough energy to escape into space from a metal or metallic compound. These are: *1*, they can be evaporated or driven out by applying heat; *2*, they can be driven out by bombardment with very small high speed particles, such as other electrons; *3*, they can be driven out of some materials by the energy in light rays (which are electromagnetic waves); and *4*, they can be jerked out by a very high positive potential.

All four of these methods are used in various types of electronic tubes to provide the free electrons on which all tubes depend for their operation. However, the first method (applying heat) is by far the most common, so we shall first deal with the *thermionic* tube. (Thermionic is pronounced *THERM-I-ON-IK:* thermo means heat, ionic refers to electrons.)

THERMIONIC EMISSION

Suppose we start with a tube consisting of a filament, made of thin resistance wire, enclosed in a glass or metal bulb from which all the air has been pumped. If we connect a battery to this filament (Fig. *1*), the current flowing through the filament will heat it, and, when the filament has become hot enough, electrons will be emitted from it. (A vacuum is necessary in the bulb to prevent the filament from burning up at the temperature it will reach, and to remove the large air molecules which would interfere with electron emission.)

Electrons are emitted from the filament because the heat produced gives them enough energy to escape from the surface of the wire. The velocities with which they escape depend upon the amount of energy they get from the heat, and this starting speed determines how far they will go. Usually, they do not have velocities sufficient to take them very far from the filament, so a number of electrons soon are "hanging around" the filament. As this "cloud" of electrons becomes thicker, they begin to repel each other, tending to force those closest to the filament back to the wire.

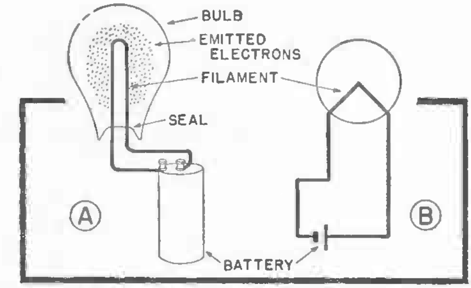

FIG. 1. When the filament is heated, electrons are emitted. Notice the symbols at B for the tube filament and for the battery.

You learned in earlier lessons that removing electrons from an electrically neutral substance makes that substance positive. That is what happens to our wire filament—it becomes more and more positive as electrons are driven off from it by heat. This positive potential tends to attract electrons from the cloud back to the filament (unlike charges attract). Some of them do return, while others are prevented from doing so by the repelling action of the electrons freshly emitted from the filament.

Eventually a state of equilibrium will be reached, with a practically constant number of electrons in the cloud about the filament, and with the number of electrons leaving the filament approximately the same as the number returning to it. The electron cloud in the space around the filament is called the *space charge*.

▶ It is important to realize that the current from the battery in Fig. *1* just *heats* the filament. The electrons emitted by the filament *do not come from this battery current*—they come from the atoms of the filament wire itself. We could heat the filament by a gas flame, or any other heating agent, and get the same electron emission for the same amount of heat. An electric current is generally used to heat the filament because this is the most convenient way to do it.

▶ Also—we show batteries only because they are a convenient way to indicate a *d.c. voltage* supply. This d.c. voltage might come from batteries, or from a power pack which converts a.c. to d.c., or from any other d.c. source. Don't think we are covering only battery type tubes—you are studying basic actions applying to *all* tubes.

THE PLATE

Now that we have a filament surrounded by a cloud of electrons, let us place a metal plate within the tube and bring a wire from this element to the outside of the tube. Further, let us connect a meter *M* to this wire, then connect another battery between the meter and the tube filament. This will give us the circuit shown pictorially in Fig. *2A*, and schematically in Fig. *2B*. For identification, we call the filament-heating battery an *A* battery, and the new battery the *B* battery, as marked in Fig. *2B*.

Suppose we first connect the *negative* terminal of the *B* battery to the new element (which we shall call a plate), and the positive terminal of this battery to the filament, as shown in Fig. *2*. (The circuit is completed from the negative *B* terminal to the plate through the meter.) We will find that the meter pointer remains at zero, showing that there is no electron flow in this "plate" circuit. There are two reasons for this. First, there is no electrical connection within the tube between the plate and the filament, so there is no metallic path for current (electrons) to follow. Second, the plate and the filament assume the potentials of the *B* battery terminals to which they are connected: the plate therefore becomes negative with respect to the filament. The *negative* plate will then *repel* the negative electrons emitted from the filament, so that they will not go to the plate and there will be no conduction through space in the tube.

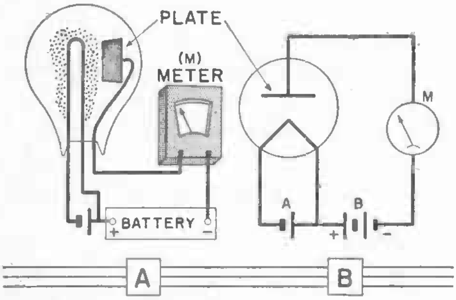

FIG. 2. Here the "plate" has been added. The meter indicates no current flow because the B battery has the wrong polarity.

▶ Now, let us turn the *B* battery around (Fig. *3*) so that the plate becomes *positive* with respect to the filament. At once, the meter will indicate that a current is flowing—because now the negatively charged electrons are attracted by the *positive* plate (unlike charges attract) and are pumped through the circuit by the *B* battery so that they flow through the meter *M*, through the *B* battery, and back to the filament.

In other words, free electrons in space obey the laws of charges—they are *repelled* by a negative plate, and are *attracted* by a positive plate. The number of electrons attracted depends on the *voltage* of battery *B* and on the *distance* between the plate and the filament. *Increasing the voltage of battery B* (thus making the plate more positive), *or decreasing the distance from the plate to the filament, or both, increases the ability of the plate to attract electrons.* Conversely, decreasing the voltage or increasing the distance decreases the attracting ability of the plate. (Of course, the distance between the plate and the filament is always fixed in any particular tube, so in a practical case, we generally consider that the voltage applied to the plate determines the ability of the plate to attract electrons.)

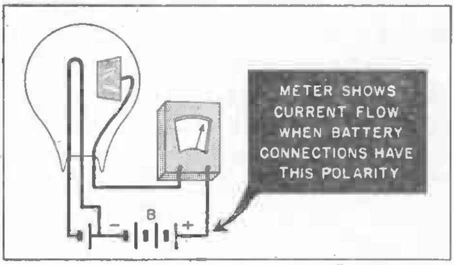

FIG. 3. The proper B supply polarity causes an electron movement from filament to plate, through the meter and the B battery back to the filament. (There must be a complete path back to the filament for there to be an electron flow. The B battery can "take in" at its positive terminal only the same number of electrons as it "lets out" of its negative terminal. Hence, free electrons are given back to the filament in exchange for those emitted.)

▶ What has happened to our space charge? Assuming average conditions, the electrons which go to the plate come from the space charge, and thus reduce the negative charge in the cloud around the filament. This, in turn, allows an equal number of electrons to leave the filament to make up for this deficit in the space charge. Thus, there is a transfer action in which electrons leave the filament and go to the space charge, while other electrons leave the space charge and go to the plate. *For most purposes, we can ignore this transfer and assume that electrons go directly from the filament to the plate, when the plate is made positive with respect to the filament by a B battery.*

This electron movement continues through the meter and the battery so that an equal number of electrons are restored to the filament to make up for those emitted. Hence, there is a "complete circuit" effect when the plate is positive with respect to the filament.

▶ *All vacuum tubes have at least two electrodes, a cathode and an anode.* The cathode is the electron emitter, and the anode (or plate) is the electron-attracting element. If these are the only electrodes in the tube, it is called a diode tube. "Diode" is pronounced *DI-OAD* (rhymes with "load"): "di" means two, and "ode" refers to electrodes or elements—hence a diode is a two-element tube.

RECTIFICATION

So far, we have described how it is possible for electrons to flow from the cathode to the plate in a tube when the plate has the proper polarity. Notice —the tube is obviously a "one-way" device, in that electrons can move *only* from the cathode to the plate, and then *only* when the plate is positive with respect to the cathode. Electrons do not normally move from the plate to the cathode.

▶ This one-way action makes a diode tube an important device in a.c. systems. Suppose we substitute an a.c. supply for the *B* battery, giving us the circuit shown in Fig. *4A*. As you know, an a.c. voltage reverses polarity periodically; so for one-half of the cycle, terminal *1* will be positive with respect to terminal *2*, while for the other half-cycle, terminal *1* will be negative with respect to terminal *2*. If our supply voltage is an a.c. sine wave, like that shown in Fig. *4B*, we will find that plate current flows in pulses like those shown in Fig. *4C*. In other words, plate current flows *only* for the portion of each voltage cycle when terminal *1* is positive with respect to terminal *2*, and does not flow for the half of each voltage cycle when terminal *1* is negative with respect to terminal *2*. In fact, we might consider the tube to be a kind of "electronic switch" that closes the tube circuit (and so permits current flow) only when the plate-to-cathode voltage has the proper polarity.

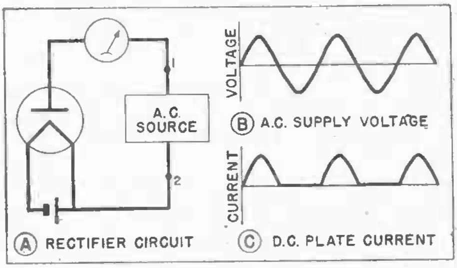

FIG. 4. A diode tube will permit current flow only when the a. c. voltage makes the plate positive with respect to the electron emitter.

Thus, plate current flows in only one direction, and so is a *direct current.* The current is *pulsating*, varying from zero to some peak value which depends on the supply voltage, but it never reverses in direction.

▶ *This is an extremely important characteristic of a tube.* When we use an *a.c. voltage* supply in the plate circuit, the plate current will be a *pulsating d.c. current*. If this d.c. current is made to flow through a resistor, it must produce a *pulsating d.c. voltage drop* across the resistor. Thus, the tube *rectifies* an a.c. voltage—that is, changes it to a d.c. voltage.

Fig. *5A* shows the same circuit given in Fig. *4A*, except that the meter in the latter has been replaced by a "load." This load might be a resistor, or a coil, or a complex electrical circuit. The tube in Fig. *5A* acts, as you have just learned, as a one-way device and permits electron flow only in the direction indicated by the arrows, (and then only when the supply voltage polarity makes the plate positive). Hence, the voltage drop across the load will be a pulsating *d.c.* voltage which has the polarity shown. (By the use of filter circuits, which you will study later, it is possible to "smooth out" the variations in the current, so that the voltage across the load is practically a steady d.c. voltage like that delivered by a battery.)

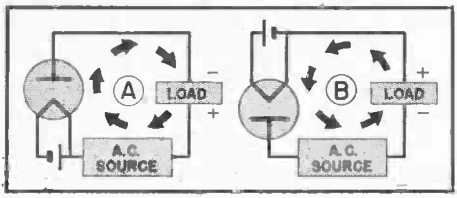

FIG. 5. The load voltage polarity is reversed by reversing the tube connections.

▶ Should we want the load voltage polarity to be reversed from that in Fig. *5A*, we need only reverse the plate and cathode connections as shown in Fig. *5B*. Electrons still can go *only* from cathode to plate, so this reversal of the tube connections changes their direction through the circuit.

Practical Uses. Radio finds a number of important uses for the one-way action and for the basic circuits shown in Fig. *5*. For instance, we can take power from an a.c. electric line and change it into a d.c. voltage which we can use to run a radio. This has made it possible to eliminate batteries when we wish to operate the radio from a power line. When a diode tube is used for this purpose, it is called a rectifier, and the circuit in which it is used is known as the "power pack" of the radio receiver.

Diode tubes have many other uses in radio which need not concern us at the moment. You will meet them all in later lessons.

▶ The one-way action of a tube is of great help to servicemen. It is frequently important to know the polarity of voltage drops in tube circuits. Now that you know electrons can pass through the tube only from the cathode to the plate, you can determine the direction of electron flow in any tube circuit just by looking at the tube. Then you can trace around the circuit and determine the polarity of the voltage drop in any device from the rule you learned earlier:

The end of any coil, condenser, or resistor which electrons enter is the negative end of that device.

For practice, use this method to find the polarity of the voltage drop across the load in Figs. *5A* and *5B*. You should arrive at the polarities indicated in these figures.

Basic Tube Construction

All tubes have a cathode and a plate, and all thermionic types have a filament. Since these elements are of such basic importance, let us take a few moments to learn just how they are made. This will teach you some important facts about the uses to which tubes can be put, and also the reasons for certain weaknesses which they have.

TUBE FILAMENTS AND CATHODES

The earliest tube filaments were made from pure metals. It was necessary to make these pure metals extremely hot before electrons could be forced out of the surface of the filament. Hence, it was necessary to find metals which would emit sufficient electrons for electronic tube purposes without being melted by the intense heat.

Pure Metals. The pure metal most commonly used for tube filaments is tungsten. This metal is capable of withstanding very high temperatures, but is a relatively inefficient electron emitter because a considerable amount of heat is necessary to get the desired degree of emission. This means the filament-heating *A* supply must furnish a great deal of power.

Today, pure metal filaments (used as electron emitters) of this type are found only in high power transmitter tubes, where the ability to withstand high temperatures and the freedom from gas troubles (to be discussed later) make such filaments desirable.

Thoriated Filaments. After the development of the tungsten filament, it was discovered that certain impurities in the metal improved its electron emitting properties. Tungsten is a hard, brittle metal, and when pure is difficult to draw into the form of wire. Engineers found that a little thorium mixed with the tungsten overcame the brittle properties, giving a more sturdy filament for light bulbs. Radio engineers tried these thoriated tungsten filaments and found them not only sturdier, but also much better as electron emitters than pure tungsten filaments.

The manufacturers subject a thoriated tungsten filament to a process called "activating" when the tube is constructed. In this process, the filament is first subjected momentarily to a high voltage overload, and then to a small voltage overload for a considerable period of time. The high flashing voltage at the beginning causes some of the thorium to flow from within the filament to the surface, and the baking process which follows causes this thorium to form a layer on the surface of the filament wire. This layer (which is about one molecule thick) has the property of increasing the electron emission tremendously. The temperature required to produce a desired number of electrons from a thoriated

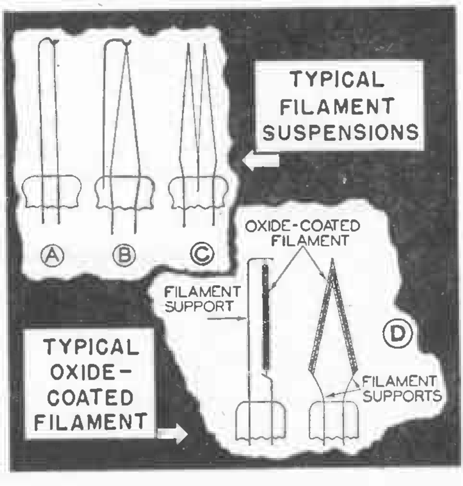

FIG. 6. Typical filaments.

tungsten filament is far lower than the temperature required to produce the same emission from a pure tungsten filament.

At one time thoriated filaments were used in practically all tubes. Today, they are found mostly in medium power transmitting tubes, having been replaced in the lower-power class and in receiving tubes by oxide-coated filaments.

Oxide-Coated Filaments. The oxide-coated filament is made by coating a filament wire of nickel or a platinum alloy with the oxides of certain metals. Oxides of barium, strontium, and calcium have been used.

Oxide coatings can be used only in tubes where the plate voltage is below 500 volts, for higher voltages jerk away the coating. Also, they can be used only in tubes where there is little chance of gas trouble. However, they are entirely satisfactory for receiving tubes and low-power transmitting tubes, where both these conditions are met.

▶ Oxide coatings are by far the most efficient electron emitters, requiring less heat than any other kind of surface for the desired degree of emission. This means that a low-power filament source can be used with an oxide-coated cathode. In fact, so little heat is needed that oxide-coated cathodes have been developed which are indirectly heated. These have proved very useful in reducing hum when tube filaments are operated from an a.c. source. (A.C. power will supply heat just as well as d.c. power, but hum is caused if the emission varies with the a.c. cycle changes. As you will learn later, a very heavy filament or an indirectly heated cathode is necessary to eliminate this hum voltage variation.)

▶ Now is a good time to clear up the meanings of the words "filament" and "cathode." The *filament* is the proper name for the resistance wire supplying the heat. The *electron emitter* is called the cathode. When the filament does the emitting, it is also the cathode. Several different filaments, which are also cathodes, are shown in Fig. *6*.

▶ In the indirectly heated cathode, the filament merely furnishes heat to the electron-emitting cathode, which is a separate element. The construction of several indirectly heated cathodes is shown in Fig. *7*. The filament is threaded through holes in a ceramic insulator, which is placed inside a nickel-alloy sleeve or "thimble." This metal sleeve has the oxide coating baked on it. (In some types, the filament wire is coated with the ceramic insulation and is then placed inside the sleeve.) The insulation prevents there being an electrical path between the cathode and the filament. Since the sole purpose of the filament in this construction is to supply heat, it is commonly called a heater. A tube using an indirectly heated cathode is frequently called a "heater type" tube, to distinguish it from the "filament

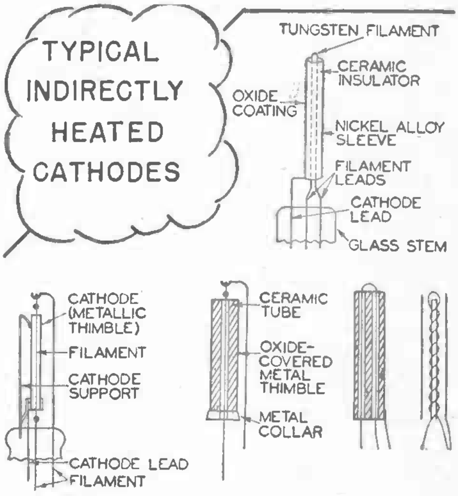

FIG. 7. A separately heated cathode emits electrons.

type" which uses the filament as the cathode.

▶ Metals stretch when heated, so the filaments in all tubes are mounted on spring supports which take up the "stretch" of the filament wire, thus preventing it from sagging and touching other elements; yet the springs allow it to shrink back to normal when the tube is not heated.

Tube filaments are delicate; a severe jar or excessive voltage will cause them to break or burn out. The proper filament voltage is so important that the tube type numbers indicate the amount to be used, as we shall see later in this lesson.

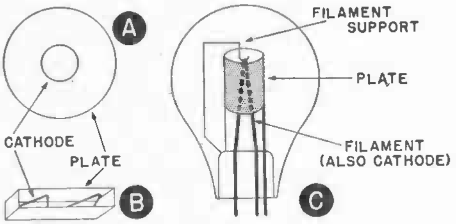

FIG. 8. Typical tube structures.

VACUUM TUBE PLATES

The tube plate is subjected to considerable heat, some radiated from the filament and some produced by the electrons bombarding the plate itself. When electrons strike the plate, they give considerable energy to it. If the plate becomes hot enough, it too will begin to emit electrons. In fact, the one-way characteristic of the tube is dependent upon whether the plate remains relatively cool. Nickel, molybdenum, carbon, and pure iron are materials that have proved suitable for use in constructing plates or anodes. The plate is generally given a dull black surface, for black surfaces radiate heat readily and therefore keep cooler than polished surfaces.

The plates of medium power tubes are often fitted with fins to improve their heat radiation. In high power tubes, water cooling or forced air draft is necessary to keep the plates at safe low temperatures.

▶ Even with the plate cool, the electrons striking it can knock other electrons loose from its surface. This effect, wherein speeding electrons knock loose other electrons from the surface of an element, is called *secondary emission.* If the plate or anode is the only positive element in the tube, this condition is not serious, as the secondary electrons will go back to the plate. In other tubes, special means are taken to eliminate the undesirable effects of this secondary emission. We shall learn what these are a little further on in this lesson.

▶ The plate shape depends somewhat on the shape of the cathode and on the structure of the other electrodes in the tube. In early tubes, it was just a flat plate off to one side. Now, it always completely surrounds the emitting sections of the cathode. If the cathode is a vertical wire or is indirectly heated, the plate will be a cylinder which surrounds the cathode, as shown in Figure *8A.*

Where the filament is constructed like an inverted *V* or *W* (as it is in Fig. *6B* or *6C*), the plate will generally be an oblong or oval structure like that in Fig. *8B.*

GAS EVACUATION

The normal tube has a very high degree of vacuum. If air is permitted in the tube, the filament will oxidize (burn up) when heated.

▶ An even more important effect of atmospheric gases within a tube is the fact that the speeding electrons will strike the gas molecules, knocking other electrons out of them. This changes the molecules into large, heavy, positive, gas ions. The cathode is negative, so the positive ions will travel to the cathode and bombard it. Oxide-coated cathodes are easily ruined by such bombardment, for the oxide layer is knocked off completely. A thoriated filament is similarly destroyed, although not as easily. A pure tungsten filament is the only type capable of withstanding much gas ion bombardment.

▶ To eliminate the effects of gas as much as possible, vacuum pumps are used to draw out air and gases. During the evacuation process, the elements within the tube are heated by induction heating apparatus, which uses large coils to induce voltages in the elements. The resulting heat tends to drive out much of the gas. We ordinarily think of metals as being absolutely solid, but they have pores which will hold gas molecules until they are driven out by such heating.

In addition to the heating and evacuation, most tubes employ "getters." A getter is a small cup containing chemicals. During the induction heating process, these chemicals vaporize and combine readily with the gas molecules, forming metal compounds which then are deposited on the cool glass envelope of the tube. This is what gives the silvery appearance many tubes have near the base of the bulb. These compounds "hold on" to the gas molecules and do not readily release them in the tube space.

▶ Tubes having oxide-coated filaments cannot be heated to as high a temperature as can those having other filaments (the oxide coating will be boiled off if too much heat is applied), so the gas evacuation is not as good in these tubes. As a result, oxide-coated cathodes can be used only in tubes that are intended for relatively low power and low plate voltage. (As the plate voltage is increased, the electron velocity is speeded up and the heating effects are increased, so that there is more danger of electrons ionizing gas molecules present in the tube space and also of knocking out gas molecules from the metals.)

A tube with a pure tungsten filament, on the other hand, can be very highly evacuated, because tungsten is not affected by high temperatures. This is one reason why high power tubes, particularly transmitting tubes operating with plate voltages above 5000 volts, usually have pure tungsten filaments.

▶ While every effort is made to eliminate gases from within *vacuum* tubes, some special "gas-filled" tubes do have certain gases deliberately introduced in them. We will study these tubes, and the reason for putting gas in them, later in this lesson.

▶ Since the tube must be sealed completely, the wire leads going to the ele-

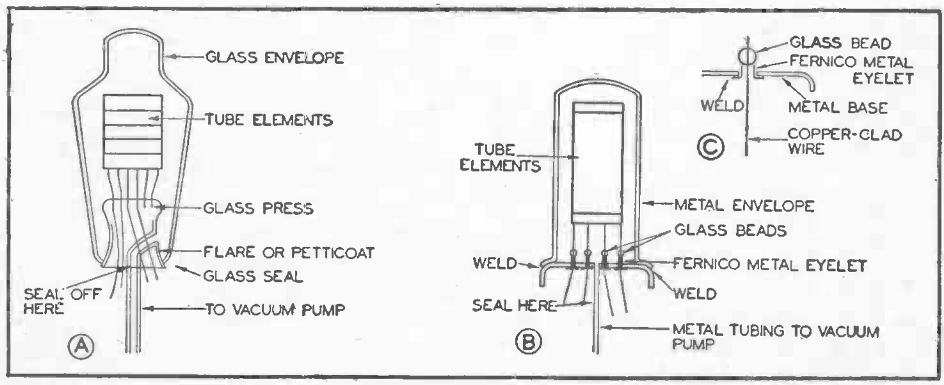

FIG. 9. A comparison of the construction of a glass envelope tube and a metal envelope tube.

ments must pass through a seal formed by a glass press or glass beads before emerging from the tube. Considerable research was necessary to find a metal to be used for these wire leads which had the same rate of expansion as the glass, so heating would not crack the seal. These wires are special alloys. The supports and connectors to the elements are welded to the wires within the tube.

▶ Fig. *9* shows the method of sealing both a glass-envelope tube and a metal-envelope tube. A metal tube differs from a glass tube in having a metal envelope instead of a glass envelope, so a metal tube and a glass tube *of the same type* are electrically identical inside their envelopes.

After the gas is evacuated, the tubing which goes to the vacuum pump is sealed off and cut. The leads emerging from the tube are then fastened to prongs in a base, so that the tube can be plugged into a socket. Circuit connections are made to the socket, so the tube elements will be connected to the tube circuit when the tube is plugged into the socket.

Basic Tube Characteristics

So far, you have learned how the diode tube can be used as a rectifier. You have also learned some facts about the constructional features of these tubes, which also apply to *all* other types of tubes.

Now, let us learn more about how tubes operate. For simplicity, we shall use the diode as an example at first, then take up other tube types when you have mastered the important fundamental facts of tube operation.

FILAMENT VOLTAGE LIMITS

Suppose we set up the circuit shown in Fig. *10* to see just what happens as the filament and plate voltages are varied. (We have shown an indirectly-heated cathode type tube in this circuit, but might equally well have used a filament-cathode tube; the following explanations apply to either type.)

Let us start out with a relatively low plate-to-cathode voltage from battery *B*. (Radiomen shorten this, calling it just "plate voltage." You know voltage exists between *two* points, so the names "plate voltage" or "grid voltage" refer to voltages between these points and some reference point, which is usually the cathode.)

Let us also set the variable resistor *R* in the filament circuit to a high value, so that very little current flows in the filament circuit. The tube filament and resistor *R* form a voltage divider. When the resistance of *R* is high, most of the voltage is across it and meter *V* shows very little voltage across the tube filament.

With very low filament voltage, the filament will not get hot enough to cause cathode emission, so the meter *I* will indicate zero plate current. Suppose we now reduce the resistance of rheostat *R* gradually. This lets more and more current flow through the filament circuit, and a greater proportion of the voltage appears across the tube filament. As a result, the filament becomes hotter, thus raising the temperature of the cathode. Soon meter *I* will indicate that a current is flowing in the plate circuit. This plate current means, of course, that electrons are being emitted by the cathode.

As we continue to decrease the value

of resistor R, the filament voltage continues to *increase* and, for a time, so does the plate current indicated by the meter I. However, we will eventually reach a point where the plate current no longer increases, even though the filament is made hotter.

Fig. *11* shows a graph of this action. As the filament voltage (E_f) is increased, the plate current (I_p) increases from A to B on the solid curve. At point B, the plate current ceases to increase much and the curve levels out toward C.

▶ Now suppose we start the experiment over, this time with a higher voltage from battery B in the plate circuit. We will again find that the plate current follows the curve from A to B, but now it goes on up along the dotted line to point D, where it levels out toward E. The higher plate voltage results in a higher plate current (the distance from B to D) before the curve levels off. Eventually, however, the leveling occurs.

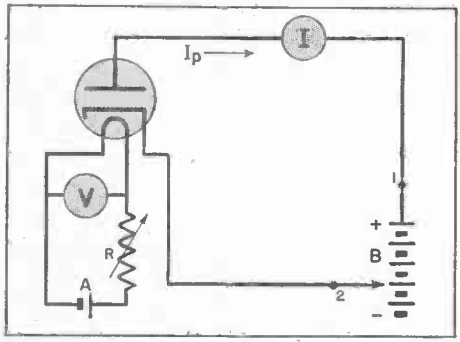

FIG. 10. A test circuit like this is used to determine the characteristics of diode tubes.

Should we continue this experiment, increasing the value of the plate voltage each time, we would find that the events repeated themselves. Higher plate voltages would result in the curve rising higher before it leveled off. However, it would always level off at some point.

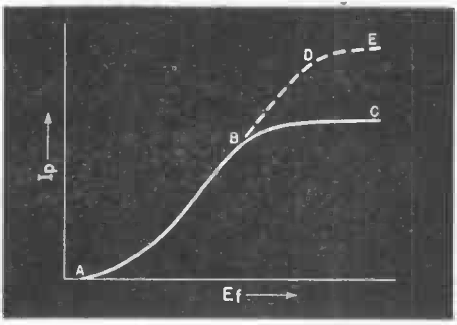

FIG. 11. How the plate current varies with different filament-heating potentials.

Temperature Saturation. We know that as the filament voltage is increased, the filament becomes hotter and hotter. This means more and more electrons are forced out of the cathode, so we might expect the plate current to continue to increase instead of leveling off. But, since the plate current finally becomes constant, evidently a point is reached at which only a constant number of the electrons forced out of the cathode go to the plate. Why don't all of them do so?

The answer lies in the space charge effect we have already studied. An electron newly emitted from the cathode is subjected to the attracting force of the plate (tending to pull it toward the plate) and also to the repelling effect of the electrons emitted just ahead of it (tending to push it back toward the cathode). When emission is low, all the emitted electrons are drawn to the plate. But as emission increases, the slower moving electrons begin to form the space charge. As the emission is further increased, electron repulsion by the space charge increases (because there are more electrons exerting a repelling force) while the attracting force of the plate remains constant. As a result, the net force pulling newly-emitted electrons to the plate decreases; this slows these electrons down, and they tend to bunch up and join the electron cloud around the cathode.

Eventually, as emission increases, this electron cloud becomes so dense that we get the space charge transfer effect we described earlier. The plate pulls a constant number of electrons out of the space charge at any given instant; this same number of newly-emitted electrons can then enter the space charge, but any excess of newly-emitted electrons over this number is forced back to the cathode. The number of electrons the plate pulls out of the space charge depends upon the plate voltage and the distance from the plate to the space charge, but *not* on the emission.

Increasing the voltage on the plate will increase the current—because it will increase the number of electrons the plate can pull out of the space charge at any given instant. This merely results in a constant plate current of higher value, however, with the space charge still forcing excess electrons back to the cathode.

This means that *for a particular plate voltage*, there is a definite limit to the amount of current which will flow in the plate circuit of the tube. The only way you can get more current in a diode tube is to increase the plate voltage. Making the filament hotter will not increase the current greatly above the point where the curve begins to flatten out. The "bend" at point *B* on the solid curve (and at point *D* on the dotted curve) is known as the knee of the curve. The flat region of the curve beyond the knee is known as the saturation region. (A radio tube is saturated when the plate can attract no greater number of the emitted electrons.)

This condition, in which increasing the filament voltage will not cause a further plate current increase, is known as *filament saturation or temperature saturation.*

Filament Voltage Ratings. If a filament is heated too high it will, of course, melt. Hence, we cannot continue to increase the filament voltage indefinitely. In fact, the tube filament is designed to have a resistance such that it will reach a desired temperature when a particular rated voltage is applied to it. (As you will learn in a moment, the rated filament voltage is different for various tube types.)

The temperature the filament will reach is made high enough so that, for any normal plate voltage, there will always be more electrons emitted from the cathode than can be attracted to the plate. This makes the plate current depend only on the plate voltage, not on the emission. In other words, tubes are usually run well into the filament saturation region, so we'll be sure to have all the electrons we need.

What filament voltage values are used? The first tubes had to use battery power supplies, so filaments were designed to operate from 6-volt storage batteries or from groups of dry cells. The first storage battery types had 5-volt filaments, and a series resistor was used with them to drop the voltage from a 6-volt battery. The resistor value was reduced as the battery voltage decreased with age—a scheme which permitted longer operation before the battery had to be recharged.

The early tungsten filament tubes required a high filament current, because the filament had to be made quite hot before sufficient emission was obtained. However, when the more efficient thoriated tungsten and oxide-coated filaments were developed, lower temperatures could be used and less current was required for filament supply.

▶ The development of a.c. power supplies freed tube filaments from the necessity of operating from battery voltage values. Step-up or step-down transformers readily deliver any desired voltage. Today, we have a.c. tubes with filaments rated at 2.5 volts, 6.3 volts, 12 volts, 25 volts, 35 volts, 50 volts, and even 117 volts. (The last named type can be connected directly across a 110-volt power line.)

You may wonder how a.c. can be used on the filament without causing plate current variations as the filament voltage varies. The answer is that filaments and cathodes are used which hold heat for an appreciable period of time. Battery tubes will warm up almost instantly, but it takes 30 to 90 seconds for a.c. tubes to "get going." These tubes hold to a practically steady temperature during the small time space of an a.c. voltage variation, so there is practically no emission variation. We have to be careful with battery tubes, however, to see that a steady d.c. is applied to the filament.

▶ The numerous filament voltage values are the result of design requirements—some were developed for a.c.-d.c. receivers; some for auto sets; some for other purposes and reasons. Modern portable battery-operated receivers were made possible by the development of an entirely new line of 1.4- and 3-volt tubes, using far more efficient oxide-coated filaments than earlier types. These tubes have such low-current requirements that they can be run for a long time on small, lightweight batteries.

Transmitting tubes and other special purpose tubes have a similarly wide range of filament voltage ratings, so that a suitable tube can be found for each application.

Voltage Tolerances. Modern a. c. type tubes will operate over a fairly wide range about their rated filament voltages. For example, tubes with filaments rated at 6.3 volts will operate satisfactorily on voltages ranging from 5.8 volts to as high as 7 volts. With filament voltages below this range, the emission may become too low for most uses, and with voltages above the range, the tube life may be shortened. (Practically all these tubes have oxide-coated cathodes from which the coating will boil off if the temperature gets too high. This will destroy a tube just as surely as a complete burn-out of the filament.) Naturally, if the voltage is too much higher than the rating, the filament will actually melt.

Modern 1.4-volt battery-type tube filaments are designed to operate from a single dry cell which has a rating of 1.5 volts, but which actually delivers 1.65 volts for a short time, then drops down to its 1.5-volt rating. The battery voltage gradually decreases to 1.2 volts; then the battery is supposed to be replaced. These tubes thus are intended to operate in the range from 1.2 to 1.65 volts. However, some circuits may cease functioning if the voltage drops below the 1.4-volt filament rating. A check of the filament voltage should be made in receivers using these tubes when they fail to work.

PLATE VOLTAGE LIMITS

Suppose we return to our circuit of Fig. *10* and this time apply the rated filament voltage so that the tube is operating in the temperature saturation region. Let us now start with zero plate voltage by moving tap *2* on plate battery *B* up to point *1*. This means that none of the battery *B* will be in the circuit.

Under this condition, we will find that the meter *I* indicates zero plate current. Now, let us move the tap *2* down battery *B* a step at a time. As we gradually increase the voltage difference between the plate and cathode, we will find that the plate current increases slowly at first, then more rapidly and steadily as the plate voltage is increased. Finally, the plate current increase begins to taper off. A plot of these results (Fig. *12*) will give us a curve which is very similar to that shown in Fig. *11*. This curve shows that for a fixed filament voltage, increasing the plate voltage above a certain value no longer gives proportional increases in plate current.

Voltage Saturation. As the plate voltage is increased, more and more electrons are drawn from the electron cloud. As we continue to increase the plate voltage, the space charge becomes less and less, thus losing its repelling effect on the electrons coming from the cathode. As a result, we will eventually reach the point where every electron the cathode can emit (at that temperature) is being drawn at once to the plate, and the space charge no longer exists. When this occurs, there is no way to increase the plate current further, except by making the filament hotter. We then have what is known as *voltage* saturation (increases in plate voltage do not produce proportional increases in plate current).

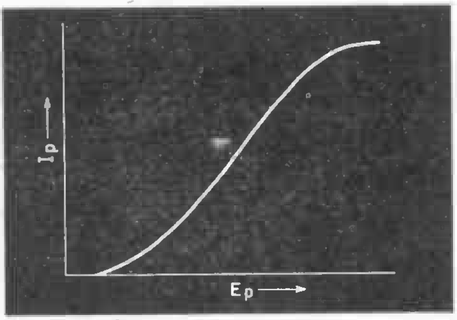

FIG. 12. How the plate current varies with the plate voltage.

If we keep the filament temperature fixed, then voltage saturation places a limit on the plate current. However, with many tubes it is impossible to reach saturation without damage to the tube—because as the voltage is increased, the plate current becomes so high that the electrons bombarding the plate can heat it to the melting point.

▶ Another factor which limits the allowable plate voltage is the spacing between the plate and other elements, and the spacing between the leads coming through the glass press or seal at the tube base. If the plate voltage becomes too high, it is possible for an arc (or electric spark) to jump between the elements. Should this arc jump between the leads in the seal, the tube will be destroyed.

The maximum plate-to-cathode voltage is always specified for each type of tube. Then, various sets of "operating voltage" values are given, which are equal to or lower than this maximum.

This rating limits the a.c. voltage we can apply in the circuit shown in Fig. *5*. It also limits the d.c. voltage we can apply, as we shall learn when we take up tubes requiring d.c. plate voltages. Incidentally, since the early tubes were intended to operate from batteries, and the standard *B* battery is a 22½ or 45-volt battery, d.c. operating plate voltages were given in multiples of these values. Thus, 45, 67½, 90, 135, and 180 volts were common operating voltages for many tubes in the early days of radio. With the advent of a.c. power supplies, which can furnish any desired d.c. voltage, tubes were free of the necessity of operating from battery voltage values. Today, the most common receiving tube plate voltage rating is 250 volts, while transmitting tube ratings range up to 10,000 volts. Tubes intended for both battery and a.c. power pack operation are still rated at plate voltages easily obtainable from batteries.

PRACTICAL FACTS

From what you have learned, you can see that there are limits to the plate and filament voltages that can be used with any particular tube. Should a tube be needed for a particular application, it is important to choose one having the proper ratings. This need for tubes designed for special purposes has led to the development of over 500 receiving type tubes alone.

▶ Fortunately it is not necessary to *learn* the values of the characteristics of all these tubes. You need to know only what these characteristics *mean* and the limits they place on tube operation. Then, like all radiomen, you can refer to a tube characteristics chart and can look up the values for any tube in which you are interested. We will go into this more thoroughly later, after we have learned more about some of the other types of tubes.

The Triode Tube

The triode (*TRY-OAD*) or three-element tube is perhaps the most important development in radio's history. The additional element used in the triode makes amplification possible. Also, this tube started the development of other multi-element tubes which have made possible circuits undreamed of in the early days of radio.

You learned in earlier lessons that a radio wave, after it is picked up by an antenna, reaches the receiver in the form of an a.c. voltage. This voltage is called a "signal" voltage. It is usually very small, and must be amplified many times before it can be used to operate a loudspeaker and give us sound. In all radios except the very simplest crystal sets, this amplification of the signal voltage is furnished by tubes. The signal is fed into a tube, and an amplified signal is developed across a load in the tube plate circuit.

Can we use a diode to amplify an a.c. signal? Going back to the diode circuit shown in Fig. *5*, you can see that the load voltage could never exceed the a.c. source value. (Kirchoff's Voltage Law: *The voltage rises equal the voltage drops.*) In fact, since there is always some loss in the tube itself (it acts with the load as a voltage divider), you actually get less voltage across the load than is furnished by the source. Therefore a diode cannot be used to amplify an a.c. signal, for the voltage developed across the load will always be smaller than the signal itself.

The triode, however, *can* be used to amplify a signal. With this tube, *the signal is used to CONTROL the voltage furnished to a load by a separate power source*, and even a very small signal can be made to control a considerable voltage. This action is obtained by applying the signal voltage between the cathode and an additional element within the tube.

HOW THE GRID WORKS

This new element is called a grid, and, as its name implies, is of open construction. This grid may be a spiral wire with large spaces between the turns, or it may be a wire mesh something like a window screen. Several typical grid constructions are shown in Fig. *13*. Since the grid is an alternate "wire and space" affair, the grid symbol on a schematic diagram is usually like that shown in *13D*, although some engineers use the *13E* symbol.

The grid is positioned closer to the cathode than it is to the plate. (This spacing is not shown on schematic diagrams because the same symbol is used for all triodes, regardless of the actual spacing.) Before studying how amplification is obtained, let us see how the grid can control the plate current. We will apply different voltages to this grid and see what happens.

Zero Grid Voltage. Suppose we first connect the grid to the cathode as shown in Fig. *14*. Connected directly by a wire this way, these two elements have no voltage between them.

If we apply a normal plate voltage from battery *B* between the plate and cathode, we will get an electron flow, and this new element will have very little to do with it. The electrons are pulled along by the positive plate potential and only those moving directly toward a grid wire will strike it and either be deflected or captured. Those electrons traveling toward the *spaces* between the grid wires will go right through these spaces and on to the plate.

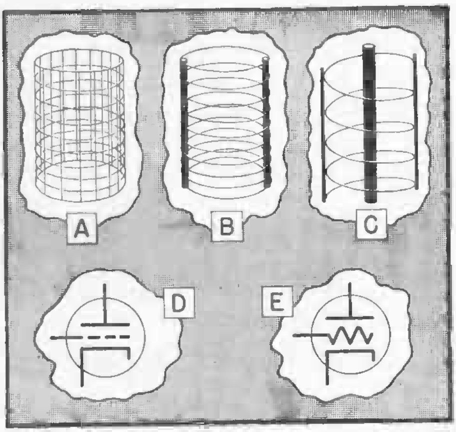

FIG. 13. Different grid structures and the symbols used to represent the grid element.

Positive Grid Voltage. Suppose we now put a small battery in the grid circuit, between the grid and cathode, as shown in Fig. *15*. You will recall that the attracting power of the plate on an electron depends both on the plate voltage and on the distance between the plate and the electron, and this attracting power is greater the closer together the plate and electron are. Exactly the same thing is true of the grid; it, too, has a greater attracting power on an electron the closer it is to the electron. Since the grid is so much closer to the source of electrons (the cathode) than the plate is, naturally the grid has far more effect on electrons emitted from the cathode than the plate has if we apply equal voltages to both the grid and plate. As a matter of fact, the difference in effect is so great that we can apply a far larger voltage to the plate than to the grid, and still the grid will have more influence over the emitted electrons. Thus, the grid in Fig. *15* will attract a great many electrons from the cathode—many more than the plate does.

If the grid were a solid plate, it would capture all of the electrons it attracts toward itself and there would be a large current in the grid-cathode circuit. However, the open grid construction prevents this; again, only those electrons which happen to strike the grid wires are captured. The others tend to go in straight lines at high speed right through the spaces between the grid wires. Once well past the grid, they come under the influence of the plate, which then collects them.

This means that *when the grid is made slightly positive, it increases the number of electrons which go to the plate.*

As the grid is made more and more positive, the plate current increases further. However, as the grid becomes increasingly more positive, it attracts more and more electrons to itself. Eventually, it would begin to rob the plate of electrons, so there is a limit to the amount of increase in plate current which we can get by making the grid positive.

Negative Grid Voltage. Now suppose we reverse the potential on the grid, making it negative (see Fig. *16*).

The grid will now repel electrons. If the negative voltage is high enough, all electron movement between the cathode and plate will be stopped; or, if the grid is made only slightly negative, the plate current will be decreased.

You can see, then, *that a voltage applied to the grid element will control or vary the plate current.* If the grid is made negative, the current decreases, while a positive grid causes a current increase. Should we apply an a.c. signal voltage between the grid and cathode, the alternate positive and negative half-cycles will produce up-and-down variations in the plate current—up when the grid is positive, down when it is negative.

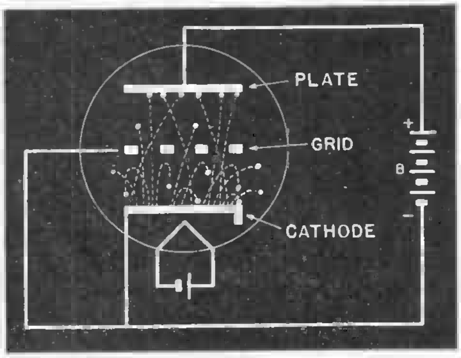

FIG. 14. **With no grid bias, an average number of electrons flow to the plate, while the rest form the space charge between the cathode and the grid.**

▶ However, we're not looking for plate current variations: what we want is an amplified signal voltage. And we can get it very simply just by connecting a "load" R_L in the plate circuit, as shown in Fig. *17*. The varying plate current then flows through resistor R_L, and the resulting voltage drop across R_L of course varies in exactly the same way as does current—which, in turn, varies in exactly the same way as does signal voltage on the grid. *Thus, each variation in the grid signal voltage causes a similar variation in the voltage drop across R_L.* In other words, the signal voltage fed to the grid is *reproduced as a similar signal voltage across R_L.*

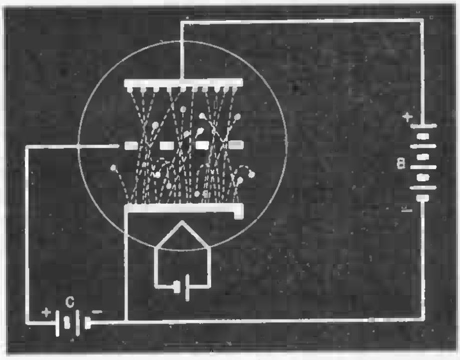

FIG. 15. **Making the grid positive greatly increases the number of electrons moving to the plate.**

▶ Notice—only a *reproduction* of the grid voltage, *not the grid voltage itself,* appears across R_L. *Always keep this point firmly in mind.* The grid voltage merely changes the plate current—*it is the changing plate current which causes the signal voltage to be reproduced across plate load R_L.*

The source of the plate current is, of course, the *B* supply—either a *B* battery or an a.c. operated power pack. None of the plate current comes from the signal source. All that the grid

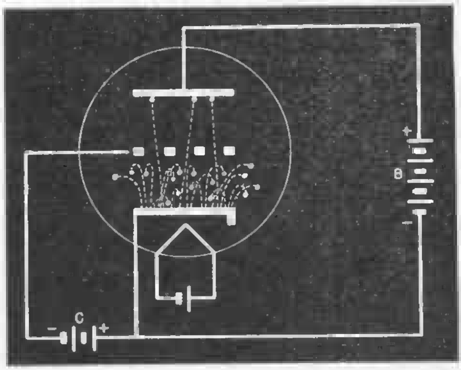

FIG. 16. **A negative grid bias reduces the plate current.**

signal does is *control* the flow of current from the *B* supply through the tube. You may find it easier to remember this action if you consider the grid to be a kind of "electrical valve" which controls the flow of plate current, but has nothing to do with supplying the plate current. (In fact, British technicians call tubes "valves" precisely because of this action.)

▶ Now, is this signal voltage developed across R_L the voltage we want? Remember, we started out with the idea of somehow using a tube to amplify a small signal voltage—that is, we wanted to produce a voltage which would have the same general *form* as our signal voltage, but would be considerably greater in *size*.

We know that the voltage across R_L has the same form as the signal voltage fed to the grid—it goes up when the grid voltage goes up, down when the grid voltage goes down. The only question is whether the voltage across R_L is bigger than the signal voltage. As you know from Ohm's Law, the voltage drop across R_L is equal to the current flowing through it (the plate current) times its resistance, or $E = I \times R_L$. This equation shows us that if R_L is large, even a fairly small plate current through it will produce a large voltage drop across it. And, by the same token, a fairly small *change* in plate current will produce a large *change* in the voltage drop across R_L.

Now, you learned a little earlier that the grid voltage is very effective in controlling the plate current: in other words, even a small change in grid voltage will produce a considerable change in plate current. And from what we said in the preceding paragraph, this change in plate current will produce a large voltage change across R_L (provided the resistance of R_L is large). Thus, a small signal voltage change fed to the grid will produce a large signal voltage change across R_L—so we have the *amplified signal voltage* we want.

▶ Where does this amplified signal voltage come from? Obviously, it is supplied by the only voltage source in the plate circuit—the *B* supply voltage. The grid voltage therefore controls the amount of the *B* supply voltage which is developed across load resistor R_L. This means that the maximum signal voltage variation we can get across R_L is equal to the total voltage furnished by the *B* supply. (Actually, we can never get this much of a variation, since a considerable amount of the *B* supply voltage is dropped across the tube itself.)

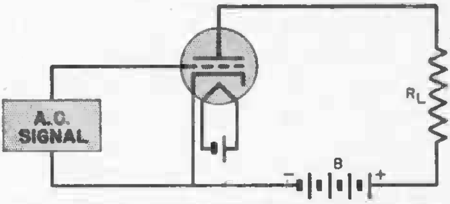

FIG. 17. The positive and negative alternations of the a. c. signal cause the plate current to vary up and down, producing a similar variation in the voltage across R_L.

THE E_g—I_p CURVE

There are limits which must be placed on the operation of triode tubes. For one thing, the amount of signal which can be applied to the grid is limited; if too much is applied, the resulting changes in the plate current will not be exact "carbon copies" of the applied signal. We then say that the tube is "distorting" the signal. Of course, we do not have to worry about this when handling small signals, but, after several stages of amplification, the signal is built up to such proportions that tubes capable of handling large grid voltage variations must be used.

To understand these limits better,

let us study a curve showing the relationships between the grid voltage and the plate current. This curve is called the grid voltage-plate current curve or the "grid-plate characteristic" curve. Radiomen generally abbreviate these terms to E_g—I_p curve or E_g—I_p characteristic.

The typical E_g—I_p curve shown in Fig. *18* has a shape similar to that of the other curves we have studied. However, we have both positive and negative values of grid voltage, so we must insert the vertical line *o-x*, representing zero grid voltage (the grid connected to the cathode with no voltage between these elements). Then, the distance along the horizontal line to the left of line *o-x* represents increasingly negative grid voltage values, while the distance to the right represents positive values.

Let us start with a highly negative grid voltage, applied in the manner shown in Fig. *16*. We represent this voltage by the distance from the *o-x* line to point *A* in Fig. *18*. With this grid voltage, there is no plate current flowing.

Now, suppose we gradually reduce this negative voltage. When we get to the value represented by point *B* plate current will begin to flow (indicated by the fact that the curve begins here). Point *B* is known as the cut-off point, because it represents the negative grid voltage which cancels the effects of the plate voltage at the cathode. Any grid voltage more negative than this will cut off the plate current.

As we reduce the negative voltage further, the plate current increases. After getting past the bend or "knee" of the curve at point *C*, the plate current increases almost in step with the grid voltage change, causing the curve to be nearly a straight line between *C* and *D*. Then, when we pass the zero grid bias line *o-x* and make the grid increasingly more positive, we find the curve begins to flatten out toward *E*.

At the same time, as the grid is made increasingly more positive, grid current has begun to flow (shown by the dotted line). The positive grid is attracting electrons to itself. The grid current increases as the grid is made more positive; in effect, the grid robs the electron stream and thus reduces the number of electrons which we might expect to go to the plate.

Usually we do not desire grid current flow at all and do not desire to have the tube operate on any curved part of its characteristic when we are trying to amplify. (As we shall learn later, a curved tube characteristic will cause distortion.)

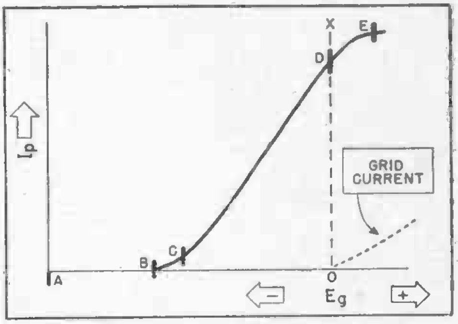

FIG. 18. This Eg—Ip curve is very important. It shows how the plate current varies with different grid voltage values.

Grid Bias. To avoid grid current, the grid is kept negative at all times by a d.c. voltage connected between the grid and cathode in the manner shown in Fig. *19*. (This voltage, commonly called a *C* voltage, is shown being furnished by a battery *C* in this figure, but other sources—which you will learn about later—are often used.) The value of this *C* voltage is chosen so that it causes the tube to operate somewhere near the middle of the straight portion of its E_g—I_p characteristic (point *F* in Fig. *20*). This fixed grid voltage is called a *bias* voltage, a name which comes from the fact that it *influences* or *controls* the initial operating plate current. For example, a bias voltage which makes the tube operate at point *F* on the characteristic in Fig. *20* sets the initial plate current at the value *M*.

After the point at which the tube operates on its characteristic has been set by applying a bias voltage, we can then apply an a.c. signal voltage to the grid. This a.c. voltage alternately adds to, and subtracts from, the grid bias voltage—that is, instead of the grid swinging negative and positive, it becomes alternately more negative and less negative.

▶For example, if the bias voltage is —10 volts, and we apply an a.c. signal having a peak value of 5 volts, then the grid voltage will change alternately from —5 to —15 volts. The grid voltage will be a pulsating d.c. voltage, since it will be a mixture of d.c. and a.c.

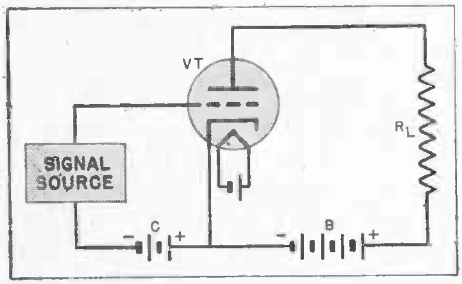

FIG. 19. Grid current flow is prevented by a negative bias.

As Fig. *21* shows, these changes in grid voltage cause alternate increases and decreases in the plate current, just as any a.c. signal would. In this figure, point *F* represents the operating point of the tube as set by the bias voltage. When the grid voltage is varied by the a.c. signal represented by *1-2-3-4-5-6*, the operating point must follow the instantaneous grid voltage up and down the operating curve between points *F*, *C* and *D*. Thus, when the grid bias is reduced by the signal swing from *1* to *2*, the grid is made less negative, so that the operating point moves *F* to *D*, permitting an increase in plate current from *7* to *8*. Similarly, during the swing from *2* to *3*, the grid is made more negative, so that the operating point moves from *D* to *C*, resulting in the plate current falling from *8* to *9*. Similarly, as the signal voltage moves from *3* to *4* to *5* to *6*, the plate current varies from *9* to *10* to *11* to *12*. Hence, the a.c. grid voltage *1-2-3-4-5-6* produces the plate current variation *7-8-9-10-11-12*.*

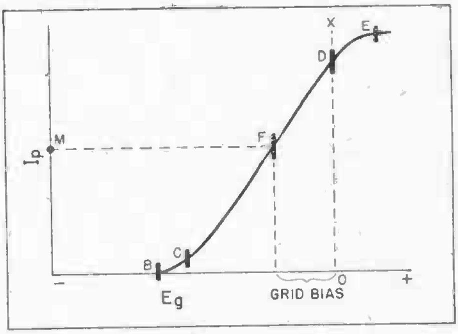

FIG. 20. Point F is the operating point, which is fixed by the bias voltage.

▶ Should the bias voltage change during operation, then the plate current would be forced to follow this change, producing variations which are not caused by the original signal. The bias supply must therefore furnish a steady d.c. voltage so that variations in the plate current will be caused only by the signal voltage.

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* A special data sheet on graphs will come to you with your graded answers for this lesson. This extra information was prepared as a part of the NRI Consultation Service, and there is no charge for it. This data sheet should be read carefully, as we feel its information will be particularly helpful with future lessons. However, remember that you don't have to draw graphs; you are expected only to be able to read them.

▶ Furthermore, the signal must not *exceed* the bias, because if it does, it can force the grid to become positive or can force the tube to operate over a curved section of its characteristic. Also, the bias must place the operating point properly on the straight portion of the characteristic curve.

As long as the tube operates along the straight-line portion of its characteristic curve, and as long as the a.c. voltage applied to the grid is not large enough to make the grid positive at any time, the plate current variation will be exactly like the grid voltage variation and will therefore produce voltage across the load resistor which is similar in form to the grid signal voltage. However, too high a signal voltage or operation over a curved portion of the characteristic will result in distortion. For example, in Fig. *22*, the grid bias is too highly negative, so the operating point *M* is too near the lower bend of the curve. The curvature of the tube characteristic causes the bottoms of the plate current pulses to be chopped off, so the curve *A-B-C-D-E-F-G* is distorted (that is, it is not the same shape as the grid signal). For perfect reproduction of the grid signal, the plate current pulses would have to follow the curve *A-B-H-D-I-F-J*.

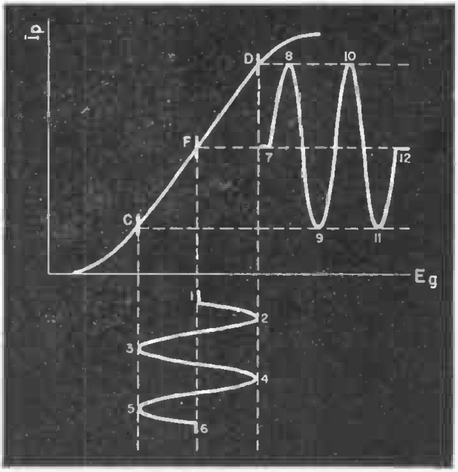


FIG. 21. The manner in which the grid signal variations increase and decrease the plate current is shown here.

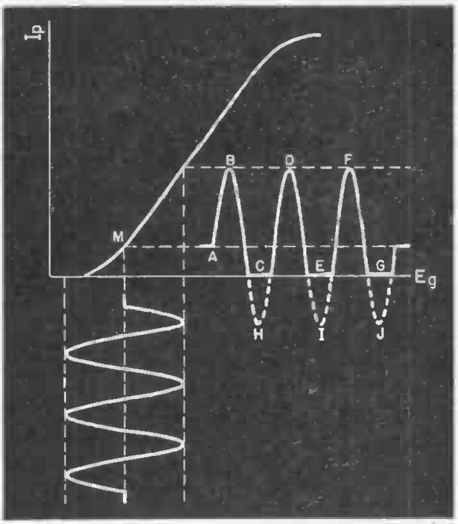


FIG. 22. If the operating point moves too far down on the curve, the plate current variations do not duplicate the entire signal.

THE TUBE AS A RESISTANCE

From what we've said about triodes, you can see that the *kind* of voltage we apply to a grid makes a vast difference in the performance and usefulness of a tube. If we apply only d.c. voltage (that is, bias voltage) to the grid, then the tube merely allows a d.c. plate current to pass through its plate circuit. A tube used under such conditions is nothing more than a resistor which limits the amount of d.c. flow from the *B* supply. When no a.c. signal is involved, we call the tube resistance its d.c. resistance. If we put a load resistor in the plate circuit, part of the voltage developed by the *B* supply will be dropped across the tube, the rest will be dropped across the load resistor. We can change the amount of current flow through the tube by changing the value of the bias voltage. The relative amounts of the battery voltage which are dropped across the tube and across the load resistor will change then.

If we increase the plate current, there will be a larger IR drop across the load resistor, and therefore a smaller drop across the tube. If we decrease the plate current, the IR drop across the load resistor will also decrease, and more of the *B* supply voltage will be dropped across the tube. In effect, a *triode* tube acts like a *variable* resistor, whose resistance we can change by changing the grid voltage. This is one way of looking at a tube—considering it as a variable resistor in series with a load resistor and a *B* supply. The resistance varies according to the signal variations, thus reproducing similar variations in the load voltage.

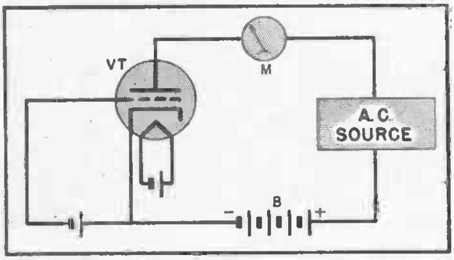


FIG. 23. Inserting an a. c. voltage in the plate circuit causes an a. c. variation in the plate current. The meter M measures only the a. c. portion of the current here.

Unfortunately, such a picture of tube operation leads into difficulties when we try to calculate the *amount* of resistance variation, as this is a quite different value from the *d.c. plate resistance*. For this reason, we use another method of representing the a.c. operation of a tube, which can be used to compute the amount of a.c. voltage produced across a plate load resistor. This representation is called the "equivalent tube circuit." But before we go into it, we must learn the meaning of two useful new terms—*a.c. plate resistance* and *amplification factor*—which are always part of any discussion of the a.c. operation of a tube.

A.C. Plate Resistance. The a.c. plate resistance is the opposition which a tube offers to the passage of a.c. through it. It can be measured with a circuit like that shown in Fig. *23*. In this circuit, we first apply normal voltages to the filament, grid, and plate of the tube, then add a known a.c. voltage to the d.c. voltage which is already applied to the plate. The addition of the a.c. to the d.c. plate voltage makes the total voltage applied to the plate alternately larger and smaller, which in turn makes the plate current alternately larger and smaller. The plate current, in other words, becomes a pulsating direct current—which, as you know, is a steady direct current to which an alternating current has been added. We can measure the a.c. part of the plate current with the a.c. meter *M*.

Next, we divide the amount of a.c. voltage applied to the plate by the amount of a.c. plate current produced. This gives us the *a.c. plate resistance* of the tube—the opposition which the tube offers to the flow of a.c. through it. (This is NOT the same value as the d.c. plate resistance of a tube, which is what we would get if we divided the d.c. voltage applied to the plate by the d.c. plate current. D.C. plate resistance is very seldom mentioned in radio work.)

Whenever you see the term "plate resistance" or the symbol r_p (sometimes R_P) used—in a tube chart, for example—you can be sure that a.c. plate resistance is meant.

This a.c. resistance will change if the filament voltage, the d.c. grid voltage, or the d.c. plate voltage is varied, so each of these voltages must be specified when we state the a.c. plate resistance of a tube. This is done in listings of tube characteristics in tube charts. The values of voltages given in these listings are generally those which would be used in some typical application of the tube concerned.

Amplification Factor. We have just seen that an a.c. voltage introduced in the plate circuit will cause an a.c. plate current, and we learned earlier in this lesson that an a.c. grid voltage will likewise cause an a.c. plate current. (In each case, of course, the a.c. plate current produced is mixed with the d.c. plate current which the *B* supply and the d.c. bias cause to flow, so the total plate current flow is a pulsating d.c.)

▶ One thing further we have learned: A grid voltage is more effective in controlling the flow of plate current than is an equal plate voltage. But—we still have not learned any way of telling *how much* more effective the grid voltage is. That is what the *amplification factor* of a tube tells us.

We could find the amplification factor of a tube with a circuit like that in Fig. *24*. First, we would turn off the a.c. source in the plate circuit, then apply a known a.c. voltage to the grid and measure (with a.c. meter *M*) the a.c plate current produced. Next, we would turn off the a.c source in the grid circuit, and would turn on the a.c. source in the plate circuit. We would adjust this a.c. plate voltage until we got the same a.c. plate current as the grid produced. Finally, we would divide the value of this a.c. plate voltage by the value of the a.c. grid voltage we used. The answer would be the *amplification factor* of the tube.

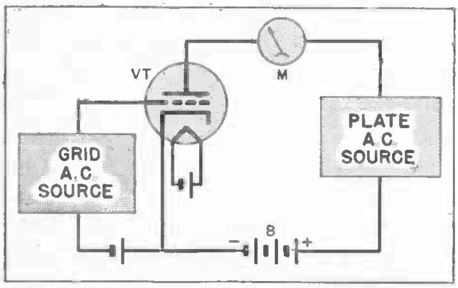


FIG. 24. The amplifying ability of the tube can be determined with this circuit.

Thus, we can define the amplification factor of a tube as the ratio of the *a.c. plate voltage* to the *a.c grid voltage* necessary to produce the *same* a.c. plate current. This gives the relative effectiveness of the plate and grid voltages. For example, if we find that an a.c. voltage of 10 volts in the plate circuit is needed to produce as much a.c. plate current as an a.c. voltage of 1 volt in the grid circuit will produce, the amplification factor of the tube is 10 ($\frac{10}{1} = 10$). In other words, the grid voltage is ten times as effective as the plate voltage in controlling the plate current. (The amplification factor is assigned the symbol "μ," the Greek letter "mu," pronounced "mew.")

The amplification factor of a tube depends upon the physical structure of the tube—the relative spacing of the grid to cathode, compared to the plate-to-cathode spacing, and the actual grid structure. It is therefore relatively constant as long as the tube is not damaged in any way that would jar the elements from their proper positions.

Equivalent Tube Circuit. Now that we know what a.c. plate resistance (R_P) and amplification factor (μ) mean, we are ready to take up the equivalent tube circuit which is so helpful when we want to learn what a.c. output to expect from a tube. This circuit is shown in Fig. *25*. It is called an equivalent circuit because, *as far as a.c. is concerned*, it behaves just like a tube connected to a load. In other words, we transfer to the plate circuit an a.c. signal *equivalent* to an amplified grid voltage, then consider *only* the *a.c.* resistance of the tube.

Notice—in this circuit we replace the tube by an a.c. generator and a series resistor, and connect these two across the load R_L. The generator has a voltage output equal to μ times e_g (e_g is the a.c. grid signal voltage) and the series resistor has the value R_P. The fact that these two elements are the equivalent of a tube (as far as a.c. is concerned) illustrates two important things: 1, that the *total a.c. signal voltage* produced in the plate circuit is equal to the *grid signal voltage* multiplied by the *amplification factor* of the tube; and 2, that part of this plate circuit signal voltage is always dropped *within the tube* across the a.c. plate resistance of the tube.

You can see at once why it is important to know the μ and R_P of an amplifier tube. The amplification factor μ tells us immediately how much the tube amplifies the grid signal. If a tube has a μ of 10, then the total signal voltage produced in the plate circuit will be 10 times the signal voltage fed to the grid.

The a.c. plate resistance R_P lets us determine how much of this amplified signal we can actually use. As you see from Fig. *25*, R_P and the load resistance R_L form a voltage divider. Part of the amplified signal voltage is dropped *within* the tube, across R_P; the rest of it is dropped *outside* the tube, across R_L. Naturally, the only part of the signal voltage that is useful to us is the part dropped across R_L, because this is the only voltage we can feed into another circuit. The signal voltage dropped inside the tube (across R_P) is wasted; the power it develops is dissipated in heating the plate.

▶ Naturally, then, the value of load resistor R_L is very important in deciding how much *useful* amplification of the signal voltage we will get. If R_L is zero, we will get no useful amplification at all; if it is very much larger than R_P, we will get a useful amplification almost as large as the μ of the tube. To distinguish between the *useful signal amplification we get out of a tube circuit* and the total signal amplification (μ), we call the former the *stage gain.* The stage gain is always, of course, less than the μ of the tube: in fact, it is equal to μ times the ratio of the plate load to the sum of the plate load and the a.c. plate resistance. Or, in equation form,

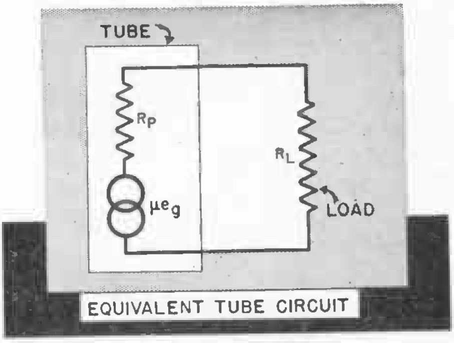


FIG. 25. The tube plate resistance and the load divide the a. c. voltage according to their values.

$$\text{Stage gain} = \mu \times \frac{R_L}{R_L + R_P}$$

This equation again shows us that the larger R_L is with respect to R_P, the greater the useful signal voltage amplification we can get out of the tube circuit. However, there are practical limits to the value of R_L; a value five to ten times the plate resistance gives about all the voltage gain possible under normal conditions. We will study this problem more when we take up amplifying stages.

▶ While on this subject, we might mention that sometimes maximum *voltage gain* may not be as desirable as maximum *power output*. For example, it takes *power* to operate a loudspeaker; transmitters depend on power increases from stage to stage, etc. As we shall learn in a later lesson, power requirements affect the value of the load chosen and the tube design.

Remember—this *equivalent tube circuit applies only to the a.c. signal-amplifying operation of the tube.* It has nothing to do with the d.c. voltages as applied to the tube (except that these voltages partially determine the R_P—and, in some special tubes, the μ—of the tube). You will meet the equivalent tube circuit many times more, both in your N.R.I. Course and in the literature of the Radio profession, because it is the most direct way to determine stage gain.

Multi-Element Tubes

We could make up any radio circuit with only the diode and triode tubes we have so far discussed. It would be impractical to do so, however, because many other types of tubes have been developed which are far more efficient for some radio uses than are diodes and triodes. We'll describe these other types briefly now, to give you an idea of their operations and uses; you'll learn all about them in later lessons of your Course.

SCREEN GRID TUBES

One important drawback of a triode, when used for radio frequency amplification, is the capacity between the grid and plate elements of the tube. These elements are conductors, separated by a dielectric (the vacuum), so that they make up a capacity (see Fig. 26). As you will learn in a later lesson, an undesirable feedback of energy occurs through this capacitive path, which causes r.f. amplifiers to become useless unless special circuits are used to cancel the effects of the feedback.

Tube manufacturers decided to improve the tube itself to eliminate this effect as much as possible. They brought out the screen grid or tetrode (four-element) tube, which has another grid located between the original grid and the plate, as shown in Fig. 27. To distinguish between these grids, the original triode grid is now called the control grid, while the second is called the screen grid. In structure, the two grids are somewhat similar.

The addition of the screen grid causes an enormous decrease in the capacity between the control grid and the plate, and so almost eliminates the undesirable feedback. (Later lessons will explain how this is accomplished.)

A positive voltage (with respect to the cathode) is always placed on the screen grid; this voltage is usually somewhere between half and full plate voltage. Since the screen is considerably closer to the cathode than the plate is, its voltage has far more effect on the electron stream than the plate voltage has. In other words, *the screen grid voltage and the control grid voltage are the important factors which determine how many electrons pass through the tube.* The plate voltage acts principally to collect the electrons pulled through the tube by the screen grid voltage, and does not have a great deal of effect on the number of electrons pulled through. In fact, if we keep the control grid and screen grid voltages steady, we can vary the plate voltage considerably without changing the plate current much.

Amplification. You will recall that the amplification factor of a tube is the ratio of the effectiveness of the grid voltage to the effectiveness of the plate voltage in controlling the plate current. In a screen grid tube, the control grid voltage is just about as effective in controlling the plate current as it is in a triode, but, as we have just seen, the effectiveness of the plate voltage is considerably reduced. This means, therefore, that the amplification factor of a screen grid tube is much larger than the amplification factor of a triode. Actually, the screen grid tube may have a μ between 100 and 600—while most triodes have a μ of 10 or less.

▶ However, as you learned in your study of the equivalent tube circuit, the amplified signal (μe_g) is divided between the tube a.c. plate resistance and the load resistance. The screen grid tube, unfortunately, has an extremely high plate resistance. In fact, it is not usually possible to bring the load resistance anywhere near the plate resistance value, so the useful amplification (stage gain) of a tetrode is considerably less than its amplification factor. Even so, a stage gain of 100 is not impossible, which is certainly a much higher stage gain than any triode can give.

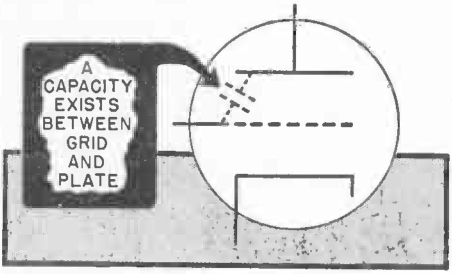


FIG. 26. The grid-to-plate capacity is troublesome in many applications.

PENTODE TUBES

The screen grid tube has the important advantages over a triode of having negligible grid-to-plate capacity and far higher gain. However, it has disadvantages when handling large signals.

Because the screen grid (which accelerates or speeds up the electrons in their journey toward the plate) is fairly close to the cathode and has a high voltage, electrons travel much faster in a tetrode than they do in a triode. As a result, when they strike the plate, there is a much greater tendency for these speeding electrons to knock other electrons loose from the plate. This effect is known as *secondary emission.*

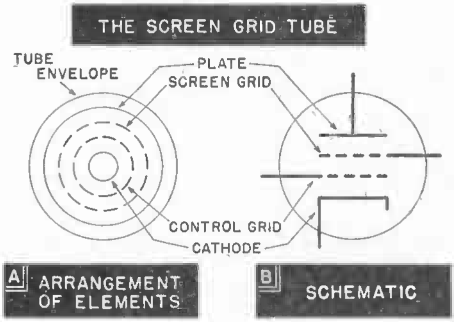


FIG. 27. The screen grid reduces the grid-to-plate capacity.

These secondary emission electrons fly off the plate. Many are attracted right back to the plate by its highly positive potential, but some go from the plate to the screen grid, which is also positive. This produces an undesirable current flow within the tube, and produces serious distortion if left unchecked. The effect is particularly noticeable as larger signals are being handled.

The *pentode* (five-element) tube shown in Fig. *28* solves this problem neatly. This tube has a third grid (a relatively coarse one, with only a few turns of wire) inserted between the screen grid and the plate. This new grid is usually connected directly to the cathode, and is at the cathode potential—that is, it is negative with respect to the screen grid and the plate. This new grid is called a suppressor grid (or sometimes a cathode grid, because it is connected to the cathode).

The operation of the tube is somewhat similar to that of the screen grid tube, in that the screen grid speeds up the electrons toward the plate. However, the suppressor grid, which is at cathode potential, slows down the electrons somewhat when they have passed the screen grid; it also reduces the velocity with which they hit the plate. (Because the suppressor is so coarse in structure, it does not interfere with the number of electrons passing through the screen to the plate.) Even so, some electrons strike the plate with sufficient velocity to knock out others, which then move into the space between the suppressor grid and plate. There they are subjected to two forces—the repelling force of the negative (cathode potential) suppressor grid and the attracting force of the positive plate. This double force makes practically all of them return at once to the plate.

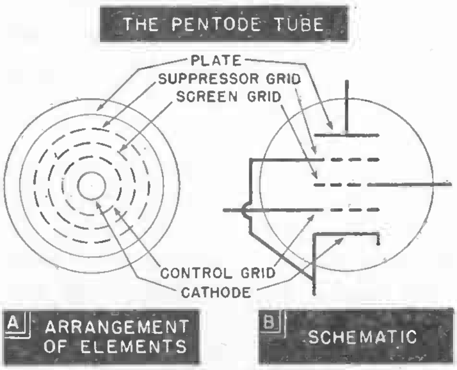
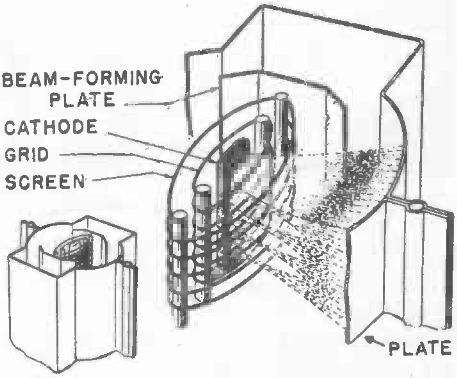


FIG. 28. The extra grid in the pentode tube reduces the effects of secondary emission.

BEAM TUBES

The *beam power tube* is another ingenious solution to this problem of secondary emission electrons. In effect, the electrons are made to act as their own suppressor grid. As Fig. *29* shows, a beam power tube has two small additional plates between the screen grid and plate. These small plates are connected to the cathode just like a suppressor grid, and so repel electrons. This forces the electrons to "bunch up" in the space between these plates and flow in two concentrated streams or "beams" between the cathode and the true plate.



Courtesy R.C.A. Mfg. Co., Inc.

FIG. 29. The electron "beam" provides its own suppression, forcing secondary emission electrons back to the plate.

This concentrated electron flow prevents secondary emission electrons from reaching the screen grid, because any secondary electrons emitted from the plate immediately encounter the electron beams and are repelled back to the plate.

SPECIAL TUBES

The *pentagrid converter* (shown schematically in Fig. *30*) is an example of a tube designed for a special purpose. The tube gets its name from the fact that it has five grids (*penta* means five), and is used as a frequency converter tube. We'll go into details of its use in later lessons. Obviously, however, with all these grids we can get many different controlling actions on the plate current.

▶ In the early days of radio, the amplification of a single tube was quite limited, so the only way of getting more amplification was to have more tubes. As a hang-over from those early days, many people still believe that the more tubes, the better the radio. This has resulted in radio manufacturers at times using separate tubes, when they could have lowered costs somewhat by using one or more of the dual tubes available.

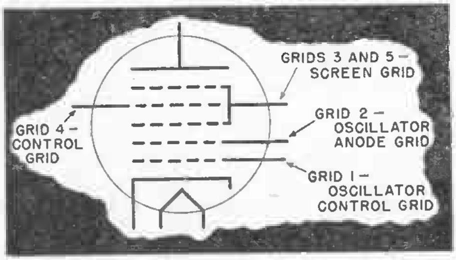


FIG. 30. A pentagrid converter tube.

▶ For example, there are many applications which require the use of two diode tubes in the same circuit. It is logical to place both these diodes in a single bulb. Naturally, since a dual tube of this kind needs only a single bulb and a single base, it is somewhat cheaper than two single tubes and permits the use of a smaller chassis.

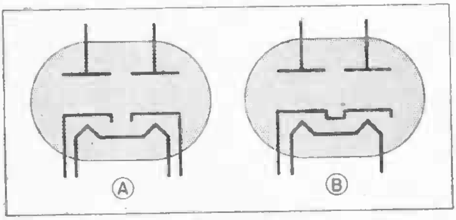


FIG. 31. Dual diodes.

The schematic symbols for typical dual diodes (double diodes) are shown in Fig. *31*. Some applications require separate cathodes as shown in Fig. *31A*, while others permit combining the cathodes as shown in Fig. *31B*.

▶ Another popular combination is that of the diode and triode tubes. The detector in most modern radios is a diode tube. Its output feeds into an audio tube, which is usually a triode. Another diode is desirable at the same point in the circuit for control purposes, so very often all three are combined in modern radios into one dual diode-triode tube. Fig. *32* shows the schematic symbol for this tube. The same cathode is used for the triode and for the two diodes.

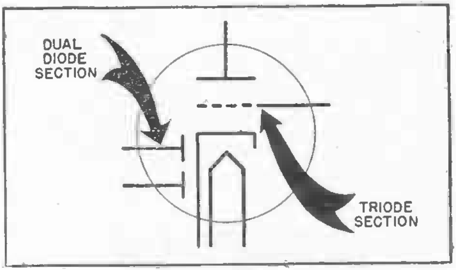


FIG. 32. Two diodes and a triode in a single envelope.

▶ Other similar combinations have been made. You will sometimes find together two triodes, a triode and pentode, two diodes and a pentode, and other similar combinations. Although these combination tubes are mounted in the same envelope, each section is generally independent of the others (except that they sometimes use the same cathode). You can always consider them to be separate tubes as far as circuit operation is concerned. We'll take up all these special tube types as we come to their uses in later lessons.

Special Purpose Tubes

There are other tubes designed for special purposes. Let's treat them briefly here, so you'll be familiar with their construction.

GAS FILLED TUBES

So far, we have been speaking entirely of vacuum tubes, which have as much air and gases removed as is economically possible or desirable. In a vacuum type tube, we do not want any gas ions to interfere with the electron movement. However, there is a special class of tubes, particularly diodes and triodes, in which a certain amount of gas is deliberately introduced.

These tubes are manufactured and the gases are evacuated in the same way as the ordinary vacuum tubes. Then, a definite, controlled amount of some particular gas is introduced in the tube to get some special action.

One result of this introduction of gas is a remarkable reduction in the plate resistance of the tube. When electrons move from the cathode to plate, they strike many of the relatively large gas molecules which are between the cathode and plate. The speed of the electrons is sufficient to knock other electrons out of these molecules. These extra electrons travel onward to the plate, along with the original electrons.

The heavy gas ions that remain are now positively charged (they have lost electrons). As a result, they move toward the cathode. When these positive ions get near the cathode, they combine with an equal number of the electrons in the electron cloud. If just the right amount of gas is used, practically all the electrons in the electron cloud will thus be removed from the cloud. In fact, the cloud will no longer exist, so all of the electrons leaving the cathode will go directly to the plate. This means a high plate current will be developed for a relatively low plate voltage.

Gas type diodes are found mostly in power supply systems, where their low plate resistance results in a smaller loss of power within the tube. The supply must be carefully designed to prevent the plate current from rising above a certain critical value, however, or too many heavy ions will be formed, with the result that the cathode surface will be bombarded by the heavy particles and the oxide coating knocked off.

▶ Gas type triodes find special uses in industrial control equipment. These tubes are designed so that the grid merely acts as a trigger, starting the plate current flow at a certain predetermined value of grid voltage and then losing all control of it. This particular action is very desirable for certain control purposes, making it possible for a low-power circuit to turn on a high-power circuit.

PHOTO-ELECTRIC CELLS

In the beginning of this lesson, we mentioned that the thermionic (heating) method was only one of the ways in which electrons could be released from a cathode. Another method is used in one type of photo-electric cell.

Certain rare earth metals have the property of releasing electrons from their surface when light falls on the surface. (This is called the "photo-electric effect.") If we use one of these metals as a tube cathode and expose it to light, electrons will escape from it. Then, if a positive element is nearby, we will get an electron flow from this photo-electric cathode to the positive element, just as in our thermionic diode tube. The amount of current depends on the number of electrons released, which in turn depends on the amount of light.

A typical photo-cell is shown in Fig. 33. The large "plate" is actually the cathode, as it is the surface on which light falls. As electrons are emitted from this surface, they travel to the thin wire, which is positively charged with respect to the cathode.

The photo-electric principle finds many uses in industrial control equipment. For example: Moving objects can interrupt a light beam shining on a photo-electric cell, thus momentarily cutting off the current through the cell and causing counting devices to operate.

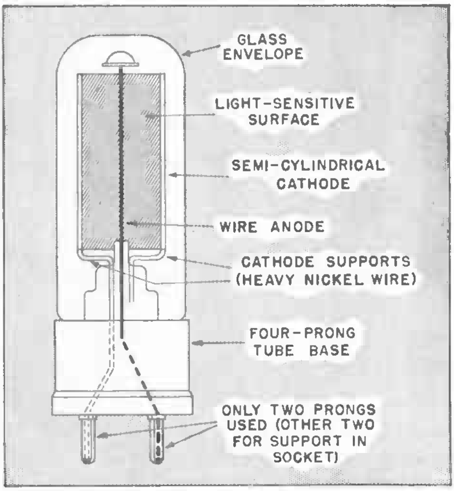


FIG. 33. A typical photoelectric cell.

▶ The television camera tube, used to pick up the image at the transmitter, is also a photo-electric device. There are many types of these tubes. One type is really a combination of thousands of miniature photo-electric cells mounted together on a plate. When exposed to a scene, the various photoelectric cells emit electrons according to the light values of the tiny segment of the scene to which each is exposed. It is possible to pick up these small charges with a scanning device and transmit them as elements of a television scene.

COLD-CATHODE TUBES

There have been several types of dual diodes (known as "cold-cathode" tubes because their cathodes are not heated) developed for power packs.

These tubes are gas-filled. When the plate element is sufficiently positive with respect to the cathode, the gas will ionize, as electrons will be pulled out of the gas molecules toward the plate. Then, the heavy positive ions will bombard the cathode surface and knock electrons loose to replace those taken from the gas by the plate. The gas molecules thus re-form (become un-ionized) and the action repeats itself continuously as long as the proper potentials are maintained between the plate and cathode.

This action is reversible, since reversing the applied voltage would cause the plate and cathode to be interchanged. If it is desired to use such a tube as a rectifier (in which current flows only one way), one surface can be treated to release electrons more readily than the other, or the element intended to be the cathode can have a far larger surface area than the plate. This makes the tube conduct better one way than the other. Rectification is not perfect, as some current can still flow in the reverse direction, but it is satisfactory for some applications.

Tube Classification Systems

There are hundreds of different vacuum tubes, so it is absolutely necessary to have some means of telling them apart. Of course, one obvious difference between tubes is the number of elements in the tube. Hence, we have diodes, triodes, tetrodes, pentodes, and others. However, these classifications are too broad to be very useful in telling tubes apart, for there are many tubes of each of these types which differ in voltage requirements and other characteristics.

Thus, we have triode tubes with low-amplification factors and triode tubes with high amplification factors. There are kinds of low-amplification tubes which differ greatly in plate resistance and in the voltages required on the filaments and other elements. Similarly, high amplification triodes are made in models requiring many different filament, grid, and plate voltages. Some of these tubes are intended to operate only from battery supplies, while others will operate with a.c. on the filament.

Furthermore, tubes vary greatly in size. There are tiny tubes for hearing aids and super-portable receivers, medium size tubes for ordinary small receivers, and full size tubes for standard radio receivers. Naturally, the basic operation of the tube is not affected by its size. However, it frequently happens that a regular size tube will not fit into a radio designed to use small tubes.

Filament Voltages. Thermionic tubes may be classified according to the filament voltage which they are designed to use. Plate or grid voltages may be abnormal for a particular tube without immediate or great damage, but if the filament voltage is too high, the filament will burn out. It is important that the filament voltage requirements be met. However, many tubes use the same filament voltages, so classification by filament voltage is (like classification by number of elements) too broad to be very useful.

Use Classification. Tubes may be classified according to their use, or rather, according to the use for which they were originally designed. Thus we have rectifiers, detectors, mixers, oscillators, r.f. and a.f. amplifiers, and power amplifiers. Often, however, it is possible to use one tube for several different purposes, so a given tube may have two or more usage classifications.

▶ Some time ago it was decided that the simplest identification system was to assign each tube type a number and to list tubes by their numbers in charts or tables of tube characteristics. We shall go into this system shortly—but first, let's learn something about how tubes differ in outside appearance.

TUBE BASES AND SOCKETS

Unlike other devices used in radio and electronic apparatus, the radio tube is a delicate part giving limited hours of service. Most manufacturers of radio tubes guarantee their products for one thousand hours. While tubes in general give much longer service than this, it is not impossible for a tube filament to burn out during the first few hours of its use. For this very practical reason, tubes must be built in such a way that they can easily be removed for testing and replacing. Hence, radio receiving tubes have bases with prongs or pins which serve as the terminals of the tube elements. These bases plug into sockets having spring contacts which bear against the prongs when the tube is in the socket. The circuit wiring is connected to the socket contacts, and thus to the tube elements when a tube is plugged in.

It is, of course, necessary to make sure that a tube will fit into its socket in only one way, so that the socket contacts will always bear against the proper prongs. In older tubes, prongs of different sizes or different prong spacing arrangements were used to make the tubes fit just one way in sockets. Of course, this system means a different socket is necessary for each tube base type.

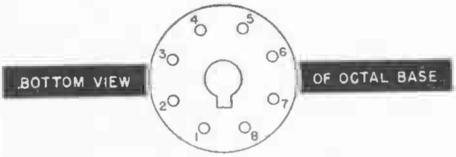


FIG. 34. The pin arrangement of an octal-based tube, which also corresponds to the bottom socket connections.

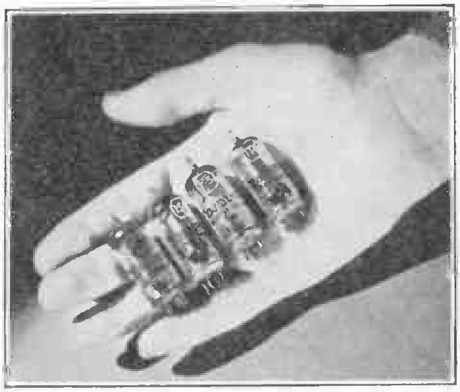
▶ Most modern tubes have "octal" bases which will fit a universal octal socket. All prongs on this base are the same size and are equally spaced. An aligning key in the center of the tube base fits a slot in the socket in only one way, thus assuring insertion of the tube in only one way.

Fig. *34* shows the prong arrangement of an octal base. This same base is used on diodes, triodes, pentodes, etc.; if any prong is unnecessary for a particular tube, it is simply left off. This does not affect the positions of the other prongs; if prong *6* in Fig. *34* is omitted, all other prongs will still remain in the same positions and will still be designated by the same numbers.

Fig. *35* shows typical tube bases of both the old and the octal types.

▶ Certain sets need tubes which will not easily loosen in their sockets. (Auto sets and portables are examples.) The "loctal" base is the answer to this. It is similar to the octal base except that the centering key has a ridge, shown in Fig. *36*, which snaps into a ring in the socket made of spring material and locks the tube in the socket. It is necessary to push a loctal-based tube sideways to release the key from the spring before it can be pulled out of the socket.

The prongs are exceptionally small on these tubes—really just projections of the connecting wires which come through the glass seal at the bottom of the tube. This eliminates the necessity for a tube base, as the glass seal positions the pins and the centering key is molded into the seal. These tubes offer advantages at ultra-high frequencies in that the elimination of the base reduces the amount of leakage at these frequencies. (Many materials are good insulators at low frequencies but become poor insulators at the frequencies used for television and f.m. broadcasting.)



Courtesy Emerson Radio & Phonograph Corp.

The relative size of miniature tubes is shown here—four are held in the palm of a hand.

▶ Hearing aids and the extremely small portables use miniature tubes, only ¾ inch in diameter and less than two inches high. Actually, these tubes have no true base; the glass-bulb bottom is flattened and has a ring of holes. The prongs (really just connecting wires, like those of a loctal tube) come through these holes, which are placed at the proper points to fit the socket.

Top Caps. The first tubes had all connections made at the base. However, when the need for reduced grid-to-plate capacity was recognized, tubes were developed with a terminal in the form of a metal cap at the top of the glass or metal envelope, in addition to the prongs or pins. Connecting the grid to the cap makes possible a maximum spacing (and therefore a minimum capacity) between the grid and plate leads. Connections are made to this cap (usually called the top cap or grid cap) by a top-cap clip. A flexible wire lead connects this clip directly to some part in the chassis of the radio apparatus; the clip must naturally be removed before the tube can be removed from its socket.

Single-Ended Tubes. The top cap connection is not too desirable from a mechanical standpoint, as loose connections frequently develop. Tube manufacturers discovered a means of eliminating the top cap without a great increase in the grid-plate capacity, so many tubes are now made with the control grid lead going to one of the prongs in the base. This is now possible because a special type of base construction is used to shield the electrode leads and prongs from each other and so reduce lead capacities. These tubes (called single-ended tubes because all connections are at the same end) permit all connections to be made underneath the chassis, simplifying the wiring and eliminating long leads through the chassis to the top cap. These tubes have either octal or loctal bases, so that they fit the corresponding socket.

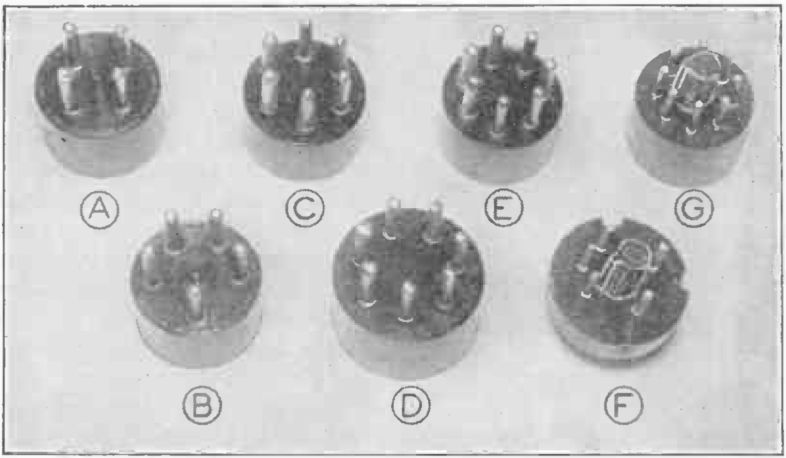


FIG. 35. Representative tube bases, showing standard prong arrangements A—a 4-prong base; B—a 5-prong base; C—a 6-prong base; D—a large 7-prong base; E—a small 7-prong base; F—an octal base having only 5-prongs; G—an octal base having all 8 prongs.

PRONG IDENTIFICATION

After base types and sizes of tubes were standardized, it became possible to number the prongs and socket clips

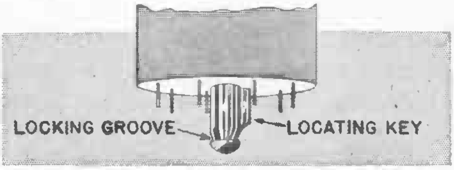


FIG. 36. The locking groove on a "loctal" base.

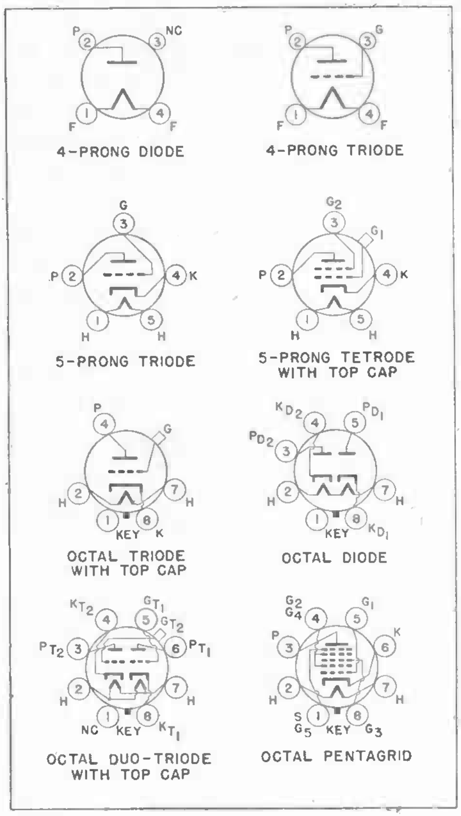


FIG. 37. These schematic symbols not only show which elements go to which prongs—they also show the relative positions of the prongs. Notice that the octal bases may not have a full set of 8 prongs but when prongs are missing, the others maintain their original spacing and numbers. These connections are correct when viewing the BOTTOM of the base or tube socket but are proper just for CERTAIN TUBES. Always consult a tube chart to determine the connections on tubes.

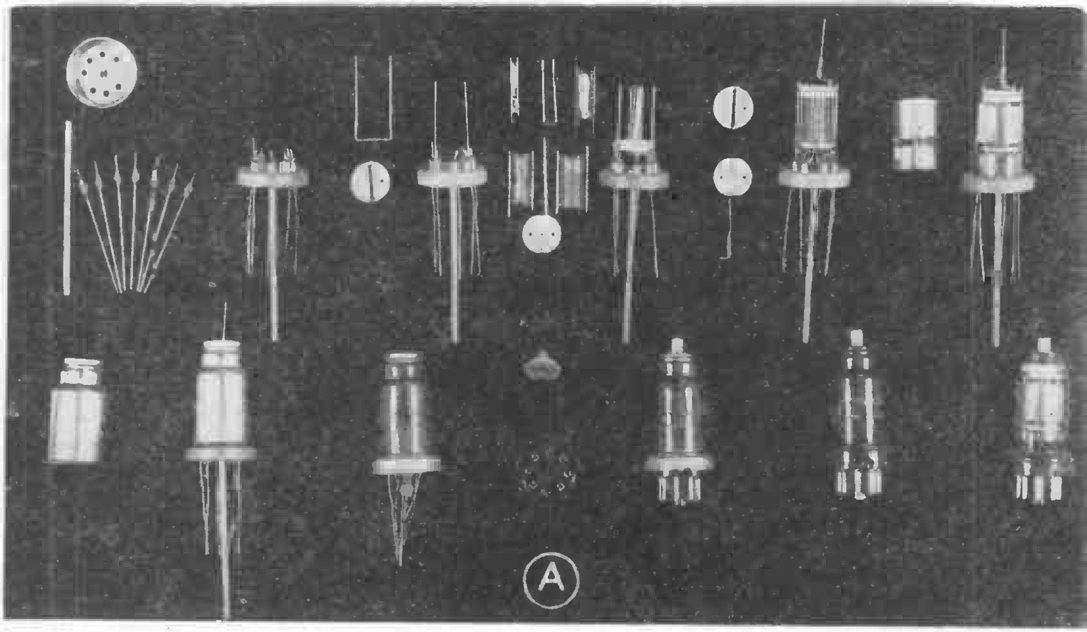
so as to identify the element connections. A standard system was developed by the Radio Manufacturers Association (R. M. A.) for this purpose. Looking at the bottom of the socket, the numbers progress *clockwise* around the socket. Examples showing the element connections for several tube types are shown in Fig. *37*. These numbers are in order when you look at the *bottom* of the socket, because this is the normal position for radio servicing.

Locating Filament Prongs. In 4, 6, and 7-prong tube standard bases, those two prongs having the highest and lowest numbers are made larger than the others, to insure that the tube is always inserted in its socket in the correct position. For example, pins 1 and 4 of a 4-prong tube would be larger than the others; these thicker prongs are always connected to the filament. In the standard 5-prong tube, all pins are of the same diameter but are so arranged that there is only one way of inserting the tube; pins 1 and 5, the filament prongs, are always close together and directly opposite a single pin. The positions of the filament prongs in octal tubes vary with different tubes, so it is generally necessary to refer to a tube chart for accurate information.

Locating Prong No. 1. You can locate any prong by remembering that the R. M. A. numbering system always progresses clockwise when you look at the bottom of the tube socket. In octal tubes, prong *1* is always in the clockwise direction from the aligning slot as you look at the bottom of the octal tube socket. Notice the examples given in Fig. *37*.

TUBE TYPE NUMBERS

Since it is clearly impractical for busy radiomen to describe a certain tube completely when speaking of it, each tube has been assigned a number. In the early days of radio, when only a few different types of radio tubes existed, there was little confusion even though numbers were assigned to new tubes in haphazard fashion; tubes such as the 01A, 12, 26, 71A, 56, 58, and 24 are examples. Notice that these numbers give no indication of the characteristics of the tubes. As the number of different types of radio tubes increased, it became increasingly more difficult to recognize



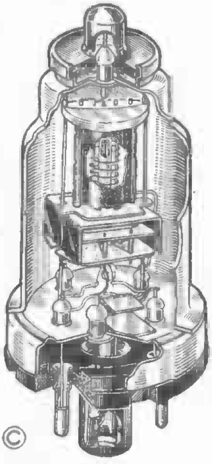
Courtesy Hygrade Sylvania Corp.

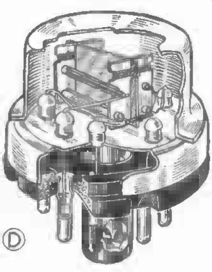
A (above). The assembly of a typical all-metal tube, the type 6A8 pentagrid converter, can be traced in the above photograph. Metal exhaust tubing and Fernico metal eyelets are welded to metal header shown at upper left, then glass beads with wire leads are threaded through eyelets and fused to them. Electrodes are welded to projecting leads, metal envelope is welded to header, tube is evacuated and sealed off, octal bakelite base and top cap are crimped into position and tube is sprayed, completing job. A completed tube with half of envelope cut away is also shown.

B (at right). This unusual drawing, giving a cut-away view of an all-metal tube, shows how connections are made to electrodes and how electrodes are mounted inside.

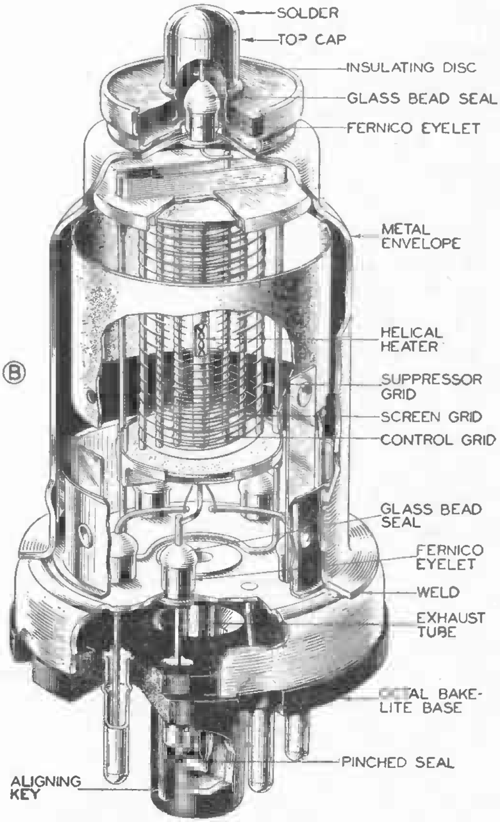
C (at left). Cut-away view showing arrangement of electrodes inside a 6Q7 all-metal duplex diode triode.

D (below). Cut-away view of 6H6 all-metal twin diode, a radio midget.





Courtesy National Union Radio Corp



Courtesy R.C.A. Manufacturing Co., Inc.

tubes. The following code, which is now standard for all new tubes, was developed by the R. M. A. to eliminate some of this confusion, as this code gives at least *some* clue to the tube type.

R.M.A. TUBE NUMBERING CODE

Each tube designation shall consist of a number (or digit), followed by a letter, which is in turn followed by another digit.

(a) The first numeral (or group of numerals) shall indicate the *filament voltage* in steps of 1 volt, using 1 to mean any voltage below 2.1; 2 to mean 2.1 to 2.9 volts; 3 to mean 3.0 to 3.9 volts; 4 to mean 4.0 to 4.9 volts; 117 to mean 117.0 to 117.9 volts, etc.

(b) The last numeral shall designate the number of useful elements (filament, cathodes, grids, plates, etc.) which are connected by wire leads to prongs or the tube cap. The filament is here counted as one element, and the envelope of a metal tube (or a shield within a glass tube) is considered as one element.

(c) The letter between the numerals shall be a serial designation which will serve to distinguish between tubes having the same number of useful elements and the same filament voltage. Rectifiers will start with Z and work backward through the alphabet, while all other tubes start with A and work up through V of the alphabet. When all 26 letters of the alphabet have been used for a given combination of first and last numbers, the next 26 new tubes with these numerals will have the letter *A* ahead of the serial designation letter; succeeding groups of 26 tubes will have B, C, D, etc., ahead of the serial designation letter. Examples: 6AB5; 6AF6.

(d) The letter *S* ahead of the serial designation letter (following the first numerals) indicates a single-ended tube. Example: 6SK7. The letter *G* following the last numeral indicates an octal-base tube having a standard glass envelope instead of a metal envelope. Example: 6Q7G. The letters *GT* following the last numeral indicate an octal base tube having an extra-small glass envelope instead of a metal envelope. Example: 6Q7GT.

▶ **The foregoing system is primarily intended to be a logical system of assigning tube numbers in such a way that *some* useful information can be conveyed to the user. However, a tube chart must be used to find the filament current, plate, and grid voltages, plate current, amplification factor, prong connections, etc.** Tubes are listed in such charts by their numbers, so you need merely look up the number of the tube in which you are interested to find its characteristics and recommended uses. Furthermore, tube charts give the tube base connections, so it is possible to find from them which prong is connected to which element. We will give more information about tube charts elsewhere in your Course.

Lesson Questions

Be sure to number your Answer Sheet 8FR-4.

Place your Student Number on *every* Answer Sheet.

***Send in your set of answers for this lesson immediately after you finish them,* as instructed in the Study Schedule. This will give you the greatest possible benefit from our speedy personal grading service.**

1. What two electrodes must *every* electronic tube have?

2. Will electrons flow through an electronic tube when the anode is *negatively* charged with respect to the hot cathode?

3. Does the A battery furnish the electrons that are emitted by a heated filament?

4. Suppose an a.c. voltage source is connected between the plate and the cathode of a diode thermionic tube. Will the resulting plate current be: *1,* a.c.; *2,* pure d.c.; or *3,* pulsating d.c.?

5. Is a tube which has an indirectly heated cathode called a *heater type* tube or a *filament type* tube?

6. What is secondary emission?

7. What is the purpose of the control grid which is placed between the cathode and the anode of an electronic tube?

   To provide better Amp. of the signal

8. Does the plate current: *1. remain constant; 2, decrease; or 3, increase;* as the C bias voltage is made more negative?

   2,

9. How many elements are there in a pentode tube?

   5

10. What does the first numeral (or group of numerals) in the R.M.A. Tube Numbering Code indicate?

YOU HAVE AN AIM IN LIFE

When you enrolled as a student member of the National Radio Institute, you took the first step on your road to success and happiness. You now have a *goal* for yourself—you have an aim in life—you are looking forward to the sort of work you like, the sort of income you want, and the respect and admiration of your friends.

Keep your goal in mind. Never forget it for a moment. Of course you will have your moments of discouragement—we all have. But if you make a thorough search for the cause of your discouragement, you will most likely find that you ate something which did not agree with you, or were kept awake last night by the neighbor's dog. Realizing this, you will put your lessons aside for the time being, and tackle them the next day with renewed vigor and a renewed determination to succeed.

Whenever you are tempted to neglect your studies, say to yourself: "I have a goal to reach and I'm going to reach it." Think how unhappy you would be if you did not have this goal. There is nothing as pathetic as a rudderless ship or a man without an aim in life.

Here's to success and happiness—*your goal.*

J. E. SMITH.

TYPICAL RECEIVER DIAGRAMS AND HOW TO ANALYZE THEM

REFERENCE TEXT 17X

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

REFERENCE TEXT

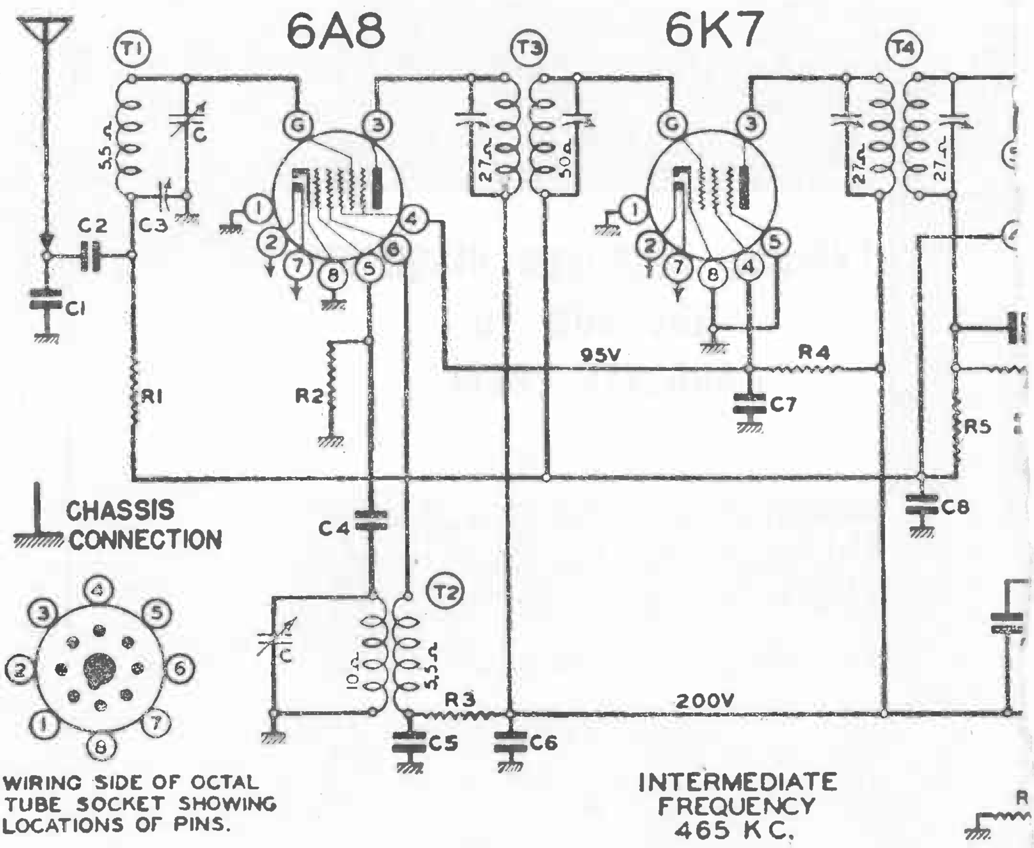


Fig. 8. Schematic circuit diagram of Truetone Model D-746 five-tube auto radio receiver. The parts list for this set is given below. Voltage values on the diagram represent d.c. voltages to chassis. All condenser values are assumed to be in microfarads. Percentages after values indicate the percent of tolerance which is permissible in the values of replacement resistors or condensers. The abbreviation w. stands for "watts."

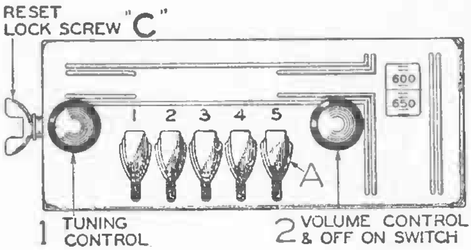


Fig. 9. Front view of Truetone Model D-746 receiver, showing automatic tuning levers. Locking screw "C" will lock in place all the stations you have selected on the automatic tuner levers. If you should desire to change any station you selected to another, loosen the locking screw "C" one or two turns, and select the new station as explained. Be sure to retighten the locking screw, otherwise the stations you have selected will not stay adjusted to the levers.

RESISTORS

R1	250M ohm—1/10 w. 20%
R2	50M ohm—1/10 w. 20%
R3	30M ohm—½ w. 20%
R4	25M ohm—1 watt 10%
R5	3 megohm—1/10 w. 20%
R6	1 megohm volume control
R7	50 ohm—1/3 w. 10%
R8	30 ohm—1/3 w. 10%
R9	2 megohm—1/3 w. 20%

the same trouble, and it is checked in the same manner as *C7*.

If excessive hum is heard, we should be on the lookout for cathode-to-heater leakage in some of the tubes, and for drying up of electrolytic filter condensers *C11* and *C12*. These two condensers should be checked by substitution, being sure to observe the polarity markings of the test condensers by connecting their positive leads to the 6X5 cathode.

Motorboating or noise originating in the a.f. section of the set (check on this by removing the 6K7 type tube to see if the noise is still present) would cause us to suspect an open in condensers *C14* and *C16*, the a.f. decoupling capacitors. They should be checked for an open by substitution. Hum might also result if these condensers are open.

Distortion and audio oscillation may be due to an open in condenser *C18*.

Excessive noise may be caused by worn vibrator contacts. In cases where it is not practical to remove the vibrator housing to see if sparking occurs at the contacts, a new vibrator should be tried, after checking condenser *C17* by replacement and measuring the value of *R15*. One terminal of this resistor must be disconnected when checking it with an ohmmeter, so that a misleading reading will not be obtained through the power transformer primary.

The spark plate condensers seldom if ever give trouble, although some vibrator hash may get into the receiver if *C19* is open.

Weak signals coupled with distortion would lead you to believe that the loudspeaker field was open. This wouldn't affect the application of correct voltages to the tube electrodes. A quick check may be made on the field by holding a screwdriver near the metal pole piece. If the field is energized there will be a pull on the screwdriver. If it is not, the field should be disconnected and checked with an ohmmeter.

If the receiver is dead and a circuit disturbance test shows all stages to be alive, you would immediately suspect failure of the oscillator. This would most probably be due to lack of plate voltage on the oscillator anode grid, pin *6* in the diagram.

Immediately you would suspect a short or leak in condenser *C5*, with perhaps opening up of resistor *R3*. If these points proved to be in good condition, you would check the 5.5-ohm winding of the oscillator coil to see if it was open.

Trouble sometimes is experienced with this type oscillator if the oscillator grid resistor changes in value. A value lower than 50,000 ohms for *R2* will frequently cause the oscillator to be dead at the low-frequency end of the dial. Sometimes a value as high as 75,000 ohms may be used. If the resistor is made too high in value, the oscillator will intermittently block, particularly at the high-frequency end of the dial.

High-resistance connections in the oscillator circuit will cause the oscillator output to be poor at the low frequencies. If the oscillator stops functioning at the high frequencies, the oscillator coil probably has absorbed moisture, and it would be best to install another. When another cannot easily be obtained, the oscillator coil can be baked in an oven to drive off the moisture.

Tracking failure of the oscillator and preselector, if not due to incorrect adjustment or a defect in condenser *C3*, is probably due to the i.f. being aligned at the wrong frequency.

Blasting and distortion on strong local stations would indicate lack of a.v.c. voltage, and this in turn would probably be due to a short in a.v.c. filter *C8* or to a short between diode plate *4* and the cathode of the 6Q7 type tube.

Automatic Tuning Set-Up. This receiver has a mechanical automatic tuning system. There are five levers on the dial by means of which five stations may be selected, as indicated in Fig. *9*. The procedure for setting these automatic tuning levers is as follows:

Make a list of local stations you tune in regularly; any number up to and including five.

Any order of grouping can be used, either by assigning call letters for the levers alphabetically or arranging them to correspond with the calibration on the dial scale.

Loosen the special locking screw ("C" in Fig. *9*) which is located on the left side of the tuner dial assembly.

Press DOWN ALL THE WAY any one of the automatic tuner levers. Holding it down FIRMLY, tune in by means of the tuning knob (No. 1) the station you have assigned to this lever. Turn the tuning knob very slowly back and forth (while still holding lever in downward position) until the signal is clearest. The station will then be accurately tuned in. Release the lever.

Press down another automatic tuner lever. Holding it down FIRMLY, carefully tune in the station assigned to this lever. Release this lever.

Follow this procedure until you have selected all of your favorite stations.

Now rotate the tuning knob (No. 1) to the right (clockwise) as far as it will turn, and tighten the special locking screw ("C").

It is VERY IMPORTANT that this locking screw is turned until it is ABSOLUTELY TIGHT.

The A.V.C. Gas Gate. You will note that diode plate *4* of the 6Q7 tube connects to the grid return to the 6K7 tube at the junction of resistor *R5* and condenser *C8*. This arrangement is known as a gas gate. If the 6K7 tube happens to become gassy, electrons will flow up through resistors *R6* and *R5* to the control grid of the 6K7 tube. This tends to make the grid of the tube positive by an amount equal to 4,000,000 ohms (*R5* + *R6*) multiplied by the gas current in amperes.

When diode plate *4* becomes positive due to gas in the 6K7, current will flow from the 6Q7 cathode to this diode plate, lowering the effective resistance of *R5* and *R6* and therefore lowering the voltage drop produced across them by the gas current.

Tracing Supply Circuits. In this, or in any other auto receiver, we only have the 6-volt storage battery in the car as a source of power. We can feed the tube filaments and loudspeaker field directly from the battery since they are designed for 6-volt operation. We must also feed the tube electrodes with the correct d.c. voltages, which in some cases will be as much as 200 volts.

D.C., as you know, cannot be stepped up. Therefore, we use a non-synchronous vibrator to interrupt the d.c. from the battery, thus changing it for all practical purposes to a.c. This a.c. may be stepped up by a power transformer, rectified by a high-vacuum rectifier tube, and the pulsating d.c. from the rectifier filtered just as in an a.c. set. The rectified and filtered d.c. is then ready to be applied to the various tube electrodes.

The diagram shows that the vibrator is used solely to interrupt the d.c. flowing through the primary of power transformer *T5*. It causes the supply current to flow first through one section of the primary and then through the other, giving the same effect as an a.c. current.

The hot (ungrounded) A lead connects to the center tap on the primary of the power transformer through switch *S1* and choke *L1*. Normally, the vibrator armature connects to terminal *2*, being held in place by spring tension.

When the set is turned on, current will flow through the armature coil of the vibrator, connected to terminals *2* and *4*. The current flow is through the coil to vibrator terminal *2*, and through the armature in contact with terminal *2* to the chassis. This will pull up the armature, causing it to make contact to terminal *3*, and breaking the contact of the armature coil to ground through terminal *2* and the grounded armature. Then the current flowing to the center tap on the primary passes through the upper section of the primary to terminal *3*, and through the armature contact to terminal *1*, which connects to the other side of the storage battery.

The breaking of the circuit through the armature coil allows the spring to return the armature to terminal *2* on the vibrator. The current then flows through the lower half of the power transformer primary through the contact at *2* and to the other side of the storage battery. The armature coil is also re-energized to pull the armature over again for another round trip. This action occurs as long as the receiver is turned on, and we have current flowing first through one half of the primary and then through the other half.

As a result of feeding the primary with alternating current, a large voltage is developed across the secondary of *T5* and is applied to terminals *3* and *5* of the rectifier tube.

Since B— is the center tap on the secondary of *T5*, the B supply electron path is from the center tap through bias resistors *R11*, *R8*, *R7* to the 6A8, 6K7 and 6K6 cathodes (in the case of the 6Q7 cathode, the path is through *R11* and *R8*), then through the tubes to the plates and other positive electrodes, back to the rectifier cathode and across to rectifier plate *3* or *5*—whichever one is positive.

Resistor *R15* is used to prevent excess voltage from being developed across the primary. Condenser *C17* is a smoothing or buffer condenser and helps to remove any irregularities in the peaks of the secondary voltage. It is also important to use the right size of condenser at this point, so that the vibrator will work smoothly and with a minimum of sparking.

The cathode currents of all tubes flow through resistors *R7*, *R8* and *R11* (with the exception of the 6Q7, which skips *R7*), and develop a voltage across these resistors. The end connected to the power transformer secondary center tap is negative, while the end connected to the chassis is positive, thus forming the bias voltages.

Filter Circuits. You will note from the diagram that the vibrator coil and the heater of the rectifier tube are fed through choke *L1*. To avoid vibrator interference, the filaments of all but the rectifier tube are fed in parallel directly from the ON-OFF switch, as is the pilot lamp. The loudspeaker field is also fed from this point, and these parts are isolated from the interference produced by the vibrator by the filter consisting of condenser *C19* and choke *L1*.

Condenser *C19* serves to prevent any low-frequency interfering vibrator signal from feeding back through choke *L1*. The two condensers marked *SP* are called spark plate condensers and are essentially similar in construction to condenser *C1* in the antenna circuit. Since they do not have any nal is now applied across *R13* through condensers *C15* at the grid end and through *C11*, *R7* and *C16* at the other end.

Power Output Stage. The signal voltage across *R13* is applied to the control grid-cathode of the 6K6 tube, the cathode connection being through *C16*.

The 6K6 tube then amplifies the signal voltage across *R13*, and we now have a very large signal current flowing through the primary of output transformer *T6*. The turns ratio of the transformer matches the voice coil impedance to the tube plate impedance. The voltage induced into the secondary and the resultant current flow through the voice coil causes the voice coil and attached cone to move in and out in step with the audio signal, and in this way the cone produces sound waves.

Signal Circuit Features. We will now consider some of the signal circuit features in this set. First, from the diagram we see that the oscillator is not equipped with a low-frequency padder condenser. We may therefore assume that the oscillator tuning condenser has specially cut plates in order to obtain tracking over the entire band. In addition, and this is peculiar only to some auto receivers, condenser *C3* serves as an r.f. padder condenser and has the duty of helping make the preselector track or follow the oscillator by the i.f. frequency difference.

Condenser *C1* has a capacity of only .00002 mfd. and consists only of two flat metal plates separated by mica. A condenser of this construction will maintain its capacity even at the high frequencies produced by the auto ignition system—in other words, it is an excellent by-pass. Condenser *C2* is of the usual wound wax paper type. Because of its construction, it actually becomes a coil at ultra-high frequencies.

Ignition interference is modulated on ultra-high frequencies. When it enters the input circuit, *C2* acting as a coil with relatively high reactance forces this signal to take the *C1* path to ground. Broadcast signals will be by-passed by *C1* to some extent, but will mainly be capacitively coupled through *C2* to the resonant circuit by condenser *C3*. At broadcast frequencies *C2* and *C3* form the low-reactance path.

Condenser *C4* serves to couple the oscillator tank circuit to the oscillator control grid, and also serves (together with condenser *C* in the oscillator circuit) as a by-pass across resistor *R2*, thus smoothing out the r.f. across this resistor.

Resistor *R3* is used to cut down on the voltage to the oscillator anode, and condenser *C5* is an r.f. by-pass condenser. Condensers *C5*, *C6* and resistor *R3* also serve to keep any variations in the power supply circuit from being applied to the oscillator anode, as this might result in hum modulation.

Condenser *C6*, which has a capacity of .05 mfd., is also the plate supply by-pass condenser for the 6A8 and 6K7 tubes. Condenser *C7*, having a capacity of .1 mfd., is the screen by-pass condenser for the first detector and i.f. tube. Resistor *R4* serves to reduce the plate supply voltage to the correct amount for the screens of these two tubes.

Condenser *C13*, besides acting as an i.f. by-pass in the plate of the 6Q7 tube, also reduces the high-frequency audio response of the receiver, thus raising the bass response.

Condenser *C18*, connected between the plate and cathode of the output tube, prevents parasitic oscillations in the output stage. The plate load, because of this condenser, is essentially capacitive at the high audio frequencies at which such oscillation would normally occur.

The A.V.C. System. There is nothing unusual about the a.v.c. circuit. The mixture of d.c. and audio voltage developed across resistor *R6* is filtered by resistor *R5* and condenser *C8* for application of d.c. voltage only to the control grid of the 6K7 i.f. tube. Further filtration is afforded by resistor *R1* and condenser *C3* for the control grid of the first detector tube. The minimum bias for these tubes is 2.2 volts and is obtained across resistor *R7*, in the main power supply system.

When no signal is tuned in, no voltage exists across *R1*, *R5* and *R6*, and the control grids and cathodes of these tubes are essentially connected across *R7*. Naturally, when a signal is tuned in, the a.v.c. voltage appears across *R6* and, being in series with *R7*, determines the new operating bias.

When the incoming signal increases in strength, the i.f. voltage applied to the cathode and diode plate 5 of the 6Q7 tube increases. This results in increased diode current and a greater voltage across *R6*. This in turn increases the negative bias of the 6A8 and 6K7 tubes, and reduces the receiver sensitivity.

When the strength of the incoming signal decreases, the rectified voltage across *R6* decreases. Since this reduces the negative bias of the 6A8 and 6K7 tubes, the receiver sensitivity increases, thus enabling us to have an automatic control of the volume.

No a.v.c. system is 100% efficient, and a change in the incoming signal strength will result in some change in the output sound level from the loudspeaker. For slight changes in signal strength, the sound level will not change perceptibly. Even for large changes in signal strength, the output level changes far less than if a.v.c. were not used.

the 1-megohm screen supply resistor to burn out, since its value is so high that even the full voltage of the power pack could not cause a great deal of current to flow through it. However, if the condenser is not shorted, resistor *18* should be checked with an ohmmeter. The resistor may be open.

Lack of plate voltage on the second detector would lead you to suspect resistors *19* and *22* and the .001-mfd. plate by-pass condenser marked *20*. Regeneration control condenser *17* might also be shorted.

Screen voltage on the output tube but no plate voltage would be due either to a short in plate by-pass condenser *24* or to an open in the primary of the output transformer. If by-pass condenser *24* breaks down to the point where it has no resistance, the power pack may be damaged or the output transformer primary may burn out. Power pack damage would be limited to the rectifier tube and the power transformer.

Lack of d.c. voltages at any point, when the rectifier, power transformer and filter condensers are in good condition, would be due either to an open in the loudspeaker field or an open in C bias resistor *30*.

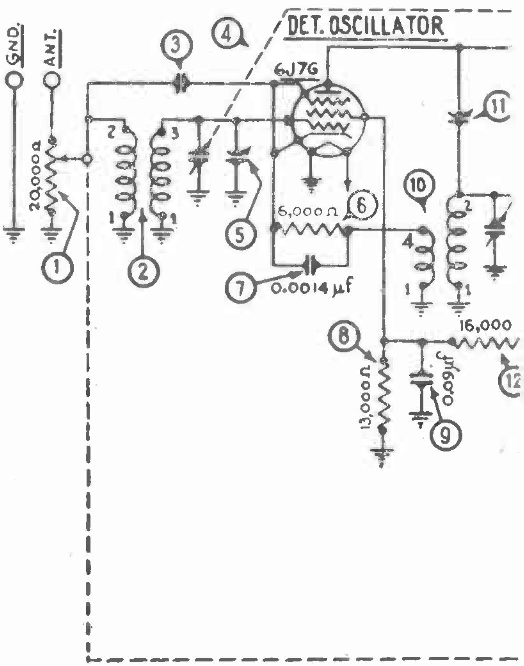
Continuity Tests. In your study of previous diagrams, you have learned that all tube electrodes at a positive potential should trace back to the rectifier filament, while those at a negative potential should trace back to either plate of the rectifier.

Here is how you can secure valuable practice: On each receiving tube, trace all screens and plates back to the rectifier filament, and all control grids, cathodes and suppressor grids back to one plate of the rectifier.

Expected Performance. The performance of this type of receiver is remarkable considering the number of tubes employed. Its good sensitivity and selectivity may be attributed to regeneration in the first and second detectors. Lack of a.v.c. makes it impractical to listen to distant stations whose carriers fade in and out.

Since the receiver is placed in a small cabinet, the loudspeaker is necessarily of the midget type, which cannot give good reproduction of the low audio frequencies. Regeneration with consequent side-band cutting reduces the high-frequency audio response. To sum up, you may expect sets of this type to give acceptable rendition of programs on local and semi-distant stations. Tone quality is passable but cannot be compared to that expected from a console type receiver.

Common Causes of Typical Troubles. The common troubles encountered in receivers of this type are low operating voltages due to defective filter condensers, and intermittent reception due to a change in value of the volume control (disconnect the slider and check the volume control with an ohmmeter). Oscillation is generally due to excess capacity (caused by incorrect adjustment) in regeneration condenser *17*, although screen bleeder *8* sometimes opens up, as does the detector-oscillator screen by-pass condenser.



A more than average amount of trouble is encountered in oscillator circuits of this type. Frequently, the oscillator refuses to function at the low-frequency end of the dial. The first thing to do is to try a new detector-oscillator tube or interchange this one with the second detector which is of the same type. When the gain of the tube falls off due to loss in cathode emission, it is harder for the oscillator to work at the low-frequency end of the dial.

When a new tube does not clear up the trouble, excessively high bias is indicated. This can be corrected by reducing the value of cathode bias resistor *6* to approximately 4000 ohms. The rule here is to use a replacement resistor having about one-third less resistance than the original.

If continued trouble is experienced, go

mounted on the chassis rather than in the i.f. transformer shield cans.

If an output meter is used, it may be connected across the voice coil of the receiver. All adjustments are to be made for maximum output. First, trimmer condenser *15* is adjusted for maximum output. Next, condenser *11* is adjusted.

Regeneration control *17* should then be turned clockwise (increase its capacity) to a point where a squeal is heard. Now back off the control by turning it counter-clockwise about ⅛ turn until the oscillation (squeal) disappears.

Repeat trimmer condenser adjustments *11* and *15*. If regeneration results, again back off control *17*.

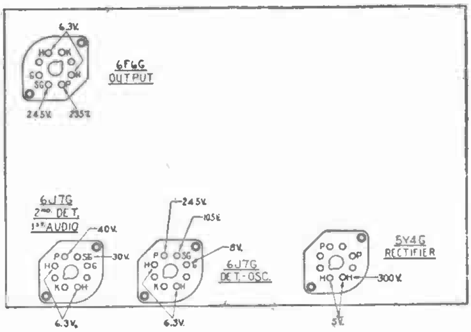


Fig. 6. Bottom-of-chassis diagram of Philco Model 37-84 receiver, showing tube socket voltages as measured from tube contacts to chassis with a 1,000-ohm-per-volt voltmeter.

Go over these adjustments two or three times to secure maximum sensitivity and selectivity. After this don't touch the adjustments again.

Tune the receiver to the high-frequency end of the dial, which is the position giving minimum capacity of the gang tuning condenser (plates out of mesh).

Reset the signal generator frequency to 1700 kc. and adjust oscillator trimmer *13*, mounted on the condenser gang, for maximum output. Then tune the signal generator to 1400 kc. and tune the receiver to the same point for maximum output. The antenna trimmer marked *5* in the diagram should then be adjusted for greatest reading on the output meter.

This completes the alignment, as no oscillator low-frequency padder is used. Tracking is obtained by means of specially cut plates. Incorrect tracking is an indication that the i.f. is aligned at the wrong frequency.

Voltage Measurements. In checking the operating voltages, be guided by the tube socket layout in Fig. 6. While the factory manual states that these voltages are to be measured from the tube contacts to the chassis, you can see that in the case of the rectifier heater voltage, you should connect the test probes to the two heater socket terminals. This is necessary since the rectifier filament is at a very high potential with respect to the chassis.

All of the d.c. voltages are to be measured from the points indicated to the chassis.

With the exception of the heaters, all measurements were taken with a d.c. voltmeter having a sensitivity of 1000 ohms per volt. The majority of multimeters now in use have a sensitivity greater than this; therefore, somewhat higher voltages are to be expected when checking circuits containing a high value of resistance, such as the plate and screen of the second detector tube.

Your voltage measurements, if properly interpreted, can often lead you directly to the source of the trouble. For example, if all the d.c. voltages are abnormally low, you would suspect defective electrolytic condensers, particularly the 8-mfd. input filter condenser.

Lack of voltage on the screen of the first detector-oscillator tube would be due, in all probability, to a short in the .09-mfd. screen by-pass condenser and perhaps to an open in the 16,000-ohm screen supply resistor marked *12*.

Abnormally high voltage on the screen, coupled with the complaint of squealing, would be due to an open in the 13,000-ohm bleeder marked *8* in the diagram.

Lack of voltage on the screen of the second detector could be due to a breakdown in the screen by-pass. A breakdown in this by-pass condenser wouldn't, in all probability, cause

PHILCO 37-84 Four-Tube A. C. Superheterodyne

SO you can see the diagram in Fig. 7 while studying this receiver, proceed as follows: Turn this page so pages 19, 20, 21 and 22 are in view. Now fold page 19 so that it covers page 20.

General Description. The Philco model 37-84 is a four-tube a.c.-operated superheterodyne receiver. It uses a type 6J7G as the oscillator-mixer-first detector, another 6J7G as the second detector, a 6F6G output tube and a 5Y4G rectifier.

In the receiver, r.f. voltage gain is obtained by resonant step-up in the tuned secondary of the antenna coil and regeneration, while most of the i.f. gain is the result of conversion gain in the detector-oscillator and regeneration in the second detector. A.F. gain is due to amplification of the audio signal in the second detector and the amplification afforded by the 6F6G output tube.

An examination of the schematic shows this receiver to be unique in that it does not use a stage of intermediate frequency amplification. This circuit is typical of a great number of midget superheterodyne receivers. The output of the first detector feeds through an i.f. transformer into the input of the second detector. Both the first and second detectors are regenerative, which tends to make up for the loss in sensitivity due to omission of the usual i.f. stage.

Signal Circuits. Signals picked up by the antenna cause a current to flow through the 20,000-ohm volume control, marked *1* in the diagram. By adjusting the position of the slider on the control, any amount of the signal voltage may be taken off and fed to the primary of the antenna transformer marked *2* in the diagram.

By mutual induction a voltage will be induced into the secondary transformer, and only the signal tuned in will undergo resonant step-up. The resonant circuit consists of the secondary coil, the tuning condenser, and trimmer condenser *5* shunting it. The signal is applied to the grid and cathode of the *DET.-OSCILLATOR* tube, the cathode connection being through oscillator feed-back coil *10* and through by-pass condenser *7*.

Regeneration is obtained by means of condenser *3*, with the feed-back path being from terminal *4* of the oscillator pick-up coil through condensers *7* and *3* to the primary of antenna coil *2*.

All i.f. oscillator and r.f. signals between terminals *4* and *1* of coil *10* are fed back to the primary of coil *2* through condensers *7* and *3*. These signals are induced into the secondary, but the secondary is tuned only to the r.f. signal. Other signals do not undergo resonant step-up, and hence effective feedback occurs only at r.f. values.

Condenser *3* is known to radio men as a "gimmick," as it consists simply of two insulated wires twisted together.

Advancing the volume control for greatest volume has the effect of producing more regeneration.

The oscillator is of the tuned plate type. The oscillator energy is fed to the tank coil through i.f. trimmer condenser *11*. The tank (coil winding *2-1* of *10*, the tuning condenser and trimmer *13*) is coupled to the cathode circuit by mutual induction through pick-up coil *4-1* of coil *10*. The voltage induced into this coil causes the grid-cathode bias of the tube to vary at the oscillator frequency. In this way, oscillation is maintained.

The incoming signal and the local oscillator signal are mixed inside the tube. As a result, we also have the intermediate frequency of 470 kc. existing in the plate circuit. Since the primary of i.f. transformer *14* with its associated trimmer *11* offers a high impedance at the intermediate frequency, we have a large i.f. voltage existing across the primary.

At the intermediate frequency, the oscillator tuning coil acts as a low-reactance path. The connection between i.f. primary trimmer condenser *11* and the white lead of the i.f. primary is through oscillator tuning coil *10* to chassis and then through condensers *28* and *29*.

An i.f. voltage is induced into the secondary of i.f. transformer *14*. Note that the i.f. transformer secondary (having a *BROWN* lead and a *BLACK & WHITE TRACER* lead) is tuned to resonance by trimmer condenser *15*.

The signal is now applied between the grid and cathode of the second detector, the grid connection being through the 4-megohm grid resistor marked *16*. The gimmick shown connected to the grid of the second detector forms a capacity across resistor *16*, thus more effectively coupling the resonated signal to the grid, and at the same time making the 6J7G an ordinary grid leak-condenser type detector.

The second detector tube will amplify the i.f. signal applied to its input. Resistor *19* acts as the i.f. plate load, the end connected to a.f. plate load *22* being at chassis potential as far as i.f. signals are concerned because of .001-mfd. condenser *20*. This has low reactance at i.f. values and high reactance at a.f. values.

The i.f. signal across resistor *19* is fed back through regeneration control conden-

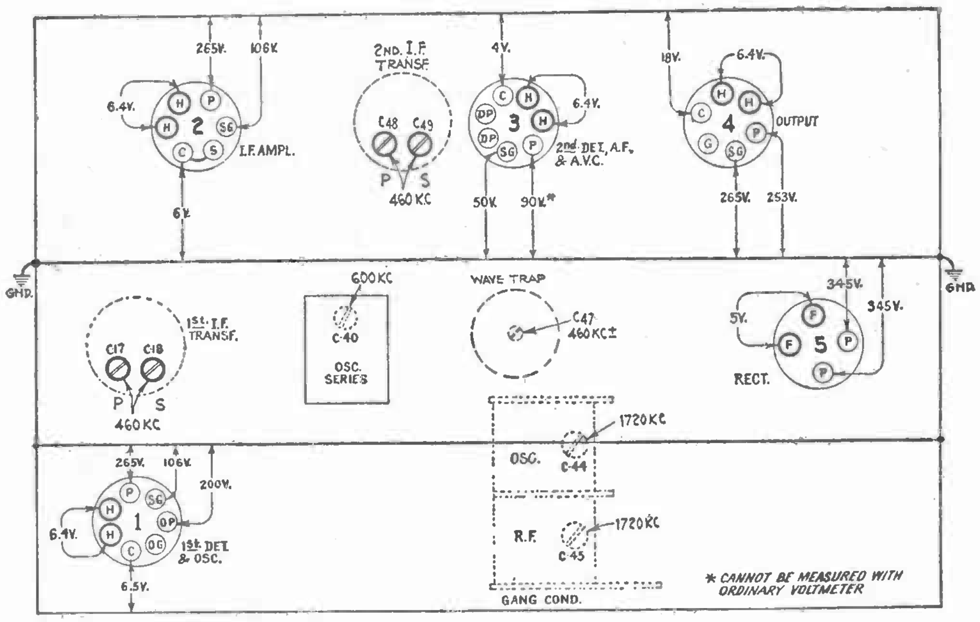


Fig. 4. Bottom-of-chassis diagram for RCA Model T5-2 receiver, showing trimmer locations and tube socket voltages (measured at a line voltage of 115 volts a.c., with volume control at maximum and no incoming signal.)

Continuity Tests. Should you wish to check continuity in any of the electrode circuits, bear in mind these rules:

1. All positive electrodes should have a conductive path to the filament (or cathode) of the rectifier tube.

2. All negative electrodes should have a conductive path to a plate of the rectifier tube.

Let's prove this by tracing a few circuits.

Starting with the plate of the 6A7 tube, trace through *L-9* and *L-14* to the filament of the 80 tube. Starting with the second grid of the 6A7, trace through *L-6* and *R-5* to the cathode of the 80 tube. Starting with the second grid of the 6D6 tube, trace to the junction of *R-18* and *R-19* and then through *R-18* and *L-14* to the filament of the 80 tube.

Turning now to a negative electrode, for example the control grid of the 6D6 tube, trace through *L-10*, *R-6*, *R-9* and *R-12* to chassis, to the center terminal of the high-voltage secondary of the power transformer, then to either plate of the 80 rectifier tube. Another example: Starting with the control grid of the 41 tube, trace through *R-14* and *R-16* to chassis and through the high-voltage secondary to either plate.

Expected Performance. This is an average receiver with respect to sensitivity and volume. Reasonably good fidelity is to be expected. An antenna 50 to 75 feet long is advisable in rural areas, but a short antenna should do in metropolitan districts. Noise-reducing doublet antennas may be advantageously utilized when electrical noise is a problem.

When switch *S-2* is closed, the input circuit of the first detector circuit is tuned to the police band. The oscillator frequency is not changed, but the second harmonic of the oscillator beats with the signals resonated by *L-2* and *C-6* to produce the desired i.f. value.

Servicing Hints. Since this receiver is quite conventional in design, most of the defects are isolated by basic methods discussed in the regular course. A few hints may prove helpful.

It is possible for the receiver to develop hum modulation without a defect in the main power pack filter. Should *C-16* open or lose its capacity, filter *R-5* and *C-16* will no longer remove a.c. ripple in the supply to the oscillator, and hum will be heard when a station is tuned in.

Leakage in *C-28* will bias the 41 tube abnormally positive and cause distortion. Leakage in *C-29*, which connects to the + B supply terminal and the 41 tube cathode, drives the grid more negative and will cause serious distortion, more noticeable on weak stations.

i.f. current returns to cathode through the parallel path formed by *C-38* and *C-36*, through the chassis, and then through *C-10*.

I.F. Amplifier and Second Detector. In a parellel resonant circuit, a large current flows in the coil-condenser circuit, hence in *L-9* a large i.f. current induces in *L-10* a corresponding i.f. signal voltage.

L-10 and *C-18* form a resonant circuit which boosts this induced voltage, and a larger voltage appears across *C-18* than that induced into *L-10*. However, the voltage across *L-10* is slightly less than that across *L-9*, as some energy is lost in the primary and secondary resonant circuits.

The voltage across *C-18* is applied to the input of the 6D6 tube through a direct connection to the grid of the 6D6 tube and a cathode connection through *C-19* and *C-20*.

As the 6D6 is a high-gain amplifier, a large i.f. voltage is developed across the plate parallel resonant circuit, *L-11* and *C-48*. The return i.f. path to cathode for this resonant circuit is through *C-38*, *C-36* and *C-20*.

The i.f. current in *L-11* induces an i.f. voltage in *L-12*. By tuning *C-49* to resonance, a large i.f. voltage appears across *C-49*; this is less than the voltage across *L-11* but many times greater than the voltage across *L-10*.

Because of the voltage step-ups in the preselector, frequency converter and i.f. stage, the voltage across *C-49* is high enough for demodulation. This voltage is rectified by one of the diodes in the 6B7 tube. The other diode is not used, and is connected directly to the chassis.

Trace from the lower diode plate through *L-12*, *R-8* and *R-9* to the cathode of the 6B7 tube. Because of rectification a pulsating d.c. current flows through this circuit, with its amplitude following the original modulation. In the detector circuit, *R-9* is the diode load across which the a.f. voltage is produced. Condenser *C-23*, resistor *R-8* and the capacitor formed by the shield over the lead which connects *R-8* and *R-9* all act together as an i.f. filter. Only the desired a.f. voltage and a d.c. voltage appear across *R-9*.

Audio Amplifier. Because of the d.c. voltage drop across *R-9*, a direct connection to the input of the first a.f. amplifier cannot be made, and a d.c. blocking condenser is therefore required. Note that the movable contact of *R-9* connects to the grid of the pentode section of the 6B7 tube through d.c. blocking condenser *C-25*. The grid also is connected to the chassis through resistor *R-11*.

For all audio frequencies except the very lowest, very little of the a.f. voltage is dropped in *C-25*. Most of this a.f. voltage is developed across *R-11* and is hence available for audio amplification. Varying the position of the movable contact of *R-9* controls the amount of a.f. voltage fed to the audio amplifier, and therefore serves as the volume control.

The connecting lead from *C-25* to the grid is shielded so that stray electric field pick-up will be kept out of the audio amplifier. The signal at this point is at a very low level, so stray a.f. signals entering at this point will give the greatest interference.

From the grid of the 6B7 tube, trace through *R-11* to chassis and from chassis through *R-12* to the cathode, thus establishing the grid to cathode path. Actually, however, a.f. signals will take the *C-26* path from chassis to cathode instead of going through *R-12*.

A pulsating d.c. current (a.f. on d.c.) will flow in the plate of the 6B7 tube. The d.c. current will be forced to take the path through *R-13* and *R-15* to the +B supply, as all other paths are blocked by condensers. A.F. currents will flow through *R-13*, *C-29* and *R-17* to chassis, and from this point through *C-26* to the cathode of the 6B7 tube. *R-13* has a high ohmic value, which means that a large a.f. voltage will appear across this resistor due to the a.f. current flowing through it. Since the a.f. reactances of *C-28*, *C-29* and *C-30* are negligible, resistor *R-14* is essentially in parallel with *R-13* and most of the a.f. voltage across *R-13* is also across *R-14*. It is the a.f. voltage developed across *R-14* that excites the grid and cathode of the 41 tube.

Any i.f. signals getting into the plate of the 6B7 are by-passed from the plate load circuit by condenser *C-27*.

In the plate circuit of the 41 pentode output tube we find output transformer *T-2* coupling the pentode tube to the loudspeaker. Condenser *C-32* is shunted across the primary to prevent parasitic oscillation in the output stage, by making the plate load substantially capacitive for high frequencies. The condenser reduces the high-frequency response, but when more bass emphasis is desired *C-31* is shunted into the circuit by switch *S-6*, thus giving the output a boomy or bass response. *S-6* is hence a one-step tone control.

Now let us trace the a.f. signal path from the primary of *T-2* to the cathode of the 41 tube. Follow the lead connecting *T-2*, *C-32* and the screen grid to *C-38* and *C-36* in the power pack, go through the filter condensers and go from the chassis through *R-17* to the cathode of the 41 tube.

Power Supply Circuit. A full-wave type 80 rectifier is used in the power pack. Power transformer *T-1* may be designed either for 60 or 25 cycles, but not for both.

Note that the 25-cycle transformer has higher primary and secondary resistance, this being the result of more turns in each section. Because of the low frequency, more core flux must be obtained with more turns are involved, the grid return of *L-2* and the rotor of *C-6* are at r.f. ground potential.

At resonance the voltage in *L-2* is stepped up, presenting to the grid-cathode of the first tube an r.f. voltage substantially greater than the voltage across *L-1* in the antenna circuit. Voltage gains of 10 times may reasonably be expected.

Frequency Converter. A pentagrid tube (one with five grids, penta meaning five) is used as an oscillator-mixer-first detector —the frequency converter of a superheterodyne receiver. Its first grid connects through condenser *C-8* to coil *L-4* and to chassis (or r.f. ground) through *C-11* in shunt with *C-40*.

Coil *L-4*, *C-11* and *C-40* are shunted by tuning condenser *C-9* and its associated trimmer *C-44* to form a resonant circuit in the oscillator circuit. This arrangement is widely used in superhet receivers in order to make the oscillator frequency, always 460 kc. (the i.f. value), different from the preselector frequency (the incoming signal frequency).

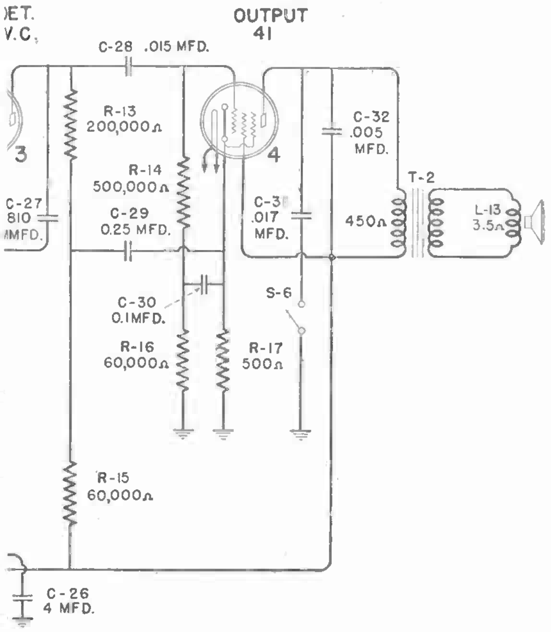


Fig. 3. Schematic circuit diagram of RCA Model T5-2 five-tube a.c. superheterodyne receiver. When switch S-2 is closed, the preselector is tuned to the 1600 kc.—3500 kc. Police Band. The second harmonic of the oscillator then beats with the incoming Police Band signals to produce the i.f. value of 460 kc.

To illustrate the action of the frequency converter, let us assume that the receiver is tuned to a 1000-kc. broadcast station. Tuning condenser sections *C-6* and *C-9* are ganged together, so that when *C-6* tunes preselector resonant circuit *L-2* and *C-6* to 1000 kc., *C-9* will cause the oscillator to generate a 1460-kc. signal. The oscillator frequency is thus 460 kc. *higher* than the incoming signal frequency, and this relationship exists at all settings of the tuning dial.

At the very high broadcast band frequencies, *C-44* is adjusted during alignment to give the desired frequency difference and is called the high-frequency trimmer. At low broadcast band frequencies, *C-40* is adjusted and is called the low-frequency trimmer or padder.

From the second grid, trace through *L-6*, then through *R-5* to the voltage supply (considered later) and through *C-16* to ground. Coil *L-6* inductively links to *L-4* and thus produces feed-back from the second grid to the first grid circuit.

If you consider that the second grid of the 6A7 tube is an anode, or oscillator plate, you will see that we have a tuned grid, tickler type feed-back oscillator circuit. The intensity of oscillation is automatically controlled by the grid bias produced by grid current flow in *R-3*. Condenser *C-8* serves as the filter condenser for the grid resistor and helps to reduce the r.f. ripples of the grid bias voltage.

The cathode, the first grid and the second grid, with their associated circuit components, set up beyond the second grid an electron cloud that is varying in intensity in accordance with the oscillator frequency. Technicians call this cloud the "virtual" cathode for the remaining tube elements, because the electrons flowing to these remaining elements come from this cloud.

The electrons which leave the virtual cathode are speeded toward the plate by the third and fifth grids (connected together internally to form the screen grid), since these electrodes are at a positive potential with respect to the virtual cathode. At the same time, the signal from the preselector is "injected" into the tube by the fourth grid, and introduces a new variation in the electrons flowing from cathode to plate.

Thus, both the preselector and local oscillator signals are mixed in the 6A7 tube. Detection takes place in the mixer section because the tube is operated as a detector and a strong beat signal (the i.f. signal) appears in the plate circuit.

Coil *L-9* and adjustable condenser *C-17* form a parallel resonant circuit in the plate circuit, absorbing power at its resonant frequency and acting as a low-reactance path for all other frequencies. The plate r.f. and prong *3* of the ballast tube, through one resistance section to prong 8, through the other resistance section to prong 7, then through the filaments of the 25Z5, 25L6, 6D6 and 6C6 tubes in series. One filament lead of the 6C6 tube is grounded to the chassis, and switch *SW* completes the filament circuit from the chassis to the other side of the power line.

The total voltage required for the filaments is 25 + 25 + 6 + 6, or 62 volts. The ballast drops the difference between 115 and 62, or 53 volts. Since the tube filaments and the ballast are self-regulating to a reasonable degree, increases and decreases in line voltage have little effect on the cathode emission of the tubes.

The pilot lamp shunts that portion of the ballast resistor between prongs 7 and 8. The resistance of this portion is so chosen that the lamp normally gets 4 volts; a 6.3-volt Mazda lamp is used, hence it will burn dimly. When the power is first turned on, however, the tube filaments have low resistance until they heat up; this causes a large current to flow, but it is partially "cushioned" by the ballast.

During the heating-up period, the voltage across the pilot lamp will be high, and the lamp will burn brightly. A 6.3 lamp normally operating at 4 volts thus provides a degree of safety from burn-out. In receivers which use this arrangement, you can expect the pilot lamp to glow brightly initially, and then dim down to a subnormal glow.

Checking Continuity in A.C-D.C. Receivers. Bear in mind that continuity tests are made with an ohmmeter while the receiver is turned off. In fact, with a universal a.c.-d.c. receiver *be sure to pull the power plug out of the wall socket.* Ohmmeter tests can then be made from tube terminals or socket prong clips, for the tubes are not conductive when power is off.

In checking this receiver you will find that all positive tube electrodes, such as the screen grid and the plate, trace to the cathode of the rectifier. This rule applies to a.c.-d.c. as well as a.c. receivers. To prove this basic servicing rule, select one tube, the 6C6 detector; trace from the plate through *R6* and *CH* to the cathode of the 25Z5.

All negative tube electrodes, such as the control grid, suppressor grid and cathode, should trace to the receiver side of the on-off switch.

Another important reference point is the cathode of the tube in the stage under test. You can place one prod of the ohmmeter on the cathode of the 6D6, the other prod on the control grid, and expect continuity. You should find continuity between other points in the grid circuit and the cathode; for example, from the movable contact of *R1* or from the junction of *R1* and *R2*.

To check for continuity in the filament supply circuit, connect the ohmmeter to the two power plug prongs and turn the switch to the ON position. A resistance much lower than 300 ohms (approximately the hot resistance of this circuit) will usually be measured.

Servicing Problems in A.C.-D.C. Receivers. Quite often electrolytic condensers *C12* and *C13* dry out, lose their normal capacitance and acquire a higher power factor; that is, they act as if a large resistance is in series with the capacity. When this occurs, the filter loses its ability to remove ripple, and hum is quite evident.

Reduction of input capacity lowers the over-all output d.c. voltage, and low volume may exist along with hum. When hum and low volume exist, try new electrolytic condensers. A short or excessive leakage in an electrolytic condenser gives the same effect, hum and low volume, and may lower the emission of the rectifier tube. Try a new rectifier tube, but before inserting it test the electrolytic condensers for resistance (each one should be substantially above 50,000 ohms when not shunted by any other part such as the field of a dynamic loudspeaker).

When you encounter distortion in an a.c.-d.c. receiver, check the filter condensers, particularly the output filter condenser, then look for gas in the output tube and for a leaky coupling condenser just ahead of the output tube (*C9* in this circuit). In either case, current will flow through the grid return resistor (*R7*), placing a positive bias voltage on the control grid of the output tube, and linear (distortionless) operation will no longer exist.

The test for gas or a leaky coupling condenser is easily made with a vacuum tube voltmeter or a high-resistance voltmeter. Connect the meter across the grid resistor, with the positive prod on the grid end. There should be no reading. If a reading is obtained, unsolder the coupling condenser. A reading now indicates a gassy output tube, and no reading now indicates a leaky coupling condenser. (In an a.c.-d.c. receiver it is necessary to unsolder the coupling condenser, because removal of the output tube would interrupt filament current and make the entire receiver inactive.)

When a tube is operated with an a.c. potential between filament and cathode, leakage resistance between the cathode and filament can give rise to serious hum. When operated from a 110-volt a.c. wall outlet, all tubes in this receiver circuit will have an a.c. voltage between cathode and filament (normally the capacity between these two electrodes introduces negligible ripple current).

Imagine, however, that the cathode of the 6C6 tube is leaking to the filament. One side

The 25Z5 tube is a twin rectifier tube used as a single diode by connecting corresponding electrodes together. Electrons will flow only from the cathodes to the plates through this tube. For a d.c. outlet the plug must be inserted in a wall outlet so that the plug prong marked + is in the + terminal of the wall outlet. The other prong is then —, as indicated.

Note that during d.c. operation the chassis is connected through switch *SW* to the negative terminal of the source, and the plate of the rectifier tube is connected to the + terminal. All circuit terminals will thus be positive with respect to the chassis.

Some voltage is dropped in rectifier tube and in choke *CH*, but most is dropped in the receiver circuit itself, which may be considered a load connected to *1* and *2*.

Terminal *1*, being nearer the + terminal of the source, is the + terminal of the power pack. As you trace from *1* through the receiver (for example, through *R6*, through the plate-cathode of the 6C6 tube, and through *R4* to the chassis), the positive potential with respect to the chassis diminishes. Point *3* is therefore positive with respect to point *4*, a condition essential for operation of the 6C6 tube.

If you insert the plug incorrectly into the outlet of a d.c. source, *5* will be negative with respect to chassis, hence *5* will be negative with respect to *6*, and electrons will not flow through the rectifier tube. The pilot lamp and tubes glow but the receiver will be "dead"; reversing the plug remedies the condition.

With an a.c. power source, *5* is alternately positive and negative with respect to the chassis. During the half cycle that *5* is positive, the 25Z5 tube is conductive and is furnishing the receiver with a high d.c. voltage. During the other half cycle, the tube is not conductive.

Most of the ripple in the resulting rectified current is eliminated by filter choke *CH* and filter condensers *C12* and *C13*. Note that the filter choke is also the field coil of the dynamic loudspeaker.

Starting with the first tube, let us trace the d.c. supply circuit through the tubes. Imagine, of course, that the tubes are operating, hence conducting.

Assuming that the negative prod of a d.c. voltmeter is on chassis, you can place the positive prod on the cathode of the 6D6 tube, the plate, and terminals *1* and *6* in rotation, and get a voltmeter reading each time. As you progress in this order the reading will become higher.

When you place the d.c. voltmeter between the cathode of the 6D6 tube and the chassis, you will find that the voltage varies as you adjust *R1;* in fact, as the receiver volume decreases this voltage increases. Here we have a volume control using variable C bias as the means of control. The grid gets this C bias from a chassis connection through coil *L2*.

Note that section *b* of *R1* shunts *L1*, for one end of *L1* and the movable contact of *R1* are connected to each other through the chassis. *R1* provides a shunt path for part of the signal current which would otherwise flow through coil *L1*. As *R1* is turned so the resistance in section *a* increases, the resistance in section *b* decreases.

Both sections of *R1* thus contribute to a reduction in volume, for increasing the resistance in section *a* increases the C bias voltage, and decreasing the resistance in section *b* increases the shunting effect across *L1*. Condenser *C6* always shunts *R2* and section *a* in *R1*, and prevents degeneration in the r.f. stage.

In the 6C6 tube stage, terminal *4*, terminal *3* and the junction point of *R5* and *R6* are increasingly more positive with respect to the chassis. The plate-cathode voltage is equal to the main supply voltage (between *1* and *2*) less the drop in *R6* and *R4*.

The drop in *R4* serves as the C bias voltage; note that the chassis end of *R4* goes to the grid through *L4*.

The screen grid voltage is obtained from the main d.c. supply but is reduced by the drop in *R5;* only the screen grid current flows through *R5* to produce this drop. R.F. screen grid current returns to the cathode through *C8* and cathode by-pass condenser *C7*.

A technician would recognize the 6C6 as a detector by the *R6-C9-R7* coupler in the plate circuit and by resonant circuit *L4-C2* in the input; this is a typical r.f. to a.f. coupling arrangement. Furthermore. *R6* is 500,000 ohms, *R5* is 2 megohms and *R4* is 25,000 ohms, indicating low plate and screen grid voltages and a high C bias voltage, all of which are essential for operation as a detector.

In the output stage, the plate supply circuit starts with chassis, continues through *R8*, then goes from cathode to plate, through the primary of *T3* and from *1* through the power pack to *2* and chassis.

The filaments are connected in series to the 115-volt supply, and will function with either a.c. or d.c. power. Let us trace this filament circuit by starting at the + terminal of the power cord plug. From here we go to *out*, bearing in mind the following two important rules for an a.c. receiver:

1. There should be continuity between all positive tube electrodes, such as plate and screen grid, and the *cathode* of the rectifier tube.

2. There should be continuity between all negative tube electrodes (such as the cathode and control grids) and either of the plates of the rectifier tube.

Having located the defective supply circuits by means of voltage measurements, you start a continuity test by attaching one ohmmeter lead to the common power pack terminal (the plate or the cathode of the rectifier tube).

Now place the other ohmmeter lead on the tube electrode terminal. (A reading will not be obtained because the circuit is defective (open) at some point or part between the ohmmeter leads.) Move this ohmmeter lead step by step toward the rectifier tube until the break is located. This is indicated when you get a reading. The circuit path which was just eliminated by moving the probe toward the rectifier tube is open.

Expected Performance. With only one r.f. stage, we should not expect great sensitivity or loud volume on distant stations.

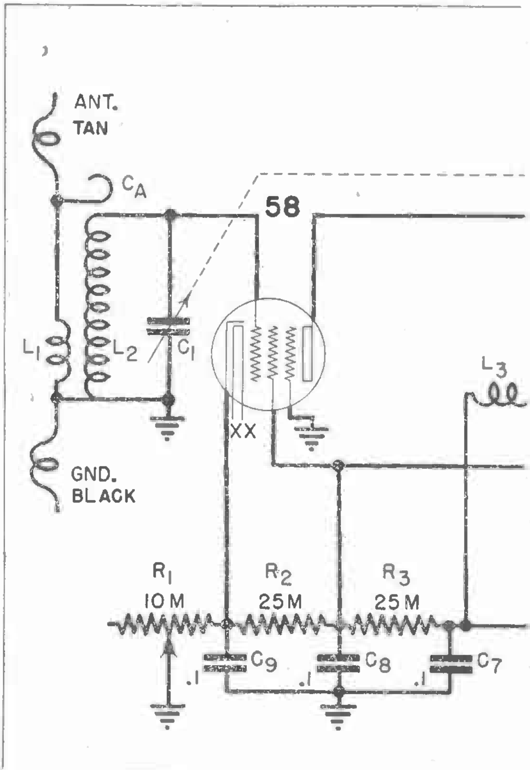
Reception of distant stations can be improved by using a long antenna, but with only two tuning circuits in the receiver, the selectivity will be poor (there may be interference between several stations when tuned to one of them).

The quality of reception can be reasonably good with a receiver of this type. The larger the receiver cabinet and the better the loudspeaker, the better will be the quality.

Servicing Hints. *Hum.* If this receiver has a loud hum, you naturally suspect the filter system of the power pack first. Check electrolytic filter condensers C_{10} and C_{11} by placing other condensers of about the same size across each of them in turn. If this does not change the hum, you know that the existing condensers are all right. You then check the 57 tube in a tube tester for cathode-to-heater leakage, and check for an open in the control grid return circuit of either the 57 or 47 tube.

Squealing. After making sure that tube shields are in place, check screen condenser C_8 by shunting it with a condenser of similar value.

Check the screen grid voltage of the 57 and 58 tubes next, because excess screen grid voltage could cause squealing. If the screen grid voltage is excessively high, R_2 may be open, so check it with an ohmmeter.



VOLTAGES

Chassis frame to

RED	240
BLUE	230
YELLOW	140
GREEN	16
57 PL.	105
58 S.G.	110
58 CA.	2
LINE	115

Hot Resistor. Suppose resistor R_7 is hot and smoking—what would you do? First you would examine the diagram to see what could cause excessive current to flow through R_7. A short in C_{11} could not do this, but a short in C_7 could.

You wouldn't have to unsolder C_7 to make an ohmmeter check—simply measure the resistance between the rectifier filament and chassis. This resistance should be about equal to R_2 plus R_3 (volume control all the way on and the set disconnected from the power line). If you obtain a reading much

Neither filament voltages nor complete filament circuits are shown on the diagram, but if we look up the 58, 57 and 47 tubes on a tube chart, we find that they all have rated filament voltages of 2.5 volts. This means the filaments of these tubes could be connected in parallel, and the *XX* markings on the filament leads and on secondary winding S_3 indicate that parallel connections are used.

According to tube charts, a type 80 rectifier tube requires a filament voltage of 5 volts. A special secondary winding S_1 is provided for the filament of the 80 tube.

The output terminals of the power pack are *1* (+) and *2* (—). From terminal *1*, we trace electron flow to the filament of the 80 tube, from there to whichever plate is positive at the time, through one half of secondary S_2 to the center tap, then through choke coil *CH* (also serving as the loudspeaker field coil) to point *2*. Resistor R_7 and the various tube circuits complete the path for electron flow from *2* to *1*.

For the plate supply circuit of the 58 tube, electrons flow from *2* (the negative output terminal) through R_7 to the chassis, through the chassis to the grounded movable contact of R_1, through one section of R_1 to the cathode of the 58 tube, from the cathode to the plate, and from the plate through L_3 to *1* (the positive output terminal).

Note that resistors R_7, R_1, R_2 and R_3 are all in series between *1* and *2*, thus forming a voltage divider. The voltage across R_2 is the screen grid voltage for the 58 tube, as the cathode and screen grid are connected to opposite ends of this resistor.

For the plate supply circuit of the 57 tube, electrons flow from *2* through R_7 to the chassis, through the chassis to the lower end of cathode resistor R_4, through R_4 to the cathode of the 57 tube, from the cathode to the plate, then through plate load resistor R_5 to terminal *1*.

For the screen grid supply circuit, electrons flow from *2* through R_7 to the chassis, through R_4 to the cathode, then to the screen grid and back through R_3 to *1*.

For the plate supply circuit of the 47 tube, electrons flow from *2* through R_7 to the chassis, through the chassis to the center tap of S_3, through the filament leads to the filament of the 47 tube, then to the plate and through the primary of output transformer T_1 to *1*. The screen grid supply circuit is the same as the plate supply circuit of this tube, except that the screen grid current does not go through the output transformer.

Voltage Measurements. In the table of voltages alongside the circuit diagram, all d.c. values are to be measured between the specified point and the chassis, with the black (negative) lead of the d.c. voltmeter going to the chassis. Measured values which are about 10% above or below the specified values can usually be considered satisfactory.

The first value in the table, 240 volts between the *RED* lead and chassis, is the power pack d.c. output voltage (between *1* and *2*) less the small voltage drop across R_7. Ten per cent of 240 is 24, so a measured value 24 volts above or below the normal value of 240 volts does not indicate trouble.

Moving to the *BLUE* plate lead of the 47 output tube, we measure its plate voltage and should get 230 volts, because there is a d.c. voltage drop of about 10 volts across the 500-ohm resistance of the primary of output transformer T_1.

The value of 140 volts between the *YELLOW* lead and the chassis represents the d.c. voltage drop across R_7 and choke *CH*.

The 16-volt value between the *GREEN* lead and the chassis is the voltage drop across R_7, which provides the C bias voltage for the 47 output tube. For the last two measurements, the voltmeter test probes must be reversed, with the positive probe going to the chassis.

When measuring between the plate of the 57 tube and the chassis, an ordinary d.c. voltmeter (having a sensitivity of 1000 ohms per volt) will read only 105 volts. A higher-resistance voltmeter would read a much higher d.c. voltage, higher than the screen grid voltage but still less than the power pack output voltage because of the drop in plate load resistor R_5.

The screen grid-to-chassis voltage of 110 volts for the 58 tube also applies to the 57 tube. This screen grid voltage is established by voltage divider network R_1-R_2-R_3. Since R_1 is a part of this network and since it is variable, all voltage measurements should be made with R_1 fully advanced (for greatest sensitivity and hence greatest volume). Under this condition, R_1 has a minimum resistance of about 250 ohms, which is necessary to prevent the C bias voltage of the 58 tube from becoming zero.

No value is given for the plate voltage of the 58 tube, since it is essentially the same as the voltage between terminal *1* and the chassis (240 volts). The d.c. voltage drop across L_3 is negligibly small.

A measurement between the cathode of the 58 tube and chassis indicates 2 volts; this is the minimum negative bias provided by R_1. As the volume control setting is reduced, this bias voltage is increased correspondingly.

Continuity Tests. When lack of expected voltage indicates absence of continuity, the radio technician makes continuity tests with an ohmmeter while the power cord plug is

TYPICAL RECEIVER DIAGRAMS AND HOW TO ANALYZE THEM

SCHEMATIC circuit diagrams of radio receivers can tell you many highly practical facts once you learn how to analyze these diagrams. The complete story of a radio receiver is condensed into its circuit diagram, with every path for signal currents and supply currents clearly shown. One glance at a diagram is enough to tell you how many tubes there are in the receiver. With a bit more study, you can find out how many other parts there are and what the electrical size of each part is.

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It is the ability to read a complete diagram, however, which makes it possible to concentrate on one section, stage or circuit of a receiver and still appreciate its relationship to the rest of the receiver.

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One important fact to recognize is that schematic circuit diagrams give electrical connections without showing actual positions of wires. Two parts which are close together on a schematic diagram may actually be at opposite ends of a receiver chassis, even though the electrical connections on the chassis are exactly the same as those on the diagram.

Although a schematic diagram is drawn without regard for actual positions of parts on a chassis, it enables you to find any part on a chassis because it indicates easily-located parts or terminals to which the leads of the desired part are connected. With the practice which you will get from studying the diagrams in this book, you should quickly learn how to find any desired part on an actual chassis.

A knowledge of what stages are in a particular receiver and how these stages operate is oftentimes highly important in the

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speedy servicing of the receiver. This means that while you are developing your ability to analyze circuit diagrams through the study of this reference book, you are also developing your ability to service radio equipment speedily. Actually, this reference book teaches you how to make schematic circuit diagrams become one of your most valuable servicing tools.

How The Diagrams Were Chosen. In choosing the diagrams for this book from the N.R.I. file of over 12,000 different radio receiver diagrams, both old and new circuits were carefully considered. Each diagram finally chosen for detailed analysis is typical of one group of receivers encountered in radio work. This means that by studying the few carefully selected circuits, you will actually become familiar with the general features of hundreds of different receivers.

The diagrams in this book are arranged so that you progress logically from simple circuits to more advanced circuits. You start with a simple t.r.f. circuit which was extremely popular some years ago and is still used in some midget table model receivers, but you soon get to the modern superheterodyne circuits which are the leaders in popularity today.

Diagram Styles. Each receiver manufacturer has his own style of drawing radio symbols and circuit diagrams. In order to make you familiar with these different styles, the diagrams in this book are presented almost exactly as they appear in the service manuals of the respective manufacturers. For this reason, many of the symbols in this book will look quite different from the symbols you have become so familiar with in regular N.R.I. lessons.

Curiously enough, you will find that no matter how the various radio symbols are drawn, you will be able to recognize them almost instantly. Sometimes their positions with respect to other parts will identify new symbols even though they appear entirely different from standard symbols. A comparison of the different ways in which tube symbols are drawn is itself a fascinating study.

General Outline. The analysis of the first receiver circuit in this book is divided into the following seven sections. The same general treatment is followed for the other circuits in the book, except that sometimes one or more of the sections are omitted to avoid repetition of basic facts which have already been covered.

1. **Identifying Tubes.** Identification of each tube stage by noting its position in the diagram with respect to the antenna, the loudspeaker, the power pack and other parts, followed by identification of the general type of receiver.

2. **Tracing Signal Circuits.** Study of the signals in each circuit, starting from the antenna and working to the loudspeaker. You deal with signal flow, signal voltages and signal currents now, without considering electrons and the direction of electron flow at all.

3. **Tracing Supply Circuits.** Tracing circuits to see how each tube electrode gets its d.c. operating voltage. You are concerned with the direction of electron flow only when it is necessary to determine the correct polarity for d.c. measurements.

4. **Voltage Measurements.** Explanation of voltage values given by the manufacturer.

5. **Continuity Tests.** Suggestions for finding breaks in circuits.

6. **Expected Performance.** What can be expected in the way of tone quality, volume, distant-station reception, and ability to separate stations.

7. **Servicing Hints.** Common defects which can occur in the receiver circuits, with clues for recognizing them and suggestions for clearing up the trouble.

Plan To Review Later. In your study of this reference book, you will occasionally encounter circuits and technical phrases which have not yet been taken up in your regular lesson texts. In such cases, simply pass over the things you cannot understand, with the thought that you will review this reference book after you have completed your FR Course and mastered all of the fundamental radio principles and basic radio circuits. Such a review will more than double the value of this reference book to you.

Rather than attempt to study this entire reference book at one time, it is suggested that you spread the study of this book out over several lessons. In other words, study only one diagram after a lesson. In this way, your mind can concentrate upon the essential information in one receiver diagram without mixing it up with other circuits.

BELMONT Series 40A Four-Tube T. R. F. Receiver

IDENTIFYING Tubes. We recognize the type 80 tube as the *rectifier* tube, for it is connected directly to T, the power transformer.

We next locate the tuning circuits which are controlled by the gang tuning condenser. There are only two: L_2-C_1 and L_4-C_2, so the type 58 tube which is between these tuning circuits is an *r.f. amplifier* tube.

The output tube always connects to the loudspeaker through an iron-core output transformer, so the type 47 tube must be the *audio output* tube.

Now there is only one tube left to identify. We know that it receives an r.f. signal from the second tuning circuit (L_4-C_2), and that it must deliver an a.f. signal to the type 47 audio output tube, so we naturally conclude that the type 57 tube is the *detector*.

We thus have one r.f. amplifier stage, a detector, an audio output stage and a rectifier. There being no oscillator tube and no i.f. amplifier stages, we can say definitely that this Belmont receiver is of the tuned radio frequency type.

Tracing Signal Circuits. Instead of antenna and ground terminals, a short length of *tan* wire serves for the antenna lead-in connection, and a similar length of black wire serves for the ground wire connection.

When a modulated r.f. signal current is picked up by the receiving antenna, it flows through primary winding L_1 to ground, inducing a corresponding modulated r.f. voltage in secondary L_2.

At the same time, some modulated r.f. current will flow directly from the antenna to coil L_2 through capacity C_A. This capacity is provided by a short length of insulated wire connected to the "hot" end of L_1 (the end farthest from ground), and wound partly around L_2 to give capacitive *link coupling*. More uniform transfer of r.f. signals over the entire tuning range is obtained by using both inductive and capacitive coupling in this way.

Tuning in a station (by turning the tuning knob) makes sections C_1 and C_2 of the gang tuning condenser have the correct values to bring both tuning circuits (L_2-C_1 and L_4-C_2) to resonance. The tuning circuits thus provide resonant step-up of the desired signal voltage and provide rejection of undesired signals.

The modulated r.f. signal voltage existing across L_2 and C_1 is applied between the control grid and cathode of the 58 r.f. amplifier tube, with the path to the cathode being completed through the chassis and r.f. bypass condenser C_9.

This voltage causes the plate current of this tube to vary above and below its normal direct current value at an r.f. rate. This r.f. plate current flows through coil L_3, which is *weakly* coupled inductively with coil L_4 in the second tuning circuit. The flow of r.f. plate current through L_3 induces the modulated r.f. signal voltage in L_4, and this undergoes resonant step-up in the second tuning circuit.

There is also some transfer of signals to tuning circuit L_4-C_2 through coupling condenser C_3, in such a way as to make the performance of the receiver more nearly uniform over the entire broadcast band.

The modulated r.f. voltage across L_4 and C_2 is applied between the control grid and cathode of the 57 tube, with C_6 and the chassis completing the path from cathode to C_2.

Bias resistor R_4 has a value of 25,000 ohms, which is high enough to make the 57 tube act as a detector. C_4 provides a shunt path to the cathode for r.f. signals in the plate circuit, so that the energy of the r.f. signal is dissipated in the tube, and only the desired audio signals flow through plate load resistor R_5.

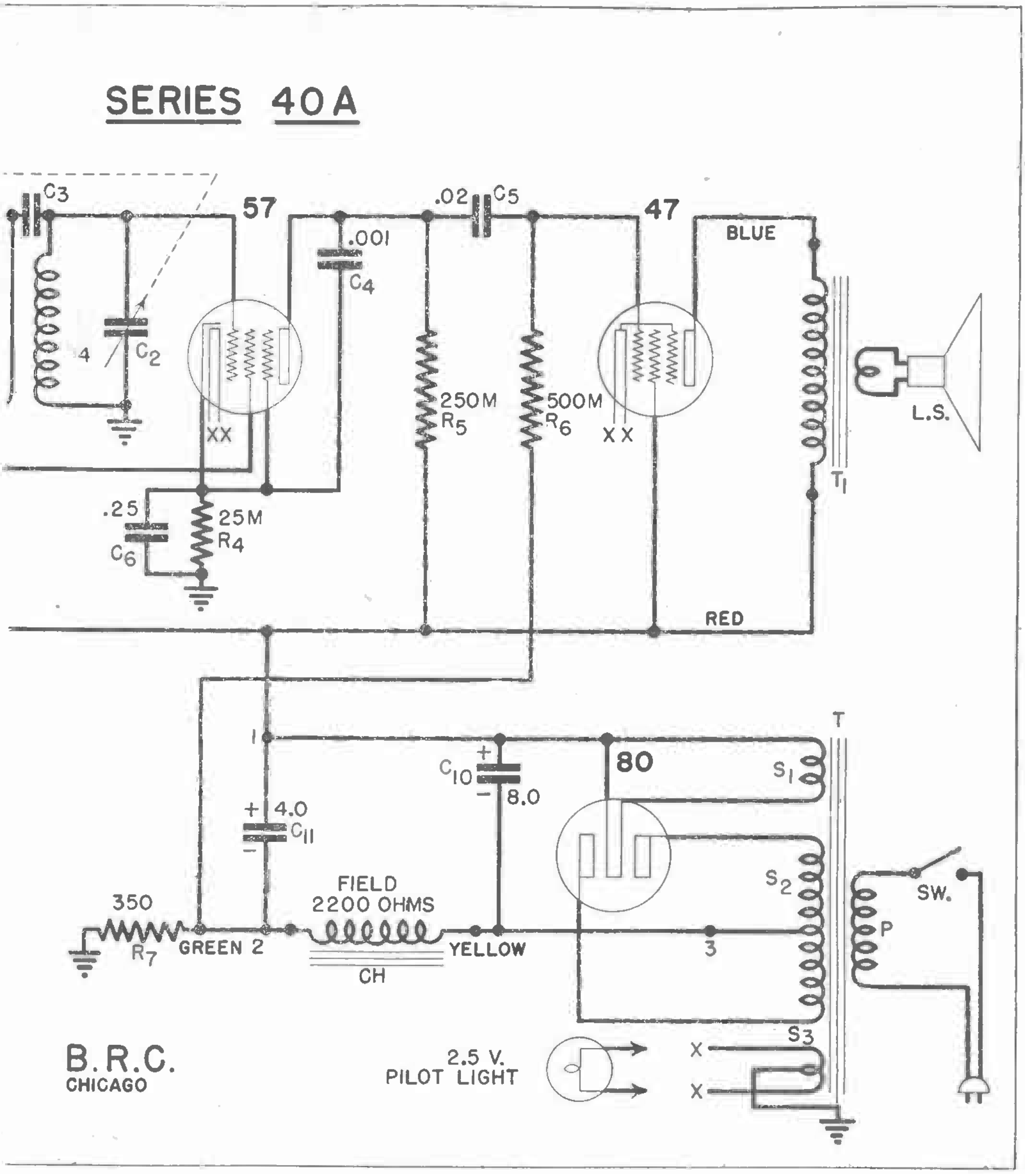
The a.f. voltage across R_5 is applied to resistor R_6 through coupling condenser C_5 and power pack filter condenser C_{11}. Both have low reactance at audio frequencies.

The a.f. voltage across R_6 is applied between the control grid and filament (acting also as cathode) of the 47 output tube, with the path from R_6 to the filament completed through R_7, the chassis and the filament wires which run from terminals XX on S_3 to filament terminals XX of the 47 tube.

The 47 output tube is a power tube, in that it converts normal grid voltage variations into large variations in the plate current. This a.f. grid voltage causes a large a.f. plate current to flow through the primary of output transformer T_1 on its way back to the filament through C_{11}, R_7, the chassis, S_3, and the filament leads of the 47 tube.

The induced voltage in the secondary of this step-down transformer T_1 sends a large a.f. current through the voice coil of the loudspeaker.

Tracing Supply Circuits. Since our receiver has a power transformer, it is an a.c. receiver. The table of *VOLTAGES* specifies 115 volts for the *LINE* voltage, but a receiver like this will work satisfactorily on line voltages anywhere between about 105 volts and 125 volts a.c.



lower than the 50,000-ohm normal value, you would test C_7 thoroughly.

Conclusion. These examples show you how radio servicemen use circuit diagrams to aid in locating trouble and making repairs in radio receivers. You are not expected to be able to make an analysis of this nature for a long time yet, but as you become familiar with the various circuits in common use and as you secure practice in reading and analyzing circuit diagrams, you will eventually find yourself able to get equally as much information from a circuit diagram.

Fig. 1. Schematic circuit diagram of Belmont Series 40A t.r.f. receiver. Numbers alongside resistors represent resistance in ohms; thus, R_7 is 350 ohms, and R_3 is 25,000 ohms. (The letter M after a resistance value represents "thousand.") Numbers alongside condensers represent capacity in microfarads; thus C_4 is .001 mfd., and C_{10} is 8.0 mfd. Solid black dots represent connections or terminals; no dots at cross-overs of lines mean no connections. An antenna 50 to 75 feet long will probably give best results in rural locations, but in cities a short antenna is usually best.

EMERSON BA-199 FIVE-TUBE A.C.-D.C. T.R.F. RECEIVER

THIS Emerson model BA-199 receiver consists of one r.f. amplifier stage using two tuned circuits, a detector and an audio output stage, all receiving d.c. operating voltages from a half-wave rectifier.

Tracing Signal Circuits. This receiver is referred to in the diagram as a 5-tube a.c.-d.c. receiver, on the basis that ballast tube *R3* is a tube. Calling a ballast a tube was once considered proper, but today only tubes in signal and supply circuits, operating by virtue of electron emission, are considered as tubes. Actually, this is a 4-tube radio receiver.

This receiver is a midget of the portable type and can be taken from room to room or to any location where 115-volt a.c. or d.c. power is available. A flexible insulated wire, permanently connected to the receiver, serves as the antenna. This wire can be hung around the room or connected to a heating radiator or some metal object in the room. This is information not given in the diagram, but worth knowing when you run across a.c.-d.c. receivers.

This antenna connects to primary winding *L1* of antenna transformer *T1* through condenser *C3*. The other end of *L1* is grounded to the receiver chassis, which in turn connects to one end of the power line through switch *SW*. The power line is used as the ground. As a rule, one of the power line wires is grounded somewhere in the house; even if it were not, its long length and its proximity to the earth would make it highly suitable for a ground.

We now realize that the chassis is connected to the power line. This means that to avoid a possible serious shock, you must keep your hands off the chassis whenever the receiver is in operation.

Condenser *C3* prevents winding *L1* from burning out if the antenna wire touches some grounded object. Without this condenser, the line plug might be inserted into the wall outlet in such a way that the chassis connects to the ungrounded side of the line. Then *L1* would be directly across the power line and would be burned out.

The r.f. current in *L1* induces an r.f. voltage in *L2*. The voltage across *L2* is stepped up due to resonance when *C1* is tuned. (Condensers *C4* and *C5* are trimmer condensers.) Capacitive link *C15* helps equalize gain over the tuning range.

The 6D6 tube amplifies the r.f. signal, so that the r.f. current in the plate circuit is greater than the r.f. current in *L2-C1*. This r.f. current is stepped up by the second r.f. transformer, and the r.f. voltage across *C2* is greater than across *C1*.

As a detector, the type 6C6 tube demodulates the modulated r.f. signal, producing an audio voltage across *R6*. Radio frequency signals resulting from detection are kept out of *R6* by by-pass condenser *C14*.

Observe that one end of *R6* goes to the chassis through condenser *C13*, a 16-mfd. electrolytic condenser. Resistor *R7* terminates at the chassis, with its other end going to the grid of the 25L6 pentode output tube and to the plate of the 6C6 tube through condenser *C9*. Thus, at all but low audio frequencies *R7* shunts *R6*.

The audio voltage across *R7* is fed to the 25L6 output tube. The cathode of the 25L6 tube goes to the chassis through *R8*, thus completing the grid circuit.

Audio current flowing in the plate circuit of the output tube passes through the primary of output transformer *T3*, flows to the chassis through *C13*, and returns to the cathode through *R8*. Transformer *T3* couples the loudspeaker to the output tube, and is designed to furnish the loudspeaker with maximum possible undistorted power.

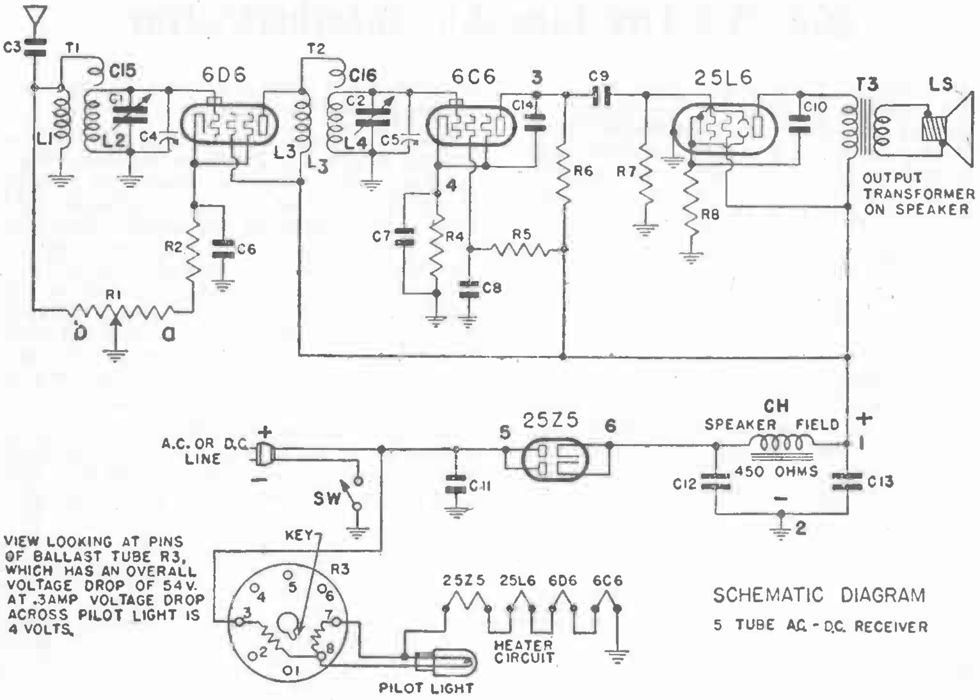
Beam power output tubes have high plate resistance, which makes them unstable when the load (the loudspeaker) is subject to a great range in load conditions. Leakage inductance, which is especially high in an inexpensive output transformer, will cause feed-back and produce undesirable oscillation, often inaudible.

Condenser *C10* is used between the plate and cathode of the 25L6 beam power output tube to by-pass higher audio frequencies. This suppresses oscillation and prevents unstable operation, since the plate load is made capacitive at those frequencies at which oscillation might occur.

Undesired signals getting into the plate circuit produce across *R8* a voltage which, being out of phase with the grid signal voltage, cuts down the undesired signals by degeneration. The desired signal is also partially weakened, but its original strength is sufficient to permit degeneration. Distortion is greatly reduced by degeneration, for undesired harmonics of the signal are attenuated.

Noise signals coming over the line are bypassed by *C11*, and do not get into the power supply and the receiver output.

Tracing Supply Circuits. All items in the lower part of the diagram are in the power pack. In this power supply, terminals *1* and *2* serve as the high-voltage d.c. source for all positive tube electrodes in the main receiver circuit.



of the filament will be grounded, so it it leaks little hum results; should the other side of the filament leak to the cathode, then the 6 volts across the 6C6 filament will be across *R4*, and an a.c. voltage gets into the grid and plate circuits.

Note that one end of the filament circuit is grounded, hence those tubes which are connected farthest away from the ground end will introduce a greater a.c. voltage. The detector tube is most affected by cathode leakage, hence its filament is connected nearest to ground.

The output stage will give the least amplification of a.c. leakage voltage so its filament is placed third from the ground. Tubes should be checked in a tube tester for cathode -filament leakage when you encounter hum troubles.

Should squeals or oscillations exist, shunt *C13* with a condenser of similar value to see if this cures the trouble. If it does, the original *C13* is open and should be replaced. Be sure the full length of the antenna is used because a short pickup will not sufficiently load the input circuit, and the least amount of feed-back will cause oscillation. Also, be sure to check *C8* and *C14* by substitution or by shunting with equivalent capacities.

Fig. 2. Schematic circuit diagram of Emerson Model BA-199 five-tube universal a.c.-d.c. receiver. The parts list for this set is given below, essentially as it appears in the manufacturer's service sheet. Note that this manufacturer uses the abbreviation mf. for microfarads, in place of mfd.

T1	Broadcast antenna coil
T2	Broadcast detector coil
T3	Output transformer
R1	Volume control—75,000 ohms, with line switch SW
R2	240-ohm, 1/2-watt wire-wound resistor
R3	Plug-in ballast tube
R4	25,000-ohm, 1/4-watt carbon resistor
R5	8-megohm, 1/4-watt carbon resistor
R6, R7	500,000-ohm, 1/4-watt carbon resistor
R8	110-ohm, 1/2-watt wire-wound resistor
C1, C2	Two-gang variable condenser
C3	.001-mf., 600-volt tubular condenser
C4, C5	Trimmers, part of variable condenser
C6, C8	.1-mf., 200-volt tubular condenser
C7	.25-mf., 200-volt tubular condenser
C9	.02-mf., 400-volt tubular condenser
C10	.05-mf., 400-volt tubular condenser
C11	.1-mf., 400-volt tubular condenser
C12, C13	Dual 16-mf., 100-volt dry electrolytic condenser
C14	.002-mf., 600-volt tubular condenser
C15, C16	Gimmicks
LS	Loudspeaker (electrodynamic)

RCA T5-2 Five-Tube A.C. Superheterodyne

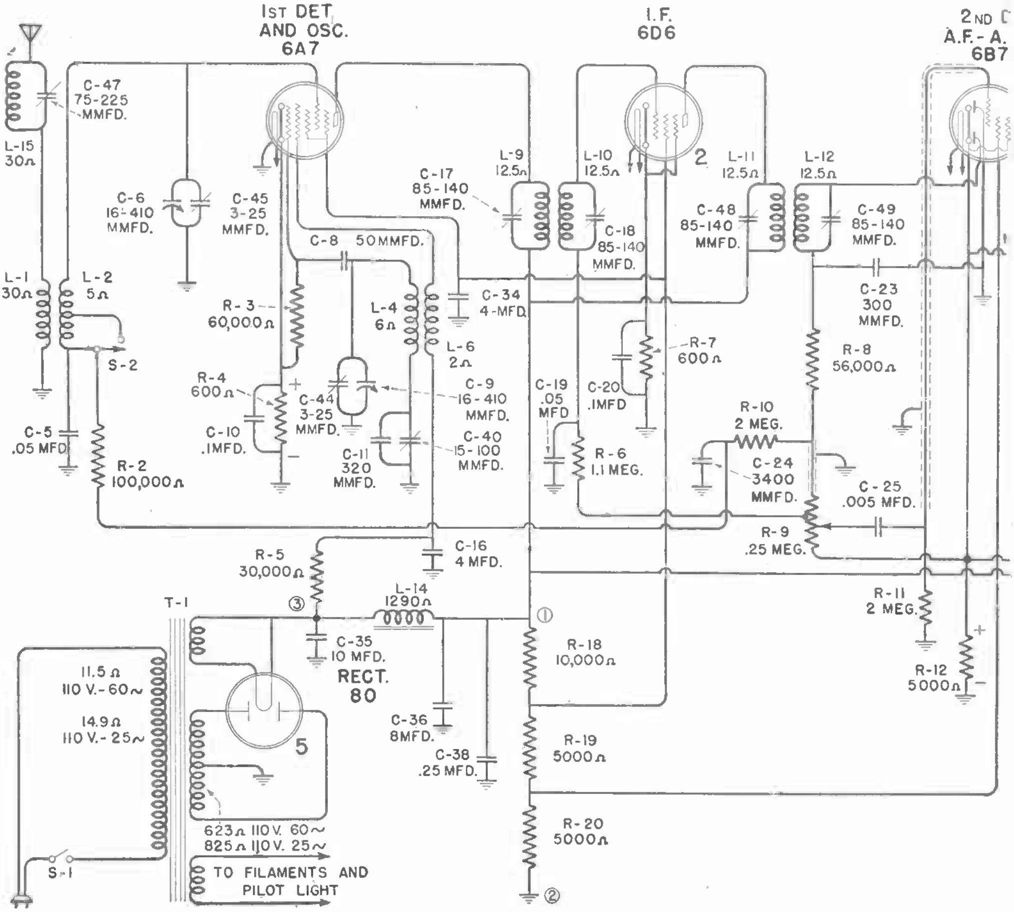
GENERAL Description. This is an a.c.-powered superheterodyne receiver employing five tubes: an 80 rectifier, a 6A7 frequency converter, a 6D6 i.f. amplifier, a 6B7 second detector-a.v.c. and audio amplifier, and a 41 power output amplifier. The circuit is conventional in most respects.

Tracing Signal Circuits. In analyzing this receiver we will trace the essential sections of a superheterodyne, namely, the preselector, frequency converter, i.f. amplifier, second detector and audio amplifier.

Preselector. A simple input circuit is used, consisting of a tuned transformer and an i.f. wave trap. The antenna signal sets up a current in primary coil *L-1*. Should interference at the i.f. value of 460 kc. be present, the wave trap consisting of *L-15* and *C-47* will present a high resistance and thereby reduce the interference current in *L-1*.

The r.f. current flowing in *L-1* induces a voltage in coil *L-2*. Trimmer condenser *C-45* in shunt with tuning condenser *C-6* is connected to coil *L-2* through condenser *C-5*. *C-45* has a capacity of 3-25 mmfd. and hence is a trimmer, while *C-6* has a capacity of 16-410 mmfd.; the arrow indicates it is a tuning condenser. *C-5* has a capacity of .05 mfd. (50,000 mmfd.), more than 100 times that of *C-6*. For this reason we may say that the reactance of *C-5* is negligible with respect to *C-6*, and *L-2* and *C-6* with trimmer *C-45* form the basic tuning circuit.

As we shall see later, the grid return of *L-2* is not directly grounded, in order that the a.v.c. voltage can feed through it to the grid of the 6A7 tube. As far as r.f. currents



to provide normal induced voltage. The 25-cycle transformer is larger and heavier than a 60-cycle transformer with the same voltage rating.

One low-voltage secondary supplies power to the filament of the 80 rectifier, and the other low-voltage secondary feeds all other tube filaments in parallel. Note the usual method of leaving out the filament connections, but indicating connections by ending short leads in arrows.

Note also that the left-hand filament lead of the 6A7 tube does not terminate in an arrow, but goes to ground. Though there is nothing to show it, this lead connects to the low-voltage winding just as do the others. You can assume this because every filament circuit in a receiver must be complete. The ground symbol is not a mistake, however, for one side of the filament is grounded to prevent r.f. pick-up.

The ends of the high-voltage secondary go to the plates of the 80 rectifier tube, while the center tap is connected to the chassis.

Choke coil *L-14* (the field of the loudspeaker), and condensers *C-35* and *C-36* are the power pack filter which terminates in the voltage divider, consisting of *R-18*, *R-19* and *R-20*.

Note that condenser *C-36*, an electrolytic condenser, is shunted by *C-38*, a .25-mfd. capacitor which is a paper condenser. (The capacity values are the clue to the condenser type.) Electrolytic condensers lose effectiveness as the frequency goes up. At high audio and radio frequencies, *C-36* may not be a good capacitive shunt on the voltage divider. Including a paper condenser insures low reactance at these frequencies.

The voltage divider serves to furnish the lower electrode voltages, but the plate-chassis voltage supply for all tubes terminates across the total voltage divider (terminals *1* and *2*).

Tracing Supply Circuits. Let us trace the d.c. supply voltages to terminals *1* and *2* for each stage in turn.

6A7 Converter. Starting with the plate, trace through *L-9* to point *1* in the power pack output. From point *2*, the chassis, continue through resistor *R-4* in the cathode circuit of the 6A7 to the cathode of this tube.

The voltage drop across *R-4* is used to bias the detector section of the 6A7 tube. The grid connection is made from the chassis end of *R-4* through *R-12*, *R-9*, *R-10*, *R-2* and *L-2* to the fourth grid of the 6A7 tube.

The a.v.c. voltage across *R-9* is added to the normal C bias voltage developed across *R-4*. The voltage across *R-12*, serving as C bias for the 6B7 pentode section, is included in this circuit and has an opposite polarity, hence the voltage across *R-4* must be made great enough to compensate for it and give the fourth grid a net negative bias with respect to its cathode even when the a.v.c. is not working.

Grid *2* is the anode for the oscillator section of the 6A7 tube. Trace through *L-6* and *R-5* to point *3* in the power pack. At point *3* the voltage is positive with respect to the chassis, and higher than point *1* by the drop in coil *L-14*. Considerable ripple exists at *3*, but is eliminated by filter *R-5* and *C-16*. *R-5* also reduces the oscillator anode voltage to the desired value.

Grid d.c. voltage is secured by self-rectification of grid current, with the current building up the d.c. voltage across *R-3*. Ripple is filtered out by *C-8*, which connects back to the cathode end of *R-3* through *L-4*, *C-11* and *C-10*. In this way the grid-cathode of the oscillator section receives its C bias. Since there is no conductive path for the voltage developed across *R-4* (it is blocked by *C-8* and the low-frequency padder), this voltage in no way influences the operation of the oscillator.

6D6 I.F. Amplifier. Here the plate connects directly to point *1* through coil *L-11*. Point *2* connects to the cathode through resistor *R-7*, which supplies the minimum C bias for the i.f. amplifier. The grid return is through *L-10*, *R-6*, *R-9* and *R-12*. Again the bias established by *R-7* must be large enough to overcome the opposing voltage across *R-12*.

Since the screen grid voltage should be less than the plate voltage, it is connected directly to a tap on the voltage divider, at the junction of *R-18* and *R-19*. (The screen grid of the 6A7 tube is likewise connected to this point in the voltage divider.) *C-34* serves as the screen by-pass, and also prevents any power pack ripple voltage from being applied to the screen grids.

6B7 A.V.C. Detector and First A.F. From the pentode plate, trace through resistors *R-13* and *R-15* to point *1* of the power pack. With 260,000 ohms in the plate circuit, the net plate-cathode voltage is lower than the power pack d.c. voltage. Resistor *R-12* in the cathode circuit furnishes the C bias for the pentode section of the tube. The grid return is through *R-11*.

Screen voltage for the 6B7 is obtained by a connection to the junction of *R-19* and *R-20* in the voltage divider. Note the lack of a screen by-pass condenser. Normally one would be used, but since the circuit is stable it has been omitted.

41 Power Output Tube. The plate connects to point *1* through the primary of the output transformer *T-2*. The screen grid connects directly to point *1*. Resistor *R-17* develops the C bias voltage as the result of screen and plate current flowing through it; its negative potential with respect to cathode is applied to the control grid through resistors *R-16* and *R-14*.

Alignment. The equipment required is a serviceman's signal generator (oscillator) and some type of output indicator.

To align the receiver, first connect the output indicator. The connection will vary with the type used. A low-range (0-7.5 volts) copper-oxide rectifier type a.c. voltmeter would be connected *across the voice coil*. A high-range (0-75 volts) a.c. voltmeter with a series blocking condenser would be connected *from the plate of the 41 tube to chassis*. A high-resistance d.c. voltmeter or a vacuum tube voltmeter would be connected *across the volume control*, which is the diode load. The negative lead of the d.c. meter would be connected to the junction of *R-10* and *R-9*. All adjustments except the wave trap are to be made for maximum output.

For all adjustments, the ground lead of the signal generator is to be connected to the receiver chassis, which may or may not have a direct connection to ground via a cold water pipe or whatever you use for a ground in your shop.

The i.f. amplifier is to be adjusted first. so the ungrounded (hot) lead of the signal generator is clipped to the top cap of the 6A7 tube. The signal generator is tuned to the i.f. value of 460 kc. Trimmer locations and aligning frequencies are given in Fig. *4*.

Tune the receiver to the low-frequency end of the dial. If squealing is noted, due to a station beating with the signal generator, change the tuning dial setting slightly so only the modulated tone of the signal generator is heard.

The volume control (attenuator) of the signal generator is adjusted to give a noticeable deflection on the output indicator, and the receiver volume control is turned on full. (The receiver volume control setting won't affect the vacuum tube voltmeter or high-resistance d.c. voltmeter readings, and can be turned down if you don't want to hear the modulated tone of the signal generator during alignment.)

Everything is now ready for i.f. alignment, and you simply adjust the i.f. trimmers in turn for greatest output indication. If the output meter tends to read off scale, use a higher range or reduce the output of the signal generator. While the order of trimmer adjustments isn't of real importance, the usual procedure is to work from the second detector back to the first detector, adjusting *C-49*, *C-48*, *C-18* and *C-17* in the order named. Their locations are shown in Fig. *4*. This completes the i.f. amplifier alignment.

The hot signal generator lead is now shifted to the aerial post of the receiver. The dial is set to the lowest broadcast band frequency, and switch *S-2* is opened. The signal generator is still producing 460 kc. Trimmer *C-47* is now adjusted for *minimum* output as shown on the output indicator. Now any i.f. interference picked up will not produce appreciable output.

Leave the signal generator connections as they are, and tune both signal generator and receiver to 1720 kc. (at the high-frequency end of the broadcast band). Oscillator trimmer *C-44* is adjusted so greatest output is obtained when the receiver is tuned exactly to the same dial marking as the signal generator. Preselector trimmer *C-45* is then adjusted for maximum output. This completes the preselector and oscillator high-frequency adjustments.

The signal generator and receiver are next tuned to 600 kc. (at the low-frequency end of the broadcast band). Padder condenser *C-40* is then adjusted for maximum output. The receiver dial setting is moved slightly above and below 600 kc., *C-40* being readjusted at each setting. The setting giving greatest output is finally chosen, even though it may not be exactly 600 kc., as perfect alignment is not always obtained in a home receiver. The high-frequency adjustment of *C-44* only is repeated, followed by any necessary readjustment of *C-40* at 600 kc. This completes the alignment, since no police band trimmers are provided.

Voltage Measurements. It is a simple matter to check the operating voltages with the aid of Fig. *4*. The arrows show in each case where to place the two voltmeter test probes. The indicated voltages enable you to choose a voltmeter range which will not be overloaded by the particular voltage you intend to measure.

An a.c. voltmeter is used to measure all heater voltages and the a.c. plate voltages of the rectifier. All other measurements are made with a d.c. voltmeter.

If your d.c. voltmeter has a sensitivity of 5000 ohms per volt or better, the plate voltage of the 6B7 pentode, marked in Fig. *4* with an asterisk (*), can be measured. With a low-sensitivity d.c. meter of 1000 ohms per volt the reading will be considerably less, as the current drawn by the meter will reduce the plate voltage while the meter is connected. This is due to the increased voltage drop across resistors *R-13* and *R-15* in the plate supply circuit.

The important thing is to know what to expect with the meter you employ. When using the d.c. voltmeter, you will connect its leads so the meter will read up-scale. You should by now know whether a tube electrode is positive or negative with regard to some other point. If you make a mistake and the meter reads down-scale, nothing will be damaged—simply reverse the meter test probes.

ser *17* and the lower tapped portion of the i.f. secondary. The phase of the feed-back voltage induced into the tuned secondary is such that it aids the original signal. This greatly strengthens the signal applied to the grid-cathode input of the second detector. In other words, we have regeneration of the i.f. signal.

Condenser *17* is adjustable, so we can feed back into the grid circuit more or less of the energy developed across resistor *19*. Increasing the capacity of *17* results in more feedback and increased regenerative effects. Too great an increase will cause oscillation and receiver squealing, however.

With the strengthened i.f. signal applied to the input of the second detector, satisfactory rectification will take place in the grid circuit. When the signal makes the grid positive, electrons flow from the cathode to the control grid, through the 4-megohm resistor and back through the secondary of the i.f. transformer to the chassis and cathode. As a result, we will have audio signal voltage appearing across the 4-megohm resistor. I.F. variations are by-passed across the resistor by means of the gimmick condenser.

This audio voltage, as you can see, is in the grid input circuit of the second detector. The tube amplifies the audio signal, and large variations occur in the plate current at an audio rate.

The amplified audio signal voltage appears across plate load resistors *19* and *22*, and all i.f. variations are by-passed around load *22* by the .001-mfd. condenser marked *20*. The audio signal voltage across *19* is not transferred to the 6F6G tube, and hence is wasted or lost. Resistor *22* is 24 times larger than *19*, hence will have 24 times as much a.f. across it. The a.f. loss in resistor *19* is thus relatively small and can be neglected.

The audio signal across plate load resistor *22* appears across the 6F6G grid resistor, marked *23* in the diagram. The signal is applied across this resistor through .015-mfd. audio coupling condenser *20* and through the 4-mfd. output filter condenser marked *29*. The voltage across resistor *23* is applied directly to the 6F6G grid and cathode through by-pass condenser *28*.

Variation in the grid voltage of the 6F6G output tube causes a large variation in plate current through the primary of output transformer *25*. This transformer has the correct turns ratio to match the loudspeaker voice coil impedance to the plate resistance of the output tube. The voltage induced into the secondary causes a large current flow through the voice coil and, as a result, the voice coil and attached cone moves in and out, producing sound.

Condenser *24*, connected to the plate of the output tube, by-passes around the plate load high audio frequencies which otherwise might feed back into the control grid circuit and cause audio oscillation. Condenser *28* completes the connection between condenser *24* and the cathode.

Tracing Supply Circuits. The bias voltage for the first detector-oscillator tube is obtained by means of a drop occurring across cathode bias resistor *6*. The end of the resistor connected to terminal *4* of the oscillator pick-up coil is at d.c. chassis potential, and is negative with respect to the end connected to the cathode. Therefore, the control grid of the tube, which is at d.c. chassis potential, is negative with respect to the cathode.

When we say a part or point is at d.c. chassis potential we mean that there is no d.c. voltage beteen that point and chassis. In other words, a d.c. voltmeter connected between the point in question and the chassis would read zero d.c. volts.

The screen voltage for the detector oscillator tube is obtained from a voltage divider which consists of resistors *12* and *8*. The screen of the tube is kept at r.f. ground potential by means of screen by-pass condenser *9* because this condenser acts as a short circuit as far as r.f. and i.f. are concerned.

The plate of the tube is supplied from the output of the power pack through the primary of i.f. transformer *14*.

Self-bias, due to grid current flow, is employed in the second detector circuit. When no signal is tuned in, the control grid of the second detector receives an intial negative bias due to convection current caused by electrons striking the grid and flowing through the grid circuit instead of passing on to the plate.

These electrons then flow through resistor *16*, producing a voltage drop across it. The number of these electrons is few but the high value of resistor *16* makes the result appreciable.

When an i.f. signal is applied to the tube input, the grid draws current whenever the signal makes the grid positive with respect to the cathode. The grid current will vary with the strength of the signal. The greater the grid current flow, the more negative the grid-cathode voltage becomes. This current and the voltage produced by it will have an average value, and this determines the grid voltage and the operating point of the tube.

The screen grid of the second detector tube is supplied through resistor *18*. The screen is kept at r.f. ground potential by means of the .09-mfd. condenser which, like the first detector screen by-pass, is marked *9*. Thus we know that the two .09-mfd. screen by-pass condensers for the first and second detectors are in the same container, since they have the same identifying number.

The plate of the second detector is supplied through resistors *19* and *22*, with *19* acting as an i.f. load resistor and *22* as the plate a.f. load.

The grid bias for the 6F6G output tube is obtained by means of the voltage drop occurring across the 325-ohm bleeder resistor marked *30*. The polarity of this voltage is indicated on the diagram. The cathode currents of all tubes and the bleeder current through resistors *12* and *8* flow through resistor *30*. The ungrounded end of the resistor is negative with respect to chassis.

Since the grid return of the 6F6G tube is connected to the ungrounded end of resistor *30* and the cathode is connected to the grounded end, the voltage across resistor *30* is applied to the grid-cathode of the 6F6G tube, through resistor *23*.

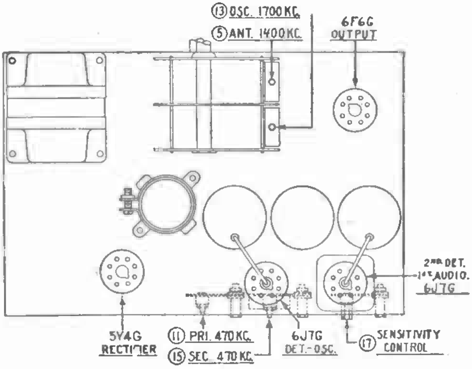


Fig. 5. Top-of-chassis diagram of Philco Model 37-84 receiver, showing locations of compensating condensers.

The screen of the output tube is supplied directly from the positive side of the power pack (B+). From B— (ground) the electrons flow through the various receiving tubes and bleeder resistors and back to B+. The electrons then flow through the speaker field (marked *27* in the diagram) to the rectifier filament. From there they go to whichever plate is positive with respect to the rectifier tube filament.

The Power Pack Filter. The loudspeaker field is used as the filter choke. In conjunction with the electrolytic condensers marked *29*, it serves to reduce the 120-cycle ripple at the output of the power unit.

Considerable ripple current flows through the field, however, and results in a 120-cycle variation in the magnetic flux. Ordinarily this would cause the voice coil to move the cone back and forth and give rise to hum.

You will note from the diagram that there is a coil directly in series with the voice coil, shown to be wound in an opposite direction. This is known as the hum-bucking coil and is wound over a section of the speaker field. Therefore, we will have hum voltage induced both into the hum-bucking coil and into the voice coil. Since these coils are wound in opposite directions, the voltages induced into them will be of opposite polarity. As a result, no hum current flows through the circuit, since the voltages are not only opposite but are also equal.

Since no current due to the loudspeaker field flux variation flows through the voice coil at the 120-cycle frequency, there will not be any tendency for the cone to move back and forth and no hum is produced by this hum source. In this way the hum-bucking coil actually bucks out any hum voltage induced into the voice coil from the loudspeaker field.

Condenser *28*, connected from the primary of the power transformer to the chassis, serves to prevent any r.f. signals which may be in the power line from getting into the receiver.

You will note that one side of each receiving tube filament is directly grounded, as is terminal *4* on the power transformer filament winding. The other leads, each terminating in an arrow, connect to terminal *3* on the filament winding, as does the ungrounded lead of the pilot lamp.

By grounding one side of the filament circuit in this manner, coupling between the different stages is eliminated, since a high r.f. or a.f. potential cannot build up between the ungrounded side of the filament circuit and chassis. This is due to the fact that the resistance between the ungrounded side of the filament and the chassis is quite low.

Any small hum or r.f. currents getting into the filament circuit will build up voltages which are very small, since voltage equals current multiplied by resistance. If we fail to ground one side of the filament circuit, the resistance from the filament to chassis will be many megohms and a small undesired current will build up a fairly large voltage.

Receiver Alignment. The alignment of this receiver is quite simple. First the i.f. amplifier is aligned. This is done by tuning the signal generator to 470 kc. (Fig. *5* shows this to be the i.f. frequency), and feeding the output into the aerial and ground posts of the receiver. The dial of the receiver should be turned to the lowest frequency (tuning condensers fully meshed), as this will result in least reduction of the signal voltage from the signal generator. The modulated tone of the signal generator will then be heard in the loudspeaker.

The actual locations of the trimmers on the chassis are shown in Fig. *5*. As in many Philco receivers, the i.f. trimmers are

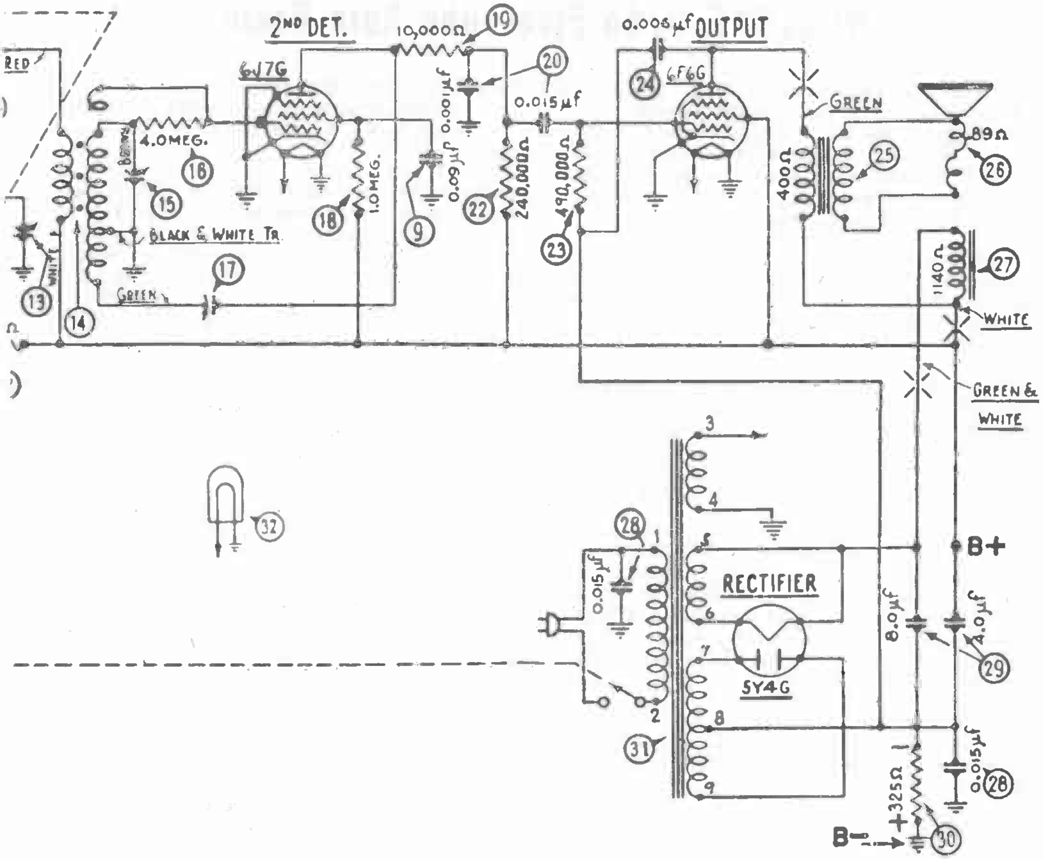


Fig. 7. Schematic circuit diagram of Philco Model 37-84 four-tube a.c. superheterodyne receiver. Note the use of the Greek letter "mu" following condenser values. This Greek letter represents "micro," and "f" stands for "farads," so this is just another way of abbreviating "microfarads."

over all connections in the oscillator circuit with a hot soldering iron. Where bolts are used to hold the stators of the tuning condensers in place, loosen and tighten these bolts one at a time, as a high-resistance joint sometimes occurs at this point and movement of the bolts will eliminate the corrosion which caused the high resistance.

If the oscillator refuses to function at the high-frequency end of the dial, this in practically every case indicates moisture absorption by the oscillator coil. The remedy is to install a new oscillator coil.

It is a good idea to draw a picture diagram showing the connections to an old coil. This will prevent you from making a mistake when installing the new coil.

A loud audio squealing heard in the re- receiver loudspeaker may be due to opening up of the 6F6G plate by-pass marked *24* or the C bias by-pass condenser marked *28*, connected across bias resistor *30*.

Distortion in this receiver is often due to leakage in the a.f. coupling condenser marked *20*, having a capacity of .015 mfd. Check for leakage at this point by measuring for voltage across resistor *23*. A d.c. voltage will not normally exist across this resistor. If it does, remove the output tube to see if it is gassy. If the voltage drops with the tube out of the circuit, gas did exist in the tube. If d.c. voltage remains, even with the tube removed, the coupling condenser is leaky.

As indicated in the diagram, the .001-mfd. plate by-pass and .015-mfd. coupling condensers are in a single container. Either can be replaced with a separate condenser, while the remaining good section can be left in the circuit.

TRUETONE D746 Five-Tube Auto Radio

GENERAL Description. The Truetone model D746 is a five-tube superheterodyne receiver having a turning range of 530 kc. to 1550 kc. It operates from a 6-volt storage battery and uses the automotive type 6.3-volt tubes. The B supply is obtained from a vibrator and a tube rectifier.

Additional data in the factory manual states that the receiver is of the single-unit type, no flexible shaft being used. The entire radio and automatic mechanical tuning mechanism is self-contained.

Five levers are provided for accurate and convenient automatic station selection, plus the conventional manual tuning control. This makes full tuning range coverage available at all times without any switching device from automatic to manual tuning.

The tube complement consists of a type 6A8 pentagrid converter, a type 6K7 remote cut-off pentode used as an i.f. amplifier, a type 6Q7 duplex diode triode used as a second detector, a.v.c. and first audio, a type 6K6 pentode output amplifier, and a type 6X5 high vacuum rectifier with indirectly heated cathode.

This set derives r.f. gain from its frequency converter and one stage of i.f., and obtains a.f. gain from one voltage amplifier and the output a.f. stage.

Tracing Signal Circuits. The signal picked up by the antenna causes a current to flow through condensers *C2* and *C3*. Condenser *C3* is not only in the input circuit but also in the first tuned circuit feeding the frequency converter tube. This is capacity coupling to the antenna, in contrast to the more usual inductive coupling found in home receivers.

The voltage applied to *C3* is stepped up by resonance. The resonant signal appearing across tuning condenser *C* is applied directly between the control grid (grid No. *4*) and cathode of the 6A8 type tube.

Frequency Converter. The local oscillator produces a signal for frequency conversion. The oscillator electrodes in the 6A8 tube are cathode (pin *8*), control grid (pin *5*) and anode (pin *6*).

When the oscillator is working, we have a variation in the electron stream passing through the oscillator anode to the screen and plate electrodes. When the incoming signal voltage is applied to the mixer grid (top cap *G*), the electron stream is again caused to vary, this time at the signal frequency. Mixing of the two signals takes place in the tube.

The oscillator frequency is always above the frequency of the incoming signal by the amount of the intermediate frequency, which in this case is 465 kc., as noted on the diagram.

Because of the curvature in the E_g-I_p characteristic of the tube operating as a detector, a beat frequency is produced in the plate circuit. The resulting 465-kc. beat builds up a large circulatory current and a high voltage in the primary of transformer *T3*. All other frequencies, such as the sum of the oscillator and incoming signal frequencies, the oscillator signal alone and the incoming signal alone, are by-passed around the primary coil by the first i.f. trimmer condenser. All signals, including the i.f. signal, are returned to the cathode through condenser *C6*.

I.F. Amplifier. By mutual induction, an i.f. signal voltage is induced into the secondary of transformer *T3*, and the resonant i.f. signal voltage appears across the secondary coil and its trimmer condenser. This signal is applied between the control grid and cathode of the 6K7 tube, the cathode connection being through condenser *C8*.

Because the primary circuit of *T4* presents a large impedance in the plate circuit of the 6K7 tube, the latter produces an i.f. voltage across the primary of *T4*, greatly amplified with respect to the input signal. A signal voltage is induced into the secondary of *T4* and after resonant step-up is large enough for rectification.

Second Detector. The upper diode plate in the 6Q7 is used for detection. When it is positive, electrons flow from the cathode to this plate, through the secondary of transformer *T4*, and through volume control *R6* back to the cathode. *R6* therefore acts as the diode load resistor, and a rectified signal appears across it. This is a combination of d.c. and the a.f. signal. Condenser *C9* serves to remove the i.f. from the diode output, so it does not appear across the volume control.

First A.F. Stage. The audio signal is fed from the variable tap on the control through condenser *C10* to the control grid of the 6Q7 tube. The signal is developed across resistor *R9* in this circuit, the low-potential end of *R9* being connected to the tube cathode and the cathode end of the volume control through condenser *C14*.

The resulting audio variations in the 6Q7 plate current cause a large audio signal voltage to be built up across resistor *R12*. *C13* serves to remove any i.f. signal which may have gotten into the plate circuit, by-passing it around the plate load and through resistor *R7* to the cathode. The amplified audio siginductive effects at ultra-high frequencies, they prevent any ignition interference produced at the car motor from entering the receiver by way of its B power supply.

By this time you have probably noticed that a filter choke is not used in the power pack system. We do have, however, two filter condensers marked *C12* and *C11*. These are 8-mfd. electrolytic condensers, and their positive leads connect together and to the cathode of the rectifier. Between their negative leads we have resistors *R8* and *R11*. These two resistors therefore have the additional duty of replacing the more familiar filter choke. The condensers have a reactance of approximately 80 ohms each at the ripple frequency. The frequency of the voltage applied to the plates of the rectifier is approximately 120 cycles, due to the vibrator design, and the rectified ripple frequency will be twice this or 240 cycles.

It is possible to use resistors *R8* and *R11* as resistive filters instead of using a regular filter choke, since their combined ohmic value is quite high compared to the reactance of *C11* and *C12* while still being low enough not to seriously reduce the d.c. supply voltage. Furthermore, as high fidelity is not a feature of this set, the a.f. section of the receiver is so designed that low frequencies of the order of 240 cycles or less are not reproduced very well.

Bias Considerations. Resistor *R2* is the oscillator grid resistor. The rectified current flowing through this resistor automatically furnishes the correct negative bias for the oscillator.

The grid bias for the triode section of the 6Q7 tube is obtained by means of the voltage drop across resistor *R8*. The grid connection, made through resistors *R9* and *R10* to the junction of *R8* and *R11*, is approximately 1.4 volts negative with respect to the cathode, which connects to the junction of *R7* and *R8*. There may be voltage variations across resistor *R8*, and these are filtered out by means of resistor *R10* and condenser *C14*.

The grid bias for the 6K6 type tube is obtained by means of the voltage drop across resistors *R7*, *R8* and *R11*. This is approximately 15 volts. Resistor *R14* and condenser *C16* serve to prevent bias voltage variations and hum across the bias resistors from getting into the grid input circuit of the output tube.

Voltage Measurements. While you will normally check the electrode voltages at the tube socket terminals, the manufacturer has indicated in the diagram strategic points at which the main supply voltages may be checked.

First, you will see the notation "200V" appearing on the plate supply line for the 6A8 type tube. This means that all points connected to this line, such as the cathode of the 6X5 or the screen of the 6K6, should measure 200 volts when the voltmeter probes are touched to either one and the chassis. The plate of the 6Q7 will be considerably less than this, due to the drop in resistor *R12*, while the voltage between the plate and chassis of the 6K6 will be approximately 15 volts less than B+ due to the drop in the primary of the output transformer. The screen to chassis voltage of the 6K6 tube will be 200 volts, since the screen is fed directly from the line marked *200 V*.

The screen voltage for the first detector and i.f. tubes is approximately 95 volts, as marked on the diagram. The C bias voltages for the 6K6 and 6Q7 tubes are approximately 15 volts and 3.6 volts respectively, as measured between the points indicated and the chassis.

The actual bias on the 6Q7, as pointed out previously, is not 3.6 volts since it only consists of the voltage drop across resistor *R8*, which is 1.4 volts. However, if the voltage from the junction of *R8* and *R11* is 3.6 volts, the voltage across *R8* will be correct. The initial bias for the 6A8 and 6K7 tubes is approximately 2.2 volts, and exists across resistor *R7*.

Continuity Tests. With the set turned off, we can check the various supply circuits for continuity with an ohmmeter.

As you already know, those points supplied with a positive potential should show continuity back to the cathode of the rectifier, the most positive d.c. point in the set. As an example, place one ohmmeter probe on the plate of the 6Q7 and the other on the cathode of the 6X5 rectifier. Continuity will be indicated through resistor *R12* and we will read a value of approximately 250,000 ohms on the ohmmeter.

A check between the screen grid (electrode *4*) of the 6A8 and the rectifier cathode will give us continuity through resistor *R4*, with a reading of approximately 25,000 ohms. A check between the oscillator anode (pin *6*) and the rectifier cathode will give us a resistance reading of approximately 30,000 ohms. The plate winding of the oscillator coil has a resistance of only 5.5 ohms and this would be negligible with respect to the value of *R3*. If you suspect a defect in this winding, it must be checked individually with a low ohmmeter range.

We can now trace the continuity between those terminals supplied with a negative potential and either plate of the rectifier, the common reference point. Put one ohmmeter test probe on the top cap of the 6A8 tube, and the other probe on one of the rectifier plates. We will then obtain a reading through *T1*, *R1*, *R5*, *R6*, *R8*, *R11*, and one-half of the power transformer secondary winding. The cathode of the 6Q7 traces back through resistors *R8* and *R11* and one-half of the power transformer secondary. The control grid of the 6K6 traces back through resistors *R13*, *R14* and the power transformer secondary to one 6X5 plate.

Alignment. The i.f. alignment of this receiver is quite conventional. As an output indicator, we could connect a vacuum tube voltmeter across diode load resistor *R6* or we could connect a low-range copper-oxide rectifier-type a.c. voltmeter across the voice coil. All adjustments are to be made for maximum output. The i.f. is 465 kc., as marked on the schematic.

The output of the signal generator, tuned to 465 kc., is connected between the top cap of the 6A8 type tube and the chassis. A reading will then be observed on the output meter, and all four of the i.f. trimmers, starting with the two on the second i.f. transformer, are to be adjusted for maximum output.

It doesn't matter whether we adjust the primary trimmer first or whether we start with the secondary trimmer. To be on the safe side, you can go over the adjustments two or three times. When a peak is finally obtained, the i.f. amplifier is correctly adjusted and the trimmers are not touched again.

The output of the signal generator is then connected to the antenna post and the receiver chassis. For best results, a dummy antenna which takes the place of the regular aerial may be used in series with the output lead of the test oscillator. This could consist of a 175-mmfd. (.000175 mfd.) condenser, as specified in the factory manual. One lead of the condenser may be connected to the antenna terminal of the receiver, and the remaining lead to the ungrounded signal generator output lead. The variable condenser of the receiver is tuned to its minimum-capacity position (plates entirely out of mesh), and the signal generator is adjusted to 1550 kc. The oscillator trimmer on the variable condenser gang is then adjusted for maximum output. The signal generator is then shifted to 1400 kc. and the signal is tuned in by rotating the receiver tuning condenser. The antenna trimmer which is mounted on the condenser gang is then adjusted to maximum output. (The antenna and oscillator trimmers mounted on the condenser gang are not shown in the diagram.)

The signal generator is next set to 600 kc., and this signal is tuned in for maximum output at about 600 kc. on the receiver dial. The padding condenser marked *C3* in the diagram is then adjusted for maximum output.

Now go back and check the antenna trimmer only at 1400 kc. If an adjustment is made, recheck *C3* again at 600 kc.

Servicing Hints. Let us suppose that the receiver is distorted and that by touching the top cap (control grid) of the 6Q7 and the chassis with your hand the distortion clears up. This definitely shows that excess bias is being applied to the 6Q7, and points to leakage in *C15* as the cause of the trouble.

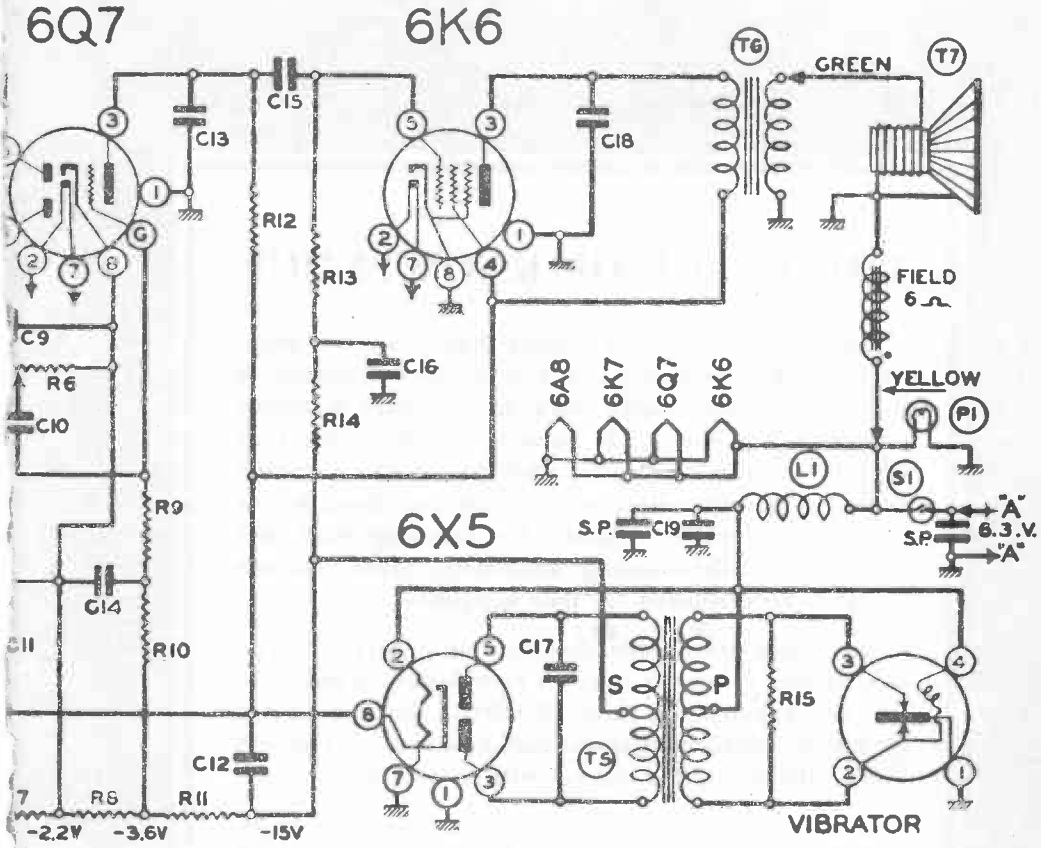
As we have already found out, the bias is due to the voltage drop across resistor *R8*. A study of the diagram shows that the cathode currents of all tubes flow through this resistor. Immediately we suspect some tube of drawing excessive plate current, since the voltage drop is excessive across *R8*. The 6K6 is the most likely offender, since it draws the most plate current.

The diagram shows that leakage in condenser *C15* would cause the plate current of the output tube to be excessive. We may check for this by connecting a voltmeter across resistor *R13*, with its positive probe going to the control grid of the tube. If voltage is measured, we withdraw the 6K6 type tube. If this causes the voltage to disappear, the tube is gassy. If the voltage is still present it is definite proof that *C15* is leaky. Normally, no voltage should exist across resistor *R13*.

You might think that a positive bias on the grid of the 6K6 would of itself cause distortion. Such is not the case, for the increase in plate current increases the voltage across resistors *R7*, *R8* and *R11* and maintains more or less normal bias for the grid of the tube. The increase in voltage across *R7*, *R8* and *R11* offsets to a certain extent the positive bias developed across *R13* and *R14* by leakage in *C15*.

It is interesting to see why touching the 6Q7 top cap and chassis lets us diagnose the trouble as excess bias. Your body has resistance and between the fingers touching the top cap and chassis there is about 50,000 ohms. Connecting the top cap to the chassis through 50,000 ohms or so simply reduces the voltage between the control grid and cathode because the voltage divides between *R9*, *R10* and your body. The voltage across *R9* and *R10* is considerably greater than the drop which acts as the bias voltage and which occurs across your body.

If the receiver squeals when a station is tuned in, we immediately suspect oscillation in the i.f. amplifier or the mixer. A glance at the diagram shows that this would most probably be due to an open in condenser *C7*. We check for this condition by letting the set squeal and by connecting another condenser across *C7*, or from pin *4* on the 6K7 tube to the chassis. If this stops the squealing, it's definite proof that *C7* is open and should be replaced. There is a possibility that an open in the plate by-pass condenser *C6* could cause



R10	1 megohm—1/3 w. 20%
R11	250 ohm—1 watt 10%
R12	250M ohm—1/10 w. 20%
R13	250M ohm—1/10 w. 20%
R14	250M ohm—1/10 w. 20%
R15	200 ohm—1/3 w. 20%

CONDENSERS

C	2-gang variable condenser
C1	.00002 Mica 20%
C2	.01 x 400 v. 25%
C3	Antenna Trimmer
C4	.00025 Mica 20%
C5	.1 x 200 v. 25%
C6	.05 x 400 v. 25%
C7	.1 x 200 v. 25%
C8	.05 x 200 v. 25%
C9	.0001 Mica 20%
C10	.01 x 200 v. 25%
C11	8. mfd. Electrolytic
C12	8. mfd. Electrolytic

C13	.0005 Mica 20%
C14	.01 x 200 v. 25%
C15	.01 x 400 v. 25%
C16	.006 x 600 v. 25%
C17	.005 x 1200 v. 10%
C18	.01 x 600 v. 25%
C19	.5 x 120 v. 50-10%

C11 and C12 in same unit

PARTS

T1	Antenna coil complete
T2	Oscillator coil complete
T3	Input I.F. 465 kc.—complete
T4	Output I.F. 465 kc.—complete
T5	Power Transformer
T6	Output Transformer
T7	5" Dynamic Speaker
L1	"A" Filter Choke
P1	6.8 v. pilot light
S1	Off-on Switch on Volume Control
SP	Spark Plates

THE VALUE OF KNOWLEDGE

Knowledge comes in mighty handy in the practical affairs of everyday life. For instance, it increases the value of your daily work and thereby increases your earning power. It brings you the respect of others. It enables you to understand the complex events of modern life, so you can get along better with other people. Thusly, by bringing skill and power and understanding, knowledge gives you one essential requirement for true happiness.

But what knowledge should you look for? The first choice naturally goes to knowledge in the field of your greatest interest—RADIO. Become just a little better informed about radio than those you will work with, and your success will be assured.

It pays to know—but it pays even more to know how to use what you know. You must be able to make *your* knowledge of value *to others*, to the rest of the world, in order to get cash for knowledge.

The N. R. I. Course gives you radio knowledge, and in addition shows how to use what you learn. Master thoroughly each part of your Course, and you'll soon be getting cash for *your* knowledge.

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TYPICAL RECEIVER DIAGRAMS AND HOW TO ANALYZE THEM

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REFERENCE TEXT

and the .000025-mfd. condenser. The antenna coil is tuned to resonance by trimmer T_6 and *V.C.*, the latter being connected to the coil through the .00004-mfd. condenser and contacts *11-5* of switch section S_1F. The .00004-mfd. series condenser is used to reduce the over-all capacity of the circuit so the ultra high-frequency f.m. band may be tuned with the regular gang tuning condenser.

Switch contacts *5-6* of S_1F connect the tuned circuit to the control grid of the 6SK7 r.f. amplifier tube through the .0003-mfd. coupling condenser, the cathode connection being through the chassis and the cathode by-pass condenser. Contacts *6-5* of switch section S_4R connect the plate circuit of the r.f. tube to its 10.000-ohm load resistor. Capacity coupling through the .0001-mfd. condenser transfers the amplified signal from the plate load resistor to r.f. transformer *7G1*. Only a small part of the possible gain of the r.f. tube is utilized due to the use of a 10,000-ohm plate load resistor, but a small value of resistance is necessary to shunt coil *7G1* and broaden the tuning.

The signal fed the r.f. coil is tuned to resonance by r.f. trimmer T_{10} and main tuning condenser *V.C.* which connects to the coil through the .00004-mfd. condenser and contacts *4-10* of switch section S_3F. Contacts *4-5* on this switch connect the resonant circuit to the 6SA7 mixer tube through the regular .0003-mfd. coupling condenser. The cathode connection is through contacts *5-6* of switch section S_8R, the oscillator coil and the chassis, so we have a duplication of the circuit used in previous band positions.

The oscillator uses coil *701* and trimmer *86-262*, with connections being the same as for previous bands. The variable condenser tunes the oscillator circuit through the .005-mfd. and .00005-mfd. condensers and contacts *11-5* of switch section S_5F. Contacts *5-6* on this switch connect the oscillator tank circuit to the oscillator grid of the 6SA7 through the .00005-mfd. coupling condenser.

Oscillations are maintained in the usual way, and the local oscillator and incoming signals are mixed within the tube. Since the oscillator and incoming signals differ by 4300 kc. (4.3 mc.), the i.f. carrier signal produced in the plate circuit of the tube has a frequency of 4.3 mc.

You will remember that in our previous discussion of the i.f. amplifier, the lower transformers were identified as being for the a.m. section. Now, of course, we are dealing with the upper or f.m. transformers. The primary of the first i.f. transformer, shunted by condenser C_8, is tuned to resonance by adjusting the iron core so that more or less of the core is inside the coil. The resonant circuit so formed offers a high impedance to the 4.3-mc. i.f. signal, and a large i.f. voltage is built up across the coil.

Resonant step-up results in a large circulatory current at the i.f. value, and the signal is induced into the secondary. The a.m. primary on the first i.f. transformer acts as a short as far as the f.m. signals are concerned, and this is also true in the case of the other a.m. circuits.

The f.m. secondary is connected to its trimmer C_9 through the low-reactance a.m. secondary when switch section S_7R is thrown to the *FM* position. Note the 50,000-ohm resistor shunted across C_9 and used to broaden the tuning of the first f.m. i.f. transformer. As was the case with the primary and all other i.f. transformers, resonance is obtained by core adjustment. The discriminator is an exception, being tuned by means of the two trimmers marked C_{14}.

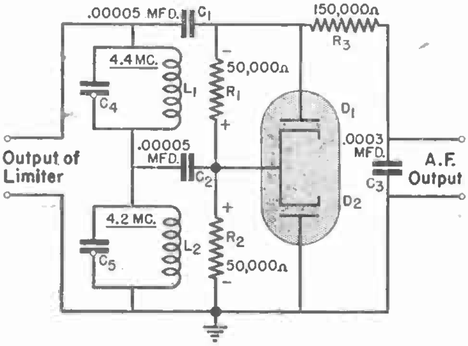


Fig. 15. Discriminator circuit. The i.f. value is 4.3 mc.

The signal applied to the input of the first i.f. tube is amplified, and appears across the broadly resonant plate load formed by coil *56-936*, C_6 and the 4000-ohm resistor. By capacity coupling through the .00005-mfd. coupling condenser and the .1-mfd. plate by-pass condenser, the signal is fed to the 500,000-ohm resistor and to the grid-cathode of the 6AC7 second i.f. tube. The cathode connection, of course, is through the cathode by-pass condenser.

The amplification contributed by the second 6AC7 tube results in a large i.f. signal across the broadly-resonant plate load formed by the transformer primary, condenser C_{10} and the 50,000-ohm shunt resistor. The signal induced into the secondary is applied directly to the grounded cathode of the 6SJ7 tube, and to its grid through the .000025-mfd. coupling condenser.

This 6SJ7, being a sharp cut-off pentode and being operated at low plate and screen grid voltages, acts as the limiter and delivers a signal of constant amplitude to the next stage, regardless of surges in signal strength that may result from static or other noise. Of course, the incoming f.m. signal must be strong enough to drive the 6SJ7 to the point where limiter action starts. The rectified voltage across the 100,000-ohm resistor in the control grid return of the 6SJ7 quency, we will find that practically all of the signal voltage appears across section *B* and is transferred to the lower 6SF5 tube.

The lower 6SF5 tube is thus a bass amplifier or bass-boosting tube. Since the amount of signal made available for the frequency-discriminating network is controlled by potentiometer *87-281*, this is the bass tone control.

The signals receiving bass-boosting action by the tube are developed across the 100,000-ohm plate load resistor. The .05-mfd. condenser across this resistor takes out signals above about 1000 cycles, so we have only the signal voltages of deep boomy bass notes across this resistor. These signal voltages are fed through control *48-281* with its 500,000-ohm shunt resistor, the .02-mfd. coupling condenser, and the 500,000-ohm resistor to the 100,000-ohm grid resistor for the 6J5 phase inverter tube. This control has no effect on bass notes because its .004-mfd. condenser is so small in comparison to the .05-mfd. plate by-pass condenser for the lower 6SF5 tube, but it does serve as a conventional type of tone control for the upper 6SF5 tube.

The upper 6SF5 tends to amplify all signals about the same amount but puts just a little more emphasis on the very high notes. It has a 500,000-ohm plate supply resistor across which the audio signals are developed. From here, the signals are fed through the 250,000-ohm resistor, the .02-mfd. coupling condenser and the 500,000-ohm resistor to the 100,000-ohm grid resistor for the 6J5 phase inverter. Thus, both 6SF5 tubes deliver signals to the phase inverter.

When the movable arm of tone control *48-281* is moved toward the .02-mfd. coupling condenser, the higher audio frequency signals (of which there are normally an over-abundance) passed by the upper 6SF5 tube are attenuated (cut down). When moved in the opposite direction, the effect is to give increased treble response, for the control then lets the over-amplified high audio frequencies come through.

The 250,000-ohm resistor between the upper 6SF5 amplifier plate and the .02-mfd. coupling condenser is used so the high audio notes will divide between them and the .004-mfd. tone control condenser when the tone control is set for minimum treble response. This arrangement also prevents interaction between the normal output circuit and the bass-boosting amplifier circuit.

The audio signals across the 100,000-ohm grid resistor are amplified by the 6J5 tube. The signals developed across its 50,000-ohm plate resistor are 180° out of phase with the grid signals, just as in any resistance-coupled stage. The signals across the 50,000-ohm plate load resistor are transferred to the input of the upper 6V6G output tube through the .02-mfd. coupling condenser and 10-mfd. filter condenser C_2.

The lower 6V6G grid is fed directly from the output of the 6SF5 tubes, and hence receives a signal 180° out of phase with that delivered to the upper 6V6G by the phase inverter tube. In this way, the 6V6G tubes are fed with signals 180° out of phase, as is necessary in any push-pull system.

The lower 6V6G receives far more signal than the 6J5, because of the 500,000-ohm and 100,000-ohm voltage divider system used to feed the latter tube. By choosing the right plate load for the 6J5, its gain is made just high enough so both 6V6G tubes receive the same amount of out-of-phase signal.

By using a push-pull arrangement, second harmonic distortion is avoided and we get the benefits afforded by the powerful 6V6G tubes. The odd harmonics, such as the third, fifth, seventh, etc., remain to be dealt with

The .002-mfd. condenser between the 6V6G plates tends to by-pass third and higher harmonics produced in the output tubes. Nevertheless, some of these harmonics will reach the voice coil and cause it to move, with consequent distortion of the clear tones which would otherwise be produced. The effect is not very bad because it is almost entirely eliminated by degeneration.

Note the 400-ohm and 25-ohm resistors shunted across the voice coil. These resistors act as a voltage divider, and the small signal voltage developed across the 25-ohm resistor acts on the grid input circuits of the 6SF5 tubes. The signals across the voice coil are 180° out of phase with the signals fed from the second detector to the volume controls and the 25-ohm resistor.

What is the effect of feeding a signal into an amplifier which is 180° out of phase with the regular signal? The effect is just the same as if we were to turn down the volume control a certain amount, for due to cancellation we are in reality feeding less signal into the amplifier input. Since all frequencies at the output transformer secondary receive exactly the same treatment, how do we discriminate against the distortion-producing harmonics? The harmonics are eliminated because they were not in the input to start with! They were produced somewhere in the a.f. amplifier, and by feeding them out of phase into the amplifier input, they are practically wiped out at their point of origin and only a trace appears across the voice coil.

After this discussion, you can now appreciate the care taken in the design of this amplifier, and can see that excellent tone quality should be expected either on a.m., f.m. or phonograph operation.

Tracing the F.M. Signals. Band switch position *5* is for f.m. reception, so we will trace the f.m. signals from the antenna to the volume control at the input of the a.f. amplifier, from which point the audio amplifier works in exactly the same manner as for a.m. reception. The three switch sections marked S_7R are all in the *FM* position now.

The f.m. signals flowing in the antenna are capacitively transferred to the antenna coil through contacts *6-5* of switch section S_2R

HOWARD Model 718FM-X Frequency Modulation Receiver

GENERAL Specifications. This Howard Model 718FM-X is a combination frequency modulation receiver with three amplitude modulation bands and six push buttons for automatic tuning on the broadcast band. The receiver is equipped with a loop for the broadcast band, has a built-in phono switch, bass and treble controls, and utilizes inverse feed-back to reduce audio distortion.

Signal Circuits. The wave-band switch presents no great difficulty in the circuit diagram of this set as shown in Fig. *12*, because all of the coils are plainly in view and their purposes evident. The switch has six sections, three facing the front of the set and three facing the rear of the set. The sections marked S_1F, S_3F and S_5F face the front of the set, and are shown as they appear when you look at the switch from the *front*. Sections marked S_2R, S_4R and S_6R face the rear of the set, and are shown as they appear when you look at the switch from the *rear*. The movable contact arms of the *F* sections rotate *counter-clockwise on the diagram* as the switch is advanced from position *1* (in which all switches are shown here) to position *5*, and the movable contact arms of the rear (*R*) sections rotate *clockwise on the diagram* as the switch is advanced.

The chart in Fig. *13* tells which switch terminals are connected together for each of the five positions. Position *1* is for push-button operation, covering the broadcast band. Position *2* is for manual tuning of the broadcast band. Position *3* gives coverage of the police and aviation bands, while position *4* covers short-wave programs, and position *5* covers the f.m. band.

Switch Position 1. We will study band switch position *1* first, and trace its circuits to the input of the i.f. amplifier. Since all switches are shown in position *1* in Fig. *12*, we can trace switch connections directly on the diagram.

When an outdoor antenna is used, signal currents flow through contacts *6-1* of switch section S_2R, and then to ground through the few turns of wire which are inductively coupled to the *LOOP* (drawn like a coil in this diagram). The loop is tuned to resonance, since it is connected through terminals *1-7* of switch section S_1F to r.f. trimmer *1*, whose button is shown as being depressed. Any signal at the resonant frequency of the loop undergoes resonant step-up when induced in the loop by antenna current through *L25*. The resulting signal is applied to the control grid of the 6SA7 first detector tube through contacts *6-5* of switch section S_3F and through the .0003-mfd. coupling condenser.

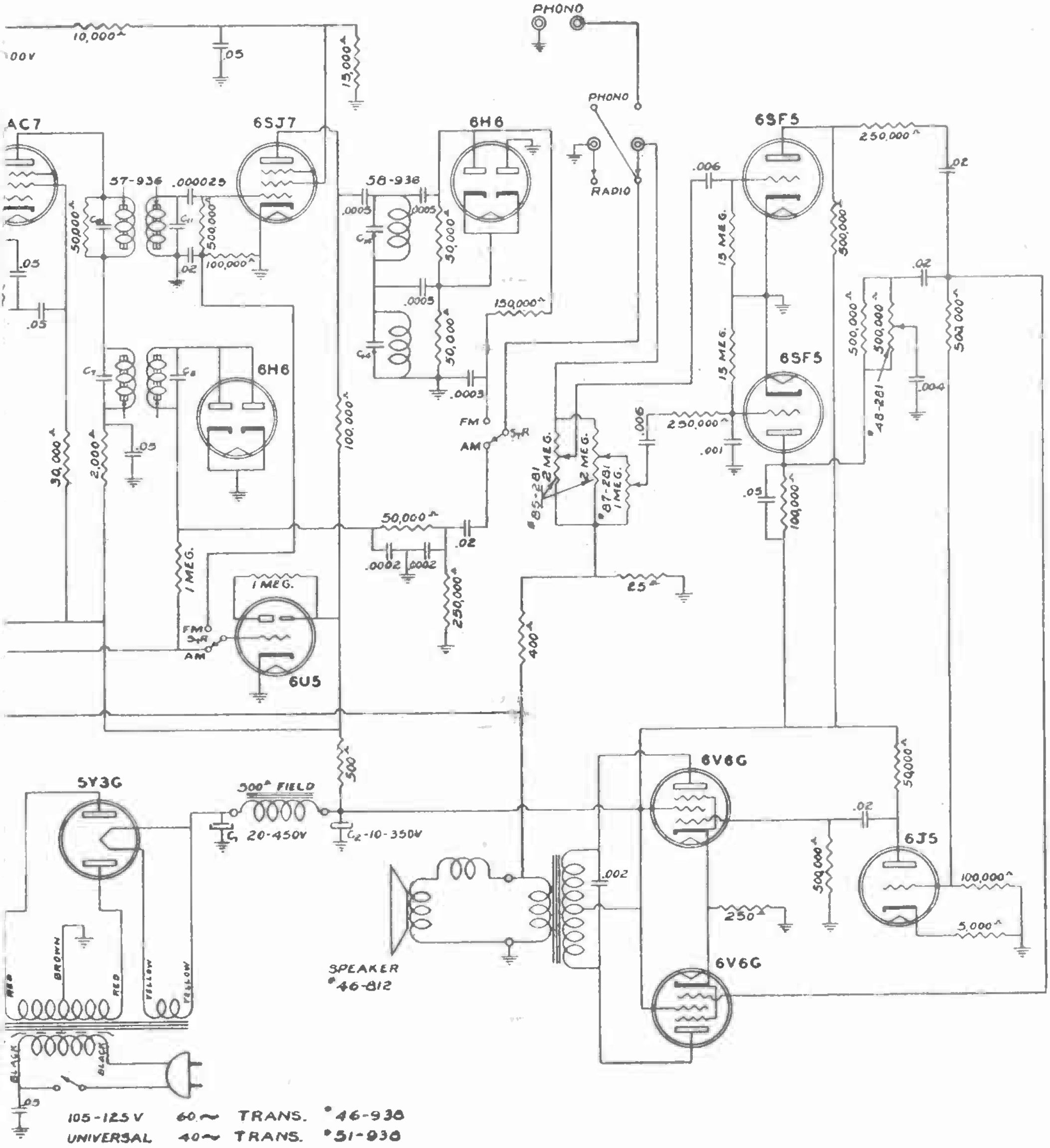
We have not mentioned the 6SK7 r.f. tube, but an examination shows that the signal is also applied to the input of this tube through contacts *7-6* of switch section S_1F and the .0003-mfd. coupling condenser for this stage. The r.f. tube will amplify this signal, but the plate of the tube connects through contacts *6-1* of switch section S_4R directly to B+. Thus, no load exists in the plate circuit and no amplified r.f. voltage is developed, even though the plate current is varying at an r.f. rate. The r.f. stage is therefore inactive when push-button tuning is used.

Now, we will investigate the oscillator. We see that the grid next to the cathode of the 6SA7 tube is the oscillator grid. It connects to the chassis through a 20,000-ohm resistor which is used for self-bias purposes. (Oscillator grid current flowing through this resistor produces the bias voltage.) The grid connects through the .00005-mfd. coupling condenser and switch contacts *6*, *1* and *7* of switch section S_5F to the oscillator tank circuit. The tuning condenser is oscillator trimmer *1*, whose push button is depressed, and the tank circuit coil is connected between switch contacts *1-2* and the padder marked *83-262*. Trimmer T_1 is the oscillator high-frequency trimmer for the broadcast band, but its capacity is negligible compared to that of the push-button trimmers.

The left-hand winding of oscillator coil *2035* is connected between the padder and ground, but has only a small effect on the inductance of the circuit. As you can see, it is in the cathode circuit of the 6SA7 tube and hence is the feed-back coil. The cathode current of the 6SA7 tube flows through this coil and induces a voltage into the tank coil. This variation in grid (tank) voltage causes

SWITCH POSITION	BAND	BAND-SWITCH SECTIONS						
		S_2R	S_1F	S_4R	S_3F	S_6R	S_5F	S_7R
1	BROADCAST, PUSH-BUTTON	6-1	6-1-7	6-1	5-6	6-1	1-6-7	AM
2	BROADCAST, MANUAL	6-2	6-2-8	6-2	1-5-7	6-2	2-6-8	AM
3	POLICE BAND	6-3	6-3-9	6-3	2-5-8	6-3	3-6-9	AM
4	SHORT-WAVE	6-4	6-4-10	6-4	3-5-9	6-4	4-6-10	AM
5	FREQUENCY MODULATION	6-5	6-5-11	6-5	4-5-10	6-5	5-6-11	FM

Fig. 13. Table showing band switch terminals which are connected together at each of the five switch positions.



A.M. I.F. 465 KC.
F.M. I.F. 4.3 MC.

(four-band, fourteen-tube f.m.-a.m. superheterodyne receiver.

tion corresponding to 1380 kc. to 1580 kc. on the broadcast band. When this set was built, the bands just below 2300 kc. and above 2500 kc. contained nothing of interest. Anything which was picked up at such frequencies was due to lack of preselection. On this band, only local police stations operating around 2400 kc. will ordinarily be heard.

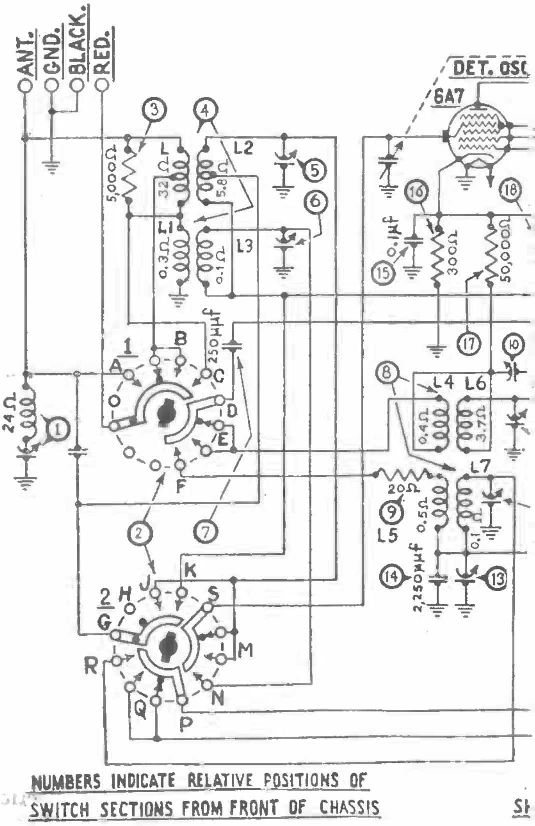
Due to the tying together of the switch contacts at *Q* on switch section *2* and the tying together of the switch contacts at *E* on switch section *1*, the oscillator connections are the same as they were for the broadcast band. This means that the oscillator will produce a frequency 460 kc. higher than the dial setting for the broadcast band, or from 990 kc. to 2180 kc. However, the preselector only works from 2300 kc. to 2500 kc., corresponding to the 1380-kc. to 1580-kc. markings on the broadcast band dial. When the set is tuned to 2300 kc., the oscillator is working as it did for 1380 kc. on the broadcast band. In other words, it is producing 1380 kc. + 460 kc., or 1840 kc. Now, if a 2300-kc. signal is picked up, the difference between it and the oscillator working at 1840 kc. is 460 kc., which is the i.f. value of the receiver. At the 2500-kc. dial setting, the oscillator is at 2040 kc., the same as it was for 1580 kc. on the broadcast band. The difference between 2040 kc. and the top of band *2* (2500 kc.) is again 460 kc., the correct i.f. value.

From these figures we see that the oscillator works below the frequency of the preselector for band *2*, and this band does not cover the entire dial. The receiver can be tuned below 2300 kc. and above 2500 kc., but the oscillator and preselector won't track exactly and satisfactory reception isn't to be expected.

Now let's go to switch position *3* in Fig. *11*. Here the antenna current flows through the primary of *L1*. Note that *L* is shorted through switch contacts *A* and *C*. If the special two-wire Philco antenna is used, the *RED* lead makes contact through switch terminal *C* directly to the antenna lead and *L1*, while the *BLACK* lead connects to the grounded end of *L1*.

By keeping the short-wave antenna currents confined to *L1*, better results are obtained. The signal current flowing through *L1* causes a voltage to be induced in *L3*. One end of *L3* connects to the a.v.c. circuit, and the other end connects to the main preselector tuning condenser through switch contacts *N* and *S* of switch section *2*. Trimmer *6* shunts the gang tuning condenser section, and is the high-frequency preselector trimmer. It is adjusted at the high-frequency end of the short-wave band.

The resonant circuit composed of *L3*, the tuning condenser and trimmer *6* selects the desired station signal, which undergoes resonant step-up. This signal is applied to the mixer input of the 6A7 tube. At the same time, *L2* is completely shorted by switch contacts *J*, *K* and *G*, thus making this coil inactive when switches are at position *3*.



NUMBERS INDICATE RELATIVE POSITIONS OF SWITCH SECTIONS FROM FRONT OF CHASSIS

The oscillator tank circuit for band *3* starts from the oscillator grid, and traces through switch contacts *P* and *R* to coil *L7*. The position of trimmer *12* indicates that it is the oscillator high-frequency trimmer; it is to be adjusted at the high-frequency end of this band.

The other end of *L7* connects to ground and to the rotor of the oscillator tuning condenser through fixed condenser *14* and adjustable condenser *13*. These condensers are in series with the oscillator tank circuit, and comprise the low-frequency padder for the short-wave band. Padder *13* is to be adjusted at the low-frequency end of this band. Resistor *18* is the oscillator grid resistor for this band.

The connection of *L5* to the padder condenser means that additional feed-back is obtained in the short-wave oscillator circuit by capacity coupling. The other end of *L5* connects through resistor *9*, switch contacts *F-D* and condenser *7* to the grid serving as the oscillator plate.

ventional, but all oscillators of this type have a bias resistor somewhere between the oscillator grid and cathode. Resistor *17* must therefore be the oscillator self-bias resistor for band *1*.

Coil *L4* is the oscillator feed-back coil, and must receive energy from grid *2* (the oscillator anode grid) of the 6A7. The connection to padder *10* means that we have capacitive coupling as well as inductive coupling from the feed-back coil to the oscillator tank circuit.

Tracing the other lead of *L4*, we go to terminal *E* on switch section *1*, and through the black "ball" contact to pole *D*. Condenser 7 is the means of coupling the feed-back coil to the oscillator plate.

We have now traced all the oscillator and preselector circuits for the broadcast band.

A quick glance at the schematic as a whole reveals much the same maze of wires as in the preselector circuits, but now you know that if you go at the problem logically and follow through each circuit one at a time, you can get any information you need for test purposes. Don't expect circuits of this sort to look easier as you progress in radio. Wave-band circuits always *look* complicated, and you always have to trace them when you need any special information from them.

The work we have done so far has been fairly straightforward. Figuring the new contacts made through the wave-band switch when it is thrown to one of the other positions is a bit more difficult.

Experience and a knowledge of how the circuits should be arranged will help you. The little black balls on the switch sections represent the movable contacts. As there are two other positions on this switch, it's not so hard to visualize the balls moving clockwise one space for each new switch position. To make this easy, the switch settings for all three ranges are drawn in Fig. *11*. We have already covered position *1* for the broadcast band, so now will examine switch position *2*.

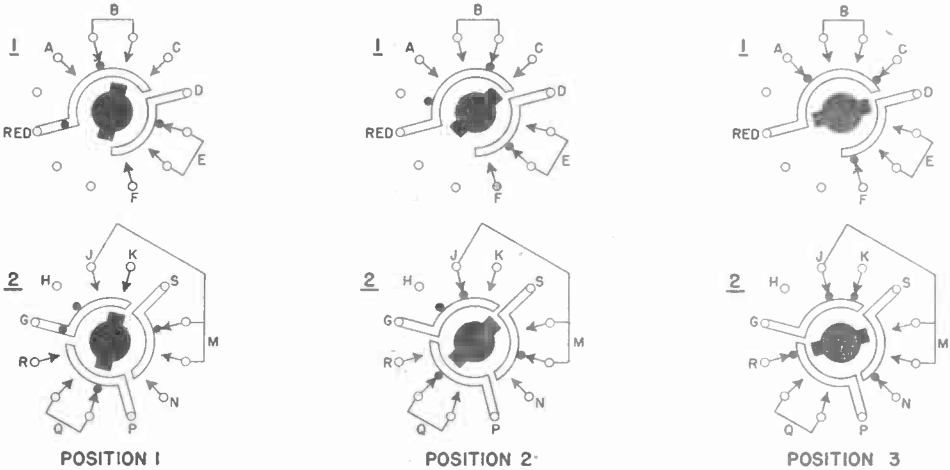
Let us assume that instead of using a Philco two-wire antenna system connected to the *RED* and *BLACK* terminals, we are using this time an ordinary aerial and ground connected to the *ANT*. and *GND*. posts. Remember that the switches are in position *2* as shown in Fig. *11*.

Antenna current now flows through the antenna primary coils *L* and *L1*, inducing voltages in *L2* and *L3*. The voltage set up in *L3* is very small and can be neglected, since *L3* is not connected to the tuning condenser.

The upper section of *L2* is short-circuited by switch contacts *G* and *J* of switch section *2*, so this portion doesn't play any part in the circuit either. Since switch contacts *G*, *J*, *M* and *S* are connected together, the tap on *L2* connects to the main tuning condenser and the 6A7 top cap. The lower section of *L2* goes to the a.v.c. circuit, then through a.v.c. condenser *25* to the grounded rotor of the tuning condenser.

The preselector section of the condenser gang therefore tunes the lower section of *L2* to resonance. The signal so chosen is applied to the mixer input of the 6A7 tube. The band coverage of this circuit is from 2300 kc. to 2500 kc.

Notice that this band is only 200 kc. wide, so only a portion of the dial is used—the por-



POSITION I POSITION 2 POSITION 3

Fig. 11. Connections made for each of the three positions of the band-changing switch are clearly shown here. Note that the black balls all advance one step clockwise as the switch is advanced from Position 1 to Position 2 and from Position 2 to Position 3.

across the other three filaments will serve as its bias (the grid circuit of the 1A5G traces from the control grid through the 2-megohm grid resistor to the chassis, through the chassis to the grounded filament lead of the 1A7G, through the 1A7G, 1H5G and 1N5G filaments in turn to the filament of the 1A5G).

When the power cord is plugged into a 110-volt a.c. line and switches *SW* are closed, the set starts operating almost immediately from batteries. After about ¾ minute of battery operation, the filament of the rectifier has warmed up sufficiently so that the 25Z6 rectifier is conductive. Now both the 6-volt filament supply circuit and the 90-volt plate supply circuit are operating as conventional half-wave rectifiers with resistor-condenser filters.

The 6-volt section of the 25Z6 provides a d.c. voltage just enough higher than the A battery voltage so this half-wave rectifier circuit supplies filament current for the four tubes and at the same time sends a small charging current through the 6-volt A battery.

In an identical manner, the 90-volt section of the 25Z6 provides a voltage enough higher than the B battery voltage so this section furnishes all plate current requirements and also sends a small charging current through the 90-volt B battery. Under these conditions, the batteries act like condensers and improve the filtering.

For 110-volt d.c. operation, the plug must be inserted in such a way that the two plates of the 25Z6 go to the positive side of the line. The rectifier sections then conduct current continuously, and the filament and plate filter supply circuits merely act as voltage dividers which cut down the 110-volt d.c. line voltage to 90 and 6 volts respectively for the receiver circuits.

With this arrangement, no switching is necessary in changing from battery to electric current operation. If the power cord is not plugged in, the set operates from its batteries. When the power cord is plugged in, the set starts operating from batteries after being turned on, but automatically changes over to a.c. operation after the rectifier tube warms up.

Whenever the set operates from a power line, the pilot lamp glows. If the electric plug is removed while the set is playing, the set keeps right on playing from its batteries but the pilot lamp goes out, showing that the line is not supplying power. If desired, the receiver can be operated from a.c. or d.c. lines even with all batteries removed.

As with all other receivers that operate from 110-volt d.c. lines, there is a right and a wrong way to put the plug into the socket. If it is in the wrong way, connecting the rectifier plates to the negative side of the line, the set will operate entirely from batteries, and the pilot lamp will not glow. Rotating the plug half a turn in the wall outlet will then make the rectifier plates positive, and the set will operate entirely from the 110-volt d.c. line as soon as the rectifier tube warms up. The pilot lamp will glow.

When the set has been used a long time on battery power and the batteries have become weak, they can be recharged rapidly by operating the set from a 110-volt a.c. or d.c. line with the 1A5G tube removed. Twenty-four hours of this charging will give about 20 hours of service on the batteries. This quick rejuvenation should not be used until the batteries get low, and then for not more than 40 hours at a time. It can be repeated a great many times.

Removal of the 1A5G type tube interrupts the filament circuit, so that only the rectifier tube draws filament current. The supply voltage then rises much higher than 6 volts, and we secure rapid charging of the rundown A battery. Also, no plate current is being drawn through the 6000-ohm B supply filter, hence a higher voltage is applied to the B batteries for charging.

This is not strictly a recharging process, since dry batteries cannot be recharged. However, the negative battery electrodes become polarized during use, raising the internal resistance of the batteries and thereby lowering their output voltages under load. This rejuvenating process depolarizes the electrodes, lowering the internal resistance and permitting normal use of the battery until such time as all of the active ingredients in the cells have been used.

Biasing Methods. As we have previously pointed out, the control grid of the 1A7G type tube is biased by the voltage drop across the volume control and half of the 1A7G tube filament. In a filament-type tube, the effective control grid voltage is that existing between the control grid and the center of the filament. Voltage measurements, however, are made between the control grid and the negative side of the filament.

The grid return of the 1N5G i.f. tube is made directly to the negative side of its filament. Therefore, the effective d.c. grid voltage is half of the filament voltage.

The diode plate of the 1H5G tube likewise returns to the negative side of its filament (through the volume control), so the plate has an initial small negative bias. This has no effect on local reception, and does not seriously interfere with reception from weak distant stations.

The control grid of the 1H5G tube connects to the positive side of its filament through a 15-megohm resistor. Some of the electrons which start out for the plate hit this grid and flow through this resistor to the filament, producing a voltage drop which serves as the negative bias for the grid of the tube. Remember that when electrons flow through a resistor, the end at which they enter is always negative with respect to the end at which they leave.

The control grid of the 1A5G tube connects to ground through a 2-megohm resistor. Reference to the simplified wiring in motion and producing sound waves. The output transformer serves to match the impedance of the voice coil to the a.c. plate resistance of the output tube.

The .002-mfd. condenser connected from the plate of the output tube to the chassis makes the plate load of the tube essentially capacitive and thereby prevents any oscillation at ultra-high audio frequencies.

The A.V.C. System. The a.v.c. system for the receiver is entirely conventional. The d.c. component of the rectified i.f. carrier current developed across the 750,000-ohm volume control is applied to the control grid of the 1A7G, after the audio signal is removed by the 1-megohm resistor and .1-mfd. condenser. A.V.C. is not applied to the control grid of the i.f. tube.

You will note that the filament end of the volume control connects to the positive side of the 1A7G filament. Therefore, the detector portion of the 1A7G tube is supplied with a slight initial positive bias. As soon as a signal is received, however, this positive bias is overcome by the negative voltage produced across the volume control.

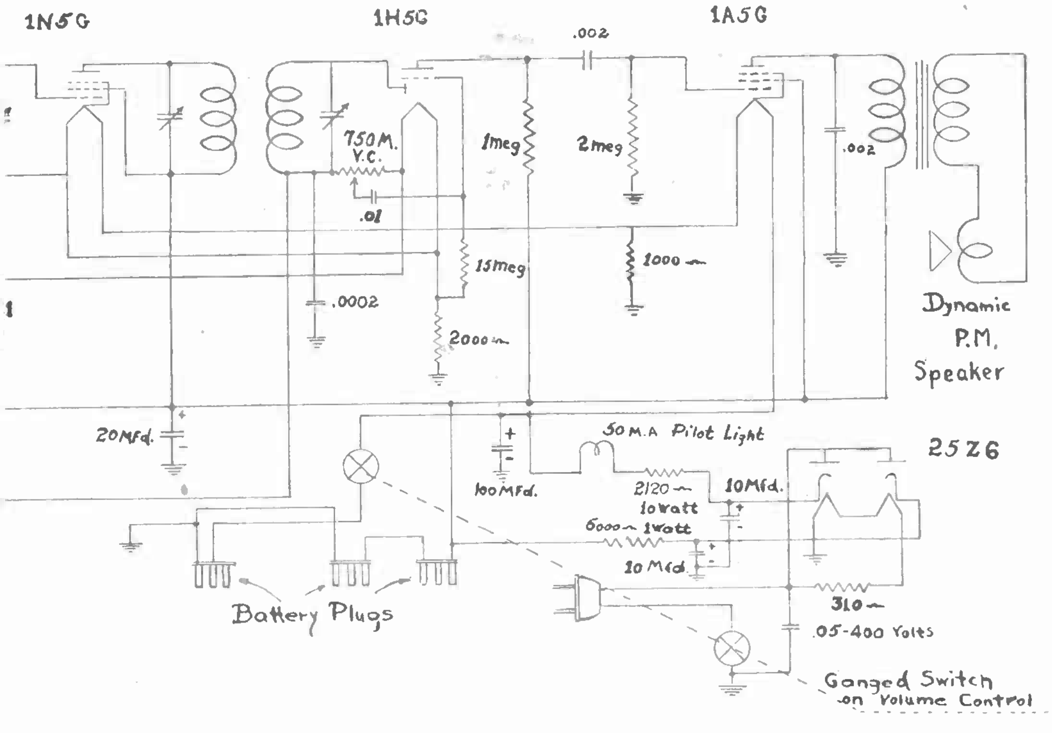
The Power Supply. At first glance, the filament and power pack connections in Fig. *8* appear somewhat unusual, but when the circuit is redrawn as in Fig. *9*, we can see that there are really four independent circuits, each quite conventional in design. Let us consider each in turn.

When the two switches marked *SW* (operated simultaneously by the volume control shaft) are open, both the 6-volt battery and the power line are disconnected from the filament circuits so the set cannot operate. The 90-volt B battery cannot supply current under this condition because the tubes are not conductive when the filaments are cold.

When switches *SW* are turned on but the power cord is not plugged in, the rectifier tube filament is not heated and hence the two sections of the 25Z6 rectifier are not conductive. The 6-volt battery now furnishes current to the filament circuits of the tubes, however, and the 90-volt B battery furnishes plate current to the four signal circuit tubes.

Examining the filament circuits of the tubes more closely, we see that the filaments of the four 1.4-volt tubes are connected in series across the 6-volt battery, with the circuit being completed through the chassis. The 1000- and 2000-ohm resistors merely provide extra paths to ground for the plate currents of the 1N5G and 1A5G tubes, so as to reduce the amount of plate current which flows through the other two tube filaments to ground.

The 1H5G filament is next to the 1A7G filament in the line-up for a definite reason, to prevent the filament voltage drop of the 1N5G from serving as bias for the 1A7G. The 1A5G is at the + end of the line-up for the opposite reason, so the 4.5-volt drops



age between the center of the filament and the negative filament terminal is added to the voltage between the negative filament terminal and the control grid.

In these special low-voltage tubes which handle only small amounts of signal voltage, the bias is quite small. The a.v.c. voltage across *R12* is added to the voltage drop in one-half the tube filament to form the bias for the 1T4 i.f. tube and the 1R5 first detector tube. Since these tube filaments are supplied with approximately 1.4 volts, half of this or .7 volt is used as the initial bias. When signals are received, the a.v.c. bias voltage is added to this. The oscillator grid of the 1R5 receives half the filament voltage plus the voltage created across *R1* by grid current through this grid resistor.

The voltage drop across *R6* due to convection current through it, plus one-half of the filament voltage, biases the pentode section of the 1S5 first audio tube.

The 1S4 power output tube requires considerable bias, more than can be readily furnished by convection current through the grid resistor or by the filament voltage drop. Bleeder bias is employed by causing the plate currents of all tubes to flow through *R11*. The voltage drop across this resistor makes the 1S4 control grid (which connects to the negative end of the resistor) negative with respect to its filament, which connects to the grounded positive end of *R11*.

Battery Economizer. We have now considered the bias arrangement of all the tubes, but the discussion of the 1S4 bias brings up another related object. As you will note, the receiver is equipped with a two-position switch called an *economizer*. By throwing this switch to the "*OUT*" position, maximum power output is obtained from the 1S4 tube, so the total *B* current drain is 7.5 milliamperes. With the switch thrown "*IN*," the *B* drain is reduced to only 5 milliamperes, a considerable saving.

The economizer increases the bias on the 1S4 tube. When the switch is "*IN*" (when the switch bars are across the upper pairs of contacts), resistor *R10* is no longer in parallel with *R11*, and the total resistance between *B*— and the chassis is increased. Therefore the voltage drop across *R11* increases, and this increase in grid bias cuts down on the 1S4 plate current.

As in any battery set, the d.c. plate and screen voltages are applied between these electrodes and the tube filaments. The filaments are grounded to the chassis as shown. Therefore, since the voltage between *B*— and the chassis is increased when the economizer switch is "*IN*," the voltage between filaments and screens and between filaments and plates has decreased. This is unimportant save in the case of the 1R5 and 1T4 screen voltages. A decrease at this point results in a loss in sensitivity. To keep the sensitivity constant, the economizer switch in the "*IN*" position shorts out *R2* in the screen supply circuit of these tubes, thus keeping the screen voltage constant and preventing a loss in sensitivity.

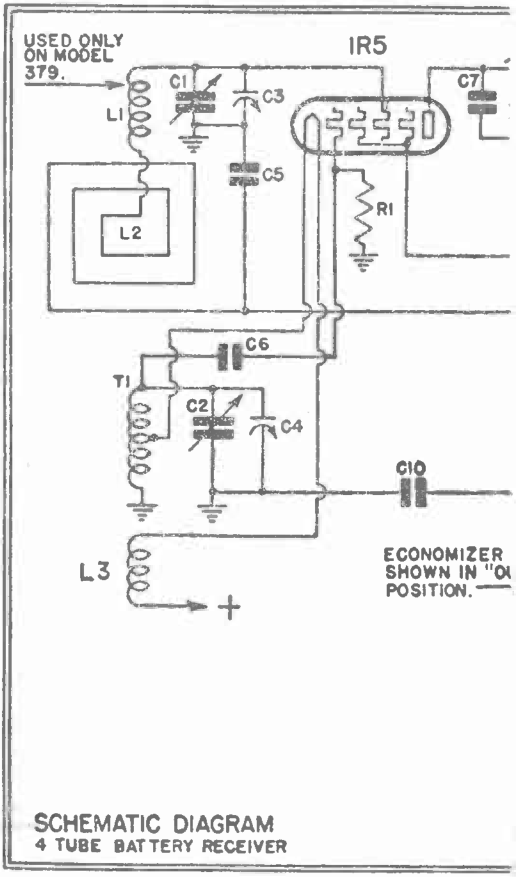


Fig. 7. Circuit diagram of Emerson Model DU-379 and DU-380 battery portable receivers.

Voltage Measurements. The operating voltages for each tube are measured with a d.c. voltmeter. The negative probe of the voltmeter goes to the negative filament terminal (grounded terminal) in each measurement except for control grid voltage, where the positive meter probe goes to ground and the negative probe to the control grid.

A definite control grid voltage will be measured only on the 1S4 tube and, due to the high resistance of *R9*, the exact voltage will not be measured. However, this control grid voltage can be checked by placing the meter probes directly across *R11* (positive probe to chassis).

Miscellaneous. The alignment of the receiver follows standard superheterodyne procedure. There are only three i.f. adjustments, since the primary of *T3* cannot be tuned. There is no low-frequency oscillator padder condenser.

the circuit is tuned to 455 kc. by adjusting the coil inductance.

The i.f. signal across the secondary of *T2* is fed to the input of the 1T4 i.f. tube, the filament connection being through *C5* and the chassis.

The 1T4 causes a large i.f. signal current to flow through the primary of *T3*. A voltage is induced into the secondary, where it undergoes resonant step-up. The primary of *T3* is untuned, and hence the coupling in this transformer may be close enough to give high gain. This is typical of any i.f. transformer where only one winding is tuned.

The large i.f. voltage across *C11* is applied to the diode and filament of the 1S5, the filament connection being through *C12*. As a result, rectification occurs, and we have the audio modulation plus a d.c. component across volume control *R5*, which is also the diode load resistor. As previously stated, *C12* prevents any i.f. voltage from being dropped across the diode load, thereby insuring that all of the signal is applied between the diode plate and filament.

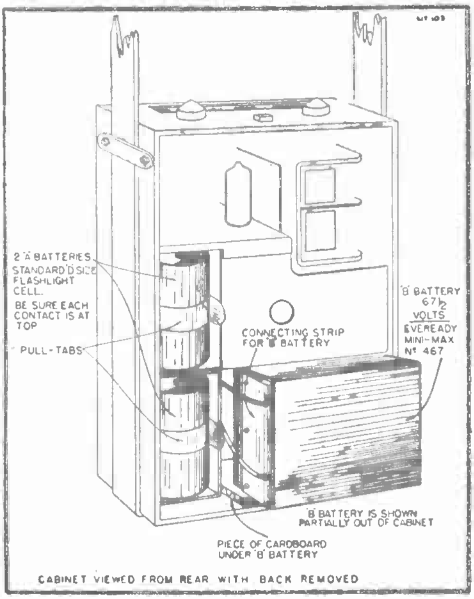
The d.c. voltage across *R5* is used for a.v.c. purposes, since it will vary directly with the strength of the carrier applied to the second detector. The ungrounded end of the resistor is negative with respect to the filament of the 1R5, which is at d.c. ground potential. Tracing the circuit from the negative side of *R5*, we see that part of this voltage is applied to the first detector control grid (third grid of the 1R5) through resistor *R4*. This resistor and condenser *C5* serve to remove the audio signal voltage, and only pure d.c. is available across *C5* for a.v.c. bias purposes.

The full d.c. voltage across *R5* is not used, for *R12* and *R4* are across *R5* and hence act as a voltage divider. The voltage across *R12*, which is in parallel with *C5*, is the a.v.c. voltage fed the 1R5 tube. Since *R4* and *R12* are both 5 megohms (the same size), both have equal voltage drops, and only half of the voltage across diode load *R5* is used for a.v.c. purposes. Thus, while a.v.c. action is reduced, the danger of cutting off the plate current of the 1R5 tube and causing blocking or motorboating on strong signals is eliminated.

The a.f. voltage across volume control *R5* is applied across resistor *R6* through coupling condenser *C13*. Since *C13* connects to the movable arm of the control, the setting of this arm will determine the amount of signal voltage fed to *R6*. As *R6* is directly in the grid input circuit of the pentode portion of the 1S5, the tube amplifies the audio signal fed it, and we have the amplified signal voltage across plate load resistor *R8*.

Condenser *C14* serves to by-pass any stray i.f. signal which may have been amplified by the tube.

The audio signal across *R8* is transferred across *R9* and *R11* through *C16*, *C10* and the chassis. The signal voltage across *R9* and *R11* is amplified by the 1S4 and delivered by impedance-matching output transformer *T4* to the loudspeaker voice coil, and is then converted into sound waves.



Rear view of Emerson Model DU-379 portable receiver, with back cover removed to show batteries. Note how the shoulder-strap antenna encircles the entire set. Control knobs and tuning dial are at top of set, between the loop straps.

Condenser *C17* prevents oscillation at high audio frequencies, and also tends to reduce harmonic distortion by acting as a by-pass for the higher audio frequencies which comprise the harmonics. In addition, inverse feed-back further reduces distortion.

As already pointed out, the input signal voltage is developed across *R9* and *R11*. No by-pass condenser is used across *R11*, and since the plate current of the 1S4 flows through this resistor, we have an audio signal produced here. This signal is 180° out of phase with the applied signal and cancels out the original signal produced across *R11*. In addition, distortion currents produced inside the 1S4 tube flow through *R11* and create voltages of the same distorted form across this resistor. These voltages were not there to start with, and they control the plate current of the tube in such a way as to reduce greatly the distortion inside the tube. The over-all loss in gain due to cancellation of desired signals across *R11* can easily be tolerated.

Biasing Methods. As you already know, the grid bias of a battery-operated filament-type tube is measured between the control grid and the negative side of the tube filament. The effective bias, however, is the difference in voltage between the center of the filament and the grid. Therefore, any volt-

The output signal induced into the secondary of *T-2* thus has only a very small amount of third harmonic distortion. The secondary has a number of taps, so that it can be connected to match most any load. The grounded secondary terminal goes to one load (loudspeaker) terminal by way of terminals *4* or *5* and *A* or *D* on the *SPK.* sockets, and the tap selected by probe lead *C* of the output transformer goes to the other load terminal through *SPK.* socket terminals *3* and *C*.

When the amplifier is to feed a device over a considerable distance, either the 125-, 250- or 500-ohm taps are used, and a special matching transformer is placed at the other end of the line. The lower-impedance taps are used for voice coils, recorder cutting heads or other low-impedance devices.

Most voice coils have an impedance of 8 ohms, so for a single voice coil we would plug probe lead *C* into the jack marked *8*. If two speakers with 8-ohm voice coils were used, the coils could be connected in parallel; the combined resistance would then be 4 ohms, and the 4-ohm tap would be used. While voice coils are not ordinarily connected in series, we could do this and get a combined impedance of 16 ohms, which would be matched by using the 16-ohm tap.

If electrodynamic loudspeakers are employed, 10 watts of field excitation is available for one 5000-ohm or one or two 2500-ohm speaker fields. The following table indicates how speaker field connections are made to the *SPK* sockets. Note that in some cases a jumper wire is used between jacks on the terminal strip marked *FIELD*.

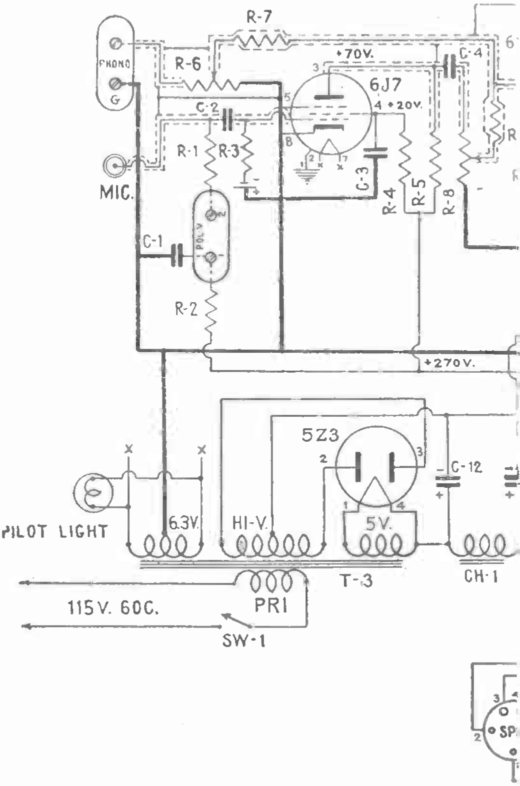
	Connect Jumper Between	Connect Field to Prongs
One 5000-ohm field..	Not used	1 and 5
One 2500-ohm field..	C and 2	2 and 5
Two 2500-ohm fields.	Not used	B & E; 2 & 5
P.M. Loudspeaker (no field)	C and 1	....

For practice, see if you can figure out the field supply circuits and the reasons for the connections given in the table. When doing this, take into consideration the ohmic values of the fields and of resistors *R-16* and *R-19*.

The power supply circuit in this amplifier does not represent anything new, being very similar to those you have already studied in receiver diagrams. The rules for tracing circuit continuity apply to this amplifier just as to receiver circuits.

Most troubles which may be expected will take the form of distortion, hum and oscillation. The usual causes are to be suspected, but shielding is particularly important in the case of hum or oscillation. The reason for hum, if shielding is not employed, has already been pointed out. The thing to watch out for is poor ground contacts on the shielding.

The shields on the control grid and plate leads of the 6V6-G tubes prevent electromagnetic and electrostatic coupling between these points and others at a lower audio potential. Suppose, for example, the plate leads of the 6V6-G tubes were inductively coupled to the input of the 6J7 tube by being close to resistor *R-3*. Signal voltage would be induced into *R-3*, and being in phase with the input signal voltage, it would cause oscillation and a loud squeal.



The capacity existing between the 6V6-G plate leads and the grounded shields also tends to prevent oscillation. Beam-power output tubes have a tendency to oscillate and these tubes, when oscillating, have been known to draw sufficient current to damage power transformers. Oscillation will be indicated by serious distortion or a dead amplifier. The d.c. voltages will be very low due to the excess current drain.

In the schematic, you will see the operating voltages marked at the points at which the voltage measurements are generally made. The d.c. voltages are measured between the points shown and the chassis.

The output filter voltage is measured between the positive lead of C-13 and the chassis, and according to the schematic you cause a pentode tube fed with a strong signal will produce very strong harmonics, and these will cause severe distortion. Push-pull action and inverse feed-back permit the use of the 6V6 pentode-type output tubes, while the signal input of the first 6J7 is too low to produce much harmonic voltage. The signal fed to the second 6J7 is, for either microphone or phonograph operation. too large to permit pentode operation of the tube.

The second 6J7 is not replaced with a regular triode tube such as a 6C5, because even when connected as a triode the 6J7 can produce more gain than a 6C5. It is necessary to use a 6C5 in the next stage, for by now the signal is so strong that it would overload the 6J7 even when triode connections were used.

The a.f. signal voltage across *R-11* is applied to grid resistor *R-12* of the 6C5 tube through coupling condenser *C-6* and filter condenser *C-10*. The signal current flowing through grid resistor *R-12* produces a voltage drop which drives the grid of the tube. *R-12* is a potentiometer, and the movable arm connects to ground through *C-7*, a .03-mfd. condenser. As the arm is moved up. more and more of the high frequencies are shorted or by-passed around *R-12*, and hence are not applied to the grid of the 6C5. In this way we achieve tone control, which permits attenuation of high audio frequencies as desired.

The a.f. signal voltage across *R-12* alternately adds and subtracts from the d.c. bias developed across *C-8* and *R-13*, making the grid first more negative and then less negative. This variation in control grid voltage causes a corresponding variation in plate current. As a result, we have a pulsating d.c. plate current flowing through plate load resistor *R-14*. Condenser *C-9* and the primary of *T-1* comprise a short path for the a.f. component, hence the effective plate load for signals is *R-14* in parallel with *C-9* and the primary of *T-1*. Since the resistance of *R-14* is much greater than the impedance of the *C-9 T-1* path at audio frequencies, practically all of the signal current passes through *C-9* and the transformer.

This method of capacity coupling is a little out of the ordinary. If *R-14* and *C-9* were not used, the primary of *T-1* would be placed right in the plate supply circuit of the 6C5. The circuit would function but the d.c. portion of the plate current would tend to saturate the transformer primary, and the mutual inductance of the transformer would decrease. This would decrease the voltage induced into the secondary, and would cause distortion since the change in flux linkage would be greater for a decrease in plate current than for an increase. For distortionless transfer of signal, the flux must follow current changes exactly. The loss in gain would be more serious at the low audio frequencies, because the primary inductance, and hence the plate load impedance, naturally decreases with frequency.

By keeping the d.c. portion of the plate current out of the primary, we avoid transformer saturation and thereby secure good low-frequency response from this stage. Resistor *R-14* and condenser *C-9* do this; the resistor supplies d.c. plate voltage to the tube, and *C-9* blocks d.c. while allowing a.c. to pass. By choosing a value of *C-9* which will resonate with the primary of *T-1* at a low audio frequency, a definite boost in gain at low audio frequencies can be obtained.

A.F. signal current flowing through the primary of *T-1* sets up a flux linkage with the secondary, inducing an a.f. voltage in each half of the secondary. These secondary windings feed the two 6V6-G tubes in the push-pull output stage, with inverse feed-back being provided in the following manner by an extra center-tapped winding on output transformer *T-2*. Let us consider secondary *8-7* of *T-1* first. Terminal *8* goes to the control grid of the upper 6V6-G output tube, while *7* goes to terminal T_2 on the special winding having a center tap marked *CT*. Resistor *R-18* (a C bias resistor in the power pack) completes the path from *CT* to ground. The voltage between *8* and *7* thus acts in series with the a.f. voltage across the lower half of the "*CT*" winding and the d.c. voltage across resistor *R-18*. In a similar manner, the signal voltage between point *5* and point *6* acts in series with the a.f. voltage across the upper half of the "*CT*" winding and the d.c. voltage across *R-18*, all feeding the control grid of the other 6V6-G tube.

The 6V6-G tubes amplify the signals applied to their grids, and the resulting plate currents flow through primaries P_1-*B* and P_2-*B* of output transformer *T-2*. Due to the push-pull action, all even harmonics produced within the tubes are canceled out.

The odd harmonics, of which the third is the strongest and hence most troublesome, are not canceled out by the push-pull arrangement, but are taken care of by inverse feed-back (degeneration). The fundamentals and odd harmonics flowing through the primaries of output transformer *T-2* induce voltages in the "*CT*" winding as well as in the regular secondary. These voltages, as you just learned, act in series with the a.f. voltages applied to the grids of the output tubes but are 180° out of phase, due to the phase reversal provided by the output tubes.

The fundamental component which is fed back out of phase cancels out some of the fundamental at the grid input, thus reducing the gain. The designer took this into account, however, and there is gain to spare. The odd harmonics are also fed into the grid input of each 6V6-G, but since they were produced inside the 6V6-G tubes, they are not originally present in the input circuit. The fed-back odd harmonics thus enter the tubes and cancel out some of the odd harmonics being produced by the tubes. Complete cancelation is impossible, for we must have some signal induced into the center-tapped secondary of *T-2* for feed-back purposes.

voltage because the two voltages are in parallel. The copper-oxide rectifiers prevent the battery from discharging through the charging circuit, because they do not allow current to pass in the reverse direction. For these reasons, the battery must be in the receiver even during a.c. operation. If the set were used on "*AC*" with the battery removed, the tubes would get excessive filament voltages and would burn out, and the vibrator and filter condensers might also be damaged.

Voltage Measurements. Figure *4* shows the socket voltage diagram for this set. The voltages given on it are measured between the points indicated and the chassis. The battery voltage is measured across the battery terminals, and the vibrator voltage is measured from *B+* to the chassis. Condenser *C21A* can easily be located in the chassis; since it is the input filter condenser, the *B+* voltage delivered by the power transformer may be measured across it. The resistance of *L5* is so low that the slight amount of voltage dropped across it will not affect the accuracy of this measurement.

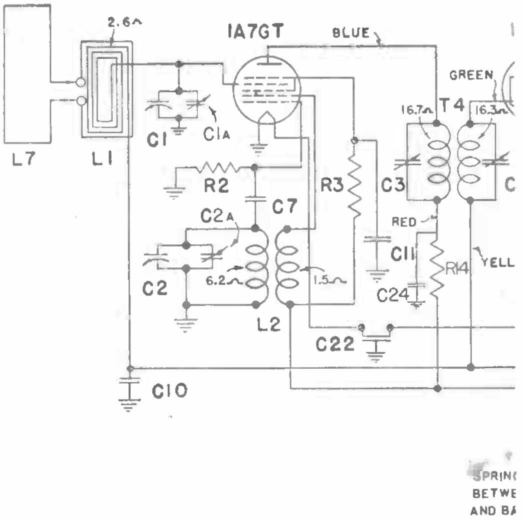
You will find that the value of *R14* is not given. Evidently the factory draftsman forgot this; such errors sometimes creep into diagrams.

If you had to replace *R14*, what would you do? First, you would consider the purpose of *R14* in the circuit. Obviously, it is not purposely used to reduce plate voltage, and neither is it a plate load. It must therefore act with *C24* as a filter to keep r.f. plate current of the 1A7GT out of the B supply. From past experience and from observing many similar circuits, we know that the resistor value is not critical and that manufacturers use values between 1000 and 10,000 ohms for this purpose. We feel sure that the choice of an average value of about 5000 ohms will work nicely.

We can get a confirmation by means of Ohm's Law if we wish. Since the plate of the 1A7GT receives 78 volts and the i.f. screen from which *R14* is fed receives 82 volts, 4 volts are dropped across *R14*. A tube chart tells us that the 1A7GT plate draws about .7 ma., and Ohm's Law says that resistance equals voltage divided by current, so by simple division we arrive at a value of about 5900 ohms for *R14*. Experience tells us that 5000 ohms is satisfactory, but if actual trial shows it to be too low, a larger resistor may easily be inserted.

Continuity Tests. Continuity tests are made in the usual way between points at a positive potential and the *B+* terminal, and between points at a negative potential and the *B—* terminal (the chassis here). *B+* is the red lead going from the junction of *R10* and *C21A* to the *B* supply.

The storage battery in this receiver must be disconnected for ohmmeter tests, just as in any other battery set. The bias cells need not be disconnected if you don't check from the grid of the 1Q5GT to chassis. However, a check directly across *R9* is perfectly all right.



POWER SELECTOR SWITCH OPERATION

POSITION	CONTACTS CONNECTED
"OFF"	ALL CONTACTS OPEN
"BATTERY"	#1 to #2; #4 to #5; #7* to #8
"AC"	#1 to #2 to #3; #4 to #5; #8 to #9
"CHARGE"	#2 to #3; #8 to #9

* #7 terminal is not connected to circuit

Fig. 5. Schematic circuit diagram of General Electric Model LB-530 a.c. or battery-operated portable receiver.

To avoid possible short-circuit readings through the vibrator contacts, the plug-in type vibrator is pulled out of its socket during ohmmeter tests.

Expected Performance. With the two stages of i.f., excellent sensitivity and adjacent-channel selectivity may be expected. Some image interference may occur due to lack of preselection, but turning the loop to a different position by rotating the entire receiver will sharply reduce the pick-up of undesired signals.

The 1Q5GT can't deliver much output power, so you won't expect high volume. Both volume and tone quality will be less than that secured with a good table model receiver, but will be entirely satisfactory for a portable.

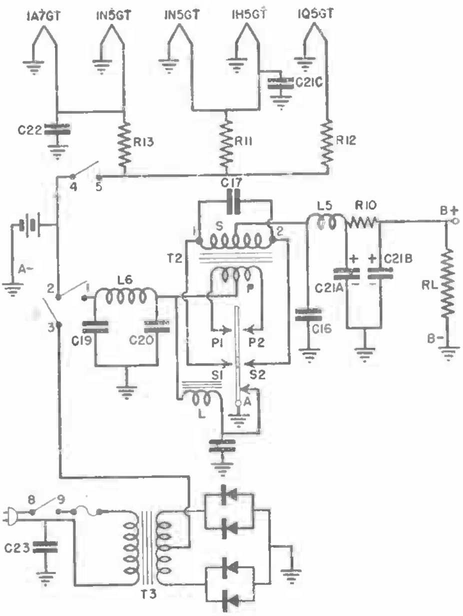


Fig. 3. Effective power pack circuit when power selector switch is set at "AC."

the electrons flow through *R10* and *L5* to get back to the center tap on winding *S*.

That portion of the induced voltage existing between the center tap and point *2* is not used now, and may be forgotten.

When the vibrator reed is pulled over to contacts *P1* and *S1* by the coil, it breaks the coil circuit at contact *A*. The natural springiness of the reed returns it to the neutral position, but the reed always overshoots the neutral position enough to make contact with *P2* and *S2*.

With contacts *P2* and *S2* grounded by the reed, we have electrons flowing from the minus battery terminal through the chassis to the reed and *P2*, then through the right-hand section of power transformer primary *P* and back through *L6* and contacts *2-1* to the battery. Since this electron flow is in the opposite direction from that which previously flowed through *P*, the induced voltage in the secondary has reversed polarity. Point *1* is now positive with respect to the center tap, which makes point *2* negative with respect to the center tap and gives electron flow through *RL* in the same direction as before.

From this, we see that the center tap on the secondary is positive with respect to whichever outer terminal (*1* or *2*) is being grounded by the vibrating reed. The vibrator thus provides full-wave rectifying action which gives a pulsating high d.c. voltage of the correct polarity between the center tap of *S* and the chassis. This pulsating voltage is filtered by *C21A*, *C21B* and *R10*, then applied to the plates and screen grids of the tubes in the receiver (connected between *B+* and *B—* like *RL*).

When the reed moves over to contacts *P2* and *S2*, it also touches contact *A*. This energizes the vibrator coil and pulls the reed over to *P1* and *S1* just as when the set was first turned on. The entire process then repeats itself.

Power Pack Circuit for "AC." When the power selector switch is set at "*AC*," contacts *1-2-3* are connected together, as also are contacts *4-5* and contacts *8-9*. The power pack circuit arrangement for this condition is represented by Fig. *3* if we close the four switches in the diagram.

The output voltage of the charging circuit is now applied directly across the battery just as in Fig. *1*. At the same time, the battery furnishes current for the tube filaments and the vibrator *B* supply. Since the charger furnishes the battery a little more current than is drawn from it by the receiver, the battery will be charged slowly while the set is playing.

The battery acts as a low-resistance bleeder across the charging circuit, and thereby keeps the charging voltage from getting too much higher than the rated filament voltages. The battery also acts like a condenser, removing the ripple from the charging voltage. When the charging voltage starts to decrease, the net voltage cannot become lower than the battery

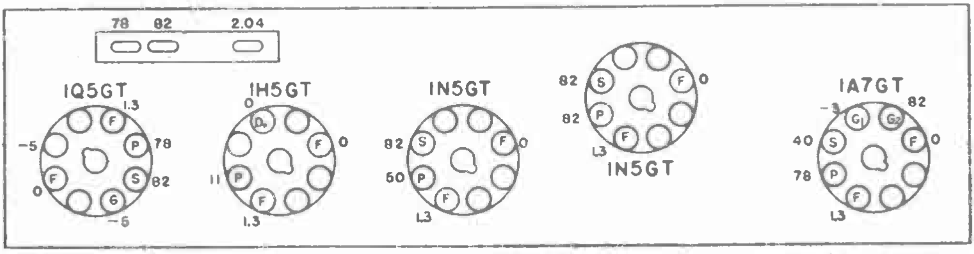


Fig. 4. Socket voltage diagram. The bias battery voltage should be measured only with a zero-current voltmeter, such as a vacuum tube voltmeter. The power switch should be set on "AC," with the charger operating. Tuning dial should be at 1000 kc., with zero volume and zero signal. Battery should measure 2.1 volts. Vibrator B+ voltage should be 95 volts d.c.

TYPICAL RECEIVER DIAGRAMS AND HOW TO ANALYZE THEM

General Electric LB-530 A.C.-BATTERY Portable

IDENTIFYING Tube Stages. When starting to identify tube stages on the circuit diagram of a receiver, we often work by a process of elimination. That is, we locate first the tubes which are easiest to identify. Knowing the stages generally used in a superheterodyne, we then concentrate on assigning the remaining tubes to the heretofore unidentified stages.

We will use this process to identify the tubes in the circuit diagram of this General Electric superheterodyne receiver (shown in Fig. *5*). (Note: By folding page 2 under page 1 you can refer to this diagram while you study, without having to turn pages back and forth.)

We can start from either end of the receiver, so let us start with the 1Q5GT tube. Since this tube feeds the loudspeaker, we know that it is the output tube.

We know that this output tube should be fed by an a.f. voltage amplifier stage, and we find its input coupled to the triode section of the 1H5GT tube by R-C network *R8-C13-R9*. The control grid is fed by the diode section of the 1H5GT through *R1*, *R7* and *C12*, hence the diode section must be the second detector and the triode section must be the first a.f. stage.

The presence of volume control *R1* in the diode circuit confirms identification of the diode section as the second detector, because the volume control in a superhet is always an a.f. voltage control. A.V.C. voltage is taken from the diode detector load through filter *R4-C10*, for application to the a.v.c.-controlled tubes.

Surprisingly, the second detector is resistance-coupled to the output of a 1N5GT tube. This form of coupling might lead us to believe that the 1N5GT was the second detector if we hadn't already identified the 1H5GT as being in this stage. A glance to the left on the schematic shows two i.f. transformers, so sufficient selectivity is provided to allow the less-expensive and broad i.f. resistance coupling to be used here.

Our knowledge of superheterodyne stage sequence tells us that the 1N5GT is an i.f. amplifier, feeding the 1H5GT. It is transformer-coupled to another 1N5GT tube whose input is likewise fed from an i.f. transformer (identified by the tuned primary and tuned secondary). Thus we know that the left-hand 1N5GT in Fig. *5* is the first i.f. amplifier.

I.F. transformer *T4* is fed by a 1A7GT whose input connects to the antenna loop and whose first grid connects to a tank circuit through condenser *C7*. There are no more tubes in the set, so the 1A7GT must be the oscillator-mixer found in every superheterodyne receiver. In this simple manner we have identified the purpose of each tube in the receiver.

Signal Circuits. The parts list under Fig. *5* indicates that *L1* is the Beam-A-Scope Loop assembly, and it must therefore act as the antenna for the receiver. The expression "Beam-A-Scope" is a trade name used by General Electric to describe their shielded loop antenna. Additional pick-up may be obtained by means of an external loop *L7* which is furnished with the receiver and can be plugged into the terminals shown on the diagram. The two loops are inductively coupled together by the single turn of wire shown around *L1* in the diagram.

Loop *L1* is tuned to resonace by condenser *C1*, so signals picked up by *L1* undergo the usual resonant step-up. The use of *L7* will cause some detuning, but the resulting loss in signal is more than made up by the greater pick-up afforded by *L7*. The incoming carrier signal to which *L1-C1* is tuned acts directly on the control grid and filament of the 1A7GT, because *C10* provides a zero-reactance path to the grounded filament at r.f. and i.f. values.

The first and second grids of the 1A7GT (counting from the filament) serve as oscillator electrodes, the first being the oscillator control grid and the second being the oscillator anode.

The incoming signal and oscillator signal are mixed within the tube, and we have a strong i.f. beat signal developed across the primary of *T4*. The signal induced into the secondary of *T4* is applied to the input of the 1N5GT first i.f. tube, the filament connection being through *C10*. The amplified signal now appears across the tuned primary of *T5*, setting up a high circulatory current at the i.f. value, and this induces the i.f. signal voltage in the secondary of *T5*. Again we have resonant step-up, and the signal voltage across the secondary is applied directly to

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the input of the second 1N5GT i.f. tube.

The resulting variations in the plate current of the second 1N5GT tube produce a large i.f. voltage across plate load resistor *R5*. This i.f. voltage is applied across resistor *R6* through condensers *C8*, *C21B* and *C9*. The i.f. voltage across *R6* feeds the diode of the 1H5GT, the filament connection being through *C9*. The diode rectifies the signal and detection takes place. The a.f. signal divides between *R6* and *R1*, but since *R1* is many times greater in value than *R6*, the a.f. signal loss across *R6* is so small that it can be forgotten.

I.F. signals are shunted around *R1* by *C9*. The d.c. component of the rectified audio signal is fed through *R4* for use as the a.v.c. voltage for the control grids of the converter tube and the first i.f. tube. *C10* acts as the a.v.c. filter condenser. That portion of the audio signal which is between the movable contact of *R1* and ground is applied across *R7* in the grid input circuit of the 1H5GT triode section through *C12*.

The amplified audio signal across triode plate load resistor *R8* is applied across the grid input of the 1Q5GT through coupling condenser *C13* and through *C21B*. Plate bypass condenser *C18* removes stray i.f. components from this signal. The plate current of the 1Q5GT, varying at an audio rate and flowing through the primary of output transformer *T1*, induces a voltage in the secondary. The resultant current through the loudspeaker voice coil sets the cone in motion, producing sound waves.

C14, connected between the plate and screen grid of the 1Q5GT, prevents audio oscillation by making the plate load capacitive at the higher frequencies where oscillation would otherwise take place. This condenser also by-passes the harmonics produced within the tube, and hence reduces distortion. The harmonics, being of a higher frequency than the fundamentals, are more easily by-passed by *C14*.

How the Tubes Are Biased. As in all filament-type battery tubes, the effective control grid voltage is the voltage between the control grid and the center of the filament. Naturally we cannot connect our voltmeter probe to the center of the tube filament, so the control grid voltage is measured between the control grid and the negative side of the filament. The tubes all have their negative filament leads grounded to the chassis, and the various grid voltage sources exist between the grids and chassis. The voltage between the center of the filament and ground (half of the filament voltage) serves as an additional bias.

The triode section of the 1H5GT is self-biased by convection currents through *R7*, which has a value of 4.7 megohms.

Bias cells (*B1*) are used to provide control grid voltage for the 1Q5GT power tube. Since *R9* has a value of 2.2 megohms, convection currents wouldn't produce much voltage across such a relatively low value of resistance in the grid circuit of a tube.

Bias cells are more expensive than a single resistor of high ohmic value, but there is a good reason for using them here. The 1Q5GT tube is subject to gas, as are so many power output tubes. If a high-value grid resistor is used with a gassy tube, the resulting gas current through the grid resistor will be opposite in direction to the convection current and much stronger. As a result, the gas current will drive the grid positive, increasing the plate current and releasing more gas, all of which causes serious distortion and shortens tube life.

Because of the low plate and screen voltages which are employed for the converter and the i.f. tubes, no external grid bias sources are necessary for these tubes. The voltages between the centers of the filaments and ground provide sufficient initial bias voltage in each case. When a signal is received, however, the a.v.c. voltage is applied to the converter and first i.f. tube control grids.

The Power Supply. The power supply of this receiver, shown inside the dotted lines in Fig. 5, is as complicated as any you will meet in ordinary receivers. This is due to the switching system and the manner in which the circuit is drawn.

The tube filaments are heated directly by the 2-volt battery, while the necessary high d.c. voltages for the tubes are furnished by a synchronous vibrator used in conjunction with a step-up power transformer and its associated filter circuit. The synchronous vibrator also operates from the 2-volt battery.

Provision has been made to charge the battery directly from the house current without removing the battery from the receiver circuit. Two charging positions are provided on the four-position power selector switch. The "*CHARGE*" position of this switch allows the battery to be charged at the rate of approximately 1.35 amperes from the house current during the period that the receiver is not being operated. The "*AC*" position of the switch allows the receiver to be operated at the same time that the battery is being trickle-charged at a low rate.

Charge Indicator. The degree of charge of the battery can be determined by removing the back cover of the radio and looking at the charge ball indicators which are visible through the hole in the metal battery case.

If the battery is fully charged, three indicator balls will be visible at the surface of the liquid in the battery. When the battery discharges, these ball indicators will sink and disappear in the following order:

1. The green ball sinks when approximately 10% of battery capacity has been discharged.

2. The white ball sinks when 50% of battery capacity has been discharged.

3. The red ball sinks when the battery is 90% discharged.

On charge, the balls rise or float in the reverse order. Charging is complete and may be stopped when all three balls appear in the opening.

To Charge Battery. The battery is charged merely by plugging the receiver power cord into an a.c. wall outlet and turning the selector switch to "*CHARGE*." The charge indicator balls should be checked frequently. Continued charging after all indicator balls are visible will not harm the battery, but will evaporate the water in it faster. A completely discharged battery will usually be restored in 20 to 30 hours.

Power Pack Circuit for "CHARGE." Setting the power selector switch to "*CHARGE*" (for charging the battery from the a.c. power line without operating the receiver) connects switch terminals *2* and *3* together, and also connects *8* and *9* together, as indicated in the box at the left of the diagram in Fig. *5*. When the power pack circuit is redrawn to show only these switch terminals and the associated parts which are effective, we secure the arrangement shown in Fig. *1*. Of course, switches *8-9* and *3-2* would be closed during charging. Charging currents can now be easily traced on this simplified circuit.

During charge, electrons must flow into the negative terminal of the battery and out of the positive terminal. The charging voltage need be only a small amount higher than the normal battery voltage of 2 volts. Transformer *T3* in Fig. *1* provides about 5½ volts a.c. between secondary terminals *x* and *y*. The four copper-oxide rectifiers, each pair in parallel, convert this to the required d.c. voltage.

When point *x* is negative, point *z* is positive. Then electrons flow from *x* through rectifier *Y2* and the chassis to the negative battery terminal, through the battery and back to *z*. Electrons only flow through the copper-oxide rectifiers in the direction from the flat plates to the triangles on the symbols, so there is no electron flow now through rectifier *Y2*.

On the next half-cycle, *y* is negative and *x* is positive, so *z* is now positive with respect to *y*. Electrons flow from *y* through *Y1* and the chassis, then through the battery in the same direction as on the previous half-cycle, adding to the charge of the battery. The electrons coming out of the positive battery terminal return to *z* through switch contacts *3-2*. We thus have a full-wave rectifier, with first one half of the transformer secondary and then the other half furnishing current to the battery.

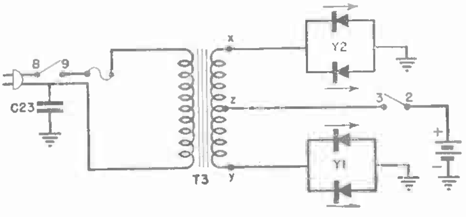


Fig. 1. Effective power pack circuit when power selector switch is set at "CHARGE." Arrows indicate direction of electron flow through rectifier units.

Power Pack Circuit for "BATTERY." When the switch is thrown to the "*BATTERY*" position for portable operation, contacts *4-5* and *2-1* are closed, giving the effective circuit arrangement shown in Fig. *2*. The filaments secure their voltage from the battery through contacts *4-5* and series resistors *R13*, *R11* and *R12*, with the circuits being completed through the chassis by means of grounds.

When the power selector switch is in its "*OFF*" position, all switch contacts are open, and the vibrator reed is in a neutral position half-way between contacts *P1-P2* and *S1-S2*. Only contact *A* on the vibrator is closed.

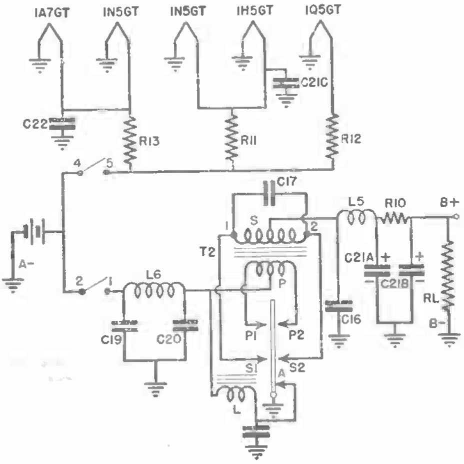
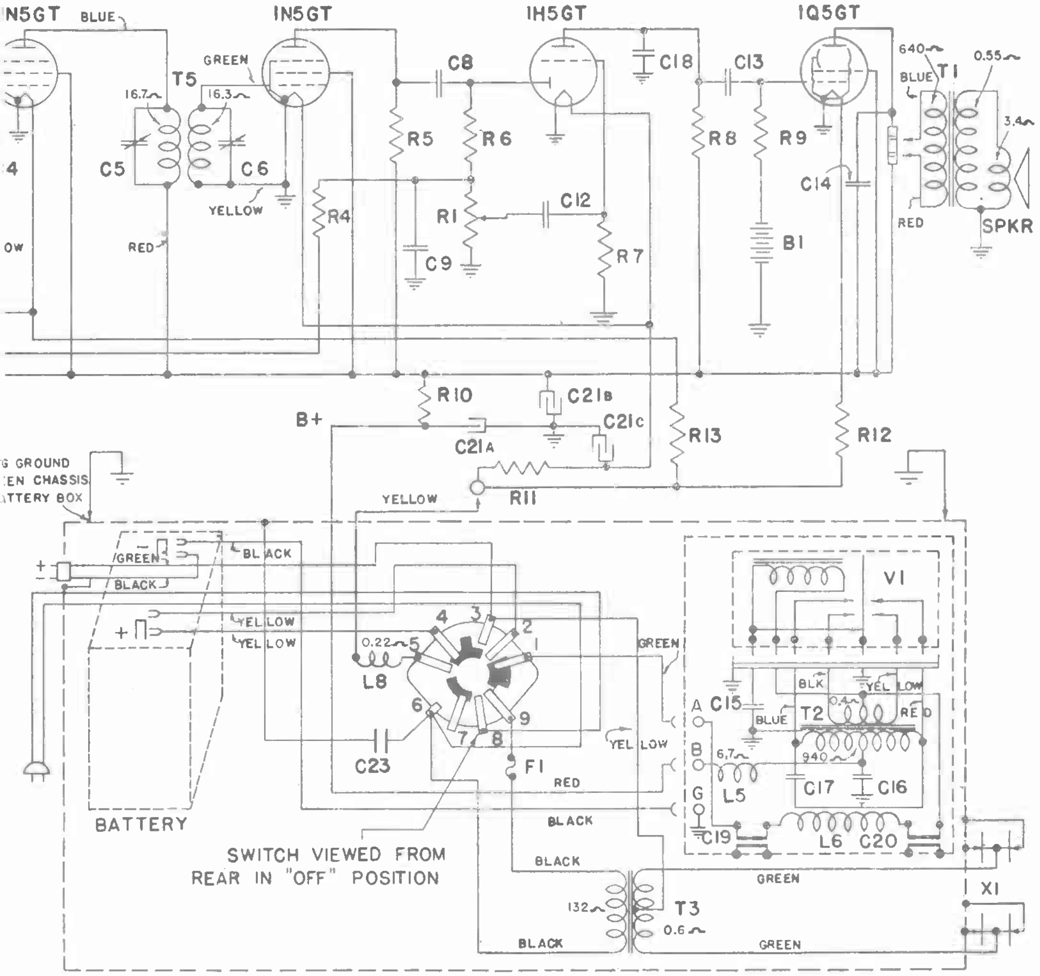


Fig. 2. Effective power pack circuit when power selector switch is set at "BATTERY."

Setting the switch to "*BATTERY*" closes switch contacts *2-1* and *4-5*, and the battery sends current through vibrator contact *A* and through the vibrator coil *L*. This energizes the coil, causing it to attract the vibrator reed. The reed is pulled toward the coil, thereby grounding contacts *P1* and *S1*. This results in electron flow from the grounded terminal of the storage battery through the reed and *P1*, through the left-hand side of the primary of power transformer *T2*, then through *L6* and switch contacts *2-1* to the positive battery terminal.

The sudden rush of current through primary winding *P* causes a high voltage to be induced into secondary *S*. Let us assume that it makes point *1* on the secondary negative with respect to the center tap. Electrons now flow from point *1* through contact *S1* to the chassis, then through all the tube loads in the receiver, represented in Fig *2* as resistive load *RL*. From the *B+* end of *RL*



C1, 2	CONDENSER—Tuning condenser and trimmers
C7	CAPACITOR—47-mmf. mica
C8, 9	CAPACITOR—100-mmf. mica
C10	CAPACITOR—.05-mfd., 200-V. paper
C11	CAPACITOR—0.1-mfd., 200-V. paper
C12, 13	CAPACITOR—.005-mfd., 600-V. paper
C14	CAPACITOR—.01-mfd., 600-V. paper
C15	CAPACITOR—0.1-mfd., 200-V. paper
C16	CAPACITOR—.05-mfd., 200-V. paper
C17	CAPACITOR—.006-mfd., 100-V. paper
C18	CAPACITOR—100-mmf., mica
C19, 20	CAPACITOR—0.5-mfd., 120-V.
C21A, 21B	CAPACITOR—15-mfd., 150-V. dry electrolytic
C21C	CAPACITOR—1200-mfd., 2-V. dry electrolytic
C22	CAPACITOR—0.5-mfd., 120-V. paper
C23	CAPACITOR—.05-mfd., 600-V. paper
R1	VOLUME CONTROL—0.5-megohm volume control
R2	RESISTOR—220,000-ohm, ½-W. carbon
R3	RESISTOR—47,000-ohm, ½-W. carbon
R4	RESISTOR—2.2-megohm, ½-W. carbon
R5	RESISTOR—27,000-ohm, ½-W. carbon
R6	RESISTOR—47,000-ohm, ½-W. carbon
R7	RESISTOR—4.7-megohm, ½-W. carbon
R8	RESISTOR—1.0-megohm, ½-W. carbon
R9	RESISTOR—2.2-megohm, ½-W. carbon
R10	RESISTOR—1,000-ohm, ½-W. carbon
R11, 12, 13	RESISTOR—8.2-ohm, ½-W. carbon
B1	CELL—5.0-V. bias cell assembly
L1	BEAM-A-SCOPE—Loop antenna assembly (inside cover)
L2	COIL—Oscillator coil
L5	CHOKE—B choke
L6	CHOKE—Vibrator choke
L7	BEAM-A-SCOPE—External loop antenna
L8	CHOKE—Filament supply choke
SW1	SWITCH—Power selector switch
T1	TRANSFORMER—Output transformer
T2	VIBRATOR—Vibrator power transformer
T3	TRANSFORMER — 50-60-cycle rectifier step-down transformer
T4	TRANSFORMER—1st i.f. transformer
T5	TRANSFORMER—2nd i.f. transformer
V1	VIBRATOR—Power supply synchronous vibrator
X1	RECTIFIER—Copper-oxide rectifier
Spkr.	SPEAKER—P.M dynamic loudspeaker

THORDARSON 15-WATT AUDIO AMPLIFIER

THIS amplifier, whose circuit diagram is shown in Fig. *6*, has sufficient power output to satisfy the requirements of many different public address installations. The versatility of the amplifier is evident when it is realized that it can be used for ordinary p.a. (public address) work, as a phonograph amplifier, for commercial or home recording, or to amplify the output of a photocell.

Starting with the output stage, we see that type 6V6-G beam power output tubes are used in a class *A* circuit. Distortion is kept below 5% even at full output by the use of inverse feed-back. This low level of distortion is quite good.

The high-impedance microphone and high-impedance phonograph channel, with independent gain controls, will allow use of any type of microphone and either a crystal or magnetic pick-up. The gain is sufficient to obtain full output either from the microphone or pick-up under normal operating conditions.

The circuit diagram shows two loudspeaker sockets, in which either electrodynamic or p.m. dynamic loudspeakers can be plugged. The power pack is designed to serve as field supply for one or two electrodynamic loudspeakers. More than two p.m. dynamic loudspeakers can be used, but normally there would be no reason to use more than two with a relatively small p.a. system like this.

When a phono pick-up is used, the leads are plugged into the jacks provided on the *PHONO* terminal strip, and microphone volume control *R-8* is set for zero volume (so its movable contact is grounded). The signal voltage from the pick-up is applied across phono volume control *R-6*, and the portion of this voltage between the movable contact and ground is applied to a voltage-dividing network consisting of resistors *R-7* and *R-9*. Only that portion of the signal across *R-9* is applied to the input of the second 6J7 tube, the a.f. signal across *R-7* being lost as far as the amplifier is concerned. This cuts the signal in half, but the gain built into the amplifier takes this into consideration.

The purpose of resistor *R-7* is to isolate phono volume control *R-6* from microphone volume control *R-8* when the microphone input is used. Under this condition, *R-6* is set to zero, and volume is controlled by *R-8*. If it were not for resistor *R-7*, control *R-6* in its off position would connect the control grid of the second 6J7 tube directly to ground, thus cutting off the microphone signals. Resistor *R-7* is 500,000 ohms, which is enough to isolate *R-6* from the microphone volume control.

Note the symbol for the microphone jack. The jack is of the telephone type, the outside shell going to ground and the hot (ungrounded) contact going to coupling condenser *C-2*. When a "mike" is plugged into this jack, one lead makes contact to the chassis through the jack shell, while the other connects to condenser *C-2*.

The mike signal is impressed through *C-2* across the single bias cell and resistor *R-3*. In this way it is fed into the input of the first 6J7 tube. This tube is connected as a high-gain voltage amplifier. The weak a.f. signal applied to its input is amplified many times, so a strong a.f. signal is developed across plate load resistor *R-5*. Capacity coupling through condensers *C-4* and *C-10* allows the signal to be applied across volume control *R-8*, whose setting governs the amount of signal fed into the second 6J7 tube.

At the microphone input, you will notice the terminal strip marked *POL-V*. This means polarizing voltage. When a condenser-type microphone is employed, a wire jumper is used to connect terminals *1* and *2* together, thus applying the necessary high d.c. voltage to the microphone plates. Here resistor *R-2* and condenser *C-1* serve as a decoupler filter, preventing any hum voltage from being applied to the condenser microphone and preventing the microphone signal from traveling through the power supply.

If a photoelectric cell of the gas-filled type is plugged into the mike jack, about 90 volts will be required to operate the cell. At terminal *1* we have about 270 volts, and when a photocell is used this is reduced to 90 volts across the mike jack by connecting a 5-megohm, 1-watt resistor between terminals *1* and *2*.

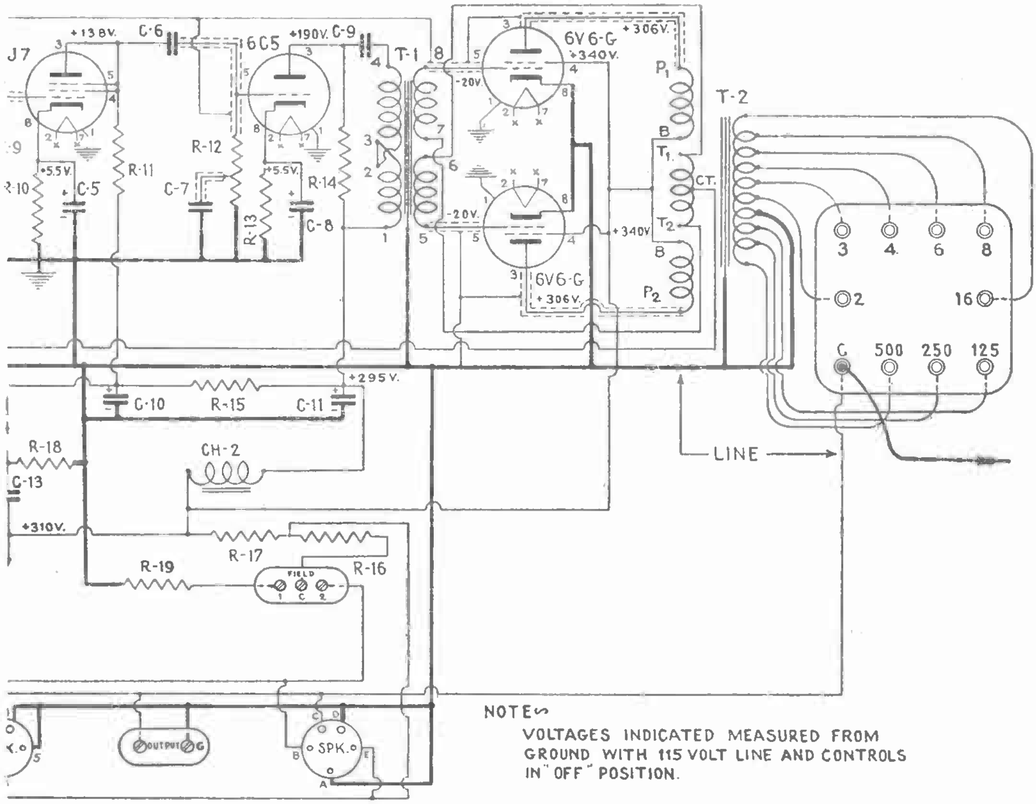
If a condenser microphone or photoelectric cell is never to be used, *R-1*, *R-2* and *C-1* are eliminated during construction of the amplifier.

The shielding of wires and parts in the circuits of the two 6J7 tubes and the 6C5 tube is very important, if hum and noise are to be eliminated. Any hum or noise signals picked up at these points would receive great amplification. If they were as strong as the a.f. signals normally existing here, they would be just as loud at the loudspeakers, thus preventing use of the amplifier.

The microphone, photocell or phono signals applied to the input of the second 6J7 tube cause a large variation in the tube's plate current. The variation in current flowing through plate load resistor *R-11* produces a strong a.f. output voltage across *R-11*.

Before we follow the signal to the next stage, note the electrode connections employed in the second 6J7 tube. With the screen grid, suppressor grid and plate tied together in this manner, the tube acts as a triode instead of a pentode. The gain as a triode is considerable, but far less than that obtained with the pentode connection used for the first 6J7 tube.

The triode connection was employed be-



NOTE:
VOLTAGES INDICATED MEASURED FROM GROUND WITH 115 VOLT LINE AND CONTROLS IN "OFF" POSITION.

Fig. 6. Circuit diagram of Thordarson-designed 15-watt a.f. amplifier. The parts values are:

T-1	Input Transformer
T-2	Output Transformer
T-3	Power Transformer
CH-1	First Choke
CH-2	Second Choke
R-1	10-meg., ½-W.
R-2	10-meg., ½-W.
R-3	5-meg., ½-W.
R-4	3-meg., 1-W.
R-5	500,000-ohm, 1-W.
R-6	1-meg. Volume Control
R-7	500,000-ohm, 1-W.
R-8	1-meg. Volume Control
R-9	500,000-ohm, ½-W.
R-10	5000-ohm, 1-W.
R-11	100,000-ohm, 1-W.
R-12	500,000-ohm Tone Control
R-13	1000-ohm, 1-W.
R-14	20,000-ohm, 1-W.
R-15	20,000-ohm, 1-W.
R-16	2500-ohm, 25-W. wirewound
R-17	1500-ohm, 25-W. wirewound
R-18	125-ohm, 25-W. wirewound, Tolerance +10%, —0%
R-19	2500-ohm, 25-W. wirewound
C-1	1-mfd., 400-V. paper
C-2	1-mfd., 400-V. paper
C-3	.04-mfd., 400-V. paper
C-4	1-mfd., 400-V. paper
C-5	10-mfd., 25-V. electrolytic
C-6	1-mfd., 400-V. paper
C-7	.03-mfd., 400-V. paper
C-8	10-mfd., 25-V. electrolytic
C-9	1-mfd., 400-V. paper
C-10, C-11	8-8 mfd., 450 W.V. electrolytic
C-12	8-mfd., 600-V. electrolytic
C-13	8-mfd., 600-V. electrolytic

should read about 310 volts. Now notice that the screens of the output tubes are marked 340 volts. The screens connect directly to the positive lead of *C-13* and hence are at the same potential as *C-13* with respect to ground. The difference between the marked voltages shows that the draftsman who made up this schematic was careless. In a case like this, you must rely on your own knowledge and be able to make up your mind that an error exists. In all probability, 340 volts and not 310 volts is correct.

Note that the 6V6-G plates are marked 306 volts. If 310 volts is right and the plates are marked correctly, there is only a drop of 4 volts across the plate windings of output transformer *T-2*. This is not reasonable. Now if 340 volts is correct, the drop across the plate windings is 34 volts, which is about the amount you would expect.

The plate voltages of the 6J7 and 6C5 tubes were probably measured with a 1000-ohm-pervolt meter. If a more sensitive meter is used, a higher voltage will be measured, since the meter will draw less current through the plate load resistors and hence won't cause as much extra voltage drop to exist across them.

EMERSON Model DU-379 and DU-380 Battery Portable

GENERAL Description. Although the diagram of this battery portable (Fig. 7) bears two model numbers, both models are essentially the same. The only difference lies in the degree of portability. The model DU-379 is an outdoor portable and may be carried by the special strap which fits over the user's shoulder. Since the loop is placed in this strap, there is a slight difference in the design of this loop and the one used in the model DU-380. Other than this, the two sets are identical and are both known as the DU chassis.

To achieve real portability, special small-size, low-current-drain tubes are used. Two flashlight cells connected in parallel serve as the *A* supply, and a special light-weight 67½-volt *B* battery is used.

The tubes and their functions, which you should be able by this time to identify without trouble, are: A 1R5 pentagrid converter tube as the oscillator-mixer-first detector; a 1T4 super control tube as the i.f. amplifier; a 1S5 diode-pentode as the second detector, a.v.c. and first a.f. amplifier; a 1S4 power output pentode to feed the loudspeaker.

Signal Circuits. There are a number of small but important variations from normal in the circuits of this receiver which make it of interest. Each item will be explained as we come to it.

Signals picked up by the loop may be tuned in by adjusting the tuning condenser dial, which controls ganged condensers *C1* and *C2*. Condenser *C1* tunes the loop, and the chosen signal receives a boost in strength due to resonant step-up.

In the shoulder-strap model DU-379, the inductance which is tuned by *C1* consists of loop *L2* and an extra inductance *L1*. In home-model DU-380, all of the inductance is concentrated in the loop, which is rigidly fastened in place, and *L1* is absent. In model DU-379, the loop shape will change as the wearer breathes and moves around. This results in some inductance change; to avoid serious detuning, most of the circuit inductance is concentrated in *L1*. Then even large changes in the loop inductance have only a small effect on the total circuit inductance and hence on tuning. The shoulder-strap loop is primarily a pick-up device rather than a tuning coil.

In both models, the resonant circuit is completed through *C5* which, as far as r.f. is concerned, acts like a short circuit.

The modulated carrier of the selected station appears across *C1*, and is applied to the input of the first detector. The filament connection is made through the chassis and the lower half of oscillator tank coil *T1*. At the same time, the oscillator signal is injected into the first detector. The two signals are mixed inside the tube. The resulting i.f. beat voltage, bearing the original carrier modulation, is applied to the primary of i.f. transformer *T2*.

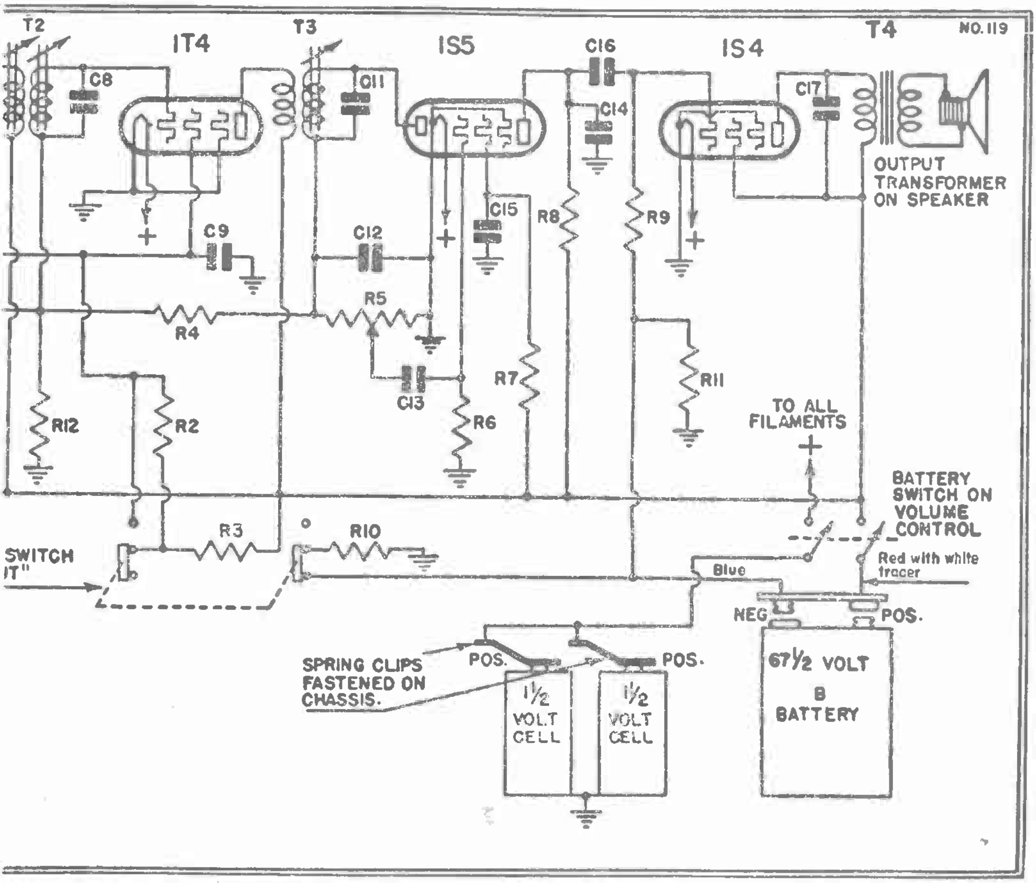
An examination shows the oscillator circuit to be different from that found with the usual pentagrid converter tube. First, you will note that we have been speaking of the 1R5 as a pentagrid converter, when only four grids are shown. The facts of the case are that the manufacturer's draftsman took a little poetic license and left out the suppressor grid, figuring perhaps that the tube drawing was going to be spread out enough as it was, and it didn't matter as far as service work was concerned. In this he was right, for the extra grid, placed between the screen and plate, connects inside the tube envelope to the negative side of the filament, and serves to prevent secondary emission from the plate to the screen. A serviceman can't get at this grid or do anything about it, so it doesn't enter as a service problem. If the grid shorts to the plate, a tube tester will show this up in the usual manner, and in the set the short, if it occurred, would appear to be between the plate and filament.

The oscillator is an ordinary Hartley with the plate grounded. Here the screen grid acts as the plate, and the screen is kept at r.f. ground potential by means of by-pass condenser *C9*. The screen also acts as the virtual cathode as far as the detector section is concerned. The third grid, which is the detector control grid, controls the stream of electrons coming through the screen grid. This electron stream is varying at the oscillator frequency, so the i.f. beat is produced in the detector (mixer) section of the tube.

Feed-back in the oscillator is obtained by causing the plate current to flow through the tapped portion of *T1*. The voltage induced into the rest of *T1* causes the circuit consisting of *T1-C2* to oscillate at its resonant frequency. The oscillator voltage is applied to the oscillator control grid through *C6*. *R1* is the oscillator grid resistor, and *L3* is used to prevent the 1R5 filament and the *A* battery from shorting the tapped section of *T1*. Such a short would prevent the oscillator from working.

Now that the oscillator has been investigated, let us return to the i.f. signal delivered by the 1R5 to resonant circuit *T2-C7* of the first i.f. transformer. This circuit is adjusted to resonance at the i.f. value (455 kc.), not by varying the capacity of *C7* but by adjusting the inductance of the primary. This winding has a pulverized iron core which can be screwed in or out of the coil to change the inductance. As more of the core is moved into the coil, the inductance is increased and the resonant frequency thereby lowered.

By mutual induction a voltage is induced into the secondary shunted by *C8*, and again



L1	Iron-core loading coil (Model DU-379 only)
L2	Shoulder-strap loop assembly (Model DU 379 only)
L2	Loop antenna (Model DU-380 only)
T1	Oscillator coil
T2	Iron-core double-tuned 455-kc. first I.f. transformer
T3	Iron-core single-tuned 455-kc. second I.f. transformer
R1	100,000-ohm ¼-W. carbon resistor
R2	5000-ohm, ¼-W. carbon resistor
R3	10,000-ohm, ¼-W. carbon resistor
R4, R12	5-megohm, ¼-W. carbon resistor (R12 is omitted on later models)
R5	Volume control, 1.5-megohm, with double pole battery switch
R6	10-megohm, ¼-W. carbon resistor
R7, R9	3-megohm, ¼-W. carbon resistor
R8	1-megohm, ¼-W. carbon resistor
R10	2200-ohm, ¼-W. carbon resistor
R11	1800-ohm, ¼-W. carbon resistor
C1, C2	Two-gang variable condenser
C3, C4	Trimmers, part of variable cond.
C5, C9, C15	0.02-mfd., 200-volt tubular cond.
C6, C12, C14	0.00011-mfd. mica condenser
C7, C8, C11	Fixed trimming condensers, contained inside i.f cans
C10	10-mfd., 100-volt dry electrolytic condenser
C13	0.002-mfd., 600-volt tubular cond.
C16, C17	0.001-mfd., 600-volt tubular cond.

4" permanent magnet dynamic loudspeaker

Double-pole, double-throw "Economizer" switch

Automatic Model P57 Three-Way Portable Receiver

GENERAL Description. The Automatic Model P57 can be powered from three different sources—self-contained batteries, a 110-volt a.c. power line, or a 110-volt d.c. power line. In other words, this is an a.c.-d.c.-battery receiver.

A study of the diagram in Fig. 8 shows that the receiver consists of a 1A7G pentragrid converter tube, a 1N5G i.f. amplifier tube, a 1H5G combination second detector—a.v.c.—first audio tube, a 1A5G power output tube and a 25Z6 rectifier.

Excellent reception can be had by using the self-contained loop aerial alone. Terminals *A* and *G* are provided, however, for connecting to an outside aerial and ground when more distant reception is required. When an aerial and ground are used, the antenna current flows through the wire placed around the outside of the loop, and induces a signal voltage into the loop.

Signal Circuits. The signal picked up by the loop is resonated by the tuning condenser, and the stepped-up signal voltage is applied to the input of the 1A7G type tube.

An r.f. oscillator signal is being produced at the same time in the 1A7G tube, due to feed-back from the oscillator coil plate winding to the tank circuit. You will note that the first two grids of the tube are used as the oscillator grid and anode electrodes. The tank circuit is coupled to the oscillator grid through the .0001-mfd. condenser. The 50,000-ohm resistor produces the oscillator grid bias due to the rectified grid current flowing through it.

The varying electron stream leaving the second grid passes through the screen grid to the plate. This electron stream is acted on by the signal voltage applied to the input of the tube, and the oscillator and incoming signals are thus mixed within the tube.

The screen surrounding the 1A7G control grid (the fourth grid from the filament) prevents any interaction between this grid and the oscillator electrodes, and also acts as a capacitive screen between the plate and the detector control grid.

The i.f. signal voltage developed across the primary of the first i.f. transformer causes a large i.f. current to flow through the transformer winding.

By mutual induction a signal appears in the secondary of the transformer and there undergoes resonant step-up. This signal is applied directly to the input of the 1N5G i.f. tube. Since this is a high-impedance pentode tube, a large i.f. voltage will be built up across the primary of the second i.f. transformer, much larger than the one which was applied to the input of the 1N5G tube.

The i.f. signal voltage induced into the secondary of the second i.f. transformer is now large enough for detection.

When the i.f. signal makes the diode plate of the 1H5G tube positive, electrons flow from the filament to this plate, through the secondary of the second i.f. transformer and through the volume control to the filament. The i.f. component is prevented from flowing through the volume control by means of the .0002-mfd. by-pass condenser connected from the hot side of the volume control to the chassis. The filament side of the volume control is grounded to the chassis by means of the .1-mfd. condenser.

The a.f. signal voltage appearing across the volume control is applied to the 15-megohm grid resistor and the grid of the 1H5G tube through the .01-mfd. coupling condenser.

The amplified a.f. signal appears across the 1-megohm plate load resistor of the 1H5G tube. This signal is also applied across the 2-megohm grid resistor for the 1A5G type tube through the .002-mfd. coupling condenser and the 20-mfd. output filter condenser, with the filament connection being through the 100-mfd. electrolytic condenser.

The application of the signal to the input of the 1A5G tube causes large changes in plate current flowing through the primary of the output transformer, and this a.f. plate current induces the signal voltage in the secondary. This causes a.f. current to flow through the voice coil, thus setting the cone

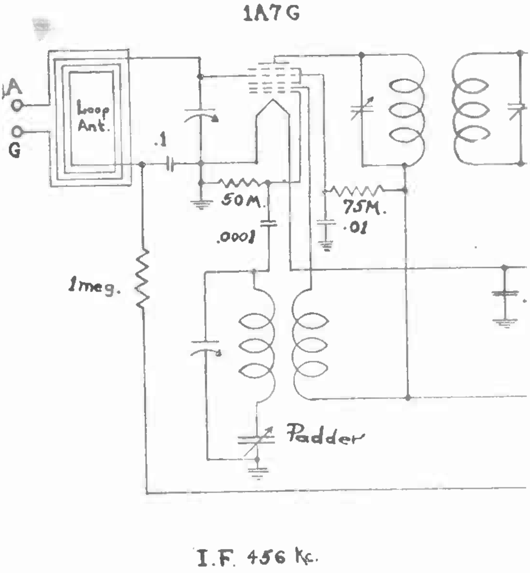


Fig. 8. Schematic circuit diagram of Automatic Model P57 combination a.c.-d.c.-battery portable 5-tube superheterodyne receiver.

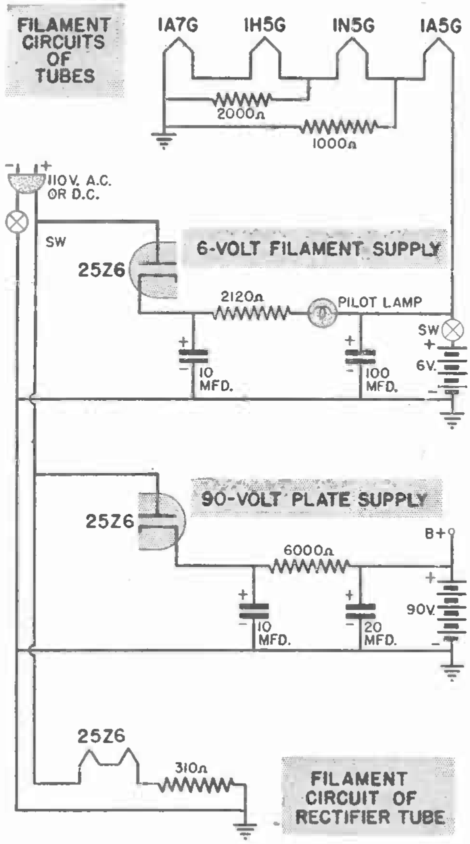


Fig. 9. The power pack and filament circuits of the Automatic Model P57 receiver have been redrawn here to show that the individual circuits are simple and quite conventional.

diagram in Fig. *9* will show that between the negative side of the 1A5G tube and the chassis we have the filaments of three tubes, each getting about 1.5 volts. This means that the grid of the 1A5G tube is about 4.5 volts negative with respect to the negative side of the 1A5G tube filament.

The 2000-ohm and 1000-ohm resistors in the filament supply circuits are used as shunts to take care of the plate currents of the tubes. Flowing through the 1A7G and 1H5G filaments are the .05-ampere filament currents and the plate currents of these tubes. The plate current of the 1N5G divides between the 2000-ohm shunt resistor and the filaments of the 1A7G and 1H5G tubes. The plate current of the 1A5G tube divides between the 1000-ohm resistor and the circuit consisting of the 1A7G, 1N5G and 1H5G filaments and the 2000-ohm shunt resistor. While the receiver would work without the shunts, the current through the filaments would be excessive and would tend to shorten tube life.

Servicing Hints. Receivers of this type are subject to the same defects as are encountered in a.c.-d.c. or battery receivers. Bear in mind, however, that when the receiver is operated from the power line, a defect in one power supply may be masked by proper operation of the other supply. For example, the rectifier tube may be worn out, but the receiver will play normally on the power line, for the batteries will furnish power. Bad batteries, on the other hand, will be masked by the power pack on power line operation.

We are most concerned here with straight battery operation, since you are familiar with a.c.-d.c. power supply troubles. About all that could occur to the power pack would be tube and filter condenser troubles, or burning out of the pilot lamp. If the pilot lamp must be replaced, use an exact duplicate as no other will work properly A burned-out pilot lamp should be replaced as soon as possible, because its failure forces the 6-volt battery to supply filament current during a.c or d.c. operation.

On battery operation, most trouble is due to worn-out batteries. If the battery voltages will not come up to normal and give satisfactory results even after prolonged operation of the receiver from the power line with the 1A5G tube removed, new batteries are necessary.

The battery voltage should be measured with the receiver operating only from batteries and all of the tubes in place. This places a normal load on the batteries, so high internal resistance which causes appreciable internal voltage drop in a bad cell will be revealed. Without normal load, a high-resistance serviceman's voltmeter won't draw enough current to produce an appreciable voltage drop in the batteries, and normal voltage will be measured even though the batteries are run-down.

Low battery voltages will usually affect the operation of the oscillator first, since this circuit is the most critical as to voltage. Since it is harder for oscillation to be maintained at the lower frequencies, the receiver will first go dead at the low-frequency end of the dial. As the batteries continue to deteriorate, the set will go dead over the entire dial, since the oscillator will refuse to operate at any point on its range.

When an oscillator goes dead in this manner, a very characteristic effect is sometimes observed; a powerful local station, usually one at the low-frequency end of the dial, will be heard regardless of how the receiver is tuned. Such an occurrence is definite proof of oscillator failure, and indicates that the set is acting as a broadly-tuned t.r.f. receiver.

About the only other trouble peculiar to battery receivers is intermittent reception and noise caused by poor or corroded connections inside of the batteries. A substitution of new batteries or a careful voltmeter check will show up such trouble.

Philco Model 610 Three-Band A.C. Superheterodyne

GENERAL Description. The Philco Model 610 is a three-band a.c.-operated superheterodyne using a type 6A7 mixer, a type 78 in the i.f. amplifier, a type 75 as a combination detector, a.v.c. and first a.f. tube, a type 42 in the power output stage and a type 80 rectifier in the power supply. All of these stages are clearly identified on the schematic circuit diagram in Fig. *10*. The wave-band coverage is: Band 1, 530-1720 kc.; band 2, 2300-2500 kc. (2.3-2.5 megacycles); band 3, 5700-18,000 kc. (5.7-18 megacycles). The design of this receiver is straightforward, the circuits being similar to those which you have already studied.

Wave-Band Switch and Circuits. A radio technician is only interested in that section or circuit in which trouble exists. He is guided to this point either by the symptoms exhibited by the receiver or by a stage isolation procedure as outlined in the Advanced Course in Radio Servicing. The rest of the receiver he ignores. With this method, he will probably escape the necessity of delving into the wave-band switching circuits.

However, if trouble is encountered in the preselector-mixer-oscillator system, he must be able to unravel the wave-band circuits and make tests on them. Furthermore, to align the set, he must be able to identify the trimmers appearing in the diagram and, from their electrical positions in the circuit, determine their purpose.

In such a case he sees the same thing you see here—a conglomeration of switch contacts, coils, condensers and wires. The expert ignores all this and sets about systematically to trace through the circuits. He knows that the 6A7 has a tuned input circuit, because no manufacturer would build a receiver without a preselector between the mixer and antenna. Furthermore, this tuned input circuit must connect between the 6A7 top cap and the a.v.c. bus. These two points are readily located in the diagram, the a.v.c. bus being the wire lead connecting to the junction of a.v.c. filter condenser *25* and filter resistor *29*.

Let us trace the tuned input circuit. We start with the 6A7 top cap, and follow the lead down to terminal *S* of switch section *2*. Looking at this section, we see that there are two other terminals like *S*, marked *G* and *P*, each feeding a different set of leads through contacts. We rightfully assume that this is a three-pole, three-position switch and that terminals *S*, *G* and *P* are input terminals for the three poles of the switch.

With the switch set to position *1* as shown in the diagram, terminal *S* makes contact only to terminal *M* through the round black "ball" which represents the movable contact element for this pole of the switch. This black ball always makes contact with *S*.

From *M* we go to the junction of trimmer *5* and tuning coil *L2*. We ignore the tap on *L2*, as a glance at terminal *G* of switch section *2* shows it isn't used. The other end of *L2* connects to the a.v.c. bus, which is the other end of the tuned input circuit we were tracing.

This gives us the general technique for tracing through the wave-band switch, and we can now trace the other circuits for switch position *1*. Coil *L3* and its primary *L1* are ignored, because coil *L2* is being used and we wouldn't expect another tuned circuit to be employed at the mixer input at the same time. Since *L2* is in use, its primary is in use, and we may be sure the primary is carrying energy delivered to it by the antenna system. The primary is checked by connecting an ohmmeter between the *ANT* lead and the chassis. We will expect a reading of about 32 ohms if everything is intact.

Switch position *1* is for the broadcast band (the lowest-frequency band on the set), because coil *L2* (connected to *S* for position *1*) has a higher resistance and hence a greater number of turns than coil *L3*. *L3* must be the short-wave coil for band *3*, since it has the lowest resistance and therefore the lowest inductance.

Since *L2* is the broadcast band antenna coil, its associated trimmer *5* is the broadcast band antenna trimmer, and is to be adjusted somewhere near the high-frequency end of its band (1400 kc. is a popular adjustment point).

Now that we have accounted for the preselector, let's take a look at the oscillator. We have two sets of coils, *L4-L6* and *L5-L7*. Coils *L6* and *L7*, being connected to trimmers, are the tank coils. Since *L6* has the greatest resistance, it is the broadcast band oscillator coil, in which we are now interested.

Again we have two reference points—the 6A7 oscillator grid, which is the first grid from the cathode, and the cathode of the 6A7. Since the cathode goes to chassis through resistor *16*, we will use the chassis for reference purposes.

Follow the lead from the oscillator grid, noting that it connects from oscillator tuning condenser *19* to pole *P* on switch section *2*.

The switch contact connects it to switch terminal *Q*, and from here we go to tank coil *L6*. This coil connects to tuning condenser *19* through condenser *10* which, being in series with the tank circuit, is the oscillator low-frequency padder. This padder, as its name implies, is to be adjusted at the low-frequency end of the broadcast band; 600 kc. is the most favored adjusting frequency.

Trimmer condenser *11*, which is in shunt with the oscillator tuning condenser, is the high-frequency oscillator trimmer. Like trimmer *5*, it is to be adjusted at 1400 kc. The position of resistor *17* is a little uncon-

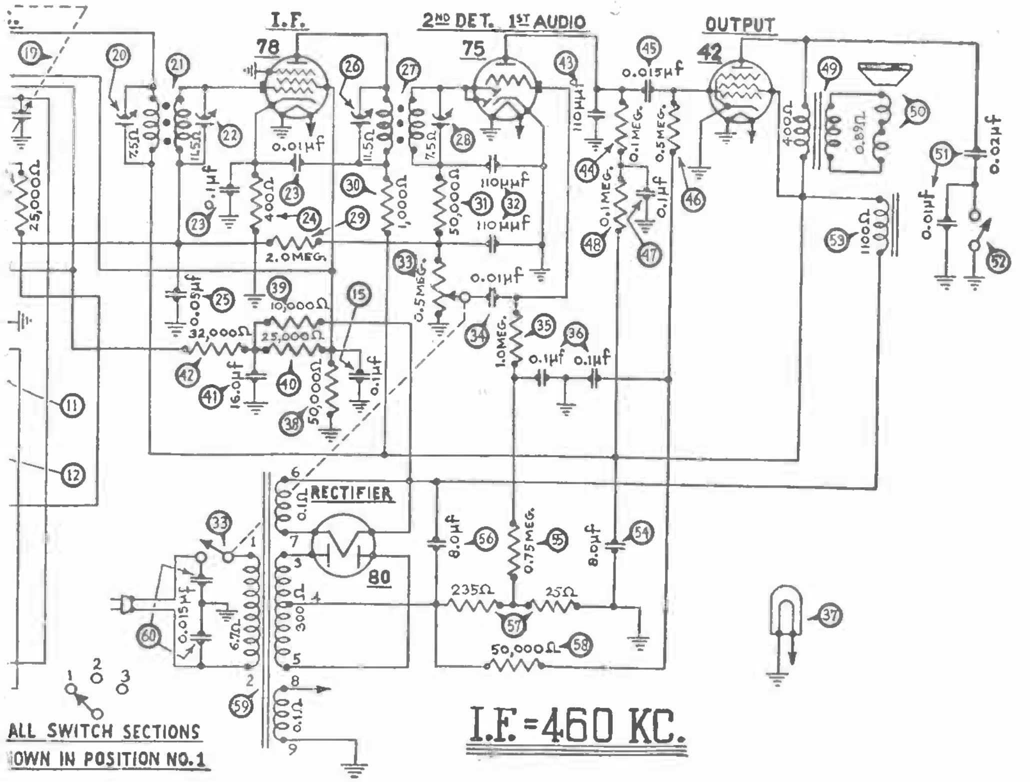


Fig. 10. Schematic circuit diagram of Philco Model 610 three-band superheterodyne receiver.

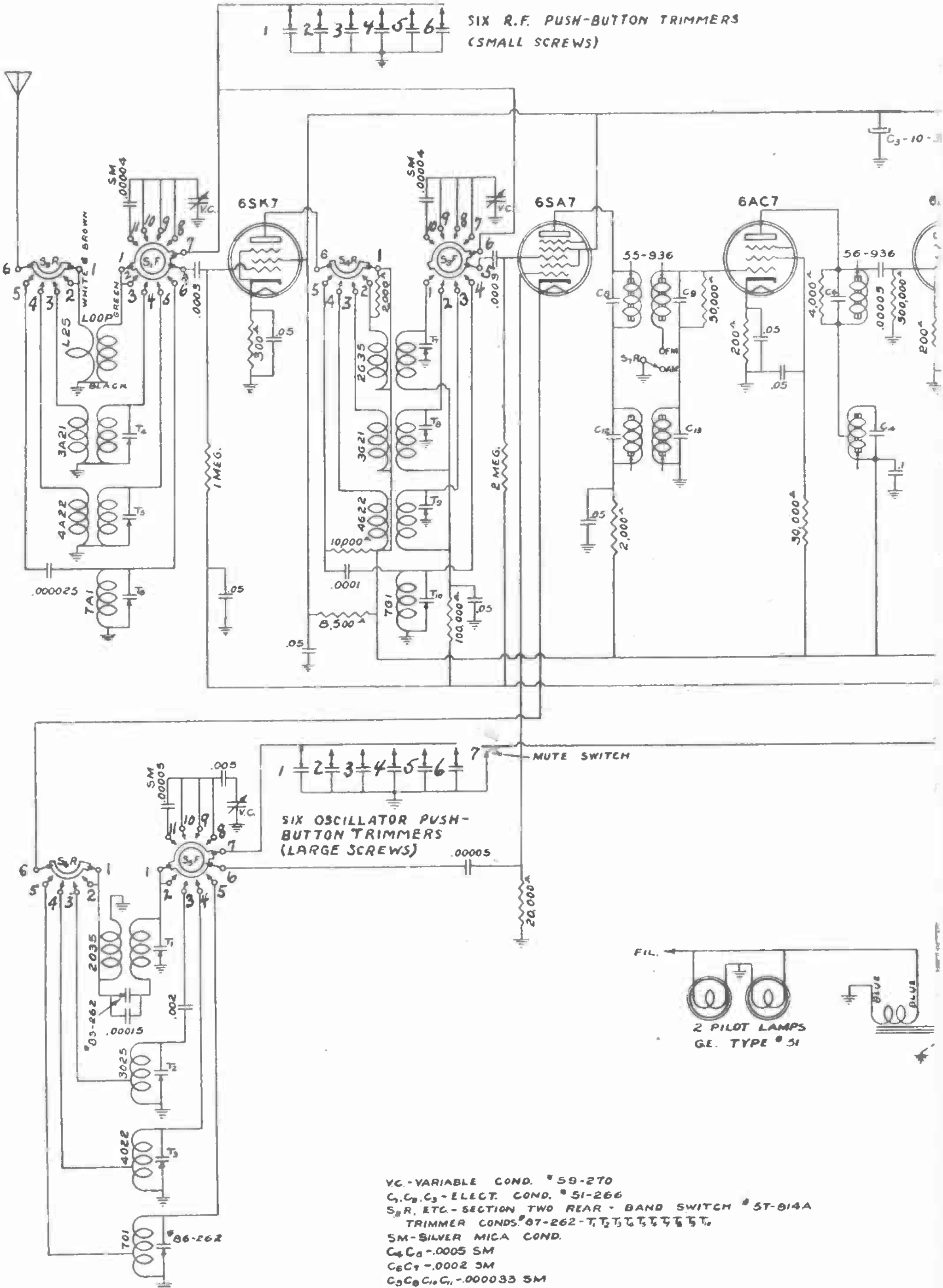
We have now investigated the important sections of the preselector and oscillator circuits for all bands. In each case, the oscillator signal and the preselector signal are mixed in the 6A7, and produce a 460-kc. beat. This is passed into the i.f. amplifier through the first i.f. transformer (*21*). After amplification by the type 78 i.f. tube, the i.f. signal is transferred to the diode detector circuit of the type 75 tube by the second i.f. transformer (*27*).

After detection, the rectified signal voltage appears across volume control *33*, which is also the diode load resistor. The signal amplified by the triode section of the 75 tube is passed by means of resistance coupling to the type 42 power output tube. The output of this tube feeds the loudspeaker voice coil through output transformer *49*.

Since this receiver was chosen to give you practice with wave-band switch circuits, we have omitted discussion of the rest of the receiver circuits. These circuits have previously been covered, and should hold no secrets from you. However, if you want a little practice you might explore their possibilities and explain them to yourself as we have done for similar diagrams.

Here is a little additional work of a practical nature. The following symptoms are often encountered in this receiver and are due to the causes listed. Try to figure out why these particular defects (causes) should result in these symptoms.

Symptom	Cause
Dead only when tone control *52* is on.	Short in .02-mfd. section of *51*.
Hum when cone is replaced.	Voice coil connections reversed.
Hum stops only when *42* is removed.	Open in right-hand section of condenser *36*.
Distorts; clears up when hand is held on 75 top cap and chassis.	Leakage in *45* or leakage in *47*.
Distorts and cuts off on strong signals when volume control is advanced.	Leakage in *34*.
Dead; circuit disturbance test shows all stages pass signal.	Open in resistor *42*.
Blasting when tuning from one station to another.	Short or leakage in condenser *25*.
Audio oscillation when tone control *52* is off.	Open in .01-mfd. section of condenser block *51*.



V.C.-VARIABLE COND. #59-270
C_1.C_2.C_3-ELECT. COND. #51-266
S_8R, ETC.-SECTION TWO REAR - BAND SWITCH #5T-814A
TRIMMER CONDS.#87-262-$T_1T_2T_3T_4T_5T_6T_7T_8T_9T_{10}$
SM-SILVER MICA COND.
C_4C_5-.0005 SM
C_6C_7-.0002 SM
$C_9C_8C_{10}C_{11}$-.000033 SM
$C_{12}C_{13}$-.001 SM
C_{14}-DUAL TRIMMER COND. #71-262

Fig. 12. Schematic circuit diagram of Howard Model 718FM-

further variations in cathode current, and in this manner oscillation is maintained. The grid bias voltage produced across the 20,000-ohm self-bias resistor prevents the cathode current from exceeding the safe rating of the tube.

Due to the oscillator action, the electron flow from the cathode through the oscillator grid and the screen grid (oscillator plate) to the plate of the 6SA7 is a pulsating stream. As far as the mixer grid is concerned, however, the screen grid is the virtual cathode which is supplying a pulsating electron stream.

At the third grid from the cathode (mixer grid), the incoming signal is applied. It mixes with the local oscillator signal, and the resulting beat (the difference between the two signal frequencies) forms the intermediate frequency.

Switch Position 2. When the band switch is thrown to manual tuning, the switch connections are those shown for position *2* in Fig. *13*. Let us analyze the circuits which are in action now.

Antenna current flows through switch contacts *6-2* of section S_2R and through the primary of coil *L25* to ground. Section S_1F connects contacts *2*, *6* and *8* together so the secondary of *L25* is tuned by variable condenser *V.C.* The signal undergoes resonant step-up, after which it is applied to the 6SK7 r.f. amplifier tube in the usual manner. The amplified signal current flows through the primary of coil *2G35*, which is shunted by a 2000-ohm resistor to broaden the tuning and thus prevent side-band cutting. A voltage is induced in the secondary, where it undergoes resonant step-up, and the resulting signal is applied to the 6SA7 input through the .0003-mfd. coupling condenser.

In the oscillator circuit, the connections and circuit action of coil *2035*, with its trimmers and padder, remain the same as for push-button operation. However, contact is made to *8* instead of *7* on switch section S_5F, to put main tuning condenser *V.C.* in the circuit in place of the push-button trimmers. Mixing occurs in the 6SA7 as before, and the i.f. signal is delivered to the i.f. amplifier.

Switch Positions 3 and 4. The circuits for these two short-wave band positions are identical to those for the broadcast band, and hence need not be traced in detail. The selector switches merely place different sets of coils in their respective circuits.

The A.M. I.F. Amplifier. From the schematic diagram, you see that there are two i.f. transformers between the mixer and the 6AC7 first i.f. tube, one for f.m. and the other for a.m. We identify the top transformer in the schematic as the f.m. transformer because its secondary connects to the *FM* terminal of S_7R. The primary of this transformer offers little opposition to the 465-kc. i.f. signal, so the a.m. signal passes through it to the primary of the a.m. transformer.

A large 465-kc. current flows in the tuned primary of the a.m. transformer, and a corresponding signal, which also undergoes resonant step-up, is induced into the secondary. This is applied to the control grid of the 6AC7 first i.f. tube through condenser C_9 and to its cathode through the chassis and the .05-mfd. cathode by-pass condenser.

The tube amplifies the signal and a large i.f. voltage is built up across the plate load. But what is the plate load? It is not the resonant circuit formed by coil *56-936* and condenser C_8, for these are shunted by a 4000-ohm resistor which is not used in a.m. loads. We can assume that condenser C_6 acts as a short across the coil and resistor at a.m. i.f. frequencies. The next device in the plate circuit is a tapped resonant circuit, and this is what serves as the a.m. plate load.

It is unusual to see a tapped resonant circuit of this sort, for only the lower coil section, between the tap and B+, acts as the load. The voltage across this section is large, due to the resonant step-up provided by tuning the circuit. This voltage is transferred through C_6, the .00005-mfd. coupling condenser and the .1-mfd. plate by-pass, and appears across the 500,000-ohm grid resistor for the next stage.

The 500,000-ohm grid resistor, therefore, shunts the lower section of the coil. The resistor is not across the entire resonant circuit, however, and because of this, a reasonable degree of selectivity is still secured. At the same time, since the entire voltage across the resonant circuit is not transferred to the grid resistor, the gain is reduced. With two stages of i.f. amplification, there is gain to spare, and the slightly broadened response curve of the i.f. amplifier results in good fidelity. The f.m. transformer is not tapped in this manner because both broad tuning and all available gain are desired.

The i.f. current flowing through the grid resistor builds up a large signal voltage across it. This voltage is applied to the grid-cathode circuit of the tube, the cathode connection being through the cathode by-pass condenser.

Amplification of the signal by the second i.f. tube results in a large signal voltage being developed across the resonant plate load formed by C_7 and the primary of the third i.f. transformer. The resonant frequency of the f.m. transformer is 4.3 mc., which is so far from 465 kc. that for all practical purposes, no a.m. signals are set up in the secondary of the f.m. transformer. However, a large i.f. signal is set up in the secondary of the last a.m. transformer, and this a.m. signal is applied to the plates and cathodes of the 6H6 second detector. The cathode connection is through the .0002-mfd. condenser and the chassis.

The A.M. Second Detector. When the i.f. signal makes the 6H6 plates positive, electrons leaving the cathodes are attracted to the plates. From there, the electron flow is through the i.f. secondary, the 50,000-ohm i.f. filter resistor and the 250,000-ohm diode load resistor to ground, then back to the 6H6 cathodes. Current flow is blocked when the signal makes the plates negative with respect to the cathodes. This is the action of a typical diode detector.

We have the rectified a.f. signal existing across the 250,000-ohm load resistor. Due to the smoothing action of the two .0002-mfd. condensers, we also have a rather large d.c. voltage across the diode load. The a.f. signal, being unaffected by the .0002-mfd. condensers, adds to this d.c. voltage and causes it to increase and decrease, forming a pulsating d.c. voltage across the load resistor. No i.f. signal appears across it because the i.f. is shunted around the diode load by the i.f. filter composed of the 50,000-ohm resistor and the two .0002-mfd. condensers.

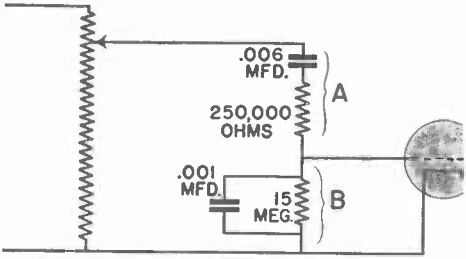


Fig. 14. Bass-boosting circuit.

The d.c. voltage across the 250,000-ohm diode load is used for a.v.c. purposes and to operate the tuning eye. The a.v.c. filter network is made up of the 1-meg. resistor connected to the tuning eye grid through switch S_7R, and the .05-mfd. condenser in the control grid return circuit of the 6SK7 tube. Note that this a.v.c. voltage is used only for a.m. reception.

The Audio Amplifier. The audio signal component across the diode load is applied across the dual volume control through the .02-mfd. d.c. blocking condenser, contact *AM* of switch S_7R, the *RADIO* contact of the *PHONO* switch and the 25-ohm resistor between the volume control and the chassis.

Now we come to a unique method of tone control which is becoming more and more popular in high-fidelity audio amplifiers. Note that the dual volume control simultaneously feeds two 6SF5 tubes, and that the outputs of these tubes feed through .02-mfd. coupling condensers into a common load consisting of 500,000- and 100,000-ohm resistors connected in series between the control grid of the lower 6V6G output tube and the chassis.

The upper 6SF5 tube and its 15-megohm grid resistor are fed by the first section of the volume control through a .006-mfd. coupling condenser, with all audio frequencies being transferred about equally well.

Potentiometer *87-281* is connected to control the amount of signal which the right-hand volume control feeds through the .006-mfd. coupling condenser and a 250,000-ohm resistor to the 15-megohm grid resistor of the lower 6SF5 tube. A .001-mfd. by-pass condenser is in parallel with the 15-meg. resistor, so the impedance of the grid input circuit is a combination of these values. This is the special arrangement which provides tone control, so let us study its action in detail.

The tone control circuit has been redrawn in Fig. *14* to simplify our discussion of it. The signal dropped across section *B* is fed to the lower 6SF5 tube for amplification, while the signal dropped across *A* is not amplified. As in any voltage divider, the voltage distribution will depend upon the ratio of impedances of the two sections. If both are equal, each will receive the same amount of voltage. If one has ten times the impedance of the other, it will have ten times as much voltage. Let's investigate.

The .006-mfd. condenser in series-section *A* has a value of about 5000 ohms at 5000 cycles, which is negligibly small in comparison to the 250,000 ohms in series, so the combined impedance of section *A* is essentially 250,000 ohms.

At 5000 cycles, the .001-mfd. condenser across shunt-section *B* has a reactance of about 30,000 ohms, as compared to 15 megohms for the resistor. This makes the combined impedance of this section only about 30,000 ohms (the lowest reactance governs the impedance of parts in parallel). Therefore, at 5000 cycles almost all of the signal is dropped across *A*, with practically none across *B*, and the lower 6SF5 tube gets very little signal voltage at 5000 cycles and higher.

At 1000 cycles, the .006-mfd. condenser has a reactance of about 30,000 ohms, and this in series with 250,000 ohms of resistance gives a combined impedance of about 252,000 ohms for section *A*.

At 1000 cycles, the .001-mfd. condenser has a reactance of around 150,000 ohms. The 15-megohm resistor shunting this has negligible effect, so the combined impedance of section *B* is essentially 150,000 ohms. Now section *B* gets almost as much of the signal as section *A*, so the lower 6SF5 tube gets quite a bit of signal voltage at 1000 cycles.

Now let's drop down to the real low notes, say 100 cycles. The .006-mfd. condenser has a reactance of about 280,000 ohms now, and this in series with a resistance of 250,000 ohms gives a combined impedance of about 375,000 ohms for section *A*. The 2-megohm reactance of the .001-mfd. condenser at 100 cycles makes the impedance of section *B* essentially 2 megohms. Our voltage divider now consists of 375,000 ohms in *A*, and 2,000,000 ohms in *B*, so section *B* gets over five times as much signal voltage as section *A* at 100 cycles. As we go still lower in freis applied to the grid of the 6U5, so that the 6U5 may be used as a tuning indicator on f.m. reception.

Due to the rectification taking place in the limiter grid circuit, the negative signal peaks are almost cut off. The missing portion of the wave form is built up, however, by the flywheel action of the 6SJ7 resonant plate load. The i.f. limiter plate load consists of the two coils, tuned by trimmers C_{14}, in parallel with the 100,000-ohm plate supply resistor. The reactance of the .0005-mfd. coupling condenser is so low that it acts as a short at the i.f. value.

The discriminator, as the second detector of an f.m. receiver is called, differs somewhat from those you studied in the text on f.m. However, it's very easy to understand.

To simplify our study of the discriminator, its circuit has been redrawn by itself in Fig. *15*.

In an f.m. system, the strength of the carrier peaks has nothing to do with the audio signal, and carrier peaks may therefore be limited without distortion of the signal. In f.m., the carrier is caused to swing above and below its assigned or resting frequency. The greater the carrier frequency excursions away from the resting frequency, the greater the audio signal strength.

The rate or frequency of these frequency deviations is controlled by the frequency of the audio signal. Suppose we had a 5000-cycle audio signal and a 1000-cycle audio signal, both of the same strength. If they were used to modulate an f.m. system, both being the same strength would cause the f.m. carrier to swing the same distance in kilocycles above and below its resting frequency. However, the 5000-cycle audio note would make the carrier swing above and below the resting frequency 5000 times each second, while the 1000-cycle note would only cause the carrier to swing 1000 times each second. In this way, these two frequencies have indelibly stamped their characteristics on the f.m. carrier.

Because variations in audio signal strength cause the carrier frequency to change so much, an f.m. receiver must tune broadly. Sharp tuning would cut down the amount of carrier frequency variation, thereby reducing the range of audio volume.

If the limiter delivers an i.f. of 4.3 mc. (the resting frequency) to the discriminator, both diode plates will receive the same amount of signal voltage, because the reactance of C_4-L_1 is equal to that of C_5-L_2. When plate D_1 is positive, electrons flow from the cathode to the plate and through R_1, producing a voltage drop having the polarity shown. On the next half cycle, D_2 conducts while D_1 rests, and the resultant diode current produces a voltage drop across R_2 with the indicated polarity.

The a.f. output voltage of the discriminator circuit appears across the outside ends of R_1 and R_2. At the resting frequency, however, the two voltages are equal and opposite, and no voltage exists between the diode plates.

We must get a difference in the amount of voltage across R_1 and R_2 before we can obtain any output. This is done by tuning C_4-L_1 to 4.4 mc., which is 100 kc. above the resting frequency, and C_5-L_2 to 4.2 mc., which is 100 kc. below the resting frequency. Now when we tune in an f.m. program, the carrier will be swinging above and below the resting value of 4.3 mc. When it swings to a higher frequency, the voltage across C_4-L_1 increases, while the voltage across C_5-L_2 decreases. The resultant changes in diode currents D_1 and D_2 cause more voltage to exist across R_1 than across R_2, and the output is the difference between the two voltage drops. When the carrier decreases in frequency, the action reverses, and since C_5-L_2 now gets the greater part of the signal voltage, the drop across R_2 is greater than the drop across R_1.

The number of times per second the carrier swings back and forth across the resting frequency governs the frequency of the a.f. output voltage of the discriminator, and the amount of variation in the carrier frequency governs the strength of the a.f. output.

As you can see, R_3 and C_3 form an i.f. filter, used so that only the pure audio output of the discriminator will be available for application to the volume control through contact *FM* of switch section S_7R and the *PHONO-RADIO* switch in Fig. *12*.

We have now covered the important signal circuit features for the entire receiver. The power supply circuits are quite conventional, and you should be able to trace them yourself without difficulty.

THE ERROR OF HASTE

The fable of the hare and the tortoise is more than an interesting childhood story—it carries an important message we sometimes forget in this age of speed.

The hare, you will recall, started off in great haste. Soon he was so far ahead of the slow-plodding tortoise that he became over-confident and took a nap. The tortoise kept going steadily and won the race.

Haste does not always mean progress. Too often it leads instead to errors, to actual waste of time and energy, and even to complete failure as in the case of the hare.

We must learn to work and wait. Take time for all things, because time often achieves results which are obtainable in no other way. Shakespeare expresses it thusly: "*Wisely and slow; they stumble who run fast.*" More emphatic still was Benjamin Franklin, who said: "*Great haste makes great waste.*"

Don't risk the dangers of haste. Keep going steadily like the tortoise, and you'll approach your goal in radio steadily, inevitably.

J. E. SMITH

INSTRUCTIONS FOR PERFORMING RADIO EXPERIMENTS 31 TO 40

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A COURSE IN PRACTICAL DEMONSTRATIONS OF RADIO FUNDAMENTALS

A PLAN FOR TODAY

I WILL AWAKEN:	With a smile brightening my face; with reverence for this new day in my life and the opportunities it contains.
I WILL PLAN:	A program which will guide me successfully past the many temptations and distractions of a busy day and bring me one step closer to my goal of success.
I WILL WORK:	With my heart always young and my eyes open so that nothing worth while shall escape me; with a cheerfulness that overcomes petty irritations and unpleasant duties; with the purpose of my work always clearly in mind.
I WILL RELAX:	When tired, so as to accumulate fresh energy and live long enough to enjoy the success my work will bring.
I WILL PLAY:	With the thought that today is my day, never to be lived over again once it is ended; with relaxation and pure enjoyment as the only purposes of play; putting work and worldly worries out of mind for this short portion of my day.
I WILL RETIRE:	With a weariness that woos sleep; with the satisfaction that comes from a day well lived, from work well done.
I WILL SLEEP:	Weary but content; with tomorrow a vision of hope.

J. E. SMITH

NATIONAL RADIO INSTITUTE
WASHINGTON, D. C.
1950 Edition

THIS EXPERIMENTAL MANUAL IS A PART OF THE
N. R. I. COURSE WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

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Instructions for Performing Radio Experiments 31 to 40

Introduction

THE next ten experiments, as well as later experiments, call for the use of a power pack which will supply a.c. and d.c. voltages having values corresponding to those encountered in actual radio receivers. Before beginning these experiments, you will assemble a power pack with the parts furnished you in Radio Kit 4RK-AC and in previous radio kits.

An a.c. source having some definite voltage and frequency is usually the main source of power for the vacuum tube system in a radio receiver, transmitter or public address system. This a.c. source is usually a wall outlet which is connected to a 115-volt, 50 or 60-cycle power line.

The main a.c. source of power cannot ordinarily be connected directly to vacuum tube circuits, for the requirements of the various tube electrodes are quite different.

Voltage Requirements of A.C. Receivers. First of all, the a.c. line voltage must be reduced to the correct lower a.c. values for heating the filaments of radio tubes. The rectifier tube in the power pack of an a.c. receiver usually requires a separate 5-volt or 6.3-volt a.c. source for its filament, and the rest of the tubes have their filaments connected in parallel to a common 6.3-volt a.c. source. (In older a.c. receivers, you may encounter tubes having 2.5-volt filaments.)

A secondary winding which is provided on the power transformer of an a.c. power pack for stepping down the line voltage to the required filament value is commonly called a *filament winding*. The power transformer which is supplied for your a.c. power pack has two filament windings, one being a 5-volt winding for the rectifier tube in the power pack, and the other being a 6.3-volt winding for the tubes which you will use in your experiments later on. Thus, you will be working with the same filament voltage values used in modern a.c. receivers.

Secondly, the a.c. line voltage must be converted to a high d.c. voltage value having as little a.c. ripple as possible, and various proportions of this maximum d.c. voltage must be distributed to the various grid and plate electrodes in the vacuum tube circuit. As you learned in your regular course, this voltage conversion is accomplished in three steps, by using a power transformer to step up the a.c. line voltage, rectifying the resulting high a.c. voltage with a rectifier tube, then filtering out the ripples in this pulsating d.c. output with a condenser-input filter system.

In addition to the two filament windings already described, the power transformer which is supplied you in Radio Kit 4RK-AC has a center-tapped 750-volt secondary winding which provides the required high a.c. voltage for the vacuum tube rectifier. This winding is commonly called the *high-voltage secondary winding*. The voltage between the center tap and each outer terminal of the winding is about 375 volts.

The a.c. power pack which you will build thus consists essentially of a power transformer, rectifier tube, choke coil and filter condensers, connected exactly like the power packs of a.c. radio receivers.

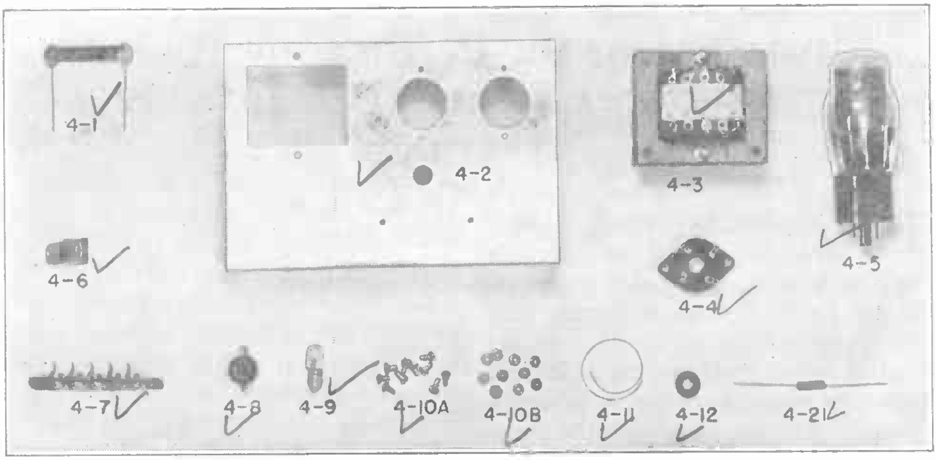


FIG. 1. The parts included in Radio Kit 4RK-AC are pictured above, and are identified in the list below. Some resistors may have a better tolerance (lower percentage tolerance) than that indicated here.

Part No.	*Description*
✓4-1*	One 50,000-ohm, 3-watt resistor with 20% tolerance (color-coded green, black, orange).
✓4-2	One cadmium-plated steel chassis bent to shape, with all holes already punched.
✓4-3	One power transformer for 115 volt, 50 or 60-cycle a.c. power.
✓4-4	One octal-type tube socket with four terminal lugs.
✓4-5	One type 5Y3G full-wave rectifier tube.
✓4-6	One slide-type power switch.
✓4-7	One 5-terminal, screw-type binding post strip.
✓4-8	One pilot lamp socket with rubber grommet.
✓4-9	One 6.3-volt pilot lamp.
✓4-10A	Ten ¼-inch long, 6-32 cadmium-plated binder-head machine screws.
✓4-10B	Ten cadmium-plated hexagonal nuts for 6-32 screws.
✓4-11	One 3-ohm length of nichrome resistance wire.
✓4-12	One small rubber grommet.
✓4-21	One 10-megohm, ½-watt resistor with 10% tolerance (color-coded brown, black, blue, silver).

* You may receive a 47,000-ohm, a 50,000-ohm, or a 51,000-ohm resistor as Part 4-1, depending on what we have in stock when we pack your kit. Use whatever value you receive for this part where the 50,000-ohm listed value is called for.

The following parts which were supplied to you in earlier radio kits will be used again in the next ten experiments, so assemble these parts along with the new parts received in Radio Kit 4RK-AC.

Part No.	*Description*
1-8D	One ⅜-inch soldering lug.
1-16✓	One 18,000-ohm, ½-watt resistor with 10% tolerance (color-coded brown, gray, orange, silver).
3-2A✓& B	Two .25-mfd., 400-volt paper condensers.
3-3✓	One dual 10-10-mfd., 450 working volts electrolytic condenser with bakelite mounting piece.
3-4✓	One 200-ohm, 1-watt resistor with 20% tolerance (color-coded red, black, brown).
3-5A✓	One 1,000-ohm, ½-watt resistor with 10% tolerance (color-coded brown, black, red, silver).
3-6A✓-B, C & D	Four 40,000-ohm, 3-watt resistors with 20% tolerance (color-coded yellow, black, orange).
3-10✓	One 10-henry choke coil with 25-ma. current rating.
3-11✓	One 5-foot power line cord with attached outlet plug.

Power Pack Experiments. With your a.c. power pack, you will demonstrate that the output voltage drops and ripple output goes up as the load on the power pack is increased. The first effect, in which the d.c. output voltage drops with load, is known as the *voltage regulation* of a power pack.

Your power pack is normally connected for full-wave rectification and a condenser-input filter system. You will disconnect one filter condenser to secure choke input, then disconnect one plate lead of the rectifier tube to secure half-wave rectification, and check the performance of the power pack with your N.R.I. Tester in each case. You will insert resistors to duplicate the practical conditions in which electrolytic condensers become defective, and make measurements which will enable you to recognize these same defects in actual receivers.

We have mentioned here only a few

of the highly practical power pack experiments presented in this manual. By the time you have completed Experiment 40, you will have a thoroughly practical understanding of power packs.

Contents of Radio Kit 4RK-AC

The parts included in your Radio Kit 4RK-AC are illustrated in Fig. *1* and listed in the caption underneath. Check off on this list the parts which you received, to be sure you have all of them. Do not destroy any of these parts until you have completed your entire N.R.I. course, for many of the parts will be used over and over again in later experiments.

IMPORTANT: If any part in your Radio Kit 4RK-AC is obviously defective or has been damaged during shipment, please return it to the Institute *immediately* for replacement.

Instructions for Assembling the A.C. Power Pack

Step-by-step instructions for assembling the a.c. power pack will now be given. Follow through these instructions slowly and carefully, doing the very best work of which you are capable, for you will use this power pack during the remainder of your practical demonstration course, and will want your unit to show professional workmanship in every soldered joint. To make sure that you do not miss any of the steps in the assembly procedure, make a check mark alongside each completed step as you go along.

The schematic circuit diagram for this power pack is presented in Fig. *2* for reference purposes. Later, you will be able to assemble radio apparatus from diagrams like this alone, but at the present stage in your course of training, we still recommend that you follow the pictorial diagrams which are presented in this manual to show each stage in the assembly procedure. Remember that we are ready to help you with advice if you should encounter any difficulty in assembling this power pack or in understanding the instructions.

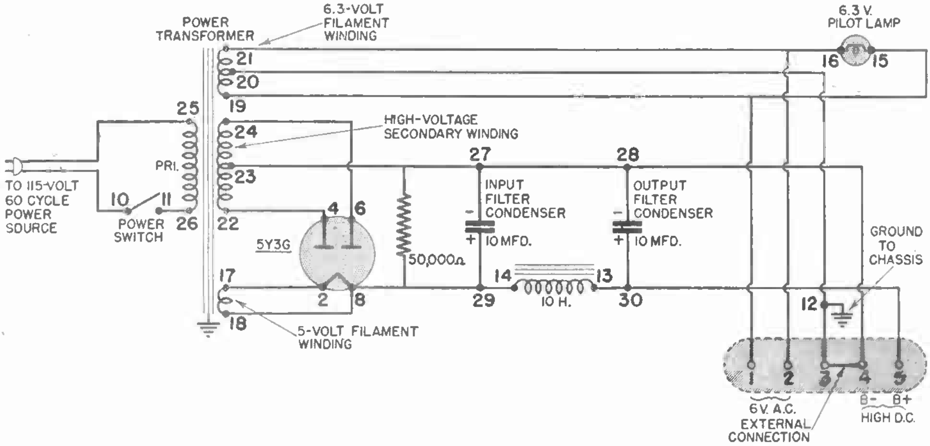


FIG. 2. Schematic circuit diagram for the a.c. power pack which you build before beginning the experiments in this manual. The terminals on this schematic diagram are numbered to correspond with the terminals shown on the semi-pictorial diagrams in Figs. *5* and *8*.

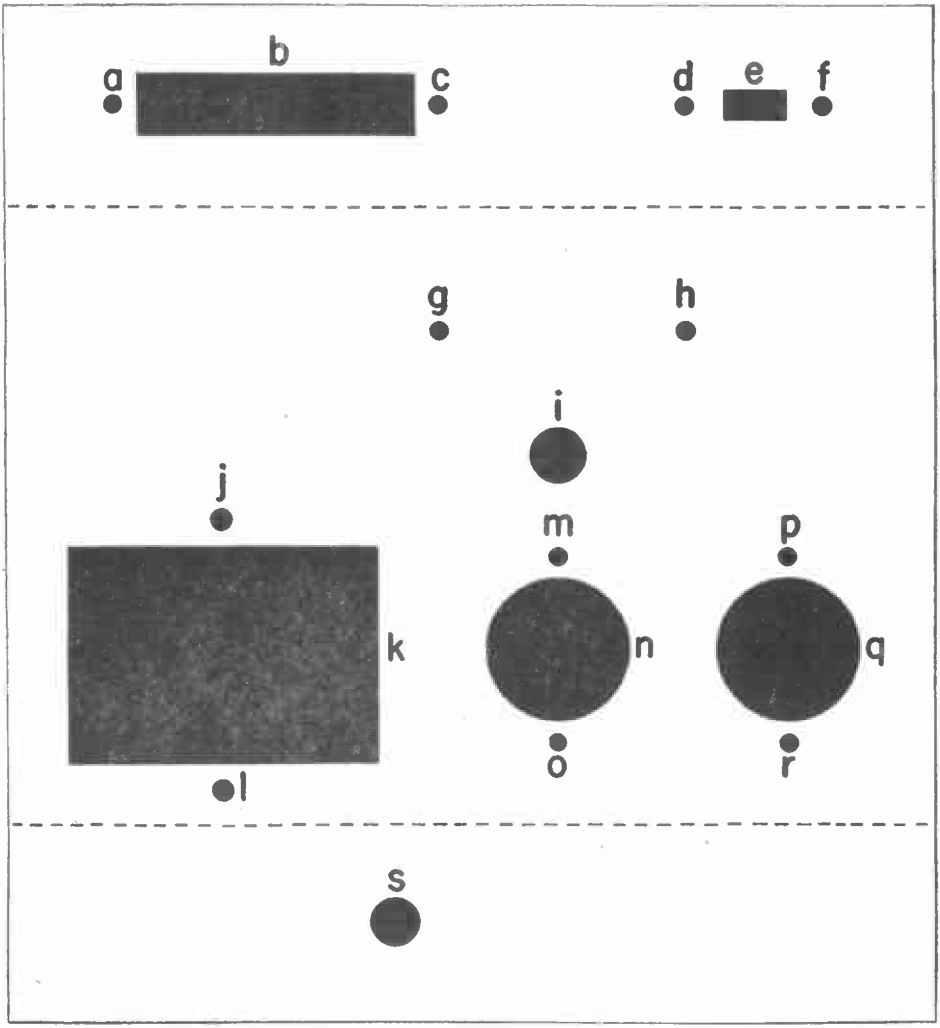


FIG. 3. Chassis layout diagram for the a.c. power pack, drawn to show what you would see if you looked at the bottom of the chassis while it was a flat sheet (before bending the sides). The holes are lettered here merely for your convenience in locating on your own chassis the correct mounting holes for the various parts; do not mark the holes in this manner on your chassis, for this diagram is entirely sufficient for assembly purposes.

Mounting the Parts on the Chassis

Step 1. To prepare for the assembly of the power pack, place before you the following parts:

50,000-ohm resistor (Part *4-1*).
Cadmium-plated steel chassis (Part *4-2*).
Power transformer (Part *4-3*).
Octal-type tube socket (Part *4-4*).
Type 5Y3G rectifier tube (Part *4-5*).
Slide-type power switch (Part *4-6*).
Five-terminal screw-type binding post strip (Part *4-7*).
Pilot lamp socket with grommet (Part *4-8*).
Pilot lamp (Part *4-9*).
Ten ¼-inch binder-head machine screws (Part *4-10A*) with ten hexagonal unts (Part *4-10B*).
Rubber grommet for power line cord (Part *4-12*).
⅝-inch soldering lug (Part *1-8D*).
Dual 10-10-mfd. electrolytic condenser with bakelite mounting piece (Part *3-3*).
Ten-henry choke coil (Part *3-10*).
Power line cord with plug (Part *3-11*).

Step 2.✓ *To mount in hole s the grommet for the power line cord,* place the chassis before you in such a position that the holes correspond with the chassis layout diagram in Fig. *3*. Hole *s* should now be near the center of the side closer to you. Take the rubber grommet (Part *4-12*) and squeeze it into an oval shape while holding it with the thumb and forefinger of your right hand. Now place the grommet in hole *s* in the manner shown in Fig. *4*, with the chassis fitting into the groove in the grommet. Carefully push the remainder of the grommet into this hole with your fingers until half the grommet is on each side of the chassis, with the chassis fitting into the rubber groove in the grommet at all points. This grommet will now have the position shown in Fig. *5*.

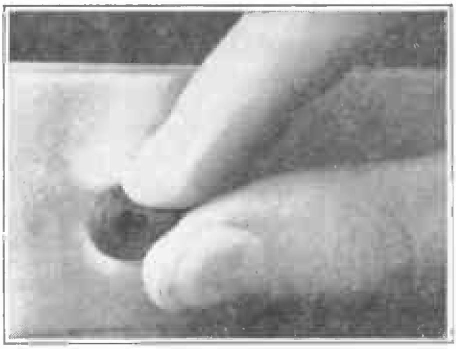


FIG. 4. Squeeze the grommet for the power line cord between your thumb and forefinger in the manner shown here while forcing it into hole *s* in the side of the chassis. This grommet can be placed in position with your fingers; it may take a little time at first, but you will soon get the "knack" of doing this radio job.

Step 3.✓ *To mount the pilot lamp socket in hole i on the chassis,* first remove the large rubber grommet from the pilot lamp socket (Part *4-8*). Squeeze this grommet into an oval shape while holding it between the thumb and forefinger of your right hand, and work the grommet into hole *i* (see Fig. *3*) on the chassis in exactly the same manner as described in Step 2 for the power line grommet. To force the pilot lamp socket itself up through the grommet which you have now inserted in hole *i*, grasp the socket near its terminal lugs with your fingers, push the threaded part gently into the grommet from the bottom of the chassis as far as it will go without forcing, turn the socket in a clockwise direction until one of the lugs touches the grommet, then rotate the socket just enough farther to line up the lugs parallel to the sides of the chassis. When looking at the bottom of the chassis, the pilot lamp socket will now appear as shown in Fig. *5*.

✓*Step 4. To mount the electrolytic condenser on the chassis,* take the bakelite mounting piece for this condenser, and hold it against the *top* of the chassis over holes *p*, *q* and *r* in such a manner that the slots have the positions shown in Fig. *5*. Bolt the piece to the chassis with two machine screws and nuts (Parts *4-10A* and *4-10B*) inserted in holes *p* and *r*, with the screw heads above the chassis.

Now take the electrolytic condenser (Part *3-3*) and insert its lugs in the slots of the bakelite mounting piece from the top of the chassis in such a

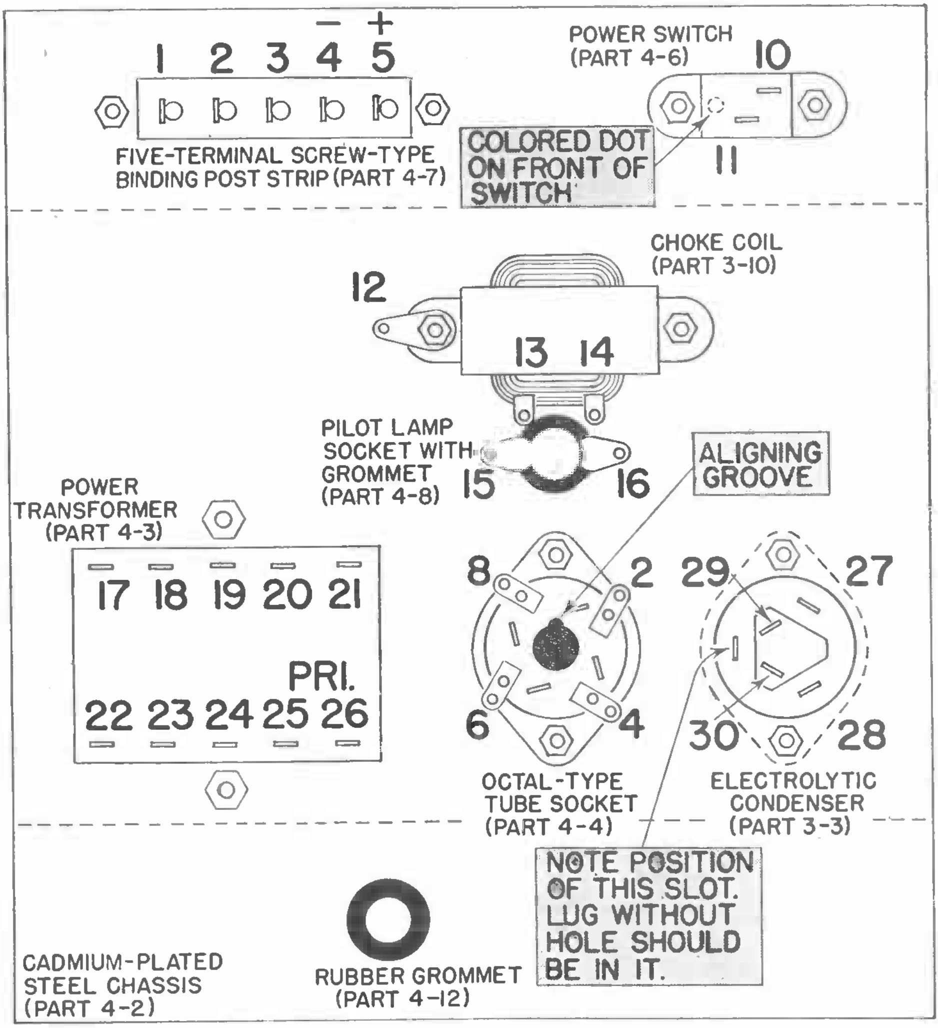


FIG. 5. Bottom view of chassis with sides spread out, showing exact positions of all parts which are mounted directly on the chassis, and showing positions of all numbers which you are to place on the chassis and on the parts with metal-marking crayon. The dotted lines indicate the positions of the bends in the chassis.

way that *the outer lug which has no hole* in it will be *next to hole n* on the chassis. If this condenser is inserted correctly, the two large inside lugs at the bottom of the condenser will be almost in line with the condenser mounting screws, as indicated in Fig. *5*.

With one hand holding the condenser in position against the top of the chassis, take a pair of ordinary pliers and twist each of the three outer lugs on the condenser a *small* amount, in the manner shown in Fig. *6*. This will hold the condenser securely in position on its mounting piece.

✓*Step 5. To mount on the chassis the socket for the rectifier tube,* take the octal-type tube socket (Part *4-4*) and hold it against the *bottom* of the chassis over holes *m*, *n* and *o* in such a way that the aligning groove in the socket is next to the pilot lamp socket (see Fig. *5*). Fasten the socket to the chassis in this position with two machine screws and nuts (Parts *4-10A* and *4-10B*), keeping the screw heads above the chassis. (Although the rectifier tube which goes into this socket has five prongs, only four of them are used in this power pack circuit. Prong *1* on the tube is a dummy, used only in special applications which require shielding the tube and grounding the shield to the chassis through this prong.)

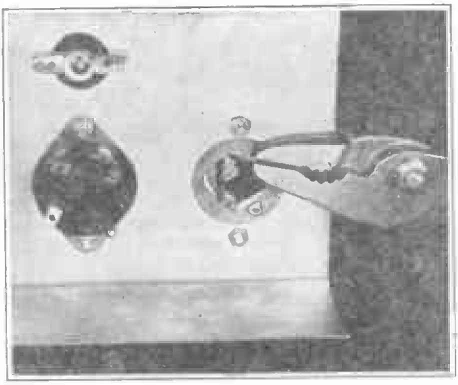


FIG. 6. This illustration shows the correct position of the bakelite mounting piece on the chassis, with the electrolytic condenser in position, and also shows how the outer lugs of the condenser are twisted with pliers to fasten the condenser unit to the bakelite mounting piece. Two of the lugs have already been twisted, and the last one is being twisted in this illustration.

Step 6.✓ *To mount the power switch on one side of the chassis,* take the slide-type switch (Part *4-6*), set the sliding button to the position in which the colored dot shows, hold the switch against the *inside* of the chassis over holes *d*, *e* and *f* in such a position that the colored dot is nearer to the center of the chassis (nearer to hole *d*), then fasten this switch to the chassis with two machine screws and nuts (Parts *4-10A* and *4-10B*), keeping the heads of the screws on the outside of the chassis.

Step 7.✓ *To mount the terminal strip on the chassis,* take the five-terminal screw-type binding post strip (Part *4-7*) and hold it against the *outside* of the chassis over holes *a*, *b* and *c* in such a manner that the numbers on the fiber strip are below the screws when the chassis is in its normal upright position, as shown in Fig. *7*. Fasten the strip to the chassis with two machine screws and nuts (Parts *4-10A* and *4-10B*), keeping the heads of the screws on the outside of the chassis.

Step 8.✓ *To mount the choke coil on the chassis,* take the 10-henry choke coil (Part *3-10*) and hold it against the *bottom* of the chassis in such a way that its mounting tabs are over holes *g* and *h* and its terminal lugs are next to the pilot lamp socket, as shown in Fig. *5*. Fasten the choke coil to the chassis with two machine screws and nuts (Parts *4-10A* and *4-10B*). Keep the screw heads above the chassis, and place a ⅝-inch soldering lug (Part *1-8D*) under the nut for hole *g*, as shown in Fig. *5*.

Step 9.✓ *To mount the power transformer on the chassis,* first take the

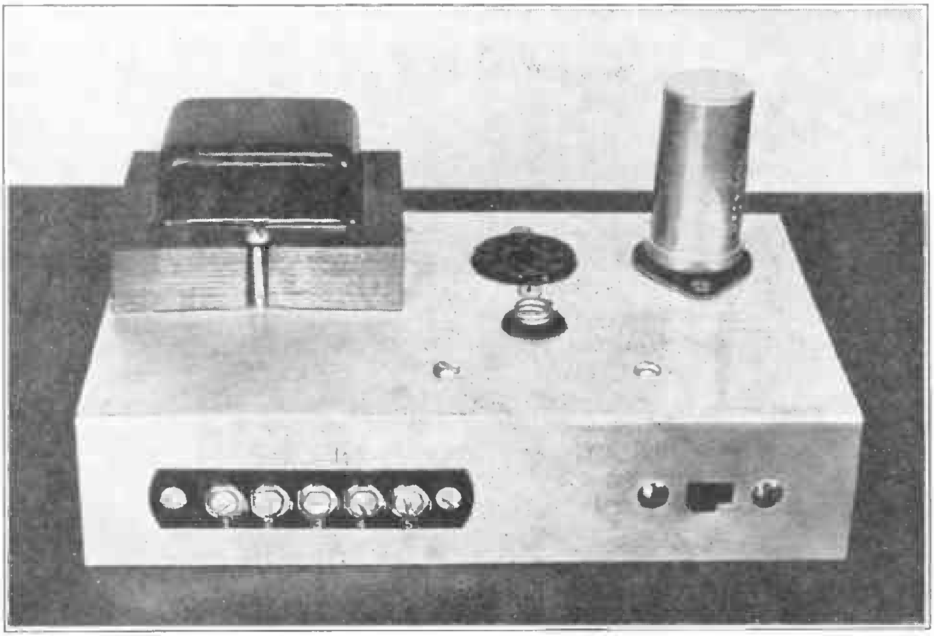


FIG. 7. View of the completed a.c. power pack before the rectifier tube and pilot lamp have been inserted in their sockets.

power transformer (Part *4-3*) and remove the nuts from the two long machine screws which go through the transformer core. Place the transformer on *top* of the chassis over holes *j*, *k* and *l* in such a way that the numbered terminals will appear in exactly the same position illustrated in Fig. *5*. Now insert the long machine screws through the power transformer mounting holes and through holes *j* and *l* respectively on the chassis. On each screw underneath the chassis, place a nut, and tighten the screws with a screwdriver, holding the nuts with ordinary pliers.

This completes the mounting of the large parts on the chassis. The top of the chassis should now appear as shown in Fig. *7*.

Step 10. To identify the terminals of the parts now mounted on the chassis, place alongside each terminal with metal-marking crayon the number indicated for that terminal in Fig. *5*. Place these numbers as nearly as possible in the positions shown in Fig. *5*. If the power transformer terminals are not marked, place the numbers on the fiber insulating material at the bottom of the transformer, or on the chassis beside the terminals. The choke coil lug numbers should be placed on the choke coil. All other numbers go directly on the chassis, as close as possible to the terminals in question. Place a — sign near output terminal *4*, and place a + sign near output terminal *5 on both sides* of the chassis.

Check your numbering carefully against Fig. *5* after you are finished, for errors in numbering will cause errors in wiring. Finally, check the terminal strip to be sure each lug is numbered the same on both sides of the chassis.

Step 11. To connect together the various terminals with hook-up wire, follow carefully the detailed step-by-

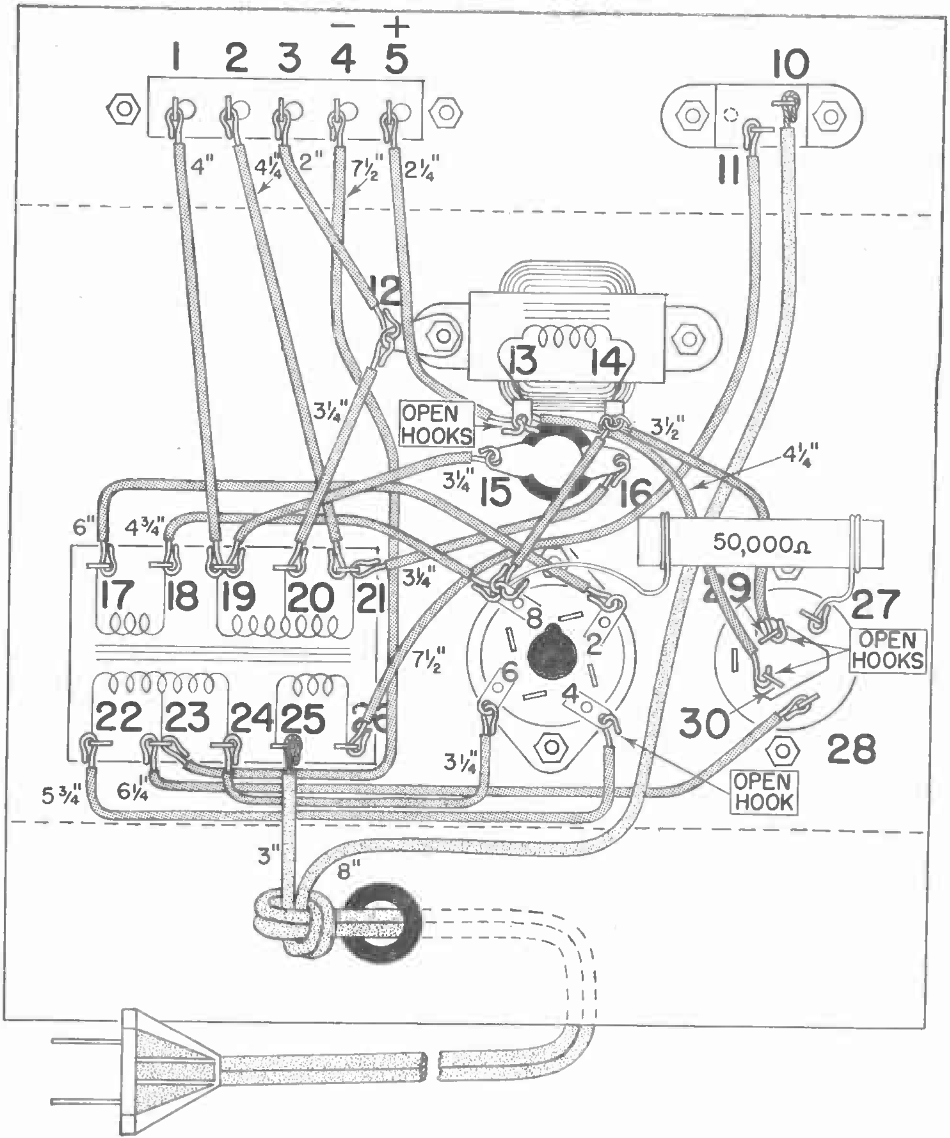


FIG. 8. Semi-pictorial wiring diagram showing how all connections are made under the chassis of the a.c. power pack. The sides of the chassis have been flattened out for clearness, but the wire lengths specified on this diagram are correct for the actual chassis.

step instructions which will now be given. Be particularly careful to make *temporary* soldered joints where specified. Use rosin-core solder (supplied in a previous kit) for all joints, and use *red* push-back hook-up wire throughout. Do not solder a joint until told to do so, for premature soldering will make it difficult for you to get additional wires into the hole in the lug. Use the semi-pictorial diagram in Fig. *8* and the photographic illustration in Fig. *9* as your guides for positioning the wiring.

Since the five terminals on the screw-type terminal strip are the output terminals of the power pack, we will refer to these terminals as the *output terminals*, to distinguish them from tube socket terminals having the same numbers.

✓*a*. Connect output terminal *4* to transformer terminal *23* with a 7½-inch length of hook-up wire, making permanent hook joints but soldering only terminal *4*.

✓*b*. Connect transformer terminal *23* to electrolytic condenser lug *28* with a 6¼-inch length of hook-up wire, making permanent hook joints and soldering both terminals this time.

✓*c*. Connect transformer terminal *17* to socket terminal *2* with a 6-inch length of wire, making permanent hook joints and soldering both terminals.

✓*d*. Connect transformer terminal *18* to socket terminal *8* with a 4¾-inch length of wire, making permanent hook joints but soldering only terminal *18*.

✓*e*. Connect transformer terminal *21* to pilot lamp socket terminal *16* with a 3¼-inch length of wire, making permanent hook joints but soldering only terminal *16*. Examine terminal *16* carefully after soldering, to be sure no part of this joint touches the chassis.

✓*f*. Connect transformer terminal *21* to output terminal *2* with a 4¼-inch length of wire, making permanent hook joints and soldering both terminals.

✓*g*. Connect transformer terminal *19* to pilot lamp socket terminal *15* with a 3¼-inch length of wire, making permanent hook joints but soldering only terminal *15*. Be sure the wire does not touch the chassis.

✓*h*. Connect transformer terminal *19* to output terminal *1* with a 4-inch length of wire, making permanent hook joints and soldering both terminals.

✓*i*. Connect transformer terminal *20* to grounding terminal *12* with a 3¼-inch length of wire, making permanent hook joints but soldering only terminal *20*.

✓*j*. Connect grounding terminal *12* to output terminal *3* with a 2-inch length of wire, making permanent hook joints and soldering both terminals.

✓*k*. Connect transformer terminal *24* to socket terminal *6* with a 3¼-inch length of wire, making permanent hook joints and soldering both terminals.

✓*l*. Connect transformer terminal *22* to socket terminal *4* with a 5¾-inch length of wire, making a *temporary* hook joint on socket terminal *4* and a permanent hook joint on terminal *22*. Solder both terminals.

✓*m*. Connect transformer terminal *26* to power switch terminal *11* with a 7½-inch length of wire, making permanent hook joints and soldering both terminals. Run this wire between the tube and pilot lamp sockets, as shown in Fig. *8*.

✓*n*. Connect choke coil terminal *13* to output terminal *5* with a 2¼-inch length of wire, making a *temporary* hook joint at terminal *13* and a permanent hook joint on terminal *5*. Solder only terminal *5*.

✓*o*. Connect choke coil terminal *13* to electrolytic condenser terminal *30* with a 4¼-inch length of wire, making *temporary* hook joints in both cases and soldering both terminals.

✓*p*. Connect choke coil terminal *14* to electrolytic condenser terminal *29* with a 3½-inch length of wire, making a *temporary* hook joint at terminal *29* and a permanent hook joint at terminal *14*, but solder only terminal *29*.

✓*q*. Connect choke coil terminal *14* to socket terminal *8* with a 2¼-inch length of hook-up wire, making per-

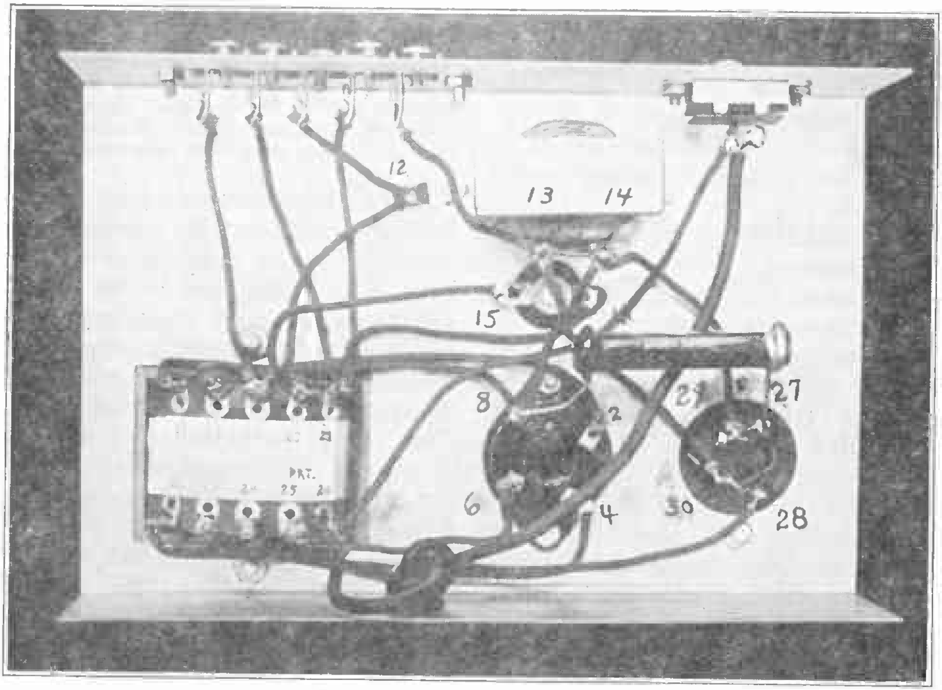


FIG. 9. Your a.c. power pack should look essentially like this under the chassis when you have completed all wiring. The positions of the various wires are not particularly important as long as they go to the proper terminals, hence some of the wires shown in this view may be in slightly different positions from corresponding wires in Fig. 8.

manent hook joints in both cases but soldering only terminal *14*.

r. Connect the 50,000-ohm resistor (Part *4-1*) between socket terminal *8* and electrolytic condenser terminal *27*, after first shortening the resistor leads so they are each about one inch long. Make permanent hook joints and solder both terminals.

s. Insert the free end of the power line cord through the rubber grommet which is in hole *s*, starting from the outside. Pull at least a foot of the cord through the grommet, then tie a simple knot in the cord in the manner shown in Fig. *8* so that there are 8 inches of wire left beyond the knot. Split this 8-inch length down to the knot by pulling the two rubber-covered wires apart with your fingers. Connect one 8-inch length of wire to power switch terminal *10* by means of a permanent soldered hook joint, after first spreading out the strands of wire and scraping them lightly with the blade of a pocket knife, then twisting the strands tightly together so you can insert them through the hole in the lug. Run the wire between the tube socket and the electrolytic condenser, and go under the 50,000-ohm resistor and the two electrolytic condenser leads, as indicated in Fig. *8*.

t. Shorten the other 8-inch length of wire to a length of 3 inches, and remove about half an inch of insulation from this shortened end either by cutting or squeezing. Be careful not to nick or cut any of the copper strands when doing this. Spread out the strands and clean by scraping, then twist them together and connect this shortened end of wire to transformer terminal *25* by means of a permanent soldered hook joint.

Step 12. To make continuity tests with the ohmmeter in your N.R.I. Tester for the purpose of checking the correctness of connections in the a.c. power pack, first prepare the ohmmeter for resistance measurements according to the "OHMMETER MEASUREMENT" instructions given in this manual.

Whenever a measurement with the N.R.I. Tester is called for in the experiments, you are expected to refer to and follow the instructions given for that type of measurement in the "OPERATING INSTRUCTIONS FOR N.R.I. TESTER" boxes which appear in this manual.

In the following continuity tests, failure to obtain the specified result indicates either a mistake in wiring or a defective part. If no mistake in wiring can be found by checking against the semi-pictorial circuit diagram in Fig. *8,* check each individual part in the circuit under consideration. If you are certain that one of the parts is defective, return it to National Radio Institute immediately.

a. Insert the rectifier tube in its socket but leave out the pilot lamp. Set the power switch to the *OFF* position (the red dot alongside the sliding button shows when this switch is *ON* but not when it is *OFF.*)

b. Check continuity between the prongs of the power cord plug with the *MEG.* range by placing the red clip on one prong, placing the black clip on the other prong, and reading the resistance in megohms directly on scale *R.* The reading should be above 50 megohms (while switch is *OFF*).

c. Leave the clips on the power cord plug prongs, but *do not* insert the plug in an outlet. Snap *ON* the switch on the power pack chassis so that the red dot shows. The meter should now read zero on scale *R.* Leave the switch in the *ON* position.

Do not touch the metal parts of the test clips with your fingers while reading resistance values on the meter; this would place the resistance of your body in parallel with that being measured, resulting in erroneous readings when checking for grounds or measuring high resistance values.

d. To check the resistance of the primary winding of the power transformer, set the selector switch to *10 × R,* leave the clips on the prongs of the power cord plug, read the meter on scale *R,* and multiply the reading by 10 to get the resistance in ohms of the circuit under test. This should be between 10 and 20 ohms, and will consist essentially of the resistance of the primary winding of the transformer.

e. To check continuity between the power plug prongs and the chassis, set the selector switch of the N.R.I. Tester at *MEG.*, place the black clip on the power pack chassis, and place the red clip in turn on each prong of the power cord plug. The meter reading should be higher than 50 megohms in each case.

f. To make sure that the high-voltage secondary circuit of the power transformer and the electrolytic condenser housing are not grounded, place the black clip on the chassis, place the red clip in turn on output terminal *4,* on socket terminal *4* and on socket terminal *6,* and measure the resistance in each case with the *MEG.* range of the N.R.I. Tester. A reading of 50 megohms or higher on scale *R* should be obtained in each case.

g. To make sure that the rectifier tube filament circuit is not grounded, place the black clip on the chassis, place the red clip on socket terminal *8,* and measure the resistance with the *MEG.* range. The meter should read higher than 50 megohms on scale *R.* Move the red clip to socket terminal *2.* Again the meter should read higher than 50 megohms.

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

OHMMETER MEASUREMENTS

1. Check the general calibration of your NRI Tester as instructed on page 14 of this Instruction Manual, and then plug the red test lead probe into the +R jack, plug the black test lead probe into the right-hand R jack, and set the selector switch at *Meg.*
2. To check the ohmmeter zero adjustment, hold the test lead clips together and turn the tester ON. The meter pointer should now indicate *O* at the right end of scale R. If it does not, adjust the tester potentiometer until it does so. *Do not, however, change the setting of the knob at the back of the meter.* IMPORTANT: Make the ohmmeter calibration as quickly as possible and then separate the test leads to prevent exhausting your batteries any more than absolutely necessary.
   Before you make any ohmmeter tests, be sure to turn power OFF any equipment (preferably by removing the power cord plug) you want to check.
3. Although you can start your ohmmeter measurements using any range of the tester, it is usually most convenient to start with the *10,000 × R* range. Place the test lead clips on the terminals between which resistance is to be measured, being careful not to touch the metal part of the clips with your hands. Disregard polarity (as indicated by the colors of the test clips) unless otherwise instructed. When you check an electrolytic condenser, however, you should *fasten the red test clip to the negative terminal* of the condenser, and *connect the black test clip to the positive terminal* of the condenser.
4. On the *Meg.* range, the R scale is read directly in *megohms.* On the *10,000 × R* range, multiply the R scale reading by 10,000 to get the resistance value in ohms. Resistance values in ohms on the *100 × R* range are obtained by multiplying the meter reading by 100; and on the *10 × R* range, by multiplying by 10.
5. If your first reading when using the *10,000 × R* range is O, the resistance value under test may be anything from 0 to 10,000 ohms. To find the actual value, turn to the *lower* ranges and take your reading on the range which gives approximately mid-scale deflection. Actual zero ohms is indicated by a full-scale deflection only when the *10 × R* range is used.
6. If your first test when using the *10,000 × R* range produces only a small deflection of the meter pointer from its normal open circuit position at the left, turn to the *Meg.* range and read the value directly in megohms. If the meter pointer remains at the left end of the R scale when using the *Meg.* range, the circuit or part under test is "open." (Such a circuit or part is often said to have "infinite" resistance).
7. If you found it necessary to turn the tester potentiometer a considerable amount to get zero adjustment when holding the test clips together, use the range which brings the meter pointer into the right half of the scale. Should it be necessary to use the left half of the scale, calibrate the tester at 0 and 3 on scale DC as instructed on page 14 of this manual under the heading "Checking the Calibration."
8. To conserve battery life, turn the tester OFF and remove both test leads just as soon as you finish a series of resistance measurements.

h. To check filter circuit continuity, set the selector switch to *10,000 × R,* then place the red clip on power transformer terminal *23* and place the black clip on socket terminal *8.* The reading should be somewhere between 40,000 and 60,000 ohms. Now move the black clip to output terminal *5,* and again measure the resistance. The reading should again be between 40,000 and 60,000 ohms.

i. To check wiring and continuity of the high-voltage secondary winding on the power transformer, measure the resistance between socket terminals *4* and *6* while using the *100 × R* range of the N.R.I. Tester. You should obtain a reading somewhere between 400 and 700 ohms.

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

CHECKING THE CALIBRATION

Before using the NRI Tester for any series of measurements, check its calibration as follows:

1. Remove both test probes, set the selector switch at *100×V* and make sure the calibrating clip is on —9C. Turn the power switch ON and tap the meter gently with a finger. The pointer should be exactly at *O* on the DC scale. If it isn't, adjust the knob at the back of the meter as may be necessary to set the pointer at zero. Look squarely at the meter and don't tilt the tester during calibration or operation.
2. Now move the calibrating clip from —9C to —7½C and see if the meter reads 1.5 on scale DC. If necessary, adjust the potentiometer on the tester chassis to get this 1.5 reading.
3. Recheck the "zero" position again by moving the calibrating clip back to —9C. The calibration procedure described above, and in previous manuals, insures maximum accuracy only over the left half of the meter scale. The right half of the scale can be checked as follows:
4. First, hold the calibrating clip on —6C momentarily, and then on —4½C and note the meter reading at each position. The desired readings are 3 and 4.5 respectively on scale DC. The difference between these values and your readings represent the amount of error in this portion of the scale. If greater over-all accuracy is desired over the entire scale, calibrate at *O* and 3 on scale DC by using —9C and —6C respectively.

   Return the calibrating clip to —9C so that the meter reads zero before beginning your measurements. Also, check the calibration from time to time during the course of an experiment to be sure accuracy is maintained.

j. To check continuity and wiring of the 6.3-volt filament supply circuit in the power pack, measure the resistance between output terminals *1* and *2* with the *10 × R* range of the N.R.I. Tester. The reading should be only a fraction of an ohm (essentially zero). If this reading is around 1000 ohms and the reading obtained in Step *12i* is less than 1 ohm, write to us immediately and give your results for this test. Do not go any further with your experiments until you hear from us, if you obtained these reversed readings.

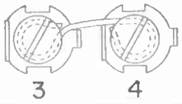


FIG. 10. Method of connecting output terminals 3 and 4 together externally with a 1½-inch length of bare hook-up wire. Note that both hooks are closed, so that the wire will stay in position when the screws are loosened to permit connecting other wires to these terminals.

k. Place the black clip on the chassis, place the red clip on output terminal *3*, and measure the resistance value with the N.R.I. Tester set to the *10 × R* range. The reading should be zero.

Step 13. To check the operation of the power pack, first place the chassis right side up with the terminal strip facing you, make sure that the rectifier tube is firmly in its socket, insert the pilot lamp in its own socket, and push the switch to its *OFF* position (red button does not show).

Next, connect output terminal screws *3* and *4* together externally with a 1½-inch length of bare hook-up wire. Do this by forming a hook in one end of the wire, hooking this over screw *4* in a clockwise direction after loosening this screw, closing the hook with pliers, then bending the wire around screw *3* in a clockwise direction and cutting off surplus wire to give an S-shaped connection like that shown in Fig. *10*. Keep these two terminals connected together.

Connect to terminal *3* the ground wire you have provided at your bench for experimental purposes. This ground wire should go to a cold water pipe or other good ground.

Insert the power cord plug into a 115-volt a.c. outlet and turn on the power pack switch. The pilot lamp should now light up, and both filament wires of the rectifier tube should appear dull red when looking straight down on top of the tube. Turn off the power pack.

CAUTION: The ground connection to output terminals *3* and *4* should be made whenever the power pack is used, to avoid getting a shock when touching the power pack chassis.

Do not touch any terminals or parts underneath the chassis of the a.c. power pack while it is in operation. The voltages present at some of these terminals are high enough to give serious electrical shocks.

If neither the pilot lamp nor the rectifier tube glows, check your source of a.c. power by plugging a table lamp or other appliance into the outlet.

Step 14. To check the d.c. output voltage of the power pack when no load is connected, first prepare the N.R.I. Tester according to the "D.C. VOLTAGE MEASUREMENTS" instructions given in this manual.

To measure the d.c. output voltage between terminals *4* and *5*, place the red clip on screw terminal *5* after first loosening this screw about ⅛-inch. Place the black clip on the wire jumper which connects screw terminals *3* and *4*, *being sure that this clip does not touch the red clip.* Turn on the a.c. power pack, then turn on the N.R.I. Tester (be sure it is set to the *100 × V* range), read the meter on the *DC* scale, and multiply your reading by 100 to get the d.c. output voltage of the power pack in volts. This voltage should be approximately 450 volts if you have assembled the power pack correctly, all parts are in good condition, and you have a normal a.c. line voltage of about 115 volts.

Turn off the power pack while watching the meter. Note that it takes several seconds for the pointer to drop down to zero; this action occurs because the electrolytic filter

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

D.C. VOLTAGE MEASUREMENTS

1. **Plug the black probe into the $-V_{DC}$ jack on the panel, and plug the red probe into the $+V_{DC}$ jack.**
2. **Set the selector switch at *100 × V*. Always start with the highest d.c. range, in order to prevent overloading of the meter.**
3. **While power is off, place the black test clip on the — terminal of the device whose voltage is being measured, and place the red clip on the + terminal.**
4. **Turn on your apparatus, then turn on the N.R.I. Tester. This order is important, as it prevents high initial voltages from making the meter pointer swing off-scale.**
5. **If the meter reading is low or zero, lower the selector switch setting one range at a time, until you reach the lowest range which does not overload the meter. IMPORTANT: When working with apparatus using heater-type vacuum tubes, wait long enough for the tubes to warm up (about half a minute is sufficient) before lowering the selector switch setting.**
6. **Read the meter on the *DC* scale, and multiply the reading by the correct factor for the range being used. For example, when using range *30 × V*, multiply the scale reading by 30; when using range *100 × V*, multiply by 100, etc.**
7. **Turn off the N.R.I. Tester first, then turn off the power source. Pull out the test probes when through using the N.R.I. Tester, to prevent draining of the C battery in case the test clips accidentally touch the tester panel or chassis.**

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

OVERLOADING OF N.R.I. TESTER

If the pointer of the meter in the N.R.I. Tester vibrates around *0* or reads slightly backwards, but a definite up-scale reading is obtained when you switch to a higher range, this is an indication that the meter was being overloaded on the lower range.

An overload will usually shift the *0* position of the pointer. This condition will be corrected automatically the next time you make an approximately full-scale voltage reading, or can be corrected immediately by lifting up the calibrating clip and touching it momentarily to the —4½C terminal on the battery block. Be sure to return the clip to —9C.

If the pointer seems to stick at the right of the full-scale position, tap the meter lightly with the finger. On voltages near full-scale values, momentum of the pointer carries it farther than the final position, but tapping frees the pointer and often allows you to secure a reading without switching to the next higher range.

condensers hold their charges for that period of time after power is removed. Now turn off the N.R.I. Tester and pull out the power cord plug.

The d.c. output voltage of your power pack will vary slightly with the line voltage, and consequently any d.c. voltage value between about 400 volts and 500 volts can be considered satisfactory for this no-load d.c. output voltage measurement.

NOTE: Although the highest division on the *DC* scale is 4.5, corresponding to 450 volts when using the *100 ×V* range, voltages up to 500 volts d.c. can be safely measured. When the pointer is between the letters *D* and *C* at the right-hand end of the scale, read the meter as 5; multiplying by 100 then gives 500 volts. For pointer positions in between 4.5 and "5," estimate the reading just as you do between other divisions on the scale.

Discussion: The sole purpose of the pilot lamp in your a.c. power pack is to serve as an indicator that the power pack is on and is delivering a useful yet dangerously high voltage. Whenever this light is glowing, do not touch any terminal of the power pack or any voltage supply terminal of the equipment connected to the power pack. If you are making voltage measurements on any connected equipment with the N.R.I. Tester, be sure to hold the test clips by their insulated handles.

After turning off the power pack, wait at least five seconds for the condensers to discharge, before touching any terminals or parts with your fingers. The condensers may deliver an unpleasant shock while discharging, even though power is off.

INSTRUCTIONS FOR PERFORMING EACH EXPERIMENT

1. **Read the entire experiment, giving particular attention to the discussion.**
2. **Perform each step of the experiment and record your results. Whenever a measurement is specified, be sure to make it exactly according to the "OPERATING INSTRUCTIONS FOR N.R.I. TESTER" given in this manual for that type of measurement.**
3. **Study the discussion and analyze your results.**
4. **Answer the report statement for the experiment. It will always be on the last page of the manual.**

EXPERIMENT 31

***Purpose:* To measure the high d.c. output voltage, the low a.c. output voltage, and the a.c. ripple voltage which is present at the d.c. output terminals of the a.c. power pack under no-load conditions.**

Step 1. To measure the d.c. output voltage of your power pack, first place the power pack in an upright position before you on the table, with the terminal strip facing you, and connect the ground wire at your workbench to output terminal screw *3.*

Check the calibration of the N.R.I. Tester by following the instructions given elsewhere.

Prepare the N.R.I. Tester to read d.c. voltages according to the "D.C. VOLTAGE MEASUREMENTS" instructions given previously. Place the black test clip on output terminal *4* of the power pack, and place the red clip on output terminal screw *5.* (Terminals *4* and *5* are the d.c. output terminals, with terminal *4* negative and terminal *5* positive.)

Insert the power cord plug into a convenient a.c. outlet, turn on the power pack switch, allow about half a minute for the power pack to reach normal operating conditions, then turn on the N.R.I. Tester and read the meter on the *DC* scale. Record your result in Table *31* as the d.c. output voltage in volts for no load.

CAUTION: As was previously pointed out, high voltages exist at some terminals underneath the power pack chassis when this unit is in operation. Therefore, do not touch any terminals under the chassis with your fingers while the power pack switch is on.

Turning off the power pack switch breaks the primary circuit of the power transformer, but the 115-volt a.c. line voltage is still present at the power transformer primary terminals and at both power switch terminals. This means that it will be necessary to pull the power cord plug out of the outlet every time you make a change in the wiring under the chassis. Remember —do not touch the two power transformer primary terminals or the power switch terminals even when the power pack switch is off, unless you have first pulled out the plug.

Step 2. To measure the a.c. filament voltages provided by your a.c. power pack, first prepare the N.R.I. Tester for a.c. voltage measurements by following the "A.C. VOLTAGE MEASUREMENTS" instructions given elsewhere in this manual.

Place the test clips on output terminals *1* and *2*, measure the a.c. voltage, and record your result in Table *31* as the a.c. output voltage in volts across the entire filament winding (between terminals *1* and *2*).

CAUTION: Always return the selector switch to the highest range (*100 × V*) when through making a voltage measurement, to prevent overloading of the meter on the next measurement. Before making a new measurement, be sure the probes are in the correct jacks for that type of measurement.

Next, place the clips on output terminals *1* and *3*, measure the a.c. voltage, and record your result in Table *31* as the a.c. output voltage across one half of the filament winding (between output terminals *1* and *3*).

STEP	NATURE OF MEASUREMENT	YOUR VALUE IN VOLTS	N.R.I. VALUE IN VOLTS
1	D.C. OUTPUT VOLTAGE BETWEEN TERMINALS 4 AND 5	500	450
2	A.C. OUTPUT VOLTAGE BETWEEN TERMINALS 1 AND 2	6.8	6.7
	A.C. OUTPUT VOLTAGE BETWEEN TERMINALS 1 AND 3	3.9	3.5
	A.C. OUTPUT VOLTAGE BETWEEN TERMINALS 2 AND 3	3.8	3.4
3	A.C. RIPPLE VOLTAGE BETWEEN TERMINALS 4 AND 5	3.8	0

TABLE 31. Record your results here for Experiment 31. All power pack measurements in this table are for normal full-wave rectification and condenser input. No load is connected to the d.c. output terminals.

To measure the a.c. voltage across the other half of the filament winding, place the clips on output terminals *2* and *3*, read the meter on the *AC* scale, and record your result in Table *31* as the a.c. output voltage between terminals *2* and *3*.

Step 3. To measure the a.c. ripple voltage value which is present at d.c. output terminals 4 and 5, leave the tester set for a.c. voltage measurements. Review the "A.C. VOLTAGE MEASUREMENTS" instructions if in doubt. Place the black clip on output terminal screw *4*, place the red clip on output terminal screw *5* (polarity *is important* in this particular measurement, as pointed out in the discussion). Read the meter on the *AC* scale, and record your result in Table *31* as the a.c. ripple voltage in volts between output terminals *4* and *5*. If the pointer flickers back and forth continually, estimate its average position. If the pointer does not move at all from zero, record your result as zero volts.

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

A.C. VOLTAGE MEASUREMENTS

1. **Plug the black probe into the —V_{AC} jack on the panel, and plug the red probe into the left-hand V_{AC} jack.**
2. **Set the selector switch at *100 × V*.**
3. **Place the test clips on the terminals between which the a.c. voltage is to be measured. The black clip should go to the terminal which is closer to ground. When both terminals have essentially the same potential with respect to ground, the polarity of the test clip connections can be disregarded.**
4. **Turn on your apparatus, then turn on the N.R.I. Tester. This protects the tester against high-voltage surges which may exist when the apparatus is turned on.**
5. **Lower the selector switch setting, one range at a time, until you reach the lowest range which does not make the meter pointer swing off-scale.**

IMPORTANT: When working with apparatus using vacuum tubes, wait long enough for the tubes to warm up (about half a minute is sufficient) before lowering the selector switch setting. This applies whenever you use the entire a.c. power pack (with the rectifier tube in its socket).

6. **Read the meter on the *AC* scale, and multiply the reading by the correct factor for the range being used.**
7. **Turn off the N.R.I. Tester first, then turn off the power source. Pull out the test probes when through using the N.R.I. Tester, to prevent draining of the C battery in case the test clips accidentally touch the tester panel or chassis.**

NOTE: When the N.R.I. Tester is being used as an a.c. voltmeter on the *V* range, a meter reading may be obtained *when only one test clip is connected.* This is due to pick-up of stray a.c. energy by the test leads. Disregard this condition, as it has no effect on the readings when both test leads are connected.

Discussion: In Step 1, you repeat your measurement of the d.c. output voltage so that you can record this value in Table *31* along with the other output voltage values of your a.c. power pack. You will use the values which you record in this table for reference purposes in connection with later experiments.

Although a.c. line voltages in this country are ordinarily somewhere around 115 volts, these voltages will vary anywhere between 110 volts and 120 volts at times, due to changes in the loads on a power system and to other conditions at the power generating station. Each variation in the a.c. line voltage will cause a corresponding variation in the d.c. output voltage of your power pack. Thus, you may get a different value if you measure this d.c. output voltage tomorrow or next week.

In boosting the a.c. line voltage, your power pack inherently amplifies the variations in the line voltage. If you are located in an industrial community where there are large varying electrical loads on the power system, you may even be able to see this variation, in the form of a continual flickering of the meter pointer when measuring the d.c. output voltage of the power pack.

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

EXTENDING VOLTAGE RANGES

As your N.R.I. Tester has a resistance of 10 megohms, you can double the values for any a.c. or d.c. voltage range of the N.R.I. Tester by inserting in series with the tester and the voltage source the 10-megohm resistor which is supplied to you as Part *4-21*.

Simply connect this resistor temporarily in series with the ungrounded test lead. The true voltage reading will then be the meter reading multiplied by *twice* the multiplying factor indicated at the selector switch setting. Thus, when using this voltage multiplier on the *100* × *V* range, a meter reading of 2.4 would correspond to 480 volts.

When dealing with voltages between about 20 and 30 volts, the use of the voltage multiplier with the *3* × *V* range will give a more accurate measurement than could be obtained with the *30* × *V* range. This is particularly true in the case of a.c. measurements.

In Step 2, you use the N.R.I. Tester as a low-range a.c. voltmeter and measure the a.c. output voltages which are provided at the output terminals of your power pack for filament heating purposes. In connecting between output terminals *1* and *2* for the first measurement, you measure the voltage across the entire filament winding (between terminals *19* and *21* in Fig. *2*). Although this voltage should normally be about 6 volts a.c., for use with 6 or 6.3-volt vacuum tube filaments, you will measure a somewhat higher voltage under no-load conditions. This is entirely normal, for the voltage will drop when vacuum tube filaments are connected to these terminals.

The circuit diagram in Fig. *2* shows that the 6.3-volt filament winding has a center tap, going to output terminal *3*. For the second and third measurements, you measure between this center tap and each of the outer terminals of the 6.3-volt filament winding. If you secure essentially equal voltage values for these two measurements, you know that the center tap has been placed in the electrical center of the filament winding, as it should be. The sum of the voltages across the two halves of the filament winding is equal to the voltage across the entire winding, but voltage values measured with the N.R.I. Tester may differ as much as 10% when checked in this manner.

In Step 3, you set the N.R.I. Tester for use as an a.c. voltmeter and con-

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

IF N.R.I. TESTER READINGS SEEM WRONG, CHECK THESE ITEMS

1. **Are the test clip, test probe and selector switch positions correct for the type of measurement you are making?**
2. **Are you reading the correct scale on the meter?**
3. **Are you multiplying the scale reading by the correct factor for the selector switch setting?**
4. **Is the calibrating clip placed on the correct permanent C battery terminal (—9C)? If through forgetfulness you leave the clip on the less negative terminal, all meter readings will be too high.**
5. **Did you follow *every step* of the instructions given in the manual for making the measurement in question?**

NOTICE: WHEN WRITING TO THE INSTITUTE REGARDING YOUR N.R.I. TESTER, BE SURE TO REFER TO IT AS THE "N.R.I. TESTER FOR EXPERIMENTS."

REDUCING LEAKAGE RESISTANCE EFFECTS

Leakage resistance in the grid circuit of the N.R.I. Tester can provide a path for direct current through the meter circuit when measuring the a.c. ripple voltage at the high-voltage d.c. output terminals, thereby giving a meter reading even when the a.c. ripple voltage is zero. The condenser which was supplied you for use between the $+V_{DC}$ jack and the left-hand V_{AC} jack behind the panel of the tester has an unusually high leakage resistance value, but moisture or dust on the condenser housing or on either side of the insulating strip which supports the jacks may provide sufficient leakage resistance to give a meter reading. Likewise, moisture or dirt on the tube base or tube socket of the N.R.I. Tester can cause grid-to-filament leakage and give the same effect. This leakage is particularly troublesome under conditions of extremely high humidity, such as in a damp basement.

To reduce the effects of leakage resistance to a minimum, turn off all apparatus, then remove the mounting screws for the jack strip on the N.R.I. Tester so you can wipe both sides of this strip with a clean cloth. Replace the jack strip, then wipe the housing of the .005-mfd. condenser carefully with the cloth, wipe the tube base between the prongs, and wipe the surface of the tube socket both above and below the chassis.

nect it to the d.c. output terminals of the power pack. When using the *AC* voltmeter range of the N.R.I. Tester in this manner, a .005-mfd. condenser in series with the measuring circuit inside the tester blocks the flow of direct current. Under this condition, the only voltage which can affect the meter reading under normal conditions is the a.c. ripple voltage which might be present at the d.c. output terminals.

Small variations in the line voltage can cause considerable flickering of the meter pointer while you are measuring the a.c. ripple voltage in the d.c. output. The power transformer increases the line voltage variations about four times, and the sudden charging and discharging of condensers in the filter system can amplify the variations still further, so that they are quite noticeable when measured with the lowest *AC* range of the N.R.I. Tester. Reading the average value over which the pointer flickers will eliminate these variations from your results.

Blistering of Paint on Resistors. The 50,000-ohm resistor under the power pack chassis develops considerable heat during normal operation of the power pack, for it is connected directly across a pulsating d.c. voltage of over 400 volts at the rectifier tube output. This heat may cause the paint on the resistor to become soft and develop blisters, but this will in no way affect the quality of the resistor or the operation of the power pack. This same blistering of paint may occur in the 40,000-ohm resistors which you use across the d.c. output terminals in the next experiment.

Bleeder Resistor. The 50,000-ohm resistor is connected across the input of the power pack filter system at all times, and serves to prevent high-voltage surges from damaging the electrolytic filter condenser when the power pack is first turned on and there is no load connected to the d.c. output terminals. This resistor is actually an internal load on the power pack, and is called a *bleeder resistor* because it draws or "bleeds" a current continuously for stabilizing purposes, regardless of what is connected externally to the power pack.

When reference is made to the power pack load, we always mean the load which is connected externally to the output terminals. You can neglect the presence of the internal bleeder resistor load during normal use of the power pack.

Instructions for Report Statement No. 31. In the preceding discussion, it was pointed out that the d.c. output voltage of your power pack will vary with the a.c. line voltage. To familiarize you with the proper and safe technique for measuring this line voltage, you are asked to make this measurement and record it in Report Statement No. 31, along with your measured value for the d.c. output voltage.

With the power pack plug pulled out, turn the power pack chassis on its back side, place one test clip on power switch terminal *10*, and place the other test clip on transformer terminal *25*, so that you will be measuring the voltage between the two leads of the power cord. Adjust the clips carefully so that they cannot loosen and touch other parts. Now prepare the tester for a.c. voltage measurements, as instructed elsewhere. Insert the power cord plug in the wall outlet, and turn on the N.R.I. Tester. Record your a.c. line voltage in volts in Report Statement No. 31. Pull out the power cord plug before touching the test clips.

Now repeat your measurement of the d.c. output voltage of the power pack, exactly as instructed in Step 1 of this experiment. Record this value also in Report Statement No. 31, as the d.c. output voltage corresponding to the line voltage value you measured. This output voltage may be different from that which you recorded in Table *31*, but you know now that this is due simply to line voltage variations.

EXPERIMENT 32

***Purpose:* To show that the d.c. output voltage of your a.c. power pack varies with the load.**

Step 1. To connect four 40,000-ohm resistors in parallel to the d.c. output terminals of the power pack so as to secure a 10,000-ohm load, first secure the four 40,000-ohm, 3-watt resistors (Parts *3-6A, 3-6B, 3-6C* and *3-6D*) which were supplied you in Radio Kit 3RK. Bend a hook in each lead of one resistor in the manner shown in Fig. *11A*, loosen the screws on output terminals *4* and *5* of the power pack, hook these resistor leads over screws *4* and *5*, then tighten the screws while holding the resistor with your fingers and exerting a gentle upward pull to keep the hooks under the screw heads. Now bend the resistor leads downward until the resistor is about on a level with the screws.

Take another 40,000-ohm resistor, tin the ends of its leads, and connect this resistor in parallel with the first one by means of temporary soldered joints after bending and arranging the leads as shown in Fig. *11B*.

Connect the remaining two 40,000-ohm resistors in parallel with the first two resistors by means of temporary soldered lap joints in the same manner, so that you now have a parallel combination of four resistors like that shown in Fig. *11C*. These give the desired equivalent resistance of 10,000 ohms.

Step 2. To measure the d.c. output voltage of your power pack with various load values, first check the calibration of the N.R.I. Tester, then prepare it for d.c. voltage measurements according to previous instructions. Place the red clip on the resistor lead which is attached to terminal *5*, bringing the clip up from under the lead as shown in Fig. *11C* to minimize chances of the clip touching the chassis. In the same manner, place the black clip on the lead which is attached to terminal *4*. Record your result in Table *32* as the d.c. output voltage when using a 10,000-ohm load.

To measure the d.c. output voltage for a 20,000-ohm load, remove two of the resistors from your parallel group by unsoldering one resistor lead in the manner shown in Fig. *11D*. The two 40,000-ohm resistors which are still connected to output terminals *4* and *5* give a load resistance of 20,000 ohms. Leave the clips connected as before, follow the "D. C. VOLTAGE MEASUREMENTS" instructions, and record the result in Table *32* as the d.c. output voltage in volts for a 20,000-ohm load.

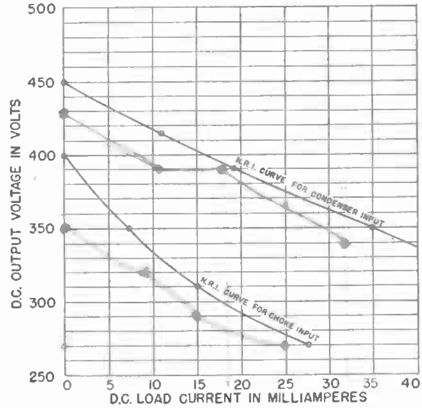
LOAD RESISTANCE IN OHMS	D.C. OUTPUT VOLTAGE IN VOLTS		D.C. LOAD CURRENT IN MILLIAMPERES	
	YOUR VALUE	N.R.I.	YOUR VALUE	N.R.I.
10,000	340	350	33	36
20,000	360	390	18	20
40,000	390	420	11	11
NO LOAD	430	450	0	0

TABLE 32. Record your results here for Experiment 32. All power pack measurements in this table are for normal full-wave rectification and condenser input. Load values are as indicated in the first column above. Always use pencil rather than ink for recording your values in the tables. Be sure you record each value in the correct position in the table.

To measure the d.c. output voltage for a 40,000-ohm load, unsolder one more resistor lead in the manner shown in Fig. *11E,* so that only one 40,000-ohm resistor is connected to terminals *4* and *5*. Record your result in Table *32* as the d.c. output voltage for a 40,000-ohm load.

To measure the d.c. output voltage for no load, remove the test clips, remove the entire resistor group from output terminals *4* and *5,* place the red clip on the screw of terminal *5,* place the black clip on the screw of terminal *4,* measure the d.c. output voltage exactly as you did in Experiment 31, and record your result in Table *32* as the no-load d.c. output voltage in volts. Pull out the power cord plug, remove the test leads entirely, and turn off the tester.

Step 3. To measure load currents for the three load resistance values used in Step 2, first connect the four 40,000-ohm resistors in parallel again by means of temporary soldered lap joints to secure a 10,000-ohm resistance. Connect one lead of this resistor group to output terminal screw *5*. Place the red test clip on the other lead of the resistor group, and place the black test clip on output terminal screw *4,* as shown in Fig. *11F*.



GRAPH 32. Plot your results for Experiment 32 on this graph and draw a smooth line through the dots to secure a d.c. load current-d.c. output voltage curve which you can compare with the N.R.I. curve for condenser input. Later, you will use values obtained in Experiment 36 to plot another curve on this graph for a choke input type of filter circuit.

Prepare the tester for direct current measurements by placing the black test probe in the *—I* jack, placing the red test probe in the *+I* jack, and setting the selector switch at *10 × I*. (This covers items 1 and 2 in the "DIRECT CURRENT MEASUREMENTS" box on page 25. The previous paragraph covered items 3 and 4, and the following paragraph here covers the remaining items—5, 6 and 7.)

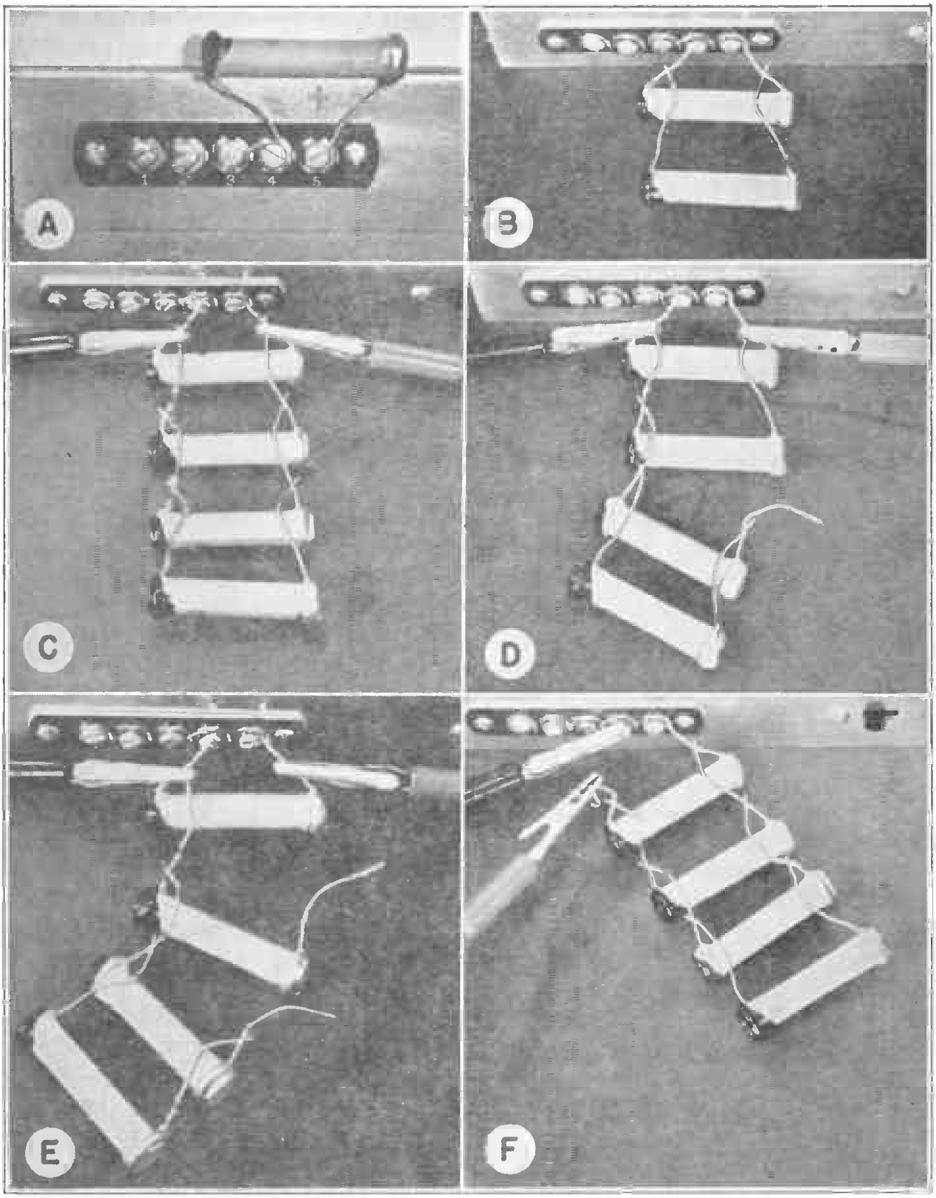


FIG. 11. Methods of connecting load resistors to the d.c. output terminals of your power pack for d.c. output voltage and d.c. load current measurements are illustrated here.

A—Method of connecting a single 40,000-ohm load resistor to d.c. output terminals *4* and *5*.

B—Two 40,000-ohm resistors connected in parallel to output terminals *4* and *5* as shown here will serve as a 20,000-ohm load.

C—Four 40,000-ohm resistors in parallel give a 10,000-ohm load. If the red and black test clips are attached in the manner shown here when making d.c. output voltage measurements, there is little possibility of the clips accidentally shorting together or touching the chassis.

D—Method of disconnecting two resistors temporarily to give a 20,000-ohm load.

E—Method of disconnecting three resistors temporarily to give a 40,000-ohm load.

F—Method of connecting the test clips for measurement of the d.c. load current through a 10,000-ohm load resistance. Note that current is measured at the grounded point (terminal *4*) in the load circuit; this keeps the chassis of the N.R.I. Tester at ground potential.

To measure the direct current flowing through the 10,000-ohm load, turn on the power pack and the tester, wait half a minute, read the meter on the *DC* scale, multiply the meter reading by 10, and record your result in Table *32* as the d.c. load current in ma. for a 10,000-ohm load.

While leaving the test probes exactly as shown in Fig. *11F*, turn off the power pack, and remove *completely* two of the resistors from the parallel group so as to secure a 20,000-ohm load. Now measure the current through this 20,000-ohm load in the same manner (you can follow the general instructions in the box on page 25 if you prefer, but *don't move the test clips)*, and record your result in Table *32* as the load current in ma. for a 20,000-ohm load.

With the test probes still exactly in the positions shown in Fig. *11F*, turn off the power pack again, and remove completely one of the remaining two 40,000-ohm resistors, so that you now have only one 40,000-ohm resistor left to serve as load. Measure the current through this 40,000-ohm load in the same manner as before, and record your result in Table *32* as the load current in ma. for a 40,000-ohm load.

When the last 40,000-ohm resistor is removed from terminal *5*, there is no load, and hence no load current can flow. *Do not make any measurement at all* for the no-load current box in Table *32;* just record a zero in this box.

Step 4. To plot a graph which will show how d.c. output voltage varies with load current, first plot on Graph *32* the d.c. output voltage you measured for no-load conditions, by placing a heavy dot at this voltage value on the vertical scale at the left of the graph. Next, locate on the horizontal scale the current value for the 10,000-ohm load, and draw a light *vertical* line through this value on the graph. Locate on the vertical scale the d.c. output voltage measured for this load value, draw a light *horizontal* line through this value, and make a heavy dot at the point where it intersects your vertical line.

In the same manner, plot in turn similar points for the 20,000 and 40,000-ohm loads. Now connect your four points together with a smooth line to give a curve of load current plotted against d.c. output voltage.

Discussion: Step 1 is a preliminary step which gives you additional experience in making the temporary soldered lap joints which are used so extensively by radio servicemen for test connections. You may have some difficulty in making these joints unless you first tin the leads individually; in fact, the professional technique for making lap joints always involves preliminary tinning of the individual parts. This eliminates the necessity for having to apply solder while actually soldering the joints, so you can hold in one hand the part being soldered, and hold the soldering iron in the other hand.

After making the six soldered lap joints called for in Step 1, check your work by wiggling the wires of each joint. Sometimes a joint which appears secure is held together only by rosin, which is an insulator; this wiggling procedure will reveal defective rosin joints by breaking the rosin bond.

When resistors of equal value are connected in parallel, the combined resistance is always equal to the value of one of the resistors divided by the number of resistors in parallel. This is a valuable rule to remember.

Although the 40,000-ohm resistors which you use in this experiment have a power-handling rating of 3 watts, it is entirely permissible to overload

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

DIRECT CURRENT MEASUREMENTS

1. Place the black test probe in the *—I* jack, and place the red test probe in the *+I* jack.
2. Set the selector switch at *10×I.*
3. Open the circuit at the point where current is to be measured. Although current can be measured anywhere in a circuit, it is best to make this measurement at a point which is at *ground* potential or as close as possible to ground potential. (Output terminal *4* of your power pack is at ground potential because the ground wire connects both to *3* and *4.)* Observance of this rule minimizes chances of getting a shock when touching the tester chassis with one hand and touching a grounded object like the power pack chassis with the other hand.
4. Place the black test clip on the grounded terminal (or lead) at the measuring point, and place the red test clip on the lead which you disconnected from this grounded terminal. This places your N.R.I. Tester *in series* with the circuit, just as it should be for all current measurements.
5. Turn on the voltage source and the N.R.I. Tester, wait about half a minute if there are any heater-type tubes in your set-up, then read the meter on the *DC* scale and multiply the reading by 10 to get the current in milliamperes.
6. If the current value is less than 4.5 ma., set the selector switch at the *I* range and read the direct current value in ma. directly on the *DC* scale.
7. Turn off the N.R.I. Tester, then turn off the power source. Pull out the test probes to prevent draining the C battery in case the test leads accidentally touch the tester panel or chassis.

IMPORTANT: For all direct current measurements, be sure to read the meter on the *DC* scale (not on scale I_M).

these resistors for short periods of time. The resulting heat may change the appearance (color) of a resistor and produce smoke, but this will not affect the electrical characteristics.

When working on this experiment, keep in mind that the load is increased by lowering (decreasing) the ohmic value of the load resistance. In other words, you have the greatest load on your power pack when all four resistors are connected in parallel to give a combined resistance of 10,000 ohms. You should therefore expect to secure the lowest d.c. output voltage when this load is employed. Increasing the value of the load resistance to 20,000 and then to 40,000 ohms reduces the loading effects, and consequently the measured d.c. output voltage should go up. Examine your results in Table *32* to verify this.

When you analyze your measured values of load current, you should find that the d.c. load voltage is the lowest and the load current is the highest for the 10,000-ohm load. When you plot the load current values on Graph *32* and draw the curve through the points, your resulting curve can be compared to the N.R.I. curve for condenser input in Graph *32*. You will see that the d.c. output voltage increases gradually to the no-load value as the load current is reduced by increasing the load resistance. Furthermore, with your curve you can determine what the d.c. output voltage will be for any intermediate value of load current.

Warning: Smoke coming from the N.R.I. Tester during direct current measurements means you have not made the correct series connection for a current measurement. Turn off the power pack at once, and move the test probes to the correct positions, as instructed in the box on page 25.

Load Current Computations. You can easily check your measured values of load current by means of Ohm's Law. To compute what the load current in amperes will be, divide the measured value of d.c. output voltage by the ohmic value of the load resistance employed. Multiplying the result by 1,000 will give you the load current in milliamperes. You can do this for one or two of the load values in Table *32* if you wish, to see how well your computed and measured values agree. Of course, you cannot expect perfect agreement because the actual ohmic values of the resistors may be as much as 20% off from rated values due to normal manufacturing tolerances.

Your a.c. power pack was designed to deliver at least 350 volts d.c. at a d.c. load current value of 25 ma., when connected to a standard 115-volt, 60-cycle power line. The curve of results obtained in the N.R.I. laboratory shows that the d.c. output voltage is well above 350 volts at this rated full-load current of 25 ma.

Your power pack is capable of delivering considerably more than the rated output current for *short* periods of time, as you actually demonstrated.

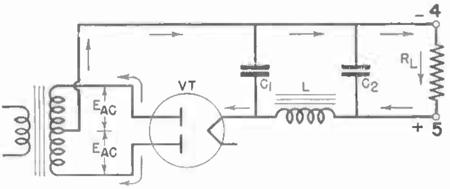


FIG. 12. Simplified schematic circuit diagram of the high-voltage section of your a.c. power pack, with arrows indicating the direction of electron flow. R_L represents an external load resistance connected to d.c. output terminals *4* and *5* of the power pack.

Review of Rectifier Action. Although the operating principles of rectifier circuits are fully covered in your regular course, now is an excellent time to review these important principles briefly, and see just why the d.c. output voltage drops as load is applied.

To explain the theoretical operation of your a.c. power pack, the simplified schematic circuit diagram in Fig. *12* will be easier to follow than the detailed schematic diagram in Fig. *2*. Rectifier tube *VT* in Fig. *12* allows each power transformer secondary voltage E_{AC} in turn to send electrons through load resistor R_L and choke coil *L* in one direction only, as indicated by arrows.

Input filter condenser C_1 (Fig. *12*) is charged by the pulsating d.c. voltage produced by the rectifier tube-transformer combination. When the pulsating d.c. source voltage drops below the condenser voltage, this condenser discharges through R_L and *L;* the condenser current then adds to the existing current flow over this path, thereby keeping the load current nearly constant despite the fact that the pulsating d.c. voltage is dropping to zero between each half cycle.

If the resistance values of *L* and R_L are reasonably high, the voltage across C_1 will more or less follow the peaks of the rectified voltage during this action.

Increasing the power pack load by reducing the resistance value of R_L affects the power pack circuit in three different ways, with each of these tending to make the d.c. output voltage drop.

First of all, an increased load makes C_1 discharge more completely in between the peaks of the pulsating d.c. voltage, with the result that the average d.c. voltage value across input filter condenser C_1 is reduced. This is one reason why the d.c. output voltage goes down as more load is applied.

Secondly, whenever direct current is drawn from the power pack, this current must flow through the d.c. resistance of the power transformer secondary winding, through the d.c. resistance of rectifier tube *VT*, and through the d.c. resistance of choke coil *L*. Increasing the load current increases the voltage drops across these three d.c. resistances, thereby reducing the amount of d.c. voltage available at output terminals *4* and *5*.

Finally, the a.c. voltage supplied by the power transformer secondary winding will drop when more current is drawn from this winding. The power transformer must supply more energy when the load is increased, and consequently the alternating currents flowing through both the primary winding and the high-voltage winding must increase when the load current increases. Each transformer winding has an a.c. resistance due to eddy current and hysteresis losses as well as normal copper losses; the increased flow of alternating current through these a.c. resistances lowers the a.c. voltage available at the terminals of the high-voltage secondary winding for rectification purposes.

Instructions for Report Statement No. 32. By referring to the curve which you plotted in Graph *32*, determine what the d.c. output voltage of your power pack will be for a d.c. load current of 25 ma. when using the condenser-input filter circuit shown in Figs. *2*, *8*, and *12*. This is done by tracing upward from 25 ma. on the horizontal scale until you intersect your curve, then tracing horizontally leftward to the vertical axis and reading the d.c. voltage value there. Record this voltage value in the space provided for this purpose in Report Statement No. 32 on the last page.

EXPERIMENT 33

Purpose: **To demonstrate the voltage regulation characteristics of both the low and high-voltage secondary windings of the power transformer in your power pack.**

Step 1. To measure the full-load and no-load voltages of the low-voltage secondary winding in your power pack, first take the length of resistance wire which is supplied as Part *4-11* and connect it between output terminals *1* and *2* on the power pack by bending an open hook in each end of the wire, slipping one hook under the screw of output terminal *1* and tightening this screw, then slipping the other hook under the screw of output terminal *2* and tightening this screw. Bend the loop of resistance wire so that it does not touch the chassis or other nearby objects. This length of wire has a resistance of 3 ohms, which is the correct value for drawing full-load current from the 6.3-volt filament winding of the power pack.

Prepare the tester for a.c. voltage measurements and place the test clips on output terminals *1* and *2* underneath the chassis. (Under-chassis connections are used because it is difficult to make the clips grip the terminal screws while they are tightened over the resistance wire.) The chassis should be resting on its back side so that these terminals will be readily accessible. Measure the a.c. voltage between terminals *1* and *2*, and record your result in Table *33* as the voltage in volts at a.c. output terminals *1* and *2* for full load of 3 ohms.

Remove the length of resistance wire from terminals *1* and *2*, measure the a.c. voltage between output terminals *1* and *2*, and record your result in Table *33* as the no-load a.c. output voltage value in volts of the 6.3-volt filament winding (between terminals *1* and *2*).

CAUTION: Do not touch the resistance wire with your fingers while the power is on, and allow ample time (about one minute) for the wire to cool after power is turned off. This wire becomes almost red hot, and can cause an unpleasant burn if touched. Use long-nose pliers if for any reason you have to handle the wire while still hot.

STEP	NATURE OF MEASUREMENT	A.C. VOLTAGE IN VOLTS	
		YOUR VALUE	N.R.I. VALUE
1	VOLTAGE AT A.C. OUTPUT TERMINALS 1 AND 2 FOR 3Ω LOAD		6.0
	VOLTAGE AT A.C. OUTPUT TERMINALS 1 AND 2 FOR NO LOAD		6.7
2	VOLTAGE AT TRANSFORMER TERMINALS 22 AND 23 FOR 10,000Ω LOAD	340	350
	VOLTAGE AT TRANSFORMER TERMINALS 22 AND 23 FOR NO LOAD	360	375

TABLE 33. Record your results here for Experiment 33. All power pack measurements in this table are for normal full-wave rectification and condenser input.

Step 2. To measure full-load and no-load a.c. voltages across one half of the high-voltage secondary winding, first connect a 10,000-ohm load to d.c. output terminals *4* and *5* by connecting the group of four 40,000-ohm resistors in parallel again with temporary soldered lap joints, then connecting the group between output terminals *4* and *5*. Be sure the resistor leads do not touch the chassis.

With the chassis resting on its back side to make the power transformer terminals accessible, measure the a.c. voltage between transformer terminals *22* and *23* and record your result in Table *33* as the a.c. voltage in volts across one half of the high-voltage secondary winding (between terminals *22* and *23*) for a 10,000-ohm load.

Remove the 10,000-ohm load from the power pack by disconnecting the group of four resistors from terminals *4* and *5*, measure the a.c. voltage again between terminals *22* and *23*, and record your result in Table *33* as the no-load a.c. voltage in volts across one half of the high-voltage secondary winding (between terminals *22* and *23*).

Discussion: In Step 1, you placed directly across the separate 6.3-volt filament winding in your power pack a resistance which draws from this winding its rated output current of about 2 amperes. When you measure the a.c. output voltage while this load is present, you find the voltage to be appreciably lower than for the corresponding no-load condition.

In Step 2, you again observe this same drop in voltage with load when you place a 10,000-ohm load across the output terminals of the power pack so as to increase the effective load on the high-voltage secondary winding of the power transformer. You have thus proved that the a.c. voltage at the high-voltage secondary winding drops when load is applied to the power pack, exactly as was pointed out in Experiment 32 (in the review of rectifier action), and have demonstrated for yourself one of the three reasons why the d.c. output voltage drops with load.

Transformer Theory. To understand why the secondary voltage of a power transformer drops as load is applied, we must review the basic action of an iron-core transformer.

Although a power transformer is one of the most efficient devices employed in the electrical and radio industries, it is by no means entirely perfect. A power transformer has copper losses, hysteresis losses and eddy current losses, and these along with the reactances of the windings serve to reduce the output voltage when the transformer is loaded.

Consideration of the equivalent transformer circuit shown in Fig. *13* will help you to understand the actions occurring in a practical transformer.

If a definite load voltage value V_L is required across load R_L in Fig. *13*, the secondary winding of the ideal transformer must supply a higher voltage E_S which will be equal to the vectorial sum of the load voltage V_L, the a.c. voltage drop across the secondary a.c. resistance value R_S, and the a.c. voltage drop across the secondary inductive reactance X_S. The higher the load current, the higher are the voltage drops across R_S and X_S, and the higher must E_S be to overcome these drops.

A definite transformer primary voltage E_P is required to provide secondary voltage E_S, assuming perfect coupling in this ideal transformer. The supply voltage E must be higher than this primary voltage, however, for it has to overcome the a.c. voltage drop across the primary a.c. resistance R_P and the a.c. voltage drop across the primary inductive reactance X_P.

We thus see that the voltage drops across the primary and secondary resistances and reactances in a power transformer make necessary a *higher* input voltage than would be required in a perfect transformer to secure a desired output voltage. This means that when the input voltage is fixed (as it is for the average power line connection), these voltage drops make the output voltage *lower* than that for a perfect transformer. Increasing the load makes these voltage drops increase, thereby reducing the output voltage still more if the input voltage remains constant.

Further study of the results you obtained in this experiment will show that at no load, the d.c. output voltage of the power pack is higher than the a.c. voltage across each half of the high-voltage secondary winding. Thus, the N.R.I. values show an a.c. secondary voltage of 375 volts and a no-load d.c. output voltage of 450 volts.

This does not mean, however, that we are getting voltage step-up in the filter circuit. The measured a.c. voltage value of 375 volts in the N.R.I. case is an *effective* or *r.m.s. value,* and the instantaneous voltage will actually swing up to 1.4 times this effective value on peaks. This means that the peak a.c. voltage value present across one half of the secondary winding is 1.4 × 375 volts, or 525 volts. This value of 525 volts represents the theoretical absolute limit of the no-load d.c. output voltage. By bridging the valleys between peaks, the filter condensers tend to make the d.c. output voltage approach this peak value during no-load conditions.

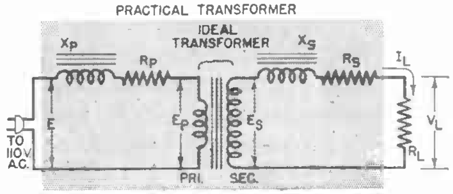


FIG. 13. Simplified equivalent circuit diagram for the primary winding and high-voltage secondary winding of a power transformer. The portion of the diagram designated as an ideal transformer has no losses. Parts X_P, R_P, R_S and X_S represent equivalent loss-producing resistances and reactances which are present in a practical iron-core transformer.

As load is applied to the power pack, the d.c. output voltage value drops, and may even go below the effective a.c. secondary voltage value, for increased load makes the input filter condenser discharge more completely during each rectified half cycle.

Instructions for Report Statement No. 33. In this experiment, you determine for yourself the effect which a load connected to the d.c. output terminals of your power pack has upon the a.c. voltage existing across one half of the high-voltage secondary winding of the power transformer. Report Statement No. 33 gives you a chance to express your own conclusion regarding this particular experiment, and at the same time tells us whether you have performed the experiment properly and mastered the important principle it is intended to demonstrate.

Turn to the last page, and place a check mark after the answer in Report Statement No. 33 which expresses the change you observed in the a.c. voltage across one half of the high-voltage secondary winding of the power transformer (between terminals *22* and *23*) when you applied a 10,000-ohm load to the d.c. output terminals of the power pack.

EXPERIMENT 34

***Purpose:* To show that most of the ripple voltage which is present across the input filter condenser of the power pack is dropped in the choke coil, and to show that the a.c. ripple voltage across the input filter condenser increases with load.**

Step 1. To measure ripple voltages in your a.c. power pack when a 40,000-ohm load is connected to the d.c. output terminals, first rest the chassis on its back side so that both the under-chassis connections and the output terminal screws are conveniently accessible. Take the group of four parallel-connected resistors used in the previous experiment, unsolder from the first resistor (the one having hooks in its lead) the other three resistors, then connect this single resistor to output terminals *4* and *5*.

Locate the 50,000-ohm bleeder resistor under the chassis (this is connected across the input of the power pack filter system, as shown in Fig. *2*). Measure the a.c. voltage across this resistor, being sure to place the black clip on the grounded resistor lead (place the black clip on the resistor

STEP	LOAD VALUE IN OHMS	A.C. VOLTAGE IN VOLTS ACROSS INPUT CONDENSER		A.C. VOLTAGE IN VOLTS ACROSS CHOKE COIL		A.C. VOLTAGE IN VOLTS AT D.C. OUTPUT TERMINALS	
		YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE
1	40,000	4.2	3.5	2.8	3.5	3.2	0
2	10,000	7.8	6.3	5	6.3	3.	0

TABLE 34. Record your results here for Experiment 34. All power pack measurements in this table are for normal full-wave rectification and condenser input.

lead going to condenser terminal *27*, and place the red clip on the resistor lead going to socket terminal *8*). Record your result in Table *34* as the a.c. voltage in volts across the input filter condenser for a 40,000-ohm load. (The bleeder resistor is in parallel with the input filter condenser.) Wait a few seconds for the condensers to discharge before touching any terminals, after turning off the power pack.

To measure the a.c. ripple voltage across the choke coil, place one clip on choke coil terminal *14*, place the other clip on choke coil terminal *13*, read the meter on the *AC* scale, and record the result in Table *34* as the a.c. voltage in volts across the choke coil for a 40,000-ohm power pack load. Polarity of the test leads is unimportant in this case. However, this measurement is made in the hot side of the circuit. This places the tester chassis at a high potential with respect to ground, so do not touch the tester chassis and the power pack chassis at the same time while power is on.

To measure the a.c. ripple voltage at the d.c. output terminals of the power pack, place the red clip on output terminal screw *5* or on the resistor lead attached to this terminal, place the black clip on output terminal screw *4*, and record your result (even if it is *0*) in Table *34* as the a.c. ripple voltage at the d.c. output terminals for a 40,000-ohm power pack load.

Step 2. To measure a.c. ripple voltage values in your power pack when a 10,000-ohm load is connected to the d.c. output terminals, first solder your parallel-connected group of three 40,000-ohm resistors (left over from the previous experiment) in parallel with the 40,000-ohm resistor which is already connected to output terminals *4* and *5*, using temporary soldered lap joints just as you did in the previous experiment. Now, repeat each of the measurements called for in Step 1. Record your values in Table *34* as the a.c. ripple voltages for a 10,000-ohm power pack load.

Allow the 40,000-ohm resistors a few minutes to cool before touching them with your fingers; they become quite hot while serving as power pack loads.

When you have completed all measurements for this step, remove the 40,000-ohm resistors from output terminals *4* and *5*, but leave the resistors connected in parallel for the present.

Discussion: This experiment shows you that even though appreciable a.c. ripple may exist at the input of the filter system in the power pack (across the input filter condenser), the filter system reduces this a.c. ripple so much that the amount of ripple present at the d.c. output terminals is negligible and is so small that it cannot ordinarily be measured with the N.R.I. Tester. You also see for yourself how an increase in load makes the input a.c. voltage across the input filter condenser go up, with the choke coil still absorbing practically all of this voltage, so that the a.c. ripple at the d.c. output terminals is still too small to be measured.

In the regular lessons of your N.R.I. course, you learned that the input condenser of a filter circuit accepts electrons and charges up whenever the voltage delivered by the rectifier tube is higher than the existing voltage across this condenser. When the rectifier tube voltage is lower than that of the input filter condenser, the condenser cannot discharge in the reverse direction through the rectifier tube, and hence it discharges through the series circuit consisting of the choke coil and the power pack load. The rate at which this input filter condenser discharges is determined by the capacity value of the condenser and the total resistance value through which it discharges (the choke coil resistance + the load resistance).

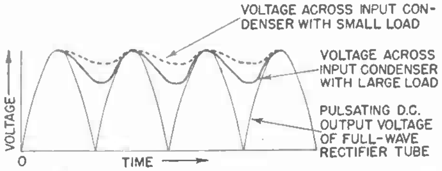


FIG. 14. Wave forms of voltages existing at different points in a power pack employing full-wave rectification and a condenser input filter.

The lower the ohmic value of the load, the lower is the total resistance through which the input filter condenser discharges; a low load resistance (corresponding to a large load) thus makes the input filter condenser discharge more completely in between peaks, as indicated by the solid-line curve in Fig. *14*. You can readily see that there is more a.c. ripple in this curve than there is in the dotted-line curve corresponding to a small load (high load resistance value). This explains why you obtained higher a.c. ripple voltage values for the 10,000-ohm load than you did for the 40,000-ohm load.

Since the choke coil and the output filter condenser are in series across the input filter condenser, these two parts really form an a.c. voltage divider connected across the input filter condenser. Therefore, according to Kirchhoff's Voltage Law, the voltage drop across each of the two parts will be proportional to the impedance of that part.

One requirement in the design of a filter circuit is a high choke coil impedance with respect to the output condenser impedance at the ripple frequency. When this condition is secured, most of the a.c. ripple voltage is dropped across the choke coil, and very little will be present across the output filter condenser and across the power pack load.

Computation. We can readily compute the fraction of the ripple voltage which is dropped across each part of this a.c. voltage divider (across the choke coil and across the output filter condenser), assuming that the choke coil (L) has an inductance of 10 henrys, and the output filter condenser (C_o) has a capacity of 10 mfd. With the full-wave rectifier circuit employed in your power pack, the ripple frequency (f) is twice the power line frequency, or 120 cycles.

At the ripple frequency, the reactance of the output filter condenser will be:

$$X_o = 1{,}000{,}000 \div (6.28 \times f \times C_o)$$
$$X_o = 1{,}000{,}000 \div (6.28 \times 120 \times 10)$$
$$X_o = 1{,}000{,}000 \div 7{,}536 = 132 \text{ ohms}$$

Under the same conditions, the reactance of the choke coil will be:

$$X_L = 6.28 \times f \times L$$
$$X_L = 6.28 \times 120 \times 10 = 7{,}536 \text{ ohms}$$

These figures tell us that the reactance of the choke coil at the 120-cycle ripple frequency is about 57 times that of the output condenser (7,536 ÷ 132 = 57). This means that 56/57 of the total a.c. ripple voltage is dropped across the choke coil, and only 1/57 of the total (a negligible amount) is present across the output filter condenser and load. Since the a.c. ripple voltage at the filter input is rarely more than 7 volts even under full load, this means that the a.c. output voltage is negligibly small even when the load is increased to the maximum value which the power pack can safely handle.

We can compare reactances rather than impedances in this analysis simply because the d.c. resistance of the choke coil is negligibly small in comparison to its inductive reactance, and the condenser resistance is even smaller in comparison to its reactance.

Instructions for Report Statement No. 34. If you performed Experiment 34 slowly and carefully, so that you appreciated the full significance of each reading obtained, you will have no difficulty now in answering Report Statement No. 34 on the last page of this manual. In this report statement, you are simply asked to tell whether increasing the load on the d.c. output section of your power pack (by reducing the ohmic value of the load resistor) makes the a.c. ripple voltage across the input filter condenser decrease, increase or remain the same. Place a check mark after the answer you consider correct in the report statement.

EXPERIMENT 35

Purpose: **To prove that the inductance of the choke coil affects the a.c. ripple output voltage but does not affect the d.c. output voltage value, and to prove that the d.c. resistance of the choke coil affects the d.c. output voltage value.**

Step 1. To replace the choke coil in your power pack with a 200-ohm resistor, first unsolder the two wires which are on choke coil terminal *13*. Connect these two wires together with a temporary soldered hook joint, then bend the wires so that this joint does not touch terminal *13* or any other terminals. Now take your 200-ohm resistor (Part *3-4*) and connect one of its leads to choke coil terminal *14* with a temporary soldered lap joint. Connect the other resistor lead to the hook joint you just made, using either a soldered lap joint or a temporary soldered hook joint.

The change which you have just made is equivalent to removing the inductance of the choke coil while leaving its d.c. resistance in the circuit.

Step 2. To measure the d.c. output and the a.c. ripple voltages when the choke coil is replaced with a 200-ohm filter resistor and a 10,000-ohm load is connected to the d.c. output terminals, first take the group of four parallel-connected 40,000-ohm resistors left over from Experiment 34, and connect these to output terminals *4* and *5*.

With the power pack resting on its back side so that under-chassis connections are accessible, measure the d.c. output voltage between output terminals *4* and *5*, and record your result in Table *35* as the d.c. output voltage with a 200-ohm filter resistor and with a 10,000-ohm load.

Measure the a.c. voltage between terminals *4* and *5* for the same conditions, and record your result in Table *35* as the a.c. ripple voltage measured at the d.c. output terminals.

For comparison purposes, record in Table *35* the d.c. output voltage value which you measured in Experiment 32 for a 10,000-ohm load while the choke coil was still in the circuit (this is the first value which you recorded in Table *32*). Record also in Table *35* the a.c. ripple voltage in volts which you measured in Experiment 34 at the d.c. output terminals for a 10,000-ohm load and a 10-henry choke coil (the last reading you recorded in Table *34*).

Protecting N.R.I. Tester Against Surges. Always turn on the power pack before you turn on the N.R.I. Tester, and always turn off the N.R.I. Tester before you turn off the power pack. This prevents damage to the N.R.I. Tester by the voltage surges which exist at the instant of turning the power pack on or off. Be sure to turn off the power pack before touching the test clips with your fingers.

Step 3. To measure ripple and d.c. output voltages while the choke coil is replaced with a 200-ohm resistor and a 40,000-ohm load is connected to the d.c. output terminals, first remove three of the 40,000-ohm resistors from d.c. output terminals *4* and *5*, so as to leave only one 40,000-ohm resistor connected to these terminals. Now repeat each of the measurements made in Step 2; that is, measure the d.c. output voltage and the a.c. ripple voltage which is present at the d.c. output terminals, and record each measured value in Table *35*.

For comparison purposes, record also the d.c. and a.c. output voltages which you obtained in Experiments 32 and 34 respectively for a 40,000-ohm load and the original choke coil connection.

Discussion: A comparison of the two d.c. output voltage values which you recorded for Step 2 in Table *35* should prove definitely that the inductance of the choke coil has no effect upon the d.c. output voltage value. In other words, you should obtain essentially the same d.c. output voltage values when the 200-ohm resistor is in the circuit as when the choke coil was in the circuit during the 10,000-ohm load measurement in Experiment 32. Any difference between your values can be due to variations in line voltage or normal tolerances in radio part values.

A comparison of the d.c. output voltage values which you recorded in Step 3 of Table *35* for the 40,000-ohm load further verifies that the d.c. output voltage is independent of the amount of inductance in the choke coil.

When you study the a.c. output voltage values recorded for Step 2, however, you note an entirely different situation. When this was measured with a 10,000-ohm load and the choke coil in the circuit, in Step 2 of Experiment 34, zero voltage was obtained. When the choke coil is replaced with the 200-ohm resistor, however, an appreciable a.c. voltage value is present at the d.c. output terminals. This is definite proof that it is essentially the inductance of the choke coil (not the resistance) which keeps down the a.c. ripple voltage at the d.c. output terminals.

STEP	CIRCUIT DATA	D.C. OUTPUT VOLTAGE IN VOLTS		A.C. VOLTAGE IN VOLTS AT D.C. OUTPUT TERM.	
		YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE
2	10,000Ω LOAD AND 200Ω FILTER RESISTOR	340	**350**	3.7	**2.4**
	10,000Ω LOAD AND 10H. CHOKE COIL	340	**350**	3	**0**
3	40,000Ω LOAD AND 200Ω FILTER RESISTOR	380	**420**	3.7	**1.2**
	40,000Ω LOAD AND 10H. CHOKE COIL	390	**420**	3.2	**0**

TABLE 35. Record your results here for Experiment 35. All power pack measurements in this table are for normal full-wave rectification and condenser input. Values on the first line in each step are obtained with a 200-ohm resistor connected in place of the 10-henry choke coil. Values in the second line of each step in the table are obtained from Tables 32 and 34.

Making the same comparison for the 40,000-ohm load value in Step 3 further emphasizes the importance of the inductance in keeping down a.c. ripple.

Since the entire load current must flow through the choke coil or filter resistor, it should be apparent that the d.c. resistance of the choke coil will affect the d.c. output voltage. The greater the resistance of this choke coil, the greater will be the voltage drop across this coil and the less d.c. voltage there will be available at the d.c. output terminals.

You learned in connection with a previous experiment that the reactance of the choke coil is about 57 times the reactance of the output condenser (the computed values were 7,536 ohms and 132 ohms respectively). When you replace the choke coil with a resistor, however, you have only 200 ohms at the choke coil position acting in series with the output condenser reactance of 132 ohms. Under this condition, almost half of the input condenser ripple voltage is present across the output filter condenser and the load. This explains why you obtained measurable a.c. output voltage values at the d.c. output terminals when the choke coil was replaced by the 200-ohm resistor.

It is permissible to use a resistor in place of a choke coil in a filter circuit only when the ohmic value of the resistor is many times the reactance of the output filter condenser. A resistance value high enough for adequate filtering can be used only when the load voltage requirements are low or the load resistance is considerably higher than the required filter resistor value.

Instructions for Report Statement No. 35. The discussion for this experiment indicates that the ohmic value of the equivalent filter resistor affects both the d.c. output voltage value and the a.c. ripple voltage value. For this report statement, you will make additional measurements to verify these statements experimentally.

Remove the 200-ohm resistor which you connected between choke coil terminal *14* and the leads formerly on terminal *13*, and connect in its place a 20,000-ohm resistor (two of your 40,000-ohm resistors connected in parallel).

With a 40,000-ohm load still connected to the d.c. output terminals, measure the d.c. output voltage across the load (between terminals *4* and *5*). Compare this measured value with the d.c. output voltage value you obtained in Step 3 of this experiment for the same 40,000-ohm load and a 200-ohm resistor in place of the choke coil. Now turn to the last page of this manual, and answer the first half of Report Statement No. 35, wherein you are asked whether the d.c. output voltage increased, decreased or remained the same when you increased the ohmic value of the filter resistor from 200 ohms to 20,000 ohms.

Next, measure the a.c. ripple voltage value at the d.c. output terminals of your power pack while the same 40,000-ohm load and 20,000-ohm filter resistor are connected. Compare your measured value for this set-up with the measured ripple voltage value recorded for Step 3 in Table *35* for the 200-ohm filter resistor and 40,000-ohm load, then answer the last part of Report Statement No. 35.

If you keep in mind that you now have a 20,000-ohm resistance acting in series with the 132-ohm reactance of the output filter condenser, you should have no difficulty in figuring out the reason for the result you obtained when you measured the a.c. ripple voltage at the output terminals.

EXPERIMENT 36

Purpose: **To determine how the filter system of your power pack performs when the input filter condenser is removed to give a choke input filter.**

Step 1. To secure a choke input connection, first remove the 20,000-ohm filter resistor which you used in place of the choke coil in the last experiment. Replace on choke coil terminal *13* the two wires which were originally on this terminal, so as to restore your power pack to its original circuit. Now disconnect the input filter condenser by unsoldering the lead which is on condenser terminal *29* and bend up this lead so it cannot touch other parts or terminals. Remove the 40,000-ohm load resistor from the d.c. output terminals.

STEP	LOAD IN OHMS	D.C. OUTPUT VOLTAGE IN VOLTS		A.C. VOLTAGE IN VOLTS AT OUTPUT TERMINALS		A.C. FILTER INPUT VOLTAGE IN VOLTS		D.C. LOAD CURRENT IN MILLIAMPERES	
		YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE
2	NO LOAD	350	*400*	2.4	*1.0*	72	*63*	0	*0*
3	40,000	320	*350*	3.4	*1.8*	102	*114*	9	*7*
4	20,000	290	*310*	3.4	*2.3*	114	*135*	15	*15*
5	10,000	270	*270*	3.7	*3.4*	129	*147*	25	*27*

TABLE 36. **Record your results here for Experiment 36. All power pack measurements in this table are for normal full-wave rectification and choke input.**

Step 2. To measure the d.c. output voltage, the a.c. ripple output voltage, and the a.c. filter input voltage with no load on your power pack and with a choke input connection (with the input filter condenser removed), measure the d.c. voltage across terminals *4* and *5*, and record your result in Table *36* as the no-load d.c. output voltage.

Measure the a.c. ripple voltage at the d.c. output terminals *4* and *5*, and record your result in Table *36* as the a.c. voltage in volts at the d.c. output terminals of your power pack.

Measure the a.c. voltage across the 50,000-ohm bleeder resistor under the chassis, and record your result in Table *36* as the a.c. filter input voltage in volts.

Since there is no load in this step, there is no d.c. load current to measure. Simply record zero for this no-load current measurement in Table *36*.

Step 3. To measure the d.c. output voltage, a.c. ripple output voltage, the a.c. filter input voltage and the d.c. load current with a 40,000-ohm load and a choke input filter circuit, first take one of your 40,000-ohm resistors (Part *3-6A*) and connect it to output terminal screws *4* and *5*.

Measure the d.c. output voltage as instructed in Step 2, and record your result in Table *36*.

Measure the a.c. ripple voltage at the d.c. output terminals as instructed in Step 2, and record your result in Table *36*.

Measure the a.c. voltage at the input of the filter as instructed in Step 2, and record your result in Table *36*.

Prepare the N.R.I. Tester for direct current measurements according to previous instructions. Measure the d.c. load current in milliamperes by disconnecting the 40,000-ohm resistor lead from output terminal screw *4*, placing the red test clip on this resistor lead, and placing the black test clip on output terminal *4*. Record your result in Table *36* as the d.c. load current in milliamperes for a 40,000-ohm load.

Step 4. To repeat your series of four measurements with a 20,000-ohm load connected to the power pack, remove the test clips and reconnect the load resistor lead to output terminal screw *4*, then connect another 40,000-ohm resistor in parallel with this first one by means of temporary soldered lap joints so as to secure a 20,000-ohm load.

Measure the d.c. output voltage in volts as instructed in Step 2, and record your result in Table *36*.

Measure the a.c. ripple output voltage in volts as instructed in Step 2, and record your result in Table *36*.

Measure the a.c. voltage at the input of the filter circuit as instructed in Step 2, and record your result in Table *36*.

Measure the d.c. load current in milliamperes as instructed in Step 3, and record your result in Table *36*.

Step 5. To repeat your series of four measurements with a 10,000-ohm load connected to the power pack, take your remaining two 40,000-ohm resistors and connect them in parallel with the two already on output terminals *4* and *5*, so that you have four parallel-connected 40,000-ohm resistors connected to these terminals to give a 10,000-ohm load. Now repeat each of the four measurements as instructed in Steps 2 and 3, and record your four results in Table *36*.

Step 6. To get a better picture of how load current varies with d.c. output voltage when the input filter condenser is disconnected, plot on Graph *32* the four sets of readings you just obtained for d.c. load current and d.c. output voltage. You received instructions in Experiment 32 for plotting values like these on a graph. Make heavy dots for each of your four points on the graph, then connect the dots together with a curve which passes through all four points. Label this as your curve for choke input, to distinguish it from the curve you previously drew for condenser input.

Discussion: Although it might be more convenient to start with a full load of 10,000 ohms and remove resistors one by one to reduce the load (as was done in Experiment 32), you follow normal laboratory procedure in this experiment by starting with no load and gradually increasing the load up to the maximum value. This procedure is preferred because there are occasions when you will not know whether some part in the circuit is capable of standing up under full-load conditions.

By starting with no load, you can at least get some of your readings before it is necessary to stop measurements because of overheating of a part. Sometimes the readings will indicate a tendency towards failure sufficiently in advance for you to stop the experiment and change the part or circuit to correct the condition. As far as actual values are concerned, you will secure the same readings regardless of whether you work from no load to full load or from full load to no load.

In this experiment, you remove the input filter condenser from your power pack circuit so as to duplicate the entirely possible condition whereby this condenser becomes defective during actual operation. When the input filter condenser is removed, the choke coil becomes the first part in the filter circuit through which the pulsating d.c. output of the rectifier tube passes. A filter circuit of this nature is commonly known as a *choke input filter,* while the original filter circuit in the power pack is known as a *condenser input filter*. Familiarity with the performance of a filter system having a defective input filter condenser will help you to recognize trouble of this type when you encounter it in radio equipment.

This experiment is important for still another reason. Although a choke input filter is rarely used in radio receivers, it is used extensively in transmitter power packs and in the high-voltage power packs of special radio apparatus. By becoming familiar with the operating characteristics of this type of filter, you acquire valuable training in these branches of radio as well as in radio receiver servicing.

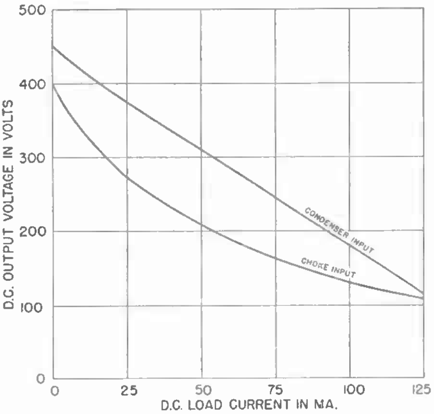


FIG. 15. Graph showing how the d.c. output voltages for condenser input and choke input in your power pack tend to become equal in value as the d.c. load current is increased up to the maximum safe current of 125 ma. which can be handled by the rectifier tube. Values for these curves can be obtained only by taking certain special precautions, because the power transformer and choke coil in your power pack are designed for maximum rated currents of only 25 ma. These current ratings are entirely ample for all experiments which you will perform with your power pack.

We can start our analysis of the results obtained in this experiment by considering the load current-d.c. output voltage curve which you plotted in Step 6. A comparison of this curve with that which you obtained in Experiment 32 shows immediately that the d.c. output voltage is lower for choke input than for condenser input. This is explained by the fact that with choke input, there is no input condenser to maintain the voltage in between the pulses of the rectifier tube output. The choke and output filter condenser merely serve to remove the a.c. component.

Voltage Regulation. To express how the output voltage of a power pack will drop when full load is applied, engineers often use a rating called *per cent voltage regulation.* This is obtained by taking the difference between the no-load and full-load voltages, dividing this difference by the no-load voltage value, then multiplying the result by 100.

There are certain special conditions in which choke input can give as good or even better voltage regulation than condenser input. For instance, the d.c. output voltage of the power pack was measured in the N.R.I. laboratory with various load values drawing up to 125 ma., using both choke input and condenser input, and the results plotted to give the curves shown in Fig. *15*. These curves show that with a 125-ma. load, the d.c. output voltages become very nearly equal for both curves.

Careful examination of the curves in the vicinity of 125 ma. shows that variations in load current in this region will cause less variation in the d.c. output voltage when choke input is used than when condenser input is used. In other words, the choke input curve is flatter than the condenser input curve at high load-current values. This verifies the statements made in your regular lessons regarding the advantages of choke input in power packs which must supply high d.c. output voltages to large varying loads, such as in the power packs of transmitters.

The curves in Fig. *15* give the voltage regulation of the entire power pack, including the power transformer. If a sufficiently large power transformer were used to eliminate the voltage regulation characteristics of the power transformer from these curves, the superiority of the choke input filter over the condenser input filter at high load current values would be much more evident.

Ripple Voltage. An examination of the a.c. voltage values which you recorded in Table *36* shows that both the input a.c. voltage to the filter and the a.c. ripple output voltage are much higher with choke input than they were for the corresponding measurements made in Experiment 34 with condenser input and recorded in Table *34*.

In the discussion of Experiment 34, we calculated that the ripple voltage was reduced about 57 times by the choke coil and output filter condenser. In the case of choke input, we can determine the ripple reduction factor for each load simply by dividing the filter input a.c. voltage by the filter output a.c. voltage.

The N.R.I. values of a.c. voltage and the resulting ripple reduction factors have been reproduced in Fig. *16* for your convenience in analyzing the results. Now we can see that for a 40,000-ohm load the ripple reduction is 63. With a 20,000-ohm load it drops slightly, down to 59, and with a 10,000-ohm load it drops down to 43. This change in the ripple reduction factor is due to the fact that the inductance of the choke coil drops as the direct current flowing through the choke coil increases.

LOAD IN OHMS	N.R.I. VALUE OF A.C. FILTER INPUT VOLTAGE IN VOLTS	N.R.I. VALUE OF A.C. FILTER OUTPUT VOLTAGE IN VOLTS	RIPPLE REDUCTION FACTOR
40,000	114	1.8	63
20,000	135	2.3	59
10,000	147	3.4	43

FIG. 16. N.R.I. values for the a.c. filter input and output voltages obtained in Experiment 36 have been repeated here for convenience in analyzing them, along with the computed ripple reduction factor values for each load resistance. The ripple reduction factor is obtained by dividing the a.c. filter input voltage for a given load by the a.c. filter output voltage obtained at that same load.

The values in Fig. *16* show clearly that the a.c. input voltage to the filter goes up as load is applied, and the a.c. ripple voltage in the d.c. output likewise increases with load. This means that you should expect to secure increased hum when you increase the load acting on a power pack in a radio receiver. A common receiver defect illustrating this characteristic is that in which a partial short circuit is developed across the power pack by failure of some part in the receiver. The increased load pulls down the output voltage, thereby reducing the volume of the reproduced program, and at the same time the increased a.c. voltage in the output produces a hum in the loudspeaker.

A comparison of the results obtained in this choke input experiment with those obtained previously for condenser input tells you what symptoms can be expected if the input condenser in a radio receiver power pack becomes defective. First of all, hum will be noticeable, for the opening of the input condenser gives a choke input filter circuit, and this delivers a higher a.c. ripple voltage to the load. Furthermore, unless the power pack happens to be operating very near the current limit of the rectifier tube (a condition rarely encountered in radio receivers), the opening of the input condenser *will make the d.c. output voltage drop,* causing reduced volume and reduced receiver sensitivity.

Instructions for Report Statement No. 36. In this experiment, you demonstrated a number of important characteristics of radio receiver power packs. Among other things, you learned that the opening or removal of the input filter condenser changes your filter circuit from condenser input to choke input, with the result that both the d.c. output voltage and the a.c. ripple output change.

To test your understanding of what you measured and studied in the experiment, you are asked in Report Statement No. 36 to specify whether the d.c. output voltage increases, decreases or remains the same when the input filter condenser of your power pack opens up while connected to a 10,000-ohm load (equivalent to changing from condenser input to choke input). Place a check mark after the answer you consider correct.

EXPERIMENT 37

Purpose: **To demonstrate that half-wave rectification gives a lower d.c. output voltage and a higher a.c. ripple output voltage than does full-wave rectification.**

Step 1. To convert your power pack circuit to a form which provides half-wave rectification, simply open the plate connection to one section of the rectifier tube by unsoldering the lead which is on socket terminal *4* and bending this lead up so that it cannot touch other terminals or parts. Leave other power pack connections as they were for the preceding experiment, so that you have a choke input filter (leave the lead still disconnected from condenser terminal *29*). Check the calibration of the N.R.I. Tester in the usual manner.

Step 2. To measure the d.c. and a.c. ripple output voltages for no load when the power pack is connected for choke input and half-wave rectification, measure the d.c. voltage between output terminals *4* and *5*, and record your result in Table *37* as the d.c. output voltage in volts for no load.

Measure the a.c. voltage between terminals *4* and *5*, and record your result in Table *37* as the a.c. ripple output voltage for no load.

Step 3. To measure the d.c. and a.c. ripple output voltages for a 40,000-ohm load when the power pack is connected for choke input and half-wave rectification, measure in turn the d.c. output voltage and the a.c. ripple output voltage of your power pack with a 40,000-ohm resistor connected to output terminals *4* and *5*. Follow exactly the same procedures specified in Step 2, and record your results in Table *37*.

Step 4. To measure the d.c. and a.c. ripple output voltages for a 10,000-ohm load when the power pack is connected for choke input and half-wave rectification, connect all four of your 40,000-ohm resistors in parallel to output terminals *4* and *5* in exactly the same manner you did for previous experiments, then measure in turn the d.c. output voltage and the a.c. ripple output voltage of your power pack by following the measuring procedures specified in Step 2, and record your results in Table *37*.

Discussion: Careful comparison of the results you obtained with corresponding load values recorded in Table *36* for choke input and *full-wave* rectification should show that half-wave rectification gives *lower d.c. output voltage* and *higher a.c. ripple output voltage* than does full-wave rectification. For example, with choke input and no load, the N.R.I. value of output voltage is 350 volts for half-

STEP	LOAD IN OHMS	D.C. OUTPUT VOLTAGE IN VOLTS		A.C. OUTPUT VOLTAGE IN VOLTS	
		YOUR VALUE	N.R.I.	YOUR VALUE	N.R.I.
2	NO LOAD	326	350	3.7	2.3
3	40,000	270	300	4.5	4.5
4	10,000	230	210	8.1	9.3

TABLE 37. Record your results here for Experiment 37. All power pack measurements in this table are for half-wave rectification and choke input.

wave rectification in Table 37, and 400 volts for full-wave rectification in Table 36. On no load, the a.c. ripple output voltage is 2.3 volts for half-wave rectification and only 1 volt for full-wave rectification.

The same factors which make the d.c. output voltage drop when half-wave rectification is employed also serve to make the a.c. output increase. First of all, with half-wave rectification only one alternation of each cycle of the a.c. secondary voltage of the power transformer is sending current through the rectifier tube. This is indicated by the filter input voltage wave shown in Fig. *17*. The filter input voltage is at zero for such a high proportion of the total time that the average d.c. voltage at the filter input is quite low for half-wave rectification.

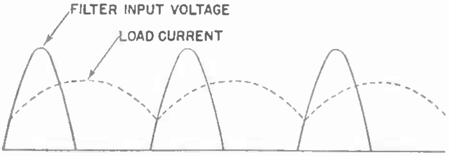


FIG. 17. Curves showing the wave form of the filter input voltage and the load current in an a.c. power pack employing half-wave rectification.

Fortunately, the choke coil prevents the load current from following too closely the fluctuations in the input voltage. The choke tends to oppose changes in the current passing through it, and consequently the load current has a wave form like that shown by the dash-dash load current curve in Fig. *17*. This is far from being a pure d.c. output, indicating that additional filtering would be needed in your power pack if it were permanently connected for choke input and half-wave rectification.

Another factor which makes half-wave rectification have a high a.c. ripple output is the fact that the fundamental ripple frequency for half-wave rectification is only 60 cycles, as compared to 120 cycles for full-wave rectification. Cutting the frequency in half cuts the reactance of the choke coil in half and doubles the reactance of the output filter condenser. As a result, the ripple reduction factor of the choke coil-output condenser combination is reduced 4 times. Dividing 57 by 4 gives only 14 as the ripple reduction factor when we have a 10-henry choke and 10-mfd. output condenser.

30 2.9

Instructions for Report Statement No. 37. So far, all of your measurements for half-wave rectification have been made with a choke input filter. To determine the effect of additional filtering upon the d.c. output voltage and the a.c. output voltage while using half-wave rectification, reconnect the input filter condenser lead to condenser terminal *29* to secure condenser input again, and repeat the series of two measurements which you made for a 10,000-ohm load in Step 4 of this experiment. Compare the d.c. output voltage value which you obtain for this condenser input measurement with that which you recorded in Table *37* for the 10,000-ohm load, then turn to the last page and answer the first half of Report Statement No. 37.

Next, compare the a.c. output voltage value which you just measured for condenser input with that which you obtained for choke input and a 10,000-ohm load in Step 4, and answer the last part of Report Statement No. 37.

Now, if you analyze your answers to this report statement, you should be able to figure out why a condenser input filter is always used in radio receiver power packs employing half-wave rectification.

Be sure to turn off the N.R.I. Tester and the power pack after completing these measurements. Leave the 10,000-ohm load connected to the power pack, since you will use this in the next experiment.

EXPERIMENT 38

Purpose: **To demonstrate that the a.c. ripple output voltage can be reduced by tuning the choke coil with a suitable shunt condenser value.**

Step 1. To tune the choke coil in your power pack approximately to resonance, take the two .25-mfd. paper condensers (Parts *3-2A* and *3-2B*), connect one in parallel with the other by means of temporary soldered joints, then connect the combination in parallel with the choke coil (across terminals *13* and *14*) by means of temporary soldered lap joints. Now disconnect the lead from condenser terminal *29* so as to secure choke input again, and check output terminals *4* and *5* to be sure the 10,000-ohm load is still connected properly to these terminals. Leave the wire disconnected from socket terminal *4* to provide half-wave rectification.

A.C. RIPPLE VOLTAGE IN VOLTS AT D.C. OUTPUT TERMINALS	
YOUR VALUE	N.R.I. VALUE
4.8	7.2

TABLE 38. Record your result here for Experiment 38. The measurement is made with half-wave rectification, choke input, a 10,000-ohm load, and a .5-mfd. condenser connected to tune the choke coil approximately to resonance.

Measure the a.c. ripple output voltage at d.c. output terminals *4* and *5*, and record your result in Table *38*.

Discussion: In an earlier experiment, you made measurements which showed that a .5-mfd. condenser will tune your 10-henry choke coil approximately to resonance at 60 cycles. Furthermore, you learned in your regular course that at resonance, a parallel resonant circuit has a much higher impedance than does the coil or condenser alone. You utilize all this information in a highly practical manner in this experiment by placing the .5-mfd. condenser across your choke coil, while the power pack is connected for half-wave rectification, choke input and a 10,000-ohm load.

As Table *38* indicates, an a.c. voltage value of 7.2 volts was obtained in the N.R.I. laboratory for this particular measurement. Comparing this value with the corresponding value obtained for a 10,000-ohm load, half-wave rectification and choke input in Table *37* (where the choke was not tuned), it is apparent that tuning the choke coil lowers the a.c. ripple output considerably.

Tuning of the filter choke coil is by no means a complete solution to the filtering problem in a half-wave rectifier, or even in a full-wave rectifier, but it does improve the filtering sufficiently to warrant its use in many radio receiver power packs. Whenever you encounter a receiver power pack in which a condenser is connected across the choke coil, you can be sure the condenser is there for the purpose of tuning the choke coil.

When tuning of the choke is incorporated in the power pack of a commercial radio receiver during design, the choke coil itself is designed to have a low a.c. resistance, so as to make its Q factor high. With a high Q factor, the impedance of the coil can be stepped up many times by tuning it to resonance, thus reducing the ripple output considerably. The 10-henry choke coil employed in your power pack has a relatively low Q factor, for it is designed primarily for use in ordinary condenser input filters where the Q factor is unimportant.

When excessive hum is encountered in a receiver which has a tuned choke coil in its power pack filter system, the condenser used across the choke coil should be checked carefully. If this condenser is open or is excessively leaky, there will be little or no impedance step-up, and the a.c. ripple or hum output will be high.

Sometimes a mechanical shock such as dropping a receiver will alter the positions of the laminations in the choke coil, thereby changing the inductance of the choke coil; in this case, a new choke or a different capacity value may be needed in order to produce resonance and eliminate hum.

Instructions for Report Statement No. 38. A .5-mfd. capacity gave a decided decrease in the hum output when connected across the choke coil; will an even greater reduction in hum be obtained with a .25-mfd. condenser, will the hum remain the same, or will you get more hum than with the .5-mfd. capacity? This is the problem in Report Statement No. 38.

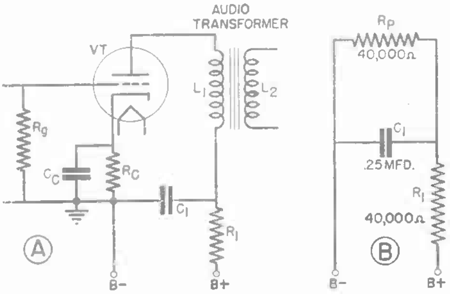


FIG. 18. Schematic circuit diagram of a typical audio amplifier stage (*A*), and the equivalent circuit diagram (*B*) which you set up to duplicate the loading effect of this stage upon a power pack to which it is connected.

In order to answer this question, remove one of the .25-mfd. condensers which you connected across the choke coil, so that only .25 mfd. is in parallel with the choke, then repeat your measurement of the a.c. ripple voltage at the d.c. output terminals.

Compare your measured value with that which you recorded in Table *38* for the .5-mfd. condenser, then turn to the last page and place a check mark after the answer which describes your result. Finally, remove the .25-mfd. condenser which you placed across the choke coil.

EXPERIMENT 39

Purpose: **To demonstrate the effectiveness of a resistor-condenser filter in reducing a.c. ripple voltage.**

Preliminary Discussion: In Fig. *18A* is shown a typical audio amplifier circuit such as might be found connected to a power pack like yours in an actual radio receiver. The terminals marked *B—* and *B+* in this circuit would go to the *B—* and *B+* terminals respectively of the power pack.

As you have already demonstrated in previous experiments, a power pack may supply a small a.c. ripple voltage value along with its normal d.c. output voltage. If this ripple voltage is allowed to affect the plate circuit of a stage like this, it will produce a corresponding hum frequency in the signal output (across primary winding L_1 of the audio transformer).

Resistor R_1 and condenser C_1 in Fig. *18A* form a filter which effectively prevents power pack a.c. ripple from entering the plate circuit. The a.c. voltage between the *B—* and *B+* terminals in Fig. *18A* is divided between C_1 and R_1, with most of the a.c. voltage being dropped across R_1. In designing a circuit like this, the reactance of C_1 is made very low in comparison to the resistance of R_1, so that only a negligibly small a.c. voltage is developed across C_1 for application to the plate circuit.

With your power pack, you can readily duplicate the conditions existing in the circuit of Fig. *18A*, and demonstrate to yourself the effectiveness of a resistor-condenser filter in reducing power pack hum or a.c. ripple. It is not necessary to use the entire vacuum tube circuit shown in Fig. *18A* for this experiment, because we can satisfactorily duplicate this circuit with two resistors and a condenser arranged as shown in Fig. *18B*. Here C_1 and R_1 are the same as in Fig. *18A*, but R_P is a 40,000-ohm resistor which essentially duplicates the total plate circuit resistance of a typical vacuum tube circuit (such as a circuit having a plate voltage of 250 volts and a plate current of 6.25 ma., corresponding to a total circuit resistance of 250 ÷ .00625, or 40,000 ohms).

By setting up the circuit shown in Fig. *18B*, connecting the *B*— and *B*+ terminals of the circuit to the corresponding terminals of your power pack, and measuring the a.c. ripple voltage first at the power pack output terminals (at the input of our resistor-condenser filter R_1-C_1), then across equivalent load resistor R_P (across the output of filter R_1-C_1), we can readily compute the ripple reduction factor of this filter combination.

Step 1. To set up the apparatus necessary for demonstrating the effectiveness of resistor-condenser filter R_1-C_1 in Fig. 18B, first connect a 20,000-ohm load to d.c. output terminals *4* and *5* by placing two of your 40,000-ohm resistors in parallel across these terminals in the manner shown in Fig. *19*. Arrange the resistors so that they rest on the table or bench top. Leave the power pack connected for half-wave rectification and choke input just as it was at the end of the preceding experiment, so that with this circuit combination and the 20,000-ohm load you are obtaining a fairly high a.c. ripple output along with the d.c. output.

Next, connect the remaining two 40,000-ohm resistors and a .25-mfd. condenser (Part *3-2A*) between output terminals *4* and *5* exactly as shown in Fig. *19*, allowing these resistors also to rest upon the table or bench top. Make temporary soldered joints in all cases.

Step 2. To measure the a.c. ripple voltage at the input of filter R_1-C_1, place the red test clip on any resistor lead going to output terminal *5*, place the black test clip on any resistor lead going to output terminal *4*, measure the a.c. voltage, and record your result in Table *39* as the a.c. ripple voltage in volts at the input of filter R_1-C_1.

To measure the a.c. ripple voltage at the output of filter R_1-C_1 (across C_1), simply move the red clip to the common junction of C_1, R_1 and R_P (Fig. *19*), leaving the black clip on a lead going to terminal *4*. Record your result in Table *39* as the a.c. ripple voltage in volts at the output of filter R_1-C_1.

A.C. RIPPLE VOLTAGE IN VOLTS AT INPUT OF FILTER R_1–C_1		A.C. RIPPLE VOLTAGE IN VOLTS AT OUTPUT OF FILTER R_1–C_1	
YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE
6.9	6.9	1.1	1.1

TABLE 39. Record your results here for Experiment 39. The measurements are for half-wave rectification, choke input, and a 20,000-ohm load connected to the d.c. output terminals of the power pack.

Discussion: You can determine the ripple reduction factor of your resistor-condenser filter R_1-C_1 simply by dividing the a.c. filter input voltage by the a.c. filter output voltage.

If we do this with the N.R.I. values, we obtain a filter reduction factor of approximately 6. (6.9 ÷ 1.1 = 6.2). If you secure approximately this ripple reduction factor with your values, you have proved experimentally that a resistor-condenser filter of this type will definitely reduce hum voltages.

The theoretical ripple reduction factor of an R-C filter can very readily be computed. With half-wave rectification, the ripple frequency is 60 cycles. At this frequency, a .25-mfd. condenser will have a reactance of 10,600 ohms.*

With a value of 40,000 ohms for filter resistor R_1, the a.c. voltages will divide in the

---

$$*X_C = \frac{1{,}000{,}000}{6.28 \times .25 \times 60}$$

$$X_C = 10{,}600 \text{ ohms}$$

ratio of 40,000 to 10,600, which is approximately 3.77. This value will then be the theoretical ripple reduction factor. The shunting effect of 40,000-ohm resistor R_P on the condenser lowers the reactance between the condenser terminals, thus increasing the ripple reduction factor of the circuit. The measured N.R.I. value of 6 is, therefore, entirely acceptable.

A.F. Filtering Action. A resistor-condenser filter (usually called simply an R-C filter) in the plate circuit of a radio receiver also serves to prevent a.f. signals in the plate circuit from entering the power pack and traveling from there to other circuits where undesirable regeneration or degeneration might be produced. Thus, filter condenser C_1 in the vacuum tube circuit of Fig. *18A* has a reactance which is low with respect to the total impedance of the signal path through vacuum tube *VT*, coil L_1 and the parallel combination of cathode resistor R_C and C_C, and hence only a small portion of the total available a.f. voltage exists across C_1 to feed back into the power pack.

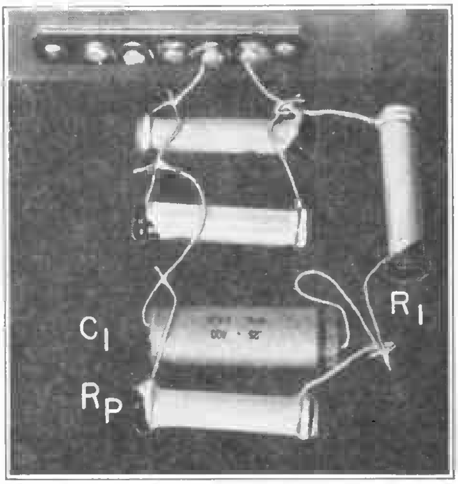


FIG. 19. Suggested method of connecting to the d.c. output terminals of your power pack a 20,000-ohm load and an arrangement of two resistors and a condenser (R_1, R_P and C_1) which duplicates the effect of a typical audio amplifier stage having an R-C filter and a total plate circuit resistance of 40,000 ohms.

R_1 in Fig. *18A* acts with the output filter condenser in the power pack as an R-C filter for a.f. signals heading in this opposite direction toward the power pack. The reactance of the output filter condenser is usually quite low at audio frequencies (is less than 200 ohms), while R_1 is generally higher than 10,000 ohms in value, so that the ripple reduction factor for a.f. signals heading toward the power pack is considerably higher than 50.

Instructions for Report Statement No. 39. Experiment 39 proved conclusively that an R-C filter connected between the power pack and a load will reduce the a.c. ripple filter voltage which reaches the load. One question still remains unanswered, however: Does the insertion of an R-C filter between source and load affect the value of the d.c. voltage applied to the load?

You will recall that resistor R_P in Fig. *18B* serves to duplicate the plate circuit resistance of an audio amplifier stage. Our question really asks, then, whether the voltage across R_P is any different from the voltage between the *B*— and *B*+ terminals in Fig. *18B*. This can be checked very easily by making two simple d.c. voltage measurements in your test circuit. Once you make these measurements and compare your readings, you will have no difficulty in answering Report Statement No. 39.

To measure the d.c. output voltage of your power pack, simply place the red clip on output terminal *5*, place the black clip on output terminal *4* (while leaving all four resistors and the condenser connected to these terminals in the manner shown in Fig. *19*), measure the d.c. voltage, and make a notation of your result in the margin of this page or elsewhere. 240

Next, measure the d.c. voltage across 40,000-ohm load resistor R_P 120 by placing the red clip on the common junction of leads from R_P, C_1 and R_1 and leaving the black clip on output terminal *4*. Record this value also in the margin of this page. Compare your two measured values of d.c. voltage, then turn to the last page and place a check mark after the answer which best describes your conclusions regarding these measurements. Unsolder R_1, R_P and C_1 in Fig. *19*, but leave the other two 40,000-ohm resistors connected to the d.c. output terminals of the power pack.

EXPERIMENT 40

***Purpose:* To show that resistance in series with a filter condenser increases the amount of ripple voltage at the output of a power pack.**

Step 1. To connect your power pack for full-wave rectification with condenser input, with a 1,000-ohm resistance in series with the input filter condenser, and with a 10,000-ohm load connected to the d.c. output terminals of the power pack, first restore full-wave rectification by reconnecting the transformer secondary lead to socket terminal *4*. Next, take a 1,000-ohm resistor (Part *3-5A*), connect one of its leads to electrolytic condenser terminal *29* by means of a temporary soldered hook joint, and connect the other resistor lead to the wire from choke coil terminal *14* which formerly went to condenser terminal *29*, as indicated by the circuit diagram in Fig. *20A*. Adjust the position of the 1,000-ohm resistor so that none of its leads are touching other uninsulated leads or terminals.

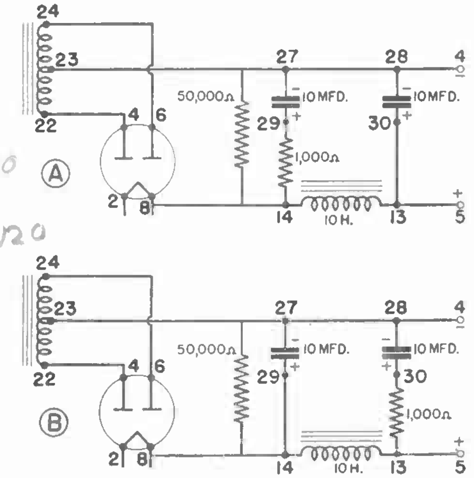


FIG. 20. Simplified schematic circuit diagrams of your a.c. power pack when connected normally for full-wave rectification and condenser input, showing how a 1,000-ohm resistor is to be inserted in series with each 10-mfd. electrolytic filter condenser in turn to duplicate the effect of a dried-out filter condenser.

Place a 10,000-ohm load across output terminals *4* and *5* by soldering the remaining two 40,000-ohm resistors in parallel with the two 40,000-ohm resistors already connected to these terminals.

Step 2. To measure the input and output a.c. voltages of the filter system in your power pack when a 1,000-ohm resistor is in series with the input filter condenser, first measure the a.c. voltage across the 50,000-ohm bleeder resistor, and record your result in Table *40* as the a.c. ripple voltage in volts at the input of the filter when a 1,000-ohm resistance is in series with the input filter condenser.

Measure the a.c. voltage between output terminals *4* and *5* for the same conditions, and record your result in Table *40* as the a.c. ripple in volts at the output of the filter when you are using a 1,000-ohm resistor in series with the input filter condenser.

Measure the d.c. output voltage of the power pack, and record your measured d.c. output voltage value in Table *40*.

Step 3. To secure a.c. ripple voltage readings at the input and output of the filter when a 1,000-ohm resistor is in series with the output filter condenser, first remove the 1,000-ohm resistor from the power pack circuit and reconnect choke coil terminal *14* directly to condenser terminal *29*. Now unsolder the lead which is on condenser terminal *30*, connect one lead of the 1,000-ohm resistor to terminal *30*, and connect the other resistor lead to the lead which you just unsoldered from *30*. This places the 1,000-ohm resistor in series with the *output* filter condenser, as shown in Fig. *20B*.

Measure the a.c. voltage across the 50,000-ohm bleeder resistor, and record your result in Table *40* as the a.c. ripple in volts at the input of the filter when using a 1,000-ohm resistor in series with the output filter condenser.

Measure the a.c. voltage at output terminals *4* and *5*, and record your result in Table *40* as the a.c. ripple in volts at the filter output.

Measure the d.c. output voltage now, and record your result in Table *40*.

Discussion: It is entirely possible for an electrolytic condenser to dry out during use, so that it becomes equivalent to a condenser in series with a resistor. When this condition is sufficiently serious, hum becomes noticeable along with radio programs; in certain cases, the d.c. output voltage may drop, so that the receiver loses sensitivity (ability to reproduce programs of distant or weak stations satisfactorily), and the reproduced program becomes distorted due to low operating voltages.

In this experiment, you introduce in series with each electrolytic filter condenser in turn a 1,000-ohm resistor which duplicates the condition whereby the electrolytic condenser has dried out.

The N.R.I. values given in Table *40* for Step 2 indicates an a.c. filter input voltage of 33 volts, as compared to only 6.3 volts for the corresponding N.R.I. measurement in Step 2 of Table *34* when no resistor was in series with the input filter condenser. This is quite a large difference, but when we compare the N.R.I. values for the a.c. ripple output, the difference is very much less. Thus, the N.R.I. value is 1 volt in Table *40* and zero in Table *34*.

This indicates that a defective input filter condenser will increase the amount of a.c. input to the filter, but the output filter condenser and choke coil together will prevent most of this a.c. ripple from entering the load. The resistance acting in series with the input filter condenser prevents this condenser from charging and discharging fast enough to hold up the filter input voltage in between peaks of the rectified output.

The N.R.I. d.c. output voltage of 325 volts for Step 2 in Table *40* is comparable with the N.R.I. value of 350 volts for a 10,000-ohm load in Table *32*. This indicates that drying out of the *input* filter condenser will cause some decrease in the d.c. output

STEP	CIRCUIT DATA	A.C. RIPPLE IN VOLTS AT INPUT OF FILTER		A.C. RIPPLE IN VOLTS AT OUTPUT OF FILTER		D.C. OUTPUT VOLTAGE IN VOLTS	
		YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE
2	1000Ω IN SERIES WITH INPUT FILTER CONDENSER	45	**33**	2.5	**1.0**	320	**325**
3	1000Ω IN SERIES WITH OUTPUT FILTER CONDENSER	7.8	**6.3**	2.8	**2.1**	350	**350**

TABLE 40. Record your results here for Experiment 40. All power pack measurements in this table are for normal full-wave rectification and condenser input, with a 10,000-ohm load connected to the d.c. output terminals of the power pack.

voltage, resulting in lowered output volume, loss of sensitivity, and possibly also in distortion.

When the 1,000-ohm resistor is placed in series with the output filter condenser to simulate a defect in this condenser, the N.R.I. value of 6.3 volts in Step 3 of Table *40* is the same as the value of 6.3 volts for the corresponding condition without the 1,000-ohm resistor in Step 2 of Table *34*. The a.c. ripple output at the d.c. output terminals is quite high, however, when the resistor is present; it is 2.1 volts in Step 3 of Table *40*, but zero in Table *34*. This indicates that drying out of the output filter condenser will definitely cause appreciable hum in a radio receiver.

Considering the d.c. output values for Step 3 of Table *40* and for the 10,000-ohm load condition in Table *32*, we find that exactly the same values were obtained in both cases. This indicates that loss of capacity in the output filter condenser will have no effect upon the d.c. output voltage. Actually, you can disconnect the output filter condenser without affecting the d.c. output voltage.

Apparently it is the output filter condenser which has the most control upon the amount of ripple in the a.c. output. Let us consider why this is so. At 120 cycles (the ripple frequency in the full-wave rectifier circuit we are now employing), the reactance of a 10-mfd. condenser is about 132 ohms. The insertion of a 1,000-ohm resistor in series with 132 ohms will make the combination essentially resistive, having a total impedance only slightly higher than 1,000 ohms. The impedance of the output filter condenser is now much closer to the impedance of the choke coil, with the result that the ripple reduction factor is greatly reduced.

Drying out of the output filter condenser creates another serious condition in a practical radio circuit. As you will recall, this condenser acts with the series resistor in the plate supply lead of each vacuum tube stage as an R-C filter which prevents a.f. plate current from entering the power pack. A reduction in the capacity of the output filter condenser reduces considerably the effectiveness of this R-C filter, with the result that a.f. and r.f. currents may enter the power pack and travel from there to other circuits, causing serious regeneration or degeneration which is evident as howling. low volume or distortion.

Instructions for Report Statement No. 40. In the discussion, we pointed out that a reduction in the capacity of the output filter condenser has essentially no effect upon the value of the d.c. output voltage. This means that there will be essentially no change in the d.c. output if one lead of the output filter condenser in a radio receiver should accidentally break or open. But what will happen to the a.c. ripple voltage at the output of the filter when this occurs? By disconnecting one lead of the output filter condenser, then measuring this a.c. ripple voltage, you can answer this question for yourself and at the same time secure the information needed to answer Report Statement No. 40.

You should still have the 1,000-ohm resistor connected in series with the output filter condenser. Unsolder this resistor from the circuit, but leave this condenser still disconnected. Now measure the a.c. ripple output voltage at output terminals *4* and *5*, and record your result in Report Statement No. 40.

Now, for your own information, compare this measured value with that which you recorded in Step 2 of Table *34* for the corresponding conditions with the output filter condenser connected (your value will be under the column in Table *34* headed *A.C. VOLTAGE IN VOLTS AT D.C. OUTPUT TERMINALS*).

Important Instructions. Restore your power pack to its original circuit by reconnecting the lead from choke coil *13* back on condenser terminal *30*. Check the wiring of your power pack now against the semi-pictorial wiring diagram in Fig. *8*, to be sure that all connections are correct. If you desire, you can now convert all temporary hook joints to permanent hook joints by squeezing the hooks with long-nose pliers while keeping the solder molten on the joint with your soldering iron.

Finally, make a check of the no-load d.c. output voltage of your power pack to be sure it is operating properly. The voltage which you measure now should correspond to that which you recorded for Step 1 in Table *31*. Be sure to turn off the N.R.I. Tester and the power pack when you have finished your work.

NOTICE: Remember that during all work with your a.c. power pack, the short length of bare wire should be left between terminals *3* and *4*, exactly as instructed in this manual, and an external ground connection should always be made to terminal *3* or *4* whenever using the power pack.

INSTRUCTIONS FOR PERFORMING RADIO EXPERIMENTS 11 TO 20

2RK-1

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WHAT'S YOUR HURRY?

Youth is eager and impatient. It seeks to achieve success at a single bound. But older people know from cruel experience that success is not acquired in a minute, nor a week, nor a month. If it were that easy to secure, every one would be a President, a Supreme Court Justice, or a millionaire captain of industry, and the world would be like a navy in which every sailor is a captain!

"Learn to walk before you run" is good grandmotherly advice. The worst type of ignorance is *not knowing how much there is to know*. Just because you have attained the first step in your climb to success, don't get the idea you can skip all the other steps.

Build gradually that ladder of knowledge and experience by which you will rise in radio. Be like the postage stamp, which sticks to one thing until it gets there, and you'll be able to stay at the top when you do arrive.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

1947 Edition

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Instructions for Performing Radio Experiments 11 to 20

Introduction

IN THE design, construction and repair of radio apparatus, circuits are highly important. You have already studied many different types of circuits in your regular course, and have learned that every circuit must have three things: *1. A source of voltage; 2. A load; 3. A transmission system* (either two simple wires or a complex arrangement of radio parts) *which connects together the source and load.*

In the next ten experiments, you will work with real radio circuits and actually demonstrate for yourself their characteristics. In one experiment, you will prove that electrons flow in a definite direction between the source and the load in a d.c. circuit. In another experiment, you will increase the source voltage and see that this makes the current increase. You will also increase the resistance in a circuit, and prove that the current decreases exactly as Ohm's Law says it will.

Four entire experiments in this manual are devoted to vacuum tube circuits. You will actually see for ourself that current can flow through e vacuum inside a tube when one ectrode is heated and another elec-ode is positively charged with re-ect to the heated electrode. You ill also perform an experiment which ows how a vacuum tube can control e flow of electrons in a circuit. By rking with vacuum tube circuits it from the start, you will become ustomed to thinking in terms of tron flow, and will soon find your- using vacuum tubes as guides to tell the direction of electron flow in any circuit.

Contents of Radio Kit 2RK-1

The parts included in Radio Kit 2RK-1 are illustrated in Fig. *1* and listed in the caption underneath. Check against this list the parts which you received, to be sure you have all of them.

If any part is obviously defective or has been damaged during shipment, please return it to the Institute *immediately* for replacement.

RMA Color Code for Resistors

Most of the fixed resistors included with NRI radio kits are marked according to the standard Radio Manufacturers' Association (RMA) color code, in addition to having the ohmic value printed on the body of the resistor. Furthermore, resistors used in commercial radio equipment are often identified only by these color code markings. (Some radio set manufacturers used private color codes for resistors. These resistors must be checked by actual measurement.) The RMA color code is presented in Fig. *2* for your convenience in referring to it while you are carrying out these experiments.

Tolerances. The standard tolerance observed by manufacturers of carbon or metalized resistors is 20%. This means that the actual value of a resistor may be as much as 20% higher or 20% lower than the rated value. For example, in the case of a 1,000-ohm resistor, the standard 20% tolerance comes to 200 ohms, and the

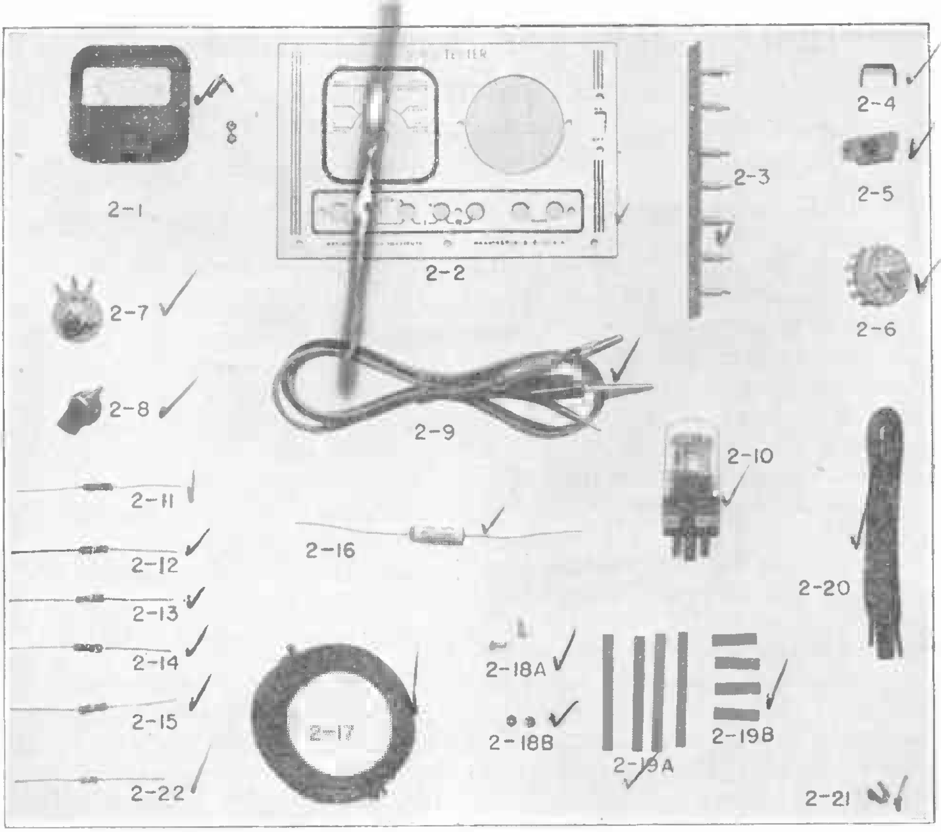

FIG. 1. The parts included in Radio Kit 2RK-1 are pictured above, and are identified in the list below. Note that the first numeral in each part number is 2; this enables you to identify these parts immediately as having been supplied to you in Radio Kit 2RK-1. When an experiment calls for a part having 1 as its first numeral, you know immediately that the part was supplied to you in Radio Kit 1RK.

Part No.	*Description*
2-1	One 0-3-ma. milliammeter with special scale and zero-readjusting knob at rear. Two mounting screws and two nuts are included with the meter.
2-2	Front panel for NRI Tester.
2-3	One 7-jack strip.
2-4	One U-shaped shorting piece for phone jacks.
2-5	One slide-type ON-OFF power switch.
2-6	One 6-position rotary selector switch.
2-7	One 1,000-ohm wire-wound potentiometer.
2-8	One bar knob for the selector switch.
2-9	One pair of test leads (one red and one black lead) with probes and alligator clips.
2-10	One type 1C5GT vacuum tube. (This tube is sometimes marked 1C5G or 1C5GT/G.)
2-11*	One 6.8-megohm, ½-watt resistor with 5% tolerance (color-coded blue, gray, green, gold).
2-12	One 3-megohm, ½-watt resistor with 5% tolerance (color-coded orange, black, green, gold).
2-13*	One .24-megohm, ½-watt resistor with 5% tolerance (color-coded, red, yellow, yellow, g (This is the same as Part *1-14*, so you can use either *2-13* or *1-14*.)
2-14*	One 910-ohm, ½-watt resistor with 5% tolerance (color-coded white, brown, brown, gold).
2-15	One 100-ohm, ½-watt resistor with 5% tolerance (color-coded brown, black, brown, gold)
2-16	One .005-mfd., 600-volt paper condenser.
2-17	One 25-foot roll of push-back hook-up wire.
2-18A	Two ¼-inch long, 6-32 cadmium-plated binder-head machine screws.
2-18B	Two cadmium-plated hexagonal nuts for 6/32 screws.
2-19A	Four ¼-inch wide, 2½-inch long tinned copper strips.
2-19B	Four ¼-inch wide, 1-inch long tinned copper strips.
2-20	One 45-inch length of black lace for fastening tester batteries to chassis.
2-21	One grid clip.
2-22*	One .22-megohm, 1/3-watt resistor with 20% tolerance (color-coded red, black and yellow

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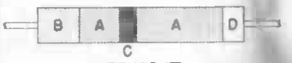
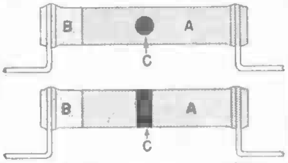
* These values are the new, post-war "standard" values and are therefore slightly different fro 6.7, .25, .2-megohm, and 900-ohm values shown in the various tables and diagrams.

RMA COLOR CODE FOR RESISTORS

METHOD I
COLOR BANDS A, B, AND C GIVE VALUE.
GOLD OR SILVER BAND D, USUALLY OMITTED, INDICATES TOLERANCE.
BLACK BACKGROUND — UNINSULATED.
TAN BACKGROUND — INSULATED.



METHOD II
BODY COLOR (A), END COLOR (B), AND DOT OR BAND COLOR (C) GIVE VALUE.
GOLD OR SILVER BAND D, USUALLY OMITTED, INDICATES TOLERANCE.



Color	Figure
BLACK	0
BROWN	1
RED	2
ORANGE	3
YELLOW	4
GREEN	5
BLUE	6
VIOLET	7
GRAY	8
WHITE	9

900

COLOR A GIVES FIRST FIGURE OF RESISTOR VALUE.

COLOR B GIVES SECOND FIGURE OF RESISTOR VALUE.

COLOR C GIVES NUMBER OF CIPHERS FOLLOWING THE FIRST TWO FIGURES.

COLOR D: GOLD BAND INDICATES ± 5% TOLERANCE.
SILVER BAND INDICATES ± 10% TOLERANCE.
NO BAND INDICATES STANDARD ± 20% TOLERANCE.

FIG. 2. The two methods being used for marking resistors according to the standard R.M.A. Color Code are given here.

When a color band is missing in non-insulated (black background) resistors marked according to Method I, assume that the color of the missing band is black.

When end color B, or dot or band C, is missing in a resistor marked by Method II, the missing marking is the same as body color *A;* thus, an all-red color-coded resistor would be 2,200 ohms.

Note that with Method I markings the color bands are all equal in width, while with Method II marking on resistors having leads coming straight out from the ends, the color bands are of different widths; this serves as a clue for telling which method of marking is employed. Resistors with side leads (shown at the right above) are not insulated.

resistor may therefore have a value anywhere between 800 ohms and 1,200 ohms. No special tolerance markings are used when a resistor has standard 20% tolerance.

In some radio circuits, better accuracy is required for resistors. With 10% tolerance, a 1,000-ohm resistor would be somewhere between 900 ohms and 1,100 ohms. When resistors with 10% tolerance are marked ac-
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Insulated Resistors. When the outer covering of a resistor is an insulating material, we have what is known as an *insulated resistor.* When marked according to Method *I* in Fig. *2,* you can identify these by the fact that they have a *tan* background color. These resistors may safely be used in contact with the chassis or other parts.

When there is no insulating covering on a ceramic fixed resistor, we have what is known as a *non-insulated* resistor. When marked according to Method *I* in Fig. *2,* these have a *black* background color. Non-insulated resistors should not be allowed to touch other parts or wires.

Many of the resistors furnished to you in NRI radio kits are of the insulated type, but nevertheless it is always good practice to position resistors so that they do not touch other parts.

Batteries Needed

The batteries needed for the ten experiments in this manual and for construction of the NRI Tester are pictured in Fig. 3. Instructions for ordering these batteries have already been sent to you.

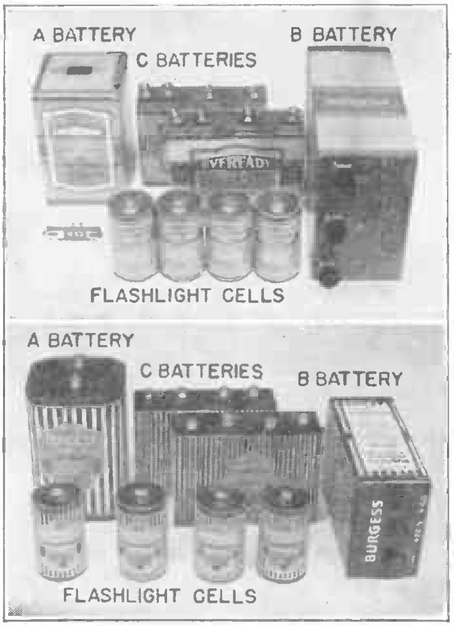

FIG. 3 The only batteries you need for Experiments 11 to 20 in this manual and for the NRI Tester are four standard No. 2 (large size) flashlight cells, one 1½-volt A battery, one 45-volt B battery and two 4½-volt C batteries. These can be the Eveready or Burgess units shown here and specified below, or any other makes having exactly the same dimensions and terminal arrangements.

The Eveready battery kit consists of the following:

- One type 742 1½-volt A battery.
- One type 1024 plug-in adapter for A battery.
- One type 762-S 45-volt B battery.
- Two type 761-A 4½-volt C batteries.
- Four type 950 flashlight cells with removable paper jackets.

The Burgess battery kit consists of the following:

- One type 4FH 1½-volt A battery.
- One type 5308 45-volt B battery.
- Two type 2370 4½-volt C batteries.
- Four No. 2 flashlight cells with removable paper jackets.

Battery kits purchased from National Radio Institute will also include a terminal identification card for C batteries.

If you followed the instructions given in the battery folder accompanying your first radio kit (1RK), you will already have a kit of batteries purchased from National Radio Institute, or from any firm handling radio parts. If for any reason you have not yet obtained your batteries, *order them immediately* because you will need them for the experiments in this manual. Write to us for a price quotation if you did not get a battery folder.

Batteries are required for every experiment in this second manual of your practical demonstration course, so order your batteries immediately (either from NRI or from a radio supply firm) if you have not already done so.

INSTRUCTIONS FOR EACH EXPERIMENT

1. **Read the entire experiment, giving particular attention to the dicussion.**
2. **Perform each step of the experiment and record your results.**
3. **Study the discussion and analyze your results.**
4. **Answer the report statement for the experiment. It will always be on the last page of the manual.**

EXPERIMENT 11

Purpose: **To demonstrate that a d.c. voltage source has polarity.**

Step 1. To provide convenient soldering terminals for the four flashlight cells, take one of the 2½-inch long tinned copper strips (Part *2-19A),* and make a rounded right-angle bend ¾ inch from one end with long-nose pliers. Now hold one of the ce
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Instructions for Performing Radio Experiments 11 to 20

Introduction

IN THE design, construction and repair of radio apparatus, circuits are highly important. You have already studied many different types of circuits in your regular course, and have learned that every circuit must have three things: *1. A source of voltage; 2. A load; 3. A transmission system* (either two simple wires or a complex arrangement of radio parts) *which connects together the source and load.*

In the next ten experiments, you will work with real radio circuits and actually demonstrate for yourself their characteristics. In one experiment, you will prove that electrons flow in a definite direction between the source and the load in a d.c. circuit. In another experiment, you will increase the source voltage and see that this makes the current increase. You will also increase the resistance in a circuit, and prove that the current decreases exactly as Ohm's Law says it will.

Four entire experiments in this manual are devoted to vacuum tube circuits. You will actually see for yourself that current can flow through the vacuum inside a tube when one electrode is heated and another electrode is positively charged with respect to the heated electrode. You will also perform an experiment which shows how a vacuum tube can control the flow of electrons in a circuit. By working with vacuum tube circuits right from the start, you will become accustomed to thinking in terms of electron flow, and will soon find yourself using vacuum tubes as guides to tell the direction of electron flow in any circuit.

Contents of Radio Kit 2RK-1

The parts included in Radio Kit 2RK-1 are illustrated in Fig. *1* and listed in the caption underneath. Check against this list the parts which you received, to be sure you have all of them.

If any part is obviously defective or has been damaged during shipment, please return it to the Institute *immediately* for replacement.

RMA Color Code for Resistors

Most of the fixed resistors included with NRI radio kits are marked according to the standard Radio Manufacturers' Association (RMA) color code, in addition to having the ohmic value printed on the body of the resistor. Furthermore, resistors used in commercial radio equipment are often identified only by these color code markings. (Some radio set manufacturers used private color codes for resistors. These resistors must be checked by actual measurement.) The RMA color code is presented in Fig. *2* for your convenience in referring to it while you are carrying out these experiments.

Tolerances. The standard tolerance observed by manufacturers of carbon or metalized resistors is 20%. This means that the actual value of a resistor may be as much as 20% higher or 20% lower than the rated value. For example, in the case of a 1,000-ohm resistor, the standard 20% tolerance comes to 200 ohms, and the

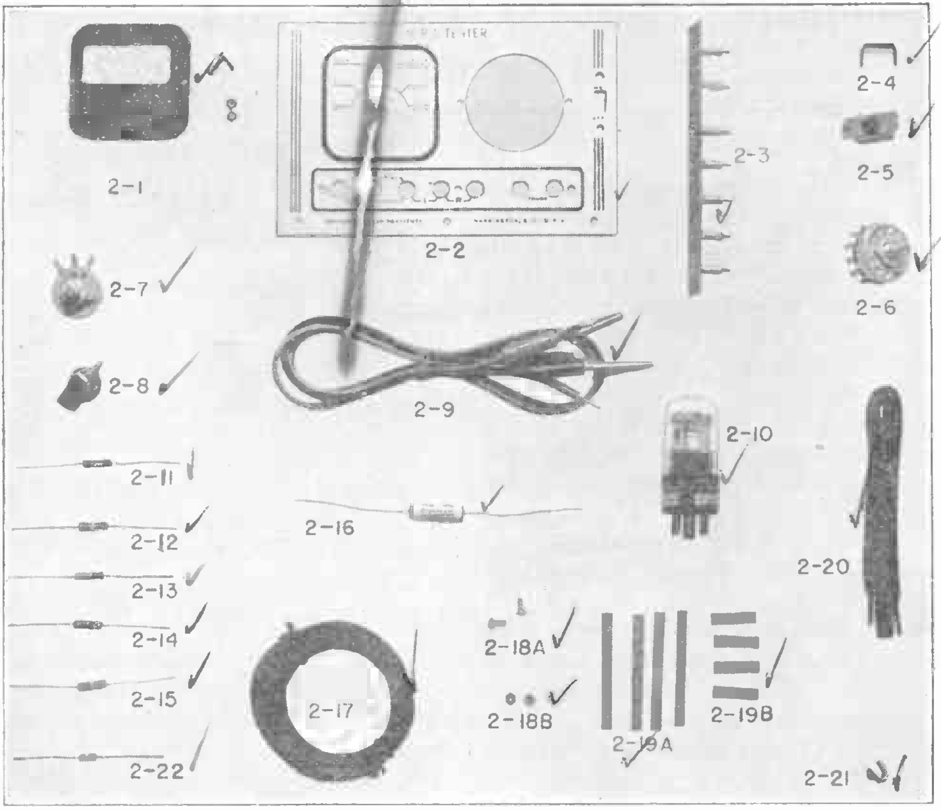

FIG. 1. The parts included in Radio Kit 2RK-1 are pictured above, and are identified in the list below. Note that the first numeral in each part number is 2; this enables you to identify these parts immediately as having been supplied to you in Radio Kit 2RK-1. When an experiment calls for a part having 1 as its first numeral, you know immediately that the part was supplied to you in Radio Kit 1RK.

Part No.	*Description*
2-1	One 0-3-ma. milliammeter with special scale and zero-readjusting knob at rear. Two mounting screws and two nuts are included with the meter.
2-2	Front panel for NRI Tester.
2-3	One 7-jack strip.
2-4	One U-shaped shorting piece for phone jacks.
2-5	One slide-type ON-OFF power switch.
2-6	One 6-position rotary selector switch.
2-7	One 1,000-ohm wire-wound potentiometer.
2-8	One bar knob for the selector switch.
2-9	One pair of test leads (one red and one black lead) with probes and alligator clips.
2-10	One type 1C5GT vacuum tube. (This tube is sometimes marked 1C5G or 1C5GT/G.)
2-11*	One 6.8-megohm, ½-watt resistor with 5% tolerance (color-coded blue, gray, green, gold).
2-12	One 3-megohm, ½-watt resistor with 5% tolerance (color-coded orange, black, green, gold).
2-13*	One .24-megohm, ½-watt resistor with 5% tolerance (color-coded, red, yellow, yellow, gold.) (This is the same as Part *1-14*, so you can use either *2-13* or *1-14*.)
2-14*	One 910-ohm, ½-watt resistor with 5% tolerance (color-coded white, brown, brown, gold).
2-15	One 100-ohm, ½-watt resistor with 5% tolerance (color-coded brown, black, brown, gold).
2-16	One .005-mfd., 600-volt paper condenser.
2-17	One 25-foot roll of push-back hook-up wire.
2-18A	Two ¼-inch long, 6-32 cadmium-plated binder-head machine screws.
2-18B	Two cadmium-plated hexagonal nuts for 6/32 screws.
2-19A	Four ¼-inch wide, 2½-inch long tinned copper strips.
2-19B	Four ¼-inch wide, 1-inch long tinned copper strips.
2-20	One 45-inch length of black lace for fastening tester batteries to chassis.
2-21	One grid clip.
2-22*	One .22-megohm, 1/3-watt resistor with 20% tolerance (color-coded red, black and yellow).

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* These values are the new, post-war "standard" values and are therefore slightly different from the 6.7, .25, .2-megohm, and 900-ohm values shown in the various tables and diagrams.

Batteries Needed

The batteries needed for the ten experiments in this manual and for construction of the NRI Tester are pictured in Fig. *3*. Instructions for ordering these batteries have already been sent to you.

FIG. 3 The only batteries you need for Experiments 11 to 20 in this manual and for the NRI Tester are four standard No. 2 (large size) flashlight cells, one 1½-volt A battery, one 45-volt B battery and two 4½-volt C batteries. These can be the Eveready or Burgess units shown here and specified below, or any other makes having exactly the same dimensions and terminal arrangements.

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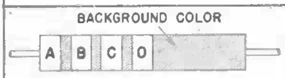
RMA COLOR CODE FOR RESISTORS



METHOD I
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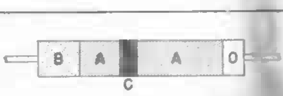

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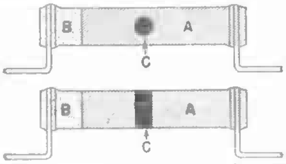

Color	Figure
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ORANGE	3
YELLOW	4
GREEN	5
BLUE	6
VIOLET	7
GRAY	8
WHITE	9

900

COLOR A GIVES FIRST FIGURE OF RESISTOR VALUE.

COLOR B GIVES SECOND FIGURE OF RESISTOR VALUE.

COLOR C GIVES NUMBER OF CIPHERS FOLLOWING THE FIRST TWO FIGURES.

COLOR D: GOLD BAND INDICATES ± 5% TOLERANCE.
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FIG. 2. The two methods being used for marking resistors according to the standard R.M.A. Color Code are given here.

When a color band is missing in non-insulated (black background) resistors marked according to Method I, assume that the color of the missing band is black.

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Note that with Method I markings the color bands are all equal in width, while with Method II marking on resistors having leads coming straight out from the ends, the color bands are of different widths; this serves as a clue for telling which method of marking is employed. Resistors with side leads (shown at the right above) are not insulated.

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In some radio circuits, better accuracy is required for resistors. With 10% tolerance, a 1,000-ohm resistor would be somewhere between 900 ohms and 1,100 ohms. When resistors with 10% tolerance are marked according to Method *I* in Fig. *2,* they will have a *silver* band at *D*.

With 5% tolerance, the range of variation would be between 950-ohm and 1,050 ohms for a rated 1,000-ohm resistor. When resistors with 5% tolerance are marked according to Method *I* in Fig. *2,* they will have a *gold* band at *D*.

Radio servicemen are rarely concerned with resistor tolerances because the standard tolerance of 20% is entirely satisfactory for the great majority of circuits. In the NRI Tester which you will soon build, however you will use some resistors having 5% tolerance.

Insulated Resistors. When the outer covering of a resistor is an insulating material, we have what is known as an *insulated resistor.* When marked according to Method *I* in Fig. *2,* you can identify these by the fact that they have a *tan* background color. These resistors may safely be used in contact with the chassis or other parts.

When there is no insulating covering on a ceramic fixed resistor, we have what is known as a *non-insulated* resistor. When marked according to Method *I* in Fig. *2,* these have a *black* background color. Non-insulated resistors should not be allowed to touch other parts or wires.

Many of the resistors furnished to you in NRI radio kits are of the insulated type, but nevertheless it is always good practice to position resistors so that they do not touch other parts.

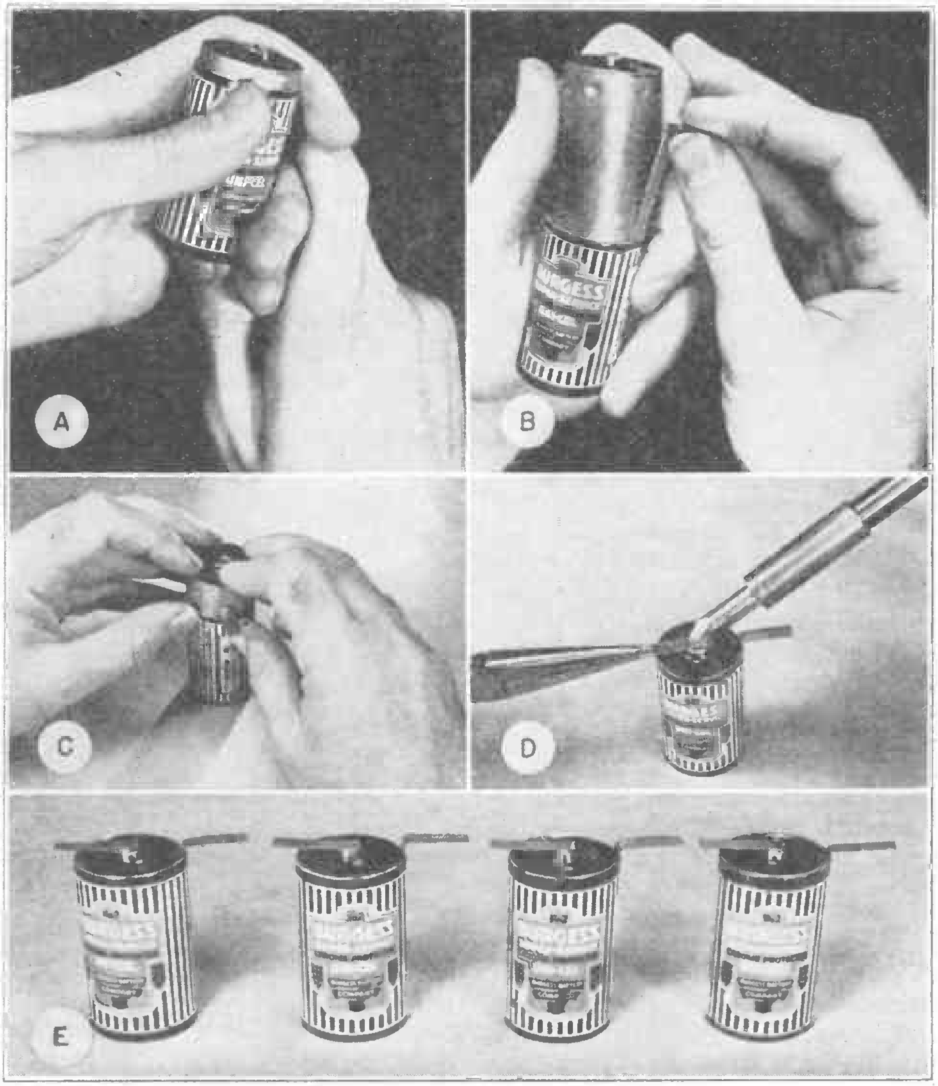

FIG. 4. Steps in providing the four 1½-volt flashlight cells with convenient soldering terminals.

is about ⅛ inch above the top of the cardboard cylinder, then push the zinc can carefully back into its housing by pressing evenly with the fingers of both hands as shown in Fig. *4C*.

In the same way, bend each of the other 2½-inch long tinned copper strips, and insert one against the zinc can of each of the other three cells.

Although the copper strips are tinned during manufacture, this original coating of solder is quite thin and is sometimes covered with grease or oxides. Additional tinning of areas to which connections will be made takes only a few minutes, and greatly simplifies future work with the strips.

Tin each of the 1-inch long strips (Part *2-19B)* on one side for about ¼ inch from one end, by grasping a strip with long-nose pliers and holding it over a flat face of the heated soldering iron in its holder, then rubbing rosin-core solder over the uppermost surface of the strip at one end.

Tin the center terminal of a flashlight cell by filing the top surface until bright (be careful not to let the file touch the exposed rim of the zinc can, for that would short-circuit the cell). The center terminals of some cells are chromium plated; solder will not readily adhere to chromium, so file away the chromium layer until a bright brass or copper color shows. Apply the heated soldering iron and rosin-core solder to the cleaned surface of the center terminal. Slide the iron back and forth over the surface to tin all parts of it uniformly with a minimum amount of solder. Do not hold the soldering iron on the terminal any longer than necessary, for excessive heat can shorten the life of a dry cell. In the same way, clean and tin the center terminals of the other three cells, one at a time.

Solder a tinned 1-inch strip to the center terminal of a cell in the following manner: Hold the strip over the center terminal with long-nose pliers in the manner shown in Fig. *4D*, so that the freshly tinned area on the strip is in contact with the center terminal and the strip lines up with the 2½-inch strip already on this cell. The two strips then project on opposite sides of the cell. Apply the heated soldering iron to the strip just long enough to fuse together the solder on the strip and the terminal. Hold the strip rigid until the solder hardens. *Do not let either the pliers or the tinned copper strip touch the metal rim of the cell;* bend the strip upward if necessary.

Solder a 1-inch strip to the center terminals of each of the other three cells in the same way. Your four cells should now appear as shown in Fig. *4E*. If you desire, you can round off the sharp corners of these terminal strips with your file.

Step 2. To assemble the chassis and panel for future use, take the NRI Tester front panel (Part *2-2)* and bolt it to the chassis (Part *1-11* from Radio Kit 1RK) with three screws (Part *1-9A* or *2-18A*) and three nuts (Part *1-9B* or *2-18B) exactly* in the manner shown in Fig. *5*.

Step 3. To mount the meter (Part *2-1) on the panel for convenience in making measurements,* place the meter in hole *q* (see Fig. *6*) from the front, and adjust its position until the holes in the meter frame coincide with panels holes *r* and *s*. Now take the meter mounting screws (these are in the small envelope in the meter box), insert them in meter mounting holes *r* and *s* from the front of the panel, then place the nuts on these screws at the back of the panel. Tighten first with the fingers, then with long-nose pliers and a screwdriver. When looking at the back of the panel now, the meter will appear as shown in Fig. *6*.

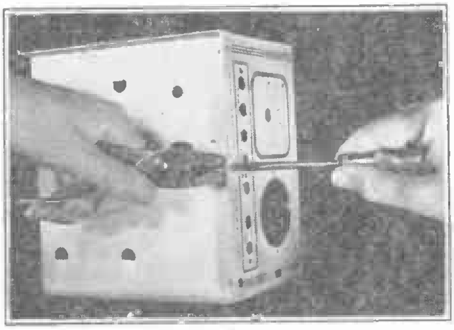

FIG. 5. Fasten the front panel to the chassis exactly as shown here. Use a medium-size screwdriver to tighten each screw while holding its nut with oridnary pliers.

Step 4. To mount the 7-jack strip

(Part *2-3) on the panel,* wipe dust off both sides of the strip, hold the strip against the *BACK* of the panel (not against the printed side of the panel) in the position shown in Fig. *6*. Fasten the strip to the panel with three screws *(1-9A* or *2-18A)* and three nuts *(1-9* or *2-18B)*. There is only one position of the strip in which the three mounting holes on the strip and panel will coincide. Shift the strip sideways slightly, if necessary, so that the jack openings showing on the printed side of the panel are centered as well as possible in the panel holes.

On the back of the panel, directly above each jack, write its terminal number with a metal-marking crayon, exactly as shown in Fig. *6*. Keep the point of the crayon sharp by trimming it off with a pocket knife or by rubbing the crayon on scrap paper to reshape the point.

Step 5. To connect the meter to two of the jacks on the panel with temporary soldered joints for convenience in making tests, remove *one* of the nuts from the positive meter terminal (this terminal is identified by a small plus sign stamped into the meter case near the terminal), place a 13/16-inch long soldering lug (Part *1-8A*) on the meter terminal after first straightening out the lug with long-nose pliers, then replace the nut and tighten with fingers and pliers while holding the lug straight down. Mark the number *15* above this lug on the meter case with crayon. In the same way, straighten another lug (Part *1-8B)*, place it on the other meter terminal (this is the negative terminal of the meter and has no marking), and mark the number *16* above this lug on the meter case.

Now cut off a 3¼-inch length from the roll of push-back wire supplied you as Part *2-17*, push the insulation back ½ inch from each end, then form a hook in one end with long-nose pliers and hook this through the + terminal lug of the meter (lug *15* in Fig. *6)*. Push the other end of the wire through the hole in the soldering lug of jack *27* and bend the wire back on itself to form a hook. In the same way, cut a 2½-inch length of push-back wire and use it to connect lug *16* (on the — terminal of the meter) to the lug on jack *28*. Solder all four of these temporary joints now with rosin-core solder.

Step 6. To set the meter point at zero, locate the knurled zero-adjusting knob at the back of the meter (the position of this knob is indicated in Fig. *6)*. With your fingers, rotate this knob first in one direction as far as it will go, then in the other direction while watching the front of the meter, to get a general idea of how the knob controls the pointer position. After this, adjust the knob carefully while tapping the meter lightly with one finger, until the pointer is exactly at the zero line on the lowest scale of the meter (this scale is marked I_M).

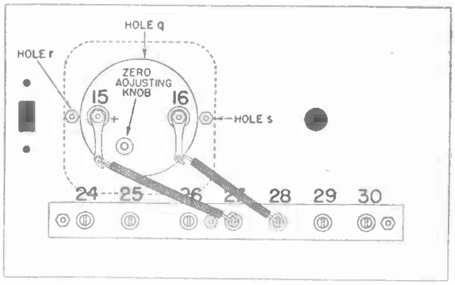

FIG. 6. *Rear* view of front panel, showing how the meter and jack strip are mounted and connected together for the experiments which are to be made before assembling the NRI Tester. The chassis is not shown in this view, but should be attached to the bottom of the panel according to instructions given in Step 2 of Experiment 11.

Step 7. To show that the meter will read up-scale when properly connected to a voltage source, first secure the pair of test leads furnished you as

Part *2-9*, and plug these into the two jacks marked *I* on the front panel; plug the red-handled probe into the *I* jack marked +, and plug the black-handled probe in the *I* jack marked —, as shown in Fig. 7. If difficulty is encountered in inserting a probe in a jack the first time, twist and wiggle the probe slightly while pushing on it, so as to loosen the spring contacts in the jack. Hold the back of the jack with one hand while doing this, to minimize the pressure exerted on the fiber jack strip.

Now attach the alligator clip of the red lead to the positive (center) terminal strip of one of the flashlight cells which you previously prepared, and watch the meter pointer while you hold the alligator clip of the black test lead on the tinned copper strip which serves as the negative terminal of this flashlight cell. As soon as you have noted the direction in which the pointer moves, open the circuit by removing one of the alligator clips, so as to avoid unnecessary drain on the cell. It is only necessary now to observe the direction in which the pointer moves; do not try to read the meter yet.

Step 8. To demonstrate that the meter will read down -scale (off-scale to the left of zero) *when improperly connected to a d.c. voltage source,* leave the test leads plugged into the panel jacks just as before, but now place the red alligator clip on the — cell terminal and place the black clip on the + cell terminal. Note the direction in which the meter pointer moves, then break the circuit by removing both alligator clips.

Discussion: The four flashlight cells which you were instructed to obtain for your practical demonstration course will be connected together in various ways to provide a variety of d.c. voltage values. The terminal strips which you place on these cells in Step 1 will greatly simplify the connecting of these cells into experimental circuits.

The important thing for you to remember in connection with these cells is that the center terminal of each cell is + (positive). The 1-inch long strip which you soldered to this center terminal thus becomes the + terminal of the cell. If you wish, you may mark a + sign on the center strip with a metal-marking crayon. The 2½-inch long strip which you inserted between the cardboard housing and the zinc case therefore becomes the — (negative) terminal.

In Steps 3, 4, and 5, you prepare the meter for use by mounting it on a vertical panel and conecting it to two of the jacks which are also mounted on this panel. When this is done, you can make connections to the meter simply by plugging your test leads into the two jacks marked *I* on the front panel. You will find that this preliminary work greatly simplifies the use of the meter during the next ten experiments.

Step 6 is intended to familiarize you with the use of the zero-adjusting knob at the back of your meter. Always tap the top of the meter lightly with the finger while adjusting the zero position of the pointer or reading low current and voltage values; the resulting slight vibration overcomes any friction which may exist at the bearings of the meter pointer.

Your meter is highly sensitive to the presence of iron, steel or any magnetic field in its vicinity. You can demonstrate this for yourself by watching the pointer while moving a pair of steel pliers or some other steel object in front of the meter.

If the meter pointer refuses to return to zero at any time even with tapping, there may be a magnetic field or magnetic material somewhere in the vicinity.* You can either readjust the zero-adjusting knob to compensate for this condition, or remove the offending material. When conducting experiments, keep all iron or steel tools at least 6 inches away from the meter. This seemingly peculiar behavior of your meter is entirely normal, and is an inherent characteristic of all magnetic vane type meters such as yours.

In Step 7 you connected the + terminal of the meter to the + terminal of the flashlight cell, and connected the — meter terminal to the — terminal of the flashlight cell. This is the correct polarity for connecting a meter to a d.c. voltage source, and you therefore obtained an up-scale movement of the meter pointer.

Now, since you know that the meter reads up-scale whenever the + meter terminal is connected to the + terminal of a voltage source, you can determine the polarity of any d.c. voltage source within the range of your meter. Simply connect the meter to the voltage source and note the direction in which the pointer moves. If the pointer moves up-scale, you then know that the red test lead (the + terminal of the meter) is on the + terminal of the voltage source. If the meter pointer reads down-scale, as it did when you reversed the meter connections in Step 8, you know that the meter is improperly connected. When this occurs, reverse the positions of the test clips immediately.

Do not leave the meter connected to the flashlight cell any longer than is necessary to observe the movement of the meter pointer. The meter draws a certain amount of current from the flashlight cell, and naturally you want to conserve the life of the cell.

In your fundamental course, you learned that electrons always flow *out of* the negative terminal of a d.c. voltage source, and flow *into* the positive terminal of the d.c. voltage source after they have traveled around the external circuit. You also learned that a *d.c.* meter should be connected *so electrons enter the negative terminal of the meter.* With these fundamental facts in mind, you can very easily trace electron flow in your simple circuit consisting of the meter connected across the flashlight cell. The electrons leave the — terminal of the cell, go through the black test lead, the — *I* jack and one length of hookup wire to the meter. The electrons then enter the — terminal of the meter (marked *16)*, flow through the coil of wire inside the meter, emerge from

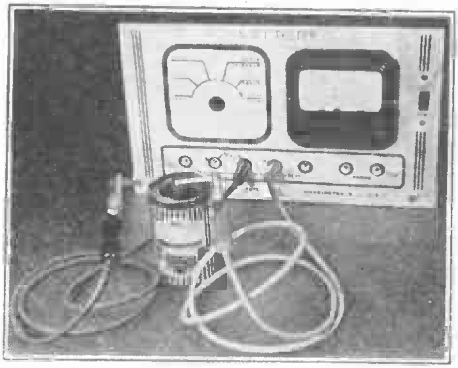

FIG. 7. Using the meter to demonstrate that a d.c. voltage source (the flashlight cell) has polarity. The meter pointer moves up-scale only when the cell is connected to the meter with proper polarity. The test leads were coiled merely to simplify taking the photograph; you will not have to bother with arranging the test leads in any particular position during experiments.

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* Overloading of the meter can also cause a shift in the zero position of the pointer. This condition will usually correct itself in a short time, but you will receive instructions later for correcting the shift immediately.

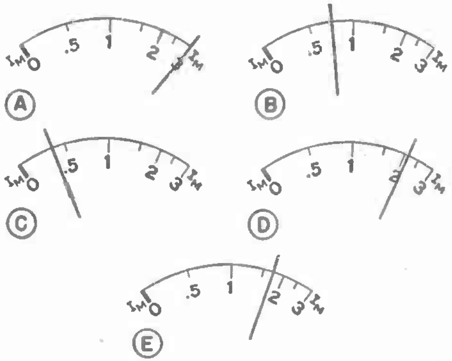


FIG. 8. Examples illustrating how to read scale I_M of your meter. The reading for *A* is 3 ma.; *B* is .75 ma.; *C* is .4 ma.; *D* is 2.1 ma.; *E* is to be read by you and the reading recorded in Report Statement No. 12. This scale indicates the current in milliamperes which is passing through the meter. These scales are reproduced here for instruction purposes; the scale on your meter may not be exactly like these, but the same scale-reading methods will apply. Disregard the other three scales on your meter for the present; they will be taken up later.

the + meter terminal (marked *15*), travel through the other length of hook-up wire to the + *I* jack, then go through the red test lead to the + terminal of the flashlight cell.

Instructions for Report Statement No. 11. The report question which checks your work on this experiment is extremely important, because knowledge of the correct answer will enable you to trace electron flow in any d.c. circuit having a meter, even when there are no vacuum tubes present to indicate the direction of flow.

Using your actual observations and the discussion material as guides, *figure out the terminal at which electrons will enter your d.c. meter when it is connected in a d.c. circuit with correct polarity so as to give an upscale deflection.* These answers are given in Report Statement No. 11 on the last page: *at the positive terminal; at the negative terminal; at both the positive and negative terminals.* Only one of these answers is correct; figure out which one it is, and make a check mark in the box following that answer.

EXPERIMENT 12

Purpose: **To demonstrate that the current which flows in a circuit will increase when the voltage is increased.**

Step 1. To learn how to read the lowest scale (marked I_M) *on your meter,* study the exact-size reproductions of this scale in Fig. *8*. Observe that the scale reads from 0 to 3; these scale values represent milliamperes of current flowing through the meter, for

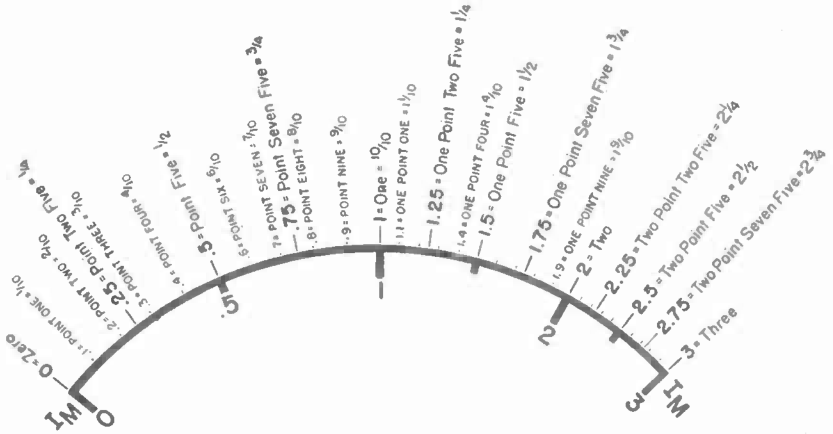


FIG. 8F. This enlarged view of the I_M scale of your meter can be used as a guide when questions arise in connection with meter readings. Various possible pointer positions are indicated by the thin lines above the scale. Estimated readings for typical positions are specified in three ways—first, as you would record the decimal value in a table; second. as a radio man would say it; third, in the form of common fractions.

your instrument is basically a milliammeter having a range of from 0 to 3 milliamperes.

When the maximum permissible current of 3 ma. is flowing through the meter, the pointer will be at *3* on scale I_M, as shown in Fig. *8A;* you would read this as 3 ma. When the pointer is on any other numbered line on this scale, the number below the line indicates the current in milliamperes.

When the pointer is on a short unnumbered line between two numbered lines, the meter reading is a value halfway between the values of the two adjacent numbered lines. Thus, you would read 1.5 ma. when the pointer is on the short line between *1* and *2,* and you would read 2.5 ma. when the pointer is on the short line between *2* and *3.*

Whenever the pointer is in between two lines on this scale, mentally divide the space between the two lines into equal smaller spaces and estimate the meter reading. For example, if the pointer is about halfway between lines marked *.5* and *1,* as in Fig. *8B,* you would estimate the meter reading to be .75 ma. If the pointer is as shown in Fig. *8C,* where it is closer to *.5* than to *0,* you might estimate the reading to be .4 ma. Finally, if the pointer is as shown in Fig. *8D,* you would estimate the reading to be about 2.1 ma. Values which you would estimate for other pointer positions are shown in Fig. *8F.*

Step 2. To secure 1.5, 3 and 4.5-volt d.c. voltage sources for this experiment, first take each cell in turn and tin the upper surface of its positive terminal strip for about one-fourth inch from the free end, then tin the under surface of its negative terminal in the same manner so as to secure surplus solder at these points. Now arrange three of your previously prepared flashlight cells exactly in the manner shown in Fig. *9A,* so that the — terminal strip of one cell is over the + terminal strip of the adjacent cell. Bend the terminal strips so that they will touch each other when they are overlapping about ¼ inch in this manner, then apply the heated soldering iron tip in turn to each point where the strips overlap. Hold the soldering iron on each of these lap joints only long enough to melt and fuse together the solder in between the strips. Fig. *9B* shows the cells connected together.

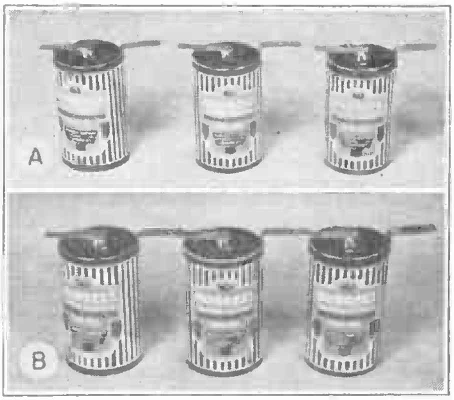


FIG. 9. Method of connecting three flashlight cells together in series aiding to permit obtaining three different values of d.c. voltage (1.5 volts, 3 volts and 4.5 volts).

Step 3. To secure practical experience in measuring the current in a circuit, attach the alligator clip of the black test lead to the — terminal at one end of your cell group. (The probes should be plugged into the panel jacks exactly as they were for Experiment 11, with red in +*I* jack and black in —*I.*) Now attach the red alligator clip to the + terminal of this same cell as shown in Fig. *10A,* so as to secure a voltage of 1.5 volts. Read on scale I_M of your meter the amount of current flowing, discon-

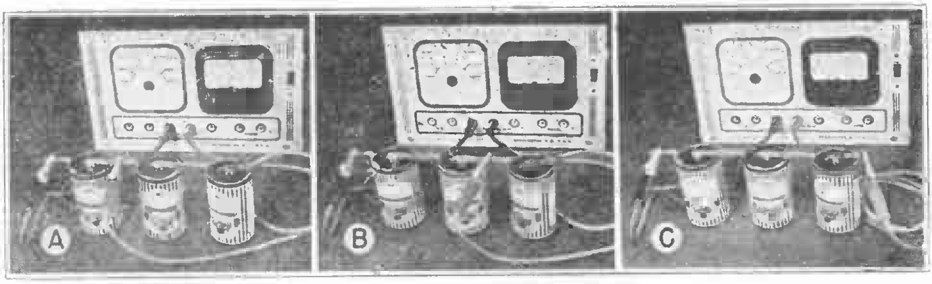


FIG. 10 These illustrations show you how to set up the three circuits in which you make current measurements as a part of Experiment 12. Note that the red probe is plugged into the $+I$ jack, and the black probe is plugged into the $-I$ jack. Leave the test probes in these jacks until you are told to remove them in Experiment 16.

nect the red clip, and record your reading in the first line of Table *12.*

Now attach the red clip to the + terminal of the middle cell as shown in Fig. *10B*, so as to secure a voltage of 3 volts. Read the meter on scale I_M just as before, disconnect the red clip, and record your result in the second line of Table *12*.

Finally, attach the red clip to the + terminal of the last cell as shown in Fig. *10C*, so as to secure a voltage of 4.5 volts. Read the meter, disconnect the red clip, and record your result in the last line of Table *12*.

CAUTION: Do not leave the meter connected to a flahlight cell or battery for more than a few minutes at a time; it is always better to disconnect one lead of the meter as soon as you take a reading, and leave it disconnected until you are ready for the next reading.

Look squarely at the meter when reading it, to secure consistently accurate readings; in other words, your eyes should be directly in front of the meter scale whenever you take a reading.

Discussion: The meter which is furnished you in Radio Kit 2RK-1 has four distinct scales. The only one which applies directly to the meter is the lowest scale, marked I_M, covering a range of from 0 to 3 ma. Ordinarily, this would be the only scale you would find on a meter of this type; the other three scales are provided for the NRI Tester in which you will use this meter after completing Experiment 20. For the present, therefore, it is entirely sufficient for you to know how to read only the lowest meter scale.

Do not worry too much about reading the meter accurately at this time. In the first place, accurate readings are seldom required in radio work. Furthermore, you will automatically acquire the ability to estimate meter readings as you secure experience with your meter. Just remember that a meter scale is like an ordinary ruler, and is read in much the same manner.

When you have a number of separate voltage sources and want to connect them together in such a way that the voltages add, you always connect them in the manner described in Step 2. This connection is known as *series aiding* (or simply as a *series connection*), for the voltage sources (flashlight cells) are connected in series in such a way that their voltages aid each other. Thus, if one cell gives 1.5 volts, two cells connected in series aiding will give 3 volts, and three cells will give 4.5 volts.

A comparison of the three meter readings which you obtained in Step 3 will show you that the current increases when you increase the source voltage from 1.5 volts to 4.5 volts. This experiment which you perform therefore proves the basic radio rule that the current in a circuit will increase when the voltage is increased. Conversely, it proves that the circuit current will decrease when the voltage is reduced.

Two factors determine the amount of current which will flow in a circuit; *the value of the source voltage, and the amount of opposition or resistance which the circuit offers to current flow.* In the three circuits which you set up in Step 3, the flashlight cells serve as d.c. voltage sources. As to resistance, we can say definitely that every electrical part has resistance. Sometimes this resistance is very large, so that electron flow is almost completely blocked, while in other cases the resistance is so small that it can be neglected.

D.C. SOURCE VOLTAGE IN VOLTS	YOUR CURRENT READING ON SCALE I_M IN MA.	N.R.I. CURRENT READING ON SCALE I_M IN MA.	COMPUTED CURRENT IN MA.
1.5	.85	.7	.75
3.0	1.6	1.6	1.50
4.5	2.4	2.3	2.25

TABLE 12. Record your results for Experiment 12 here

In the circuits of Step 3, each 1.5-volt dry cell has a resistance of about .5 ohm. The terminal strips, the test leads, the alligator clips, the jacks on the panel and the lengths of hook-up wire also have resistance, but in each case this resistance is lower than .5 ohm. The milliammeter has a resistance of about 2,000 ohms; this is so much higher than the resistance of the other parts in the circuit that we can call it the predominant resistance and neglect all other resistance. We thus have voltages of 1.5, 3 and 4.5 volts respectively, acting in a simple circuit having an effective total resistance of about 2,000 ohms.

Computing Circuit Current. Let us see what the value of circuit current will be when computed according to Ohm's Law for our first circuit, in which a d.c. voltage source of 1.5 volts is sending electrons through a circuit having a resistance of 2,000 ohms.

As you learned in your regular lessons, Ohm's Law says that the current in amperes is equal to the voltage in volts divided by the resistance in ohms. In our case, then, the current in amperes will be equal to 1.5 divided by 2,000, which is .00075 ampere. To convert this current value into milliamperes, we multiply by 1,000, and get .75 ma. as the computed value of circuit current. This computed value is listed in Table *12,* for convenience in comparing it with your own reading and with the reading of .7 ma. which we obtained in the NRI laboratory.

If the reading which you obtained is fairly close to the computed value (any reading between .5 ma. and 1.0 ma. can be considered as sufficiently close for all practical purposes in this particular experiment), you can consider that you have proved the validity of Ohm's Law in your d.c. circuit.

Whenever you double the source voltage value, as you did by adding another dry cell to your circuit, you would naturally expect that the current would double also. According to Ohm's Law, 3 volts acting on 2,000 ohms gives a current of 3 divided by 2,000, or .0015 ampere. This corresponds to 1.5 milliamperes, a computed value of circuit current which is exactly twice the value you computed for a 1.5-volt d.c. source. Likewise, your own current reading for 3 volts should be approximately twice the reading which you obtained for 1.5 volts.

With a d.c. source voltage of 4.5 volts, you would expect the computed current value to be three times that obtained with 1.5 volts. Dividing 4.5 by 2,000 gives .00225 ampere, which is equal to 2.25 ma. This is exactly three times the value computed for 1.5 volts, as you expected. Compare you own current reading for 4.5 volts with the computed value; if your reading is somewhere between 2 and 3 ma., you can consider your work on this experiment to be entirely successful, and you can consider that you have demonstrated how Ohm's Law holds true in a simple d.c circuit.

Extra Information. You could safely apply as high as 6 volts directly to your meter without damaging it, since the full-scale value is 3 ma. (6÷2,000 =.003, or ma.). Your milliammeter can thus be used as a 0-6 volt d.c. voltmeter simply by multiplying the readings on scale I_M by 2. When using your meter in circuits having voltages higher than 6 volts, however, special precautions must be observed; these will be taken up later. In other words, never connect your meter alone directly to the terminals of a 22.5-volt or 45-volt B battery.

Some milliammeters have very much lower resistance than the meter which you used in Step 3. For this reason, never connect *an unknown milliammeter* across a dry cell *or any other voltage source* until you know exactly what the characteristics of the meter are. In some cases you may burn out the meter when doing this, for even the 1.5-volt value of a single dry cell may send through the meter a larger current than that for which it was designed.

Instructions for Report Statement No. 12. The question for this experiment is a test of your ability to read the meter on scale I_M with reasonable accuracy for practical radio work. After you have completed this experiment and studied the discussion, turn to the exact-size reproduction of this meter scale in Fig. *8E* and figure out what the meter reading would be when the pointer is at the position shown. Now turn to Report Statement No. 12 on the last page, and place a check mark in the box following the meter reading which you consider to be correct for Fig. *8E.*

EXPERIMENT 13

Purpose: **To demonstrate that the current flowing in a circuit will be reduced when the resistance in the circuit is increased, and to prove for yourself the basic fact that the current is the same at all points in a series circuit.**

Step 1. To measure the current before and after you insert a 900-ohm resistance into a simple d.c. circuit, connect your meter across the group of three flashlight cells just as you did for the final measurement in Experiment 12, read the meter on scale I_M, disconnect the red clip, and record the current value on the first line in Table *13.*

As explained on page 2, parts 2-11, 2-13, and 2-14 now have the new postwar "standard" values of 6.8 megohms, .24-megohms, and 910 ohms, respectively. Use them in place of the 6.7-megohm, .24-megohm, and 900-ohm values shown in the following tables and diagrams. They will give essentially the same results for the experiments as the old values, and they will tend to improve the accuracy of the NRI Tester you are to build.

Now solder one lead of a 910-ohm resistor (Part *2-14*) to the + terminal at the end of the cell group, in the manner shown in Fig. *11.* To make this temporary soldered joint, simply tin the end of the resistor lead liberally with rosin-core solder, hold

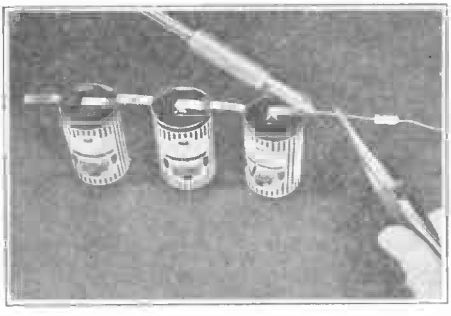


FIG. 11. To solder a resistor to a battery terminal strip by means of a lap joint, tin both the lead and the end of the strip, hold the resistor on the terminal strip with long-nose pliers as shown here, and apply the heated soldering iron.

this lead over the positive terminal strip with long-nose pliers, apply the heated soldering iron tip to the lead, then remove the iron and hold the resistor rigid until the solder hardens. Now attach the red clip to the other lead of this resistor while still leaving the black clip on the — terminal of the cell group, read the meter on scale I_M, disconnect the red clip, and record the result on the second line in Table *13*.

STEP	NATURE OF MEASUREMENT	YOUR CURRENT READING ON SCALE I_M IN MA.	N.R.I. CURRENT READING ON SCALE I_M IN MA.	COMPUTED CIRCUIT CURRENT IN MA.
1	CURRENT THRU METER. (E = 4.5 V.)	2.5	2.3	2.25
	CURRENT THRU 900Ω AND METER (E = 4.5 V.)	1.7	1.6	1.55
2	CURRENT AT POINTS 8—9	1.7	1.6	1.55
	CURRENT AT POINTS 6—7	1.7	1.6	1.55
	CURRENT AT POINTS 4—5	1.7	1.6	1.55
	CURRENT AT POINTS 2—3	1.7	1.6	1.55

TABLE 13. Record your results for Experiment 13 here.

Step 2. To prove that the same current flows through all parts of a series circuit, measure the current at three different points in a circuit with your milliammeter, in the following manner:

Cut off an 11-inch length of push-back hook-up wire (Part *2-17*), push back the insulation for about ¾ inch from each end, then solder one end to negative cell terminal *1* in Fig. *12A* by means of a lap joint after first applying additional solder to the top surface of this terminal.

Now attach the red clip to resistor lead *8*, and attach the black clip to the other end of the hook-up wire (marked *9* in Fig. *12A*). Read the meter on scale I_M, disconnect both the red and black clips, and record the result in Table *13* as the current flowing at points *8-9* in your circuit.

Next, measure the current at points *6-7* by unsoldering resistor lead *7* from postive terminal *6*, then soldering end *9* of the hook-up wire to resistor lead *8* by means of a temporary hook joint as shown in Fig. *12B*. Attach the red clip to positive terminal *6*, and attach the black clip to resistor lead *7*. Read the meter on scale I_M, remove both clips, and

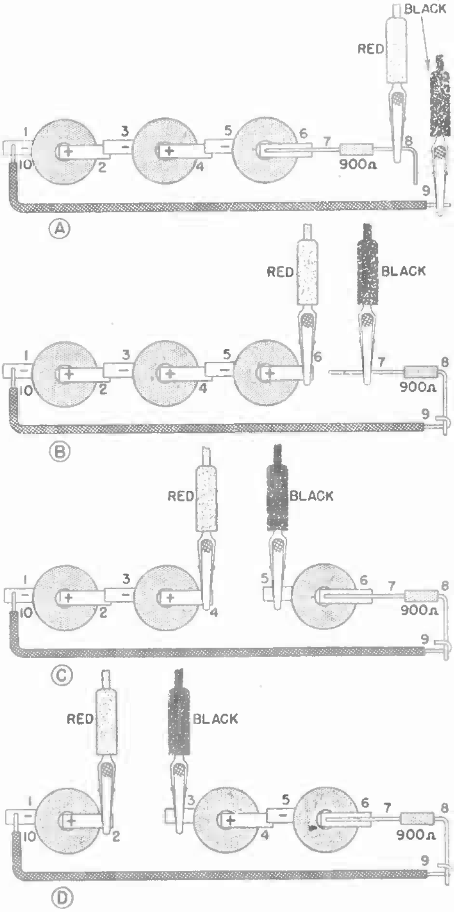


FIG. 12. Use these four milliammeter connections to prove for yourself that the same current value flows through all points in a series circuit.

record the result in Table *13* as the current flowing at points *6-7*.

Now separate terminal strips *4* and *5* by applying the heated soldering iron to the lap and moving the cells apart. Resolder resistor lead *7* to terminal *6*, as shown in Fig. *12C*. Attach the red clip to terminal *4*, and attach the black clip to terminal *5*. Read the meter on scale I_M, remove both clips, and record your result in Table *13* as the current flowing at points *4-5*.

Separate terminal *2* from terminal *3* by unsoldering. Resolder terminal *4* to terminal *5* as shown in Fig. *12D*. Place the red clip on terminal *2*, and place the black clip on terminal *3*. Read the meter on scale I_M, remove both clips, and record your result in Table *13* as the current flowing at points *2-3*. Do not disconnect this set-up yet, because you will make one more measurement with it for Report Statement No. 13 after studying the discussion.

Discussion: For your first measurement in Step 1, the meter reading should be essentially the same as for the last measurement you made in Experiment 12, since the circuits are identical. When you increase the circuit resistance by inserting a 910-ohm resistor in the circuit, as you did for the second measurement in Step 1, you are increasing from 2,000 ohms to 2,910 ohms the opposition which the circuit offers to electron flow. According to Ohm's Law, the current will decrease when the circuit resistance is increased, hence the second reading which you record in Table *13* should be smaller than the first reading. If you do obtain this smaller reading, you know that you have performed the experiment correctly and have verified Ohm's Law again.

Computing Circuit Current. With a circuit resistance of 2,910 ohms and a voltage of 4.5 volts, Ohm's Law tells us that the circuit current in amperes will be 4.5 divided by 2,910, or .00155 ampere. This is equivalent to 1.55 ma. The second value which you recorded in Table *13* should correspond approximately to this computed value.

If you measure essentially the same meter readings at the four points where you measure current in Step 2, you have proved the fundamental radio principle that *the current is the same at all points in a series circuit.* Remember to tap the top of the meter lightly each time before you take a reading when the pointer is near zero, so as to offset bearing friction. Remember to look squarely at the meter from a position directly in front of it when taking a reading. If you read the meter from an angle, you will obtain a different value than if you were reading it properly.

In any series circuit, the voltage source "feels" the total resistance of the circuit, regardless of where or how this resistance is distributed throughout the circuit. As a result, only the correct current (correct electron flow) for the total circuit resistance can flow, and this current will be the same value at all points in the series circuit.

Instructions for Report Statement No. 13. In order to answer this report statement and prove that you have mastered the measuring techniques involved, connect three dry cells, the meter, a 910-ohm resistor and an 18,000-ohm resistor all in series and measure the current flowing in this circuit.

You can arrange these parts in any desired order as long as they are all in series; thus, you could have the meter connected to terminals *2* and *3* as shown in Fig. *12D*, and insert the 18,000-ohm resistor (Part *1-16*) between *1* and *10* after unsoldering the wire from terminal *1*. The total circuit resistance is now 2,000 + 910 + 18,000, which is 20,910 ohms.

Compare your measured current value in ma. for this circuit with the current obtained in Step 2 for a total circuit resistance of 2,910 ohms, then turn to the report statement on the last page and place a check mark in the box following the answer which describes your result. 1,7

EXPERIMENT 14

***Purpose:* To demonstrate that a milliammeter in series with a resistor can be used as a voltmeter.**

Step 1. To obtain a meter reading when a 4.5-volt d.c. source is connected in series with your meter and an 18,000-ohm resistor, take the 18,000-ohm resistor which was supplied you as Part *1-16* in Radio Kit IRK and solder one lead of it to the — terminal of your 3-cell battery in the manner shown in Fig. *13A*. Now attach the black clip to the other lead of this resistor, and attach the red clip to the + terminal of your group of cells. Read the meter on scale I_M, remove both clips, and record your result in Table *14* as the current in ma. flowing through this circuit when the source voltage E is 4.5 volts. The meter reading will be very low, less than .25 ma., but estimate its value roughly.

Step 2. To secure a meter reading when a 45-volt battery is connected in series with your meter and an 18,000-ohm resistor, unsolder the 18,000-ohm resistor from the flashlight cell group, bend a large hook in a clockwise direction at the end of one resistor lead with long-nose pliers, then attach this lead to the —B terminal of your 45-volt B battery, as shown in Fig. *13B*. This terminal is simply marked "—" on most B batteries, but from now on we will refer to it as the "—B" terminal (pronounced *minus bee*), just as radio men do. To make the connection to —B, loosen the knurled nut, hook the lead around the screw in a clockwise direction as shown in Fig. *14*, then tighten the nut.

Whenever you make a temporary connection to a terminal screw or part with a wire or lead, bend the

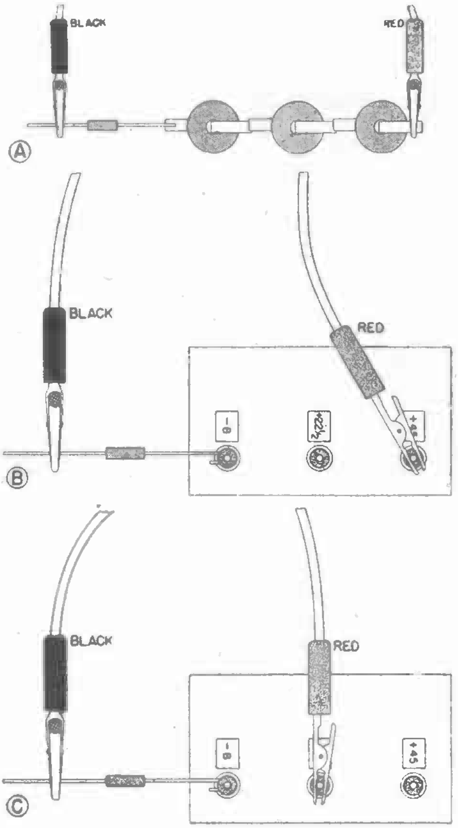


FIG. 13. The three circuits illustrated here all have the same total resistance (the meter with its resistance of 2,000 ohms is not shown, but is connected to the other ends of the two test leads in each case), but each circuit has a different voltage. In Experiment 14 you measure the current in each circuit and note its relationship to the circuit voltage, thereby demonstrating how a milliammeter can be used as a voltmeter.

hook in a clockwise direction as indicated in Fig. *14*, so that the hook will close rather than spread apart when you tighten the nut.

Now attach the black clip to the other resistor lead, and attach the red clip to the +45 terminal of your B battery. Read the meter on scale I_M, remove the red clip, and record your result in Table *14* as the current in ma. flowing through this circuit when the source voltage is 45 volts.

Step 3. To secure a meter reading when a 22.5-volt battery is connected in series with your meter and an 18,000-ohm resistor, place the red clip on the +22½ terminal of your B battery without disturbing the black clip or changing any other part of the circuit. This arrangement is shown in Fig. *13C*. Read the meter on scale I_M, remove both test clips, and record your result in Table *14* as the current in ma. flowing through this circuit when the source voltage *E* is 22.5 volts. Finally, disconnect the resistor from the battery.

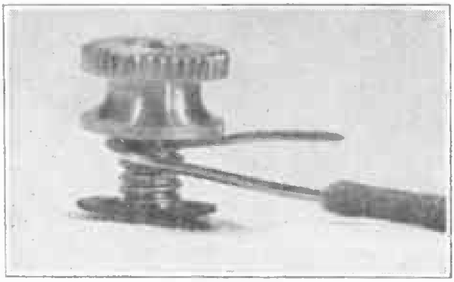


FIG. 14. Whenever you connect a wire or lead to a terminal screw, always bend the hook in a clockwise direction as shown here. This is the same direction in which you turn the nut when tightening it, and therefore the hook will tend to close rather than spread apart and come off when the nut is tightened. Lock washers are not necessary on battery terminals during experimental work, but when used, they help to prevent the terminal nut and wire from loosening.

CAUTION: Do not connect a 22.5 or 45-volt battery directly to the meter terminals (without the 18,000-ohm current-limiting resistor). Any voltage higher than 6 volts may damage the meter if applied directly.

Discussion: With an 18,000-ohm resistor in series with the 2,000-ohm resistance of your meter, the total circuit resistance becomes 20,000 ohms. This is ten times the resistance of the circuit using the meter alone. According to Ohm's Law, the circuit current should be reduced ten times (to 1/10 of its original value) when the circuit resistance is increased ten times. In Step 1 of Experiment 13 you obtained a current value somewhere near 2.25 ma. for a circuit including only the meter and a 4.5-volt battery, so you would naturally expect the meter reading in Step 1 of this experiment to be about 1/10 of this value, or about .2 ma.

Computing Circuit Current. According to Ohm's Law, the circuit current in amperes for the circuit used in Step 1 will be 4.5 divided by 20,000, which is .000225 ampere, or .225 ma.

In Step 2, you increased the battery voltage to 45 volts, while still keeping the circuit resistance at 20,000 ohms. If Ohm's Law holds true, this ten-times increase in voltage will make the current increase ten times. The current reading which you obtain for Step 2 should therefore be approximately ten times the reading you obtained for Step 1.

Computation. According to Ohm's Law, the current for Step 2 will be 45 divided by 20,000, which comes out to be 2.25 ma. This is exactly ten times the computed current value obtained for Step 1.

When you use a 22.5-volt d.c. source in Step 3, you are cutting the voltage to half the value employed in Step 2. If the current you measure is likewise cut approximately in half, you have again checked Ohm's Law.

Computation. According to Ohm's Law, the computed current for Step 3 is 22.5 divided by 20,000, which is 1.13 ma.

Now study your results in Table 14 for a few minutes. Note that the current increases in proportion to increases in the voltage, and the current decreases likewise in proportion to decreases in the voltage. Thus, there is a definite relationship between the meter reading and the voltage employed in the circuit. In fact, if you marked 4.5 volts on your meter scale at the pointer position obtained in Step 1, marked 45 volts at the pointer position obtained in Step 2, and marked 22.5 volts at the pointer position for Step 3, then filled in the missing voltage values on the scale by repeating the experiment for other known voltages, *you would use your meter with its 18,000-ohm resistor to read voltages directly.*

STEP	NATURE OF MEASUREMENT	YOUR CURRENT READING ON SCALE I_M IN MA.	N.R.I. CURRENT READING ON SCALE I_M IN MA.	COMPUTED CIRCUIT CURRENT IN MA.
1	CURRENT THRU 18,000Ω AND METER. (E = 4.5 V.)	.3	.2	.225
2	CURRENT THRU 18,000Ω AND METER. (E = 45 V.)	2.4	2.1	2.25
3	CURRENT THRU 18,000Ω AND METER. (E = 22.5 V.)	1.1	1.0	1.13

TABLE 14. Record your results for Experiment 14 here.

In other words, this experiment has shown definitely that *any milliammeter can be used to measure higher voltages than could safely be applied to the meter alone, provided a series resistor of the proper value* (such as the 18,000-ohm resistor employed in this case) *is used to extend the voltage range,* and the meter scale is recalibrated to read in volts instead of in milliamperes.

A current of 3 ma. through your meter will give you a full-scale deflection on scale I_M. Since the meter has a resistance of 2,000 ohms, Ohm's Law tells us that the voltage needed for a full-scale deflection will be .003 times 2,000, or 6 volts. In other words, if you connected your meter *alone* to a 6-volt battery, you would secure approximately a full-scale deflection on scale I_M.

To measure voltages up to 6 volts with your meter, connect the meter directly to the voltage source with the proper polarity, read the meter on scale I_M, and multiply the scale reading by 2 to get the actual voltage in volts. Thus, a scale reading of 2.25 would correspond to 4.5 volts.

By placing an 18,000-ohm resistor in series with your meter, you can increase the total circuit resistance ten times, and can safely apply ten times as much voltage to the meter circuit without exceeding the safe current of 3 ma. To prove this, we again resort to Ohm's Law.

Computation. Let us say that we have the maximum safe meter current of 3 ma. flowing through the circuit resistance of 18,000 ohms + 2,000 ohms. According to Ohms' Law, the voltage required to send .003 ampere (3 ma.) through a total resistance of 20,000 ohms is .003 × 20,000, or 60 volts. Thus, the insertion of an 18,000-ohm resistor in series with your meter allows you to apply voltages up to 60 volts to your measuring circuit without making the meter read higher than 3 on scale I_M.

To measure d.c. voltages up to 60 volts, connect your meter in series with an 18,000-ohm resistor to the terminals of the voltage source (being sure to get the correct polarity), read the meter on scale I_M, and multiply the scale reading by 20 to get the actual voltage in volts.

When a resistor is placed in series with a meter in this manner to increase the voltage range, the resistor is known as a *voltage multiplier.*

To make your meter read up to 600 volts, which is 100 times the voltage which gives full-scale deflection of the meter alone, the meter and voltage multiplier together must have a resistance of 100 times 2,000 ohms, or 200,000 ohms. Since the meter alone has a resistance of 2,000 ohms, the voltage multiplier should have a value of 198,000 ohms. With this 198,000-ohm series resistor or voltage multiplier, you could then read voltages directly up to 600 volts on your meter simply by multiplying the reading on scale I_M by 200.

Multiplier Circuit Arrangement. By providing a number of different series resistors of the proper values, along with a switch which permits inserting any one of them in series with the meter, a milliammeter like yours can be made to serve for a number of different voltage ranges. Many of the meters used in radio work, particularly in professional multimeters, are arranged in this manner.

Ohms-Per-Volt Rating. With the meter resistance of 2,000 ohms used alone, the maximum voltage range is 6 volts; with a series resistor being used to increase the meter circuit resistance to 20,000 ohms, the maximum voltage range is 60 volts; with a total meter circuit resistance of 200,000 ohms, the maximum voltage range is 600 volts. When we divide the meter circuit resistance by the maximum voltage range in any one of these cases, we get 333 ohms. This value is known as the *ohms-per-volt rating* of your meter, and is an indication of its sensitivity when used as a voltmeter.

A common sensitivity rating for meters used in radio work is 1,000 ohms-per-volt. Some voltmeters have sensitivities of 5,000 ohms-per-volt, while a few even go as high as 20,000 ohms-per-volt. The vacuum tube voltmeter which you will build after completing this group of ten experiments has a full-scale sensitivity of over 2,000,000 ohms-per-volt on one range, and all of the other ranges are higher than 20,000 ohms-per-volt. This means that your instrument will be comparable with the best individual meters employed in radio work.

Voltage Multiplier Rule. To find the cor*rect value for a voltage multiplier resistor which is to give a desired voltage range, *multiply the ohms-per-volt rating of the meter by the maximum voltage range desired, then subtract from the resulting value the resistance of the meter itself.

Instructions for Report Statement No. 14. The question for this experiment checks your mastery of the discussion, so do not try to answer Report Statement No. 14 until you understand fully every single sentence in the discussion. You should realize that any d.c. milliammeter can be used as a d.c. voltmeter, and should have a general understanding of how voltage multiplier resistors can be used to increase the voltage range.

Here is the test problem: Suppose you are using your meter as a 0-60 volt d.c. voltmeter (by placing an 18,000-ohm voltage multiplier resistor in series with the meter) to measure an unknown d.c. voltage. You connect the meter and multiplier to the terminals of the voltage source with proper polarity and get a reading of 2 on scale I_M. What is the actual voltage of this source? Figure it out, referring to the discussion again if necessary, then place a check mark after the value which you consider to be correct in Report Statement No. 14 on the last page.

EXPERIMENT 15

Purpose: **To demonstrate the use of shunt resistors for increasing the current range of a milliammeter.**

Step 1. To secure experience in using your milliammeter with a 100-ohm shunt resistor for measuring higher current values, take a 100-ohm resistor (Part *2-15)* and connect it to the meter terminal lugs with temporary soldered joints as shown in Fig. *15A*.

Take a 910-ohm resistor (Part *2-14*) and connect one of its leads to the —B terminal of your B battery, as shown in Fig. *15B*. With the test leads still in the *I* jacks exactly as shown in Fig. *7*, attach the black clip to the other lead of the 910-ohm resistor.

Now complete the circuit by attaching the red clip to the +45 battery terminal. Read the meter on scale I_M, remove the red clip immediately from the +45 terminal, then record your reading in Table *15*. Do not leave the red clip connected to the +45 terminal any longer than is necessary to secure the reading, for otherwise you will exhaust the B battery.

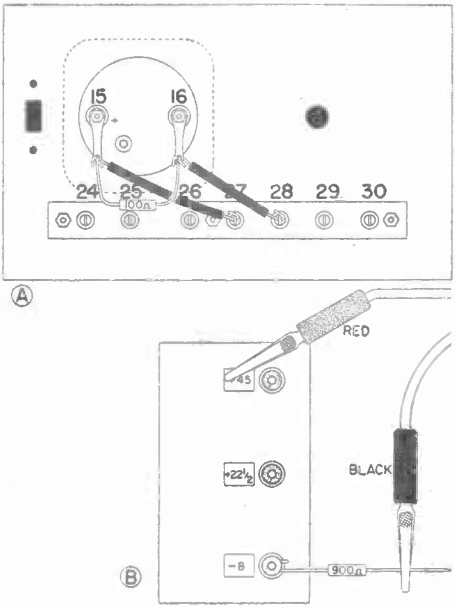


FIG. 15. By placing a 100-ohm shunt resistor across your meter in the manner shown at *A* here, you are able to measure (Experiment 15) the current in the circuit shown at *B*, even though this current is considerably higher than the 3-ma. maximum value which can be passed through the meter alone.

STEP	NATURE OF MEASUREMENT	YOUR METER READING ON SCALE I_M	N.R.I. METER READING ON SCALE I_M	COMPUTED METER CURRENT IN MA.
1	CURRENT THRU 900Ω AND METER SHUNTED BY 100Ω (E = 45 V.)	2.2	2.2	2.14

TABLE 15. Record your results for Experiment 15 here.

Discussion: In a circuit consisting of a 45-volt battery and a total resistance of 910 + 100 ohms, the current would be 45 ma. (45 divided by 1,010 = .045 ampere, or 45 ma.). This current cannot be measured directly with your meter, since the maximum current the meter can safely pass is 3 ma. In this experiment, we use a shunt resistor (100 ohms) to increase the range of the milliammeter enough to permit measurement of this high current.

In the circuit of Fig. *15*, the 100-ohm resistor is connected directly across the meter terminals. Let us see how this shunt resistor (usually called a *shunt*) limits the meter current to a safe value.

First of all, when a 2,000-ohm meter is connected across a 100-ohm resistor, the original total circuit resistance of 1,010 ohms (910 + 100) will be changed slightly. With 2,000 ohms in parallel with 100 ohms, the combined resistance is 95 ohms; 910 + 95 gives a total circuit resistance of 1,005 ohms. The change is so small, however, that for all practical purposes we can consider this total resistance to be still 1,010 ohms, and the circuit current still 45 ma. through the battery and the 910-ohm resistor.

When the 45-ma. circuit current reaches the parallel combination of the 100-ohm resistor and the meter, the current divides between these two parts. Naturally, most of the current goes through the 100-ohm resistor since it offers much lower opposition than does the 2,000-ohm resistance of the meter. Let us see exactly how the current divides.

Computation. Imagine that the 100-ohm resistor is replaced with twenty separate 2,000-ohm resistors connected in parallel. The combined resistance of this group of twenty resistors will be 100 ohms. (When resistors of equal value are connected in parallel, their combined resistance is equal to *the resistance of any one of them divided by the number of resistors* which are in parallel.)

When the meter is added in parallel with these twenty imaginary 2,000-ohm resistors, we will have twenty-one identical 2,000-ohm paths for current between the meter terminals. Each resistor will carry an equal amount of current, and the value of this current will be 1/21 of the total circuit current of 45 ma. In other words, the current through the 2,000-ohm meter (and through each imaginary 2,000-ohm resistor) will be 45 ma. divided by 21, or about 2.14 ma. Compare this computed value of meter current with the value you obtained and with the value of 2.2 ma. which we obtained in the NRI laboratory.

Since the meter gets only 1/21 of the total current, multiplying the meter reading on scale I_M by 21 will give us the actual circuit current when the meter is used with a 100-ohm shunt resistor. Multiplying the maximum meter reading of 3 ma. by 21 gives 63 ma. as the new full-page range of the milliammeter when used with a 100-ohm shunt.

The number by which we multiply the meter reading is called the *multiplying factor* or scale conversion number.

When using the meter with a 100-ohm shunt as a 0-63 ma. d.c. milliammeter, read the meter on scale I_M and multiply the scale reading by 21 to get the actual current value in ma.

Practical Extra Information on Meter Shunts. When the current range of a meter is to be increased a definite number of times, place across the meter terminals a shunt resistor having a resistance equal to *the meter resistance divided by "one less than the multiplication factor desired."* For example, if you wished to increase the range of your 2,000-ohm milliammeter to 30 ma., which is an increase of ten times, you would use a shunt resistor equal to 2,000 divided by 9, or 222 ohms.

If we know the current value flowing in a circuit, we can find the multiplying factor for a meter-shunt combination by dividing the known current value by the meter reading for that current. For example, with a known current of 45 ma. and a meter reading of 2.2 (the NRI value obtained in this experiment), we would divide 45 by 2.2 and get 20.45 as the multiplying factor. When we consider the normal tolerances of the meter, resistors and batteries, this is very close to the computed correct value of 21. Even if we called it 20, as a practical radio man would probably do, the results would still be more than accurate enough for ordinary radio purposes.

When the resistance of a meter is not known and cannot conveniently be measured, the radio engineer prefers to use a somewhat different method for determining the required value for a shunt resistor. First of all, he determines the voltage required across the meter to give a full-scale deflection. This same voltage will act upon the shunt which is to be connected in parallel with the meter. He knows that the meter and shunt together must pass the new full-scale value of current, while the meter alone will pass its normal full-scale current value. Subtracting the meter current from the new full-scale value gives the current flowing through the shunt resistor at a full-scale deflection. The engineer then uses Ohm's Law, and divides the shunt resistor voltage by the shunt resistor current; this gives him the required value of shunt resistance.

Here is an example: The range of a 1-ma. milliammeter is to be increased to 10 ma. by means of a shunt resistor. The engineer knows (or determines experimentally) that a voltage of .05 volt will send the normal full-scale value of current through the meter. This value of .05 volt is then the shunt voltage. The current flowing through the shunt at the new full-scale current value will be .01 ampere minus .001 ampere, or .009 ampere. The shunt resistance value will therefore be .05 divided by .009, which is 5.55 ohms.

Instructions for Report Statement No. 15. In order to supply the correct answer for this report statement, place the red clip on the +22½ terminal of the B battery while leaving everything else the same as for Step 1. Hold the clip on the +22½ terminal only long enough to read the meter on scale I_M. You will then be using your meter with its 100-ohm shunt as a 0-63 ma. milliammeter, and will be measuring the current flowing in a series circuit consisting of a 22.5-volt battery and a 910-ohm resistor. Record your meter reading on scale I_M in the first space in Report Statement No. 15 on the last page. Next, multiply your meter reading by 21 to get the actual current, and record this value in the second space in Report Statement No. 15.

EXPERIMENT 16

***Purpose:* To demonstrate that a milliammeter can be used to measure resistance.**

Step 1. To connect your meter into a series ohmmeter circuit like that shown in the circuit diagram of Fig. 16, and to secure experience in measuring resistance values with this series ohmmeter, first remove the red and black test leads from the *I* jacks on the panel. Now remove the 100-ohm shunt resistor from the meter terminals, and disconnect the hook joint on jack *28* at the back of the panel without disturbing the other end of this lead. Place a small piece of cardboard (about 3 inches by 6 inches in size) on top of the chassis for insulating purposes, then place the group of three flashlight cells on this cardboard in the manner shown in Fig. *17A,* with the — terminal of cell group near meter terminal *16*. Now solder the lead from terminal *16* to this — cell terminal by means of a lap joint.

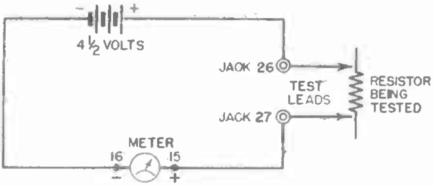
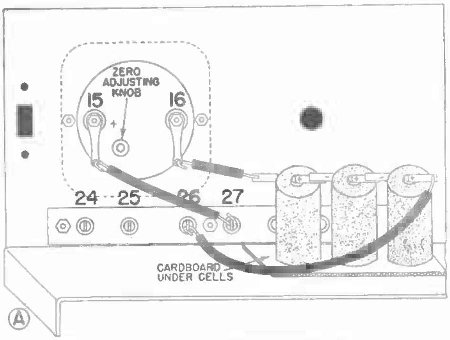


FIG. 16. Schematic circuit diagram for a series ohmmeter.

With about a 9-inch length of hookup wire, connect the + terminal of the cell group to jack *26,* as shown in Fig. *17A,* making a lap joint at the cell and a hook joint at the jack.

Plug the test leads into the two *R* jacks on the front of the panel, as shown in Fig. *17B*. (The colors of the leads may be disregarded when making measurements of resistor values.) Your series ohmmeter is now ready for use.

Connect an 18,000-ohm resistor (Part *1-16)* to your ohmmeter by placing one test lead clip on each lead



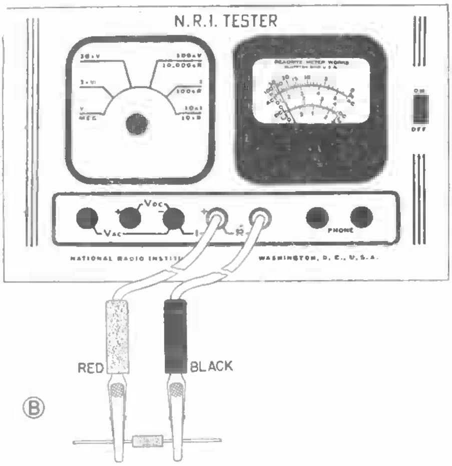


FIG. 17A (above). Rear view of panel, showing connections for the series ohmmeter which you set up in Step 1 of Experiment 16.

FIG. 17B (below). Method of connecting a resistor to the series ohmmeter.

of the resistor, as shown in Fig. *17B*. Read the meter on scale I_M, record your result on the first line in Table *16*, then disconnect the 18,000-ohm resistor completely.

Connect a 910-ohm resistor (Part *2-14*) to your ohmmeter by placing one clip on each resistor lead. Read the meter on scale I_M, record your result in Table *16*, and disconnect the resistor.

Connect a 100-ohm resistor (Part *2-15*) to your ohmmeter by placing one clip on each resistor lead. Read the meter on scale I_M, record your result in Table *16*, and disconnect the resistor.

Finally, try your ohmmeter with essentially zero resistance, by attaching one test lead clip to the other clip. Read the meter on scale I_M, record your result in Table *16* (on the zero-resistance line), then separate the test clips.

Important: Before beginning Step 2, read the report statement instructions at the end of this experiment and make the additional series ohmmeter measurement which is required.

Step 2. To connect your meter into a shunt ohmmeter circuit like that shown in the circuit diagram of Fig. 18A, and to secure experience in measuring resistance with a shunt ohmmeter, connect your parts in the manner shown in Fig. *18B*, in the following order:

Unsolder the group of three cells used in the previous step.

Unsolder the joint at jack *26*, then connect one end of the unsoldered lead to meter terminal *15* by means of a temporary soldered hook joint. To do this, apply the heated soldering iron to this soldering lug to melt the solder, then hook the wire into the hole in this lug alongside the wire already there. Or, if you prefer, simply make a lap joint on the lug.

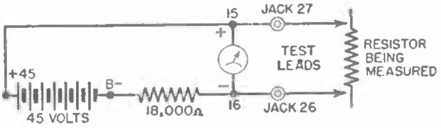


FIG. 18A. Schematic circuit diagram for a shunt ohmmeter.

Solder to jack *26* the free end of the lead which is still on meter terminal *16*.

Solder a 5-inch length of hook-up wire to one lead of the 18,000-ohm resistor (Part *1-16*) by means of a temporary hook joint. Connect the other end of this wire to the lug on meter terminal *16* with a temporary soldered hook or lap joint.

Bend a large hook in the other end of the resistor lead, and connect this lead to the —B terminal of your B battery.

Turn the chassis around, and connect the alligator clips to the leads of the 910-ohm resistor (Part *2-14*) while leaving the probes in the *R* jacks. Last of all, take the 9-inch lead on meter terminal *15* and connect its free end to the +45 terminal of your battery. Read the meter on scale I_M, disconnect the lead from the +45 terminal *immediately* to conserve battery life, and record your result in the fifth line of Table *16*.

Connect a 100-ohm resistor (Part *2-15*) to this shunt ohmmeter in place of the 910-ohm resistor, reconnect the lead to the +45 terminal, read the meter on scale I_M, disconnect the lead from the +45 terminal, and record your result in Table *16*.

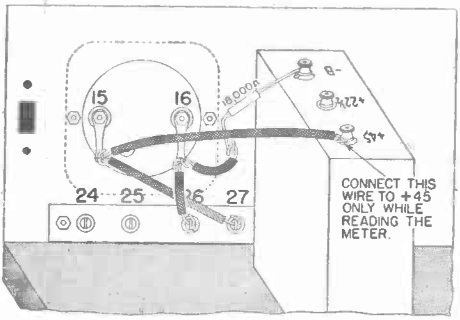


FIG. 18B. Rear view of panel, showing connections for the shunt ohmmeter which you set up in Step 2 of Experiment 16.

Finally, place essentially zero resistance across your shunt ohmmeter by connecting one clip to the other, reconnect the lead to +45, read the meter on scale I_M, disconnect the lead from +45, separate the clips, and record your result on the last line in Table *16*. Disconnect the set-up completely now by unsoldering and removing the resistor and the four lengths of hook-up wire, but *do not* remove the meter, its soldering lugs, or the jack strip. Separate the flashlight cells.

STEP	RESISTANCE BEING MEASURED IN OHMS	YOUR CURRENT READING ON SCALE I_M IN MA.	N.R.I. CURRENT READING ON SCALE I_M IN MA.	COMPUTED CIRCUIT CURRENT IN MA.
1	18,000	.2	.2	.225
	900	1.7	1.5	1.55
	100	2.24	2.2	2.14
	0	2.5	2.3	2.25
2	900	.8	.7	.74
	100	.15	.1	.12
	0	0	0	0

TABLE 16. Record your results for Experiment 16 here.

Important: Be sure to save all pieces of hook-up wire, no matter how small, for they can be used over and over again in later experiments.

Discussion: When using the group of three dry cells as the voltage source for a series ohmmeter in Step 1, the wiring is simplest if you place the cells on the chassis as shown in Fig. *17A*. However, when you are doing this be sure to use the piece of cardboard under the cells, to prevent the exposed cell bottoms from shorting through the chassis and draining the cells.

A *series-type* ohmmeter is basically an instrument in which the resistor being measured is connected in series with a milliammeter and a d.c. voltage source. The two test leads, which are plugged into the *R* jacks, serve as the terminals of your series-type ohmmeter. When these terminals are separated, corresponding to an infinitely high resistance value, no current flows through the meter and consequently it reads zero. When a resistor is connected to the ohmmeter terminals, the current flow as indicated by the meter will depend upon the voltage being used and upon the total circuit resistance (the meter resistance plus the value of the resistance being measured.)

Circuit Current Computation. By means of Ohm's Law, we can compute the current very easily in the ohmmeter circuit when an 18,000-ohm resistor is being measured (Step 1). Since the meter has a resistance of 2,000 ohms, the total circuit resistance in this case is 20,000 ohms. Dividing the circuit voltage of 4.5 volts by 20,000 ohms gives a current of .000225 ampere, or .225 ma.

With a 910-ohm resistor, the computed current becomes 1.55 ma., while for a 100-ohm resistor the computed current is 2.14 ma. With zero resistance across the ohmmeter leads in Step 1, the computed circuit current is limited only by the meter resistance, and is therefore 2.25 ma., just as was calculated for the same condition in Experiment 12. You can thus see that as we decrease the ohmic value of the resistor in a series-type ohmmeter circuit, the meter current goes up. Conversely, *increasing* the resistance makes the meter current go down.

By using additional resistors of known values, or by computation, we can determine what the meter reading on scale I_M would be for any resistor value. A scale giving values in ohms rather than in milliamperes could then be marked on the meter, so that resistance could be measured directly whenever a 4.5-volt battery was used in series with the meter. This is the basic principle of the widely used series-type ohmmeter.

In an actual commercial series-type ohmmeter, the voltage employed is sufficient to give slightly higher than a full-scale meter reading, and a variable resistor is placed in series with the meter or shunted across the meter. This resistor can be adjusted to make the meter read exactly full-scale when the ohmmeter leads are clipped together. This scheme therefore permits compensation for the natural reduction in battery voltage with age. The variable resistor which is used with the meter for this purpose is sometimes called the *zero ohmmeter adjustment.*

Theoretically, every ohmmeter scale should cover all resistance values from zero to infinity. Actually, however, the most useful range of an ohmmeter is that near the middle of its calibrated scale. Resistance values are always indicated on the remaining portions of the scale, but readings in these portions cannot be estimated with reasonable accuracy. For this reason, it is often advisable to provide several different resistance ranges for use with one meter.

The useful range of an ohmmeter can be increased by providing means for employing either higher or lower d.c. voltages, and by providing for each voltage value a series resistor which will limit the circuit current to the full-scale meter value when the ohmmeter terminals are shorted.

In Step 2, you deal with the basic principle of what is called a *shunt-type ohmmeter.* In this circuit, the meter and the 18,000-ohm resistor are connected in series with the 45-volt d.c. source at all times, and the terminal leads for the ohmmeter go to the meter terminals. When the clips are disconnected, the circuit current is somewhere near the computed value of 2.25 ma. (This was calculated in connection with Step 2 of Experiment 14.)

When your shunt-type ohmmeter is connected to a 910-ohm resistor, the computed value of circuit current is .74 ma. The resistor provides an alternative path around the meter for current, and consequently we secure a lower meter reading than for the condition where no resistor is connected to the ohmmeter. With a 100-ohm resistor, the shunt path across the meter has even lower opposition to current flow, and consequently the meter reading drops still lower, to a value somewhere near the computed value of .12 ma. (Computations are not given since they are essentially the same as previous computations.)

Finally, when the ohmmeter clips are connected together to correspond to a zero-resistance condition, the meter is completely shorted and the reading drops to zero.

Thus, with a shunt-type ohmmeter the meter reading decreases as the value of the resistance being measured decreases. This is just exactly the opposite of the action observed for a series-type ohmmeter. Again, the meter could be calibrated and its scale marked to indicate directly the values of resistors being measured.

In commercial shunt-type ohmmeters, the scales are marked directly in ohms. Furthermore, the voltage source employed is high enough to give higher than full-scale deflection, and a variable resistance is inserted in series with the battery to permit compensation for natural aging of the battery.

As a general rule, series-type ohmmeters are employed for measuring high resistance values, and shunt-type ohmmeters are employed for measuring low resistance values. You can readily identify these types, for on a shunt-type ohmmeter the zero of the scale is always at the left, while with a series-type ohmmeter it is at the right.

Extra Information. When a series-type ohmmeter is properly adjusted, the insertion of a series resistor equal to the initial resistance of the circuit will cut the meter current in half, and consequently the meter pointer will take a mid-scale position.

When a shunt-type ohmmeter is properly adjusted, shunting the meter with a resistor equal in value to the meter resistance will cut the meter current in half, and the meter pointer will take a mid-scale position (assuming the meter resistance is negligibly low in comparison with the resistance value employed in series with the meter and battery).

To find the resistance of a d.c. milliammeter, connect the meter, a high-value variable resistance (about 50,000 ohms) and a voltage source all in series, choosing a voltage value which will give a full-scale meter reading when the variable resistance is adjusted. Now take another variable resistance of about the same value, shunt it *across* the meter, and adjust this second variable resistance until the meter reads exactly half of its full-scale current value. The ohmic value of the shunt variable resistance will now be exactly equal to the resistance of the meter, and can be measured with a conventional ohmmeter. This procedure is especially valuable when the resistance of a meter is so low that an ohmmeter battery would send an excessively large current through it during an ordinary resistance measurement.

Instructions for Report Statement No. 16. In order to supply the answer to this report statement, you must make one additional measurement with the series ohmmeter set-up described in Step 1 and shown in Fig. *16*. Secure a meter reading for a parallel combination of 910-ohm and

100-ohm resistors by placing one lead of each resistor in the jaws of the red clip, and placing the other resistor leads in the black clip. Read the meter on scale I_M, compare your reading with those you obtained in Step 1, then turn to the last page and make a check mark after the answer in Report Statement No. 16 which describes your result. Now carry out Step 2 of this experiment.

Instructions for Mounting Batteries on Chassis

Step 1. To prepare for assembly of individual batteries in a compact group on the chassis, place before you the following batteries and parts:

One 1 1/2-volt A battery.
Eveready 742 with plug-in adapter, Burgess 4FH, or equivalent.

One 45-volt B battery.
Eveready 762-S, Burgess 5308, or equal.

Two 4 1/2-volt C batteries.
Eveready 761-T, Burgess 2370, or equivalent with four screw terminals, marked +, —1½, —3 and —4½.

One Battery Terminal Card.
This card is furnished with C batteries purchased from NRI. If you get your batteries elsewhere, you can make your own card according to later instructions.

One length of black lace (Part *2-20*).

Corrugated cardboard (from battery shipping carton or any other box).

About 3 1/2 feet of ¾-inch wide friction tape (not furnished or absolutely needed, but will keep the batteries from sliding. You can buy a small roll from any hardware or dime store).

Assembled chassis and panel, with meter and jack strip mounted on panel.

One 2-inch length of hook-up wire.

The detailed battery instructions which start with Step 3 apply specifically to Eveready batteries. For those who use other makes of batteries, special instructions are given at the end of each step whenever necessary. In general, however, the battery assembly procedure is practically the same for all makes of equivalent batteries.

You will find that the instructions specify placing strips of black friction tape between the batteries. This is an optional procedure which you do not have to do unless you desire. The friction tape prevents the batteries from sliding out of position when you turn the chassis over to change connections underneath.

Note: If for any reason you are using batteries having different shapes or dimensions than the specified Eveready or Burgess units, you may change the arrangement of the batteries on the chassis or change the wire lengths, provided *that you make the same electrical connections to the batteriy terminals as are specified in this manual.*

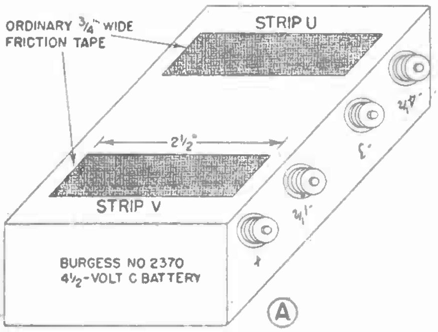
Experiment with different positions until you secure an arrangement which gives a compact group fitting within the battery tabs on the chassis, with all battery terminals at the top or facing the front panel so the terminals will be accessible and battery connecting leads will be as short as is practical. If at all possible, arrange the two C batteries exactly as in Figs. 19B *and* 19C.

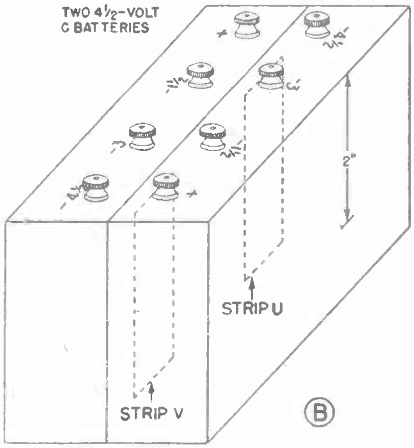
Step 2. Identify on top of the chassis with metal marking crayon the six holes which you previously marked *a, b, c, d, e* and *f* under the chassis. Do this carefully, one hole at a time, to make sure that each hole is marked the same above the chassis as it is below. These letters on top of the chassis should face the front panel, and should be in the positions shown in Fig. *21B.* If it is difficult for you to make neat letters while the panel is attached, you can temporarily remove the front panel. Be sure to replace the panel after you finish the lettering.

Step 3. Place one of the Eveready C batteries (761-T) in front of you, in exactly the position shown in Fig. *19A,* so that the terminals have *exactly* the positions shown in the diagram. Cut two strips of friction tape, each 2½ inches long,, and place these on the uppermost side of the battery in the manner shown for strips *U* and *V* in Fig. *19A*. Now place the other C battery on top of this, in such a way that its + terminal is next to the —4½ terminal of the first C battery. Set the two batteries upright now in the position shown in Fig. *19B*.

Note: For other makes of batteries, bear in mind that the strips of friction tape should be as long as possible without projecting beyond the batteries.

Step 4. Cut three pieces of corrugated cardboard from the packing carton in which the batteries were shipped. Make one piece 4 inches long and 2½ inches wide, and mark it with the letter *X*. Make the other two pieces each 4 inches long and 2¾ inches wide, and mark them *Y*. These will be used as packing around the 1½-volt A battery, so that four batteries can later be assembled into a uniform pack as shown in Fig. *19C*.





FIGS. 19A and 19B. Assembly of C batteries. The strips of friction tape are not absolutely essential but prevent the batteries from sliding out of position.

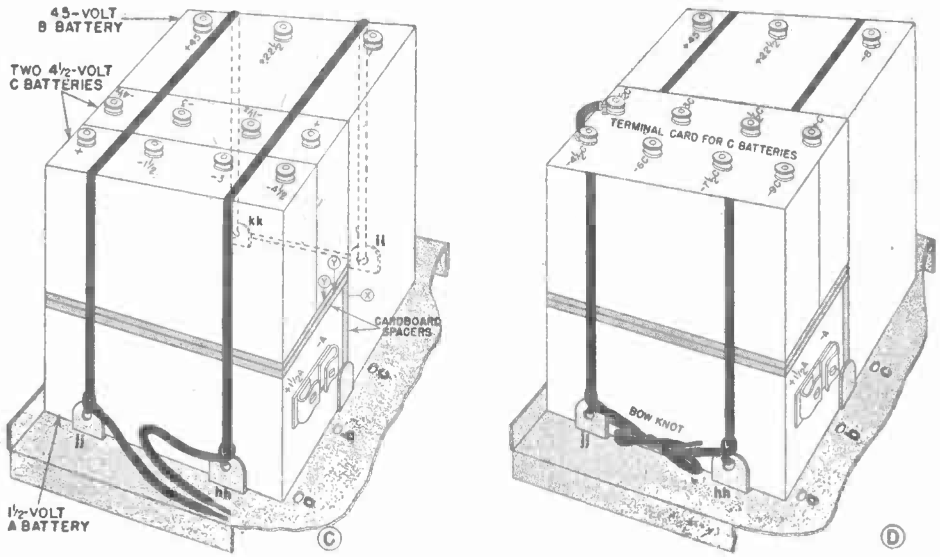
Note: For other battery makes, cardboard spacers may not be needed, or may have to be of different sizes. Bear in mind that spacers are used only to give a neat appearance to the battery group.

Step 5. Take the type 1024 plug-in adapter and push it into the holes found in the end of the Eveready 742 1½-volt A battery. The two adapter prongs are of different size, so there is only one position in which the adapter will fit. Now turn the battery so the + terminal of the adapter is at your *left*, and place the marking +1½A on the battery directly above the + terminal, as shown in Fig. *19C*. Next, place the marking —A on the battery directly above the — terminal. You can use your metal-marking crayon for these markings if you keep its point sharp.

Note: Some makes of A batteries will have standard terminal nuts and screws rather than a plug-in connecting system. On these, just mark the — terminal as —A, *and mark the + terminal* +1½A *so as to conform to the marking in Figs.* 19C *and* 19D.

Step 6. Set your metal chassis in front of you with the panel facing you, so that battery tabs *hh* and *jj* on the chassis are at your left as in Fig. *19C*. Lay the 1½-volt A battery on the chassis, against these tabs, exactly as in the diagram.

Now cut six pieces of friction tape, each 3 inches long. Place one piece lengthwise on top of the A battery, and place another piece of tape lengthwise on the right side of the A battery. These pieces of tape will



Figs. 19C and 19D. Method of arranging the specified Eveready batteries on the chassis.

prevent the cardboard spacers from sliding out of position.

Place the smaller cardboard spacer (marked *X*) against the right side of the A battery, and place a 3-inch length of tape lengthwise on the right side of this spacer.

Now set the B battery on the chassis in an upright position, with the — terminal nearer the front panel, as in Fig. *19C*.

Place one of the larger cardboard spacers (marked *Y*) on top of the A battery, place a 3-inch length of tape lengthwise on this spacer, then place the remaining spacer *Y* on top. Now place the two remaining lengths of tape on top of the last cardboard spacer, arranging them lengthwise about ½ inch apart so that one strip will be under each of the C batteries which you now place in position exactly as shown in Fig. *19C*.

Step 7. Take the 45-inch length of black lace (Part *2-20*) and tie one end to battery tab *hh* with a simple knot, as shown in Fig. *19C*, leaving about 4 inches of lace projecting beyond the tab so you can tie a bow knot with it later. When pulled tight, this simple knot will hold adequately for your purpose.

Now run the lace across the tops of the batteries, and thread it through battery tab hole *ii* from the *inside* (lift up the B battery temporarily to do this). Bring the lace over to tab *kk* now and thread it through the hole from the *outside*. From *kk*, run the lace back over the tops of the batteries to tab *jj*, and thread it through the hole in this tab. Go over the entire length of lace to pull it tight with your fingers and make the lace lie flat, then tie a simple knot at tab *jj* just as shown in Fig. *19C*.

To prevent the lace from slipping while tying the knot, you can place the blade or shank of a medium-size screwdriver between the tab and the battery block, as shown in Fig. *19E*. Finally, tie a bow knot with the loose ends, as shown in Fig. *19D*.

Note: The 45-inch lace should be long enough to go twice across any combination of other makes of batteries, but in *some cases it may not be necessary to tie the bow knot. With smaller batteries, it may be possible to run the lace three times across the group, from hh to ii to jj to kk. Any lacing arrangement which keeps the batteries securely on the chassis is satisfactory.*

Step 8. Remove the nuts from all eight C battery terminals. If there are lock washers on the terminals, remove these also and set them aside. You do not have to use lock washers on battery terminals during your experimental work.

Take the battery terminal card furnished with your NRI batteries, and cut out each of the eight rectangles with a sharp pen knife. Now push the card over the C battery terminal screws in exactly the position shown in Fig. *19D*, then replace the battery nuts. When a terminal screw does not fit into a hole in the card, you can either enlarge the hole with a pen knife or, in the case of the Eveready 761-T unit, move the terminal screw a small amount.

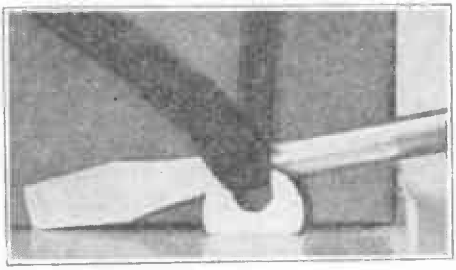


FIG. 19E. Method of holding the lace with a screwdriver while tying the final knot at battery tab *jj*.

Connect a 2-inch length of hook-up wire between the two C battery terminals identified as —4½C on the card, so as to place the two C batteries in series. This wire *must remain in this position* for the entire life of the C batteries.

From now on, all C battery connections will be specified *by the new terminal markings* on the card.

Note: To make a terminal identification card for C batteries obtained elsewhere than from NRI, cut out a piece of stiff paper or smooth carboard having the approximate size of the top area of both C batteries (for two average-size C batteries, the card dimensions will be 2⅞" × 4"). Place this card over the C battery terminals after removing the terminal nuts and washers, and press down on each terminal screw in turn with your thumb or one of the terminal nuts, so the screws will project up through the card. Finally, mark your card in exactly the same way as the card shown in Fig. 19D, using pen and ink or any other means.

Step 9. If necessary, mark your B battery terminals to conform to the markings in Fig. *19D*, since all B battery connections in the future will be specified by these markings. This will usually mean only changing the — marking to —B, which can be done with crayon. With the batteries now securely tied in position, you can turn the chassis upside down whenever necessary during the following experiments, without having the batteries fall off or slide out of position.

IMPORTANT: Lead lengths specified in this lesson are based upon the dimensions of Eveready batteries. If your batteries have different dimensions, it will be best to disregard specified lead lengths and use the procedure followed by experienced radio men when wiring up a circuit.

GENERAL WIRING PROCEDURE

1. Locate on your apparatus the two terminals between which the wire is to be connected. Use the pictorial or semi-pictorial wiring diagrams as guides.

2. If you have a used piece of wire which will reach between the two terminals, proceed to connect it.

3. If no suitable length is available, connect one end of your roll of wire to one of the terminals. Run the wire over to the other terminal. Cut the wire to the required length, and complete the connection.

EXPERIMENT 17

Purpose: **To demonstrate that electrons will flow from the cathode to the plate in a vacuum tube when the filament is heated and the plate is placed at a positive potential with respect to the cathode.**

Step 1. To connect your type 1C5GT pentode tube into the circuit shown in Fig. 20A, wherein it is used as a simple diode tube with a plate voltage of 22.5 volts and with your meter connected to measure the plate current, connect together the tube socket, the meter and the batteries according to the circuit shown in Fig. *20B,* in the following manner:

Turn the chassis upside-down, take a 1-inch length of hook-up wire from which you have removed all insulation, and use it to connect together tube socket terminals *3* and *4* with temporary hook joints as shown in Fig. *21A.* Leave these joints unsoldered for the present.

Connect together tube socket terminals *5* and *7* with a 1¾-inch length of hook-up wire; make temporary hook joints but leave them unsoldered.

Take a 4-inch length of hook-up wire, push one end through hole *b* from the top of the chassis far enough to reach terminal *2,* then make a hook joint between the wire and terminal *2,* as shown in Fig. *21A.*

Take a 5-inch length of hook-up wire, push it through hole *e* from the top of the chassis far enough to reach tube socket terminal *3,* then form a hook joint at this terminal.

Take a 4½-inch length of hook-up wire, push it through hole *c* from the top of the chassis far enough to reach terminal *7,* then form a hook joint at this terminal.

Now solder the connections to tube socket terminals *2, 3, 4, 5* and *7.*

Turn the chassis over, locate the wire which comes up through hole *e,* and connect it to the soldering lug of meter terminal *16* with a temporary soldered hook joint, as shown in Fig. *21B.*

Take a 10-inch length of hook-up wire and connect one end of it to the soldering lug on meter terminal *15* by means of a temporary soldered hook joint.

Take the wire which comes up through hole *c,* and connect it to the —A terminal of the A battery. Since this terminal has a Fahnestock clip rather than a screw terminal, the connecting procedure is a bit different. First, push the insulation back from

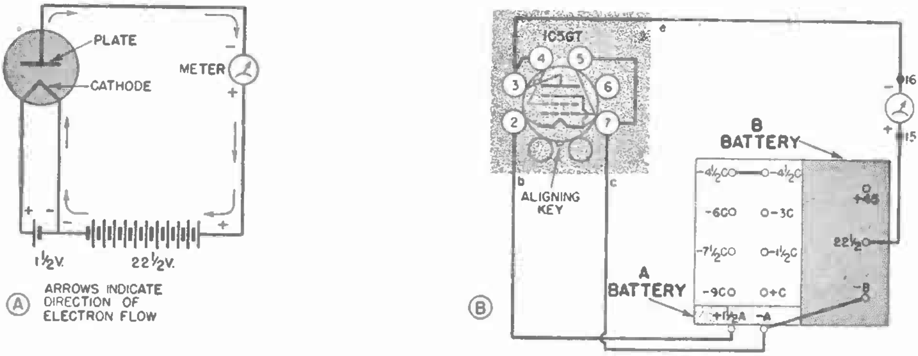


FIG. 20. Schematic circuit diagram *(A)* and semi-pictorial wiring diagram *(B)* for Step 1 of Experiment 17, in which you connect your type 1C5GT tube as a diode. The shaded area around the tube symbol in *B* indicates that connections to the tube socket are under the chassis. The letters e, b and c around this shaded area indicate the chassis holes through which the leads are run.

the end of the lead for about half an inch. Now bend the wire into the position shown in Fig. *21C*, so that the bare end of the wire is directly in front of the center of the Fahnestock clip. Grasp the wire with two fingers of your right hand, press the flat end of the clip with the thumb of your left hand, and insert the wire in the clip just as shown in Fig. *21D*.

In essentially the same manner, take the wire which comes through hole *b* in the chassis and insert it in the +1½A clip from the bottom, as shown in Fig. *21B*.

Take an 8½-inch length of wire, push back the insulation from one end, and insert this end in the —A Fahnestock clip from above, as shown in Fig. *21E*, after first pressing on the flat end of the clip to make room for the wire. (The wire already in the —A clip should stay in position when you press; if it drops, bend the wire upward so it stays in position even when the gripping action of the clip is released by thumb pressure.) Bring the wire from —A diagonally upward

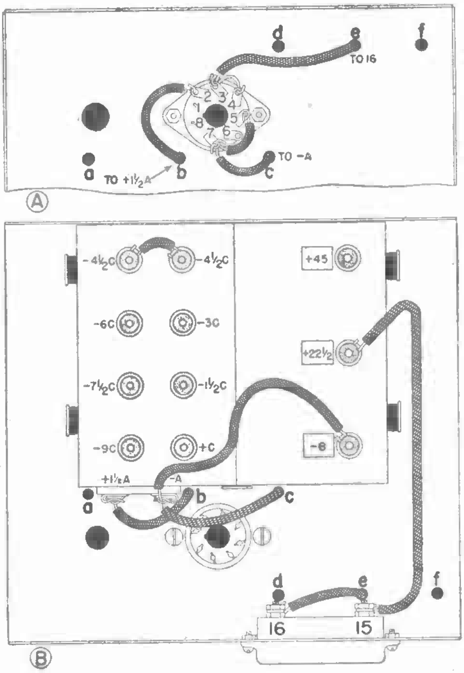


FIG. 21. Under-chassis *(A)* and above-chassis *(B)* connections for Step 1 of Experiment 17.

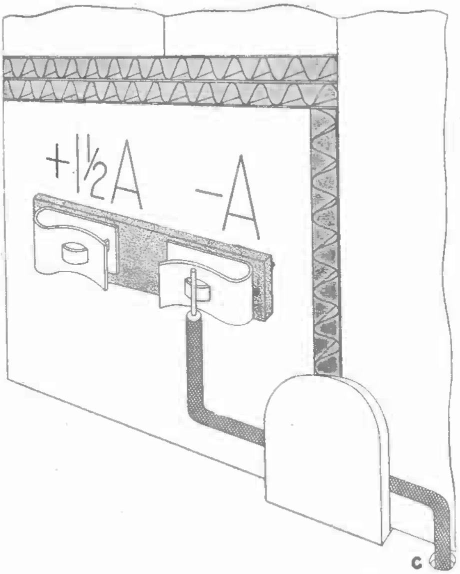
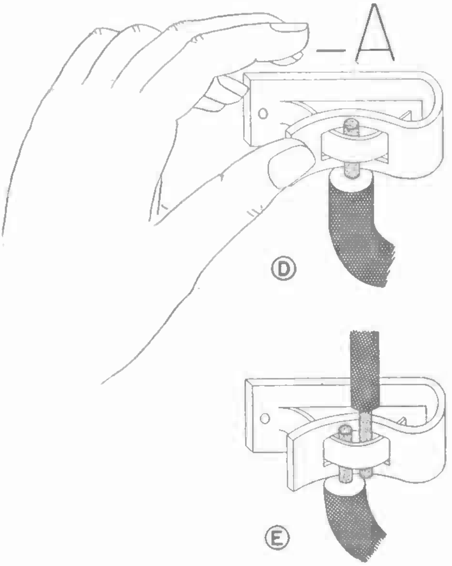


FIG. 21C. When two wires are to be inserted in a Fahnestock clip, bend the first wire so it will stay in this position by itself, before attempting to insert the wire in the clip.



FIGS. 21D and 21E. To insert a wire in a Fahnestock clip, press on the flat end of the clip with your thumb, as shown at *D*. Two wires can readily be placed in one clip, as at *E*.

FIG. 21F. Hold a radio tube in the manner shown here when pushing it into or removing it from a socket. Make sure that the aligning key on the tube base is in the aligning slot on the tube socket before attempting to push a tube into its socket. Most of the downward pressure is applied by the thumb and forefinger gripping the base. It may be necessary to apply pressure also on the top of the glass envelope, and rock the tube gently from side to side while pushing downward, for the contacts in a new socket are sometimes a bit stiff. Use the same grip and rocking motion for pulling out the tube.

to the top of the B battery, form a loop on top of the B battery as shown in Fig. *21B,* then connect the wire to the –B terminal. This wire is purposely made longer than necessary, so you can move it to another terminal in Step 3.

Take the lead which you previously soldered to meter terminal *15,* and connect it to the +22½ terminal of the B battery. Watch the meter when you make this connection; there should be no movement of the pointer whatsoever.

Check your work very carefully against the diagrams in Figs. *20B, 21A* and *21B*, to make sure that every single wire is connected exactly as shown in these illustrations. This final checking of your work is extremely important, for a single error can damage circuit parts or discharge the battery. Do not probe carelessly around the wiring or terminals with a screwdriver or other metal part, for this tool may accidentally short-circuit certain terminals.

Insert the type 1C5GT tube (Part *2-10)* in its socket from the top of the chassis, by first setting the central black aligning pin of the tube base over the central hole in the socket, holding the tube upright while rotating it with the fingers until the aligning key and slot match and the tube drops down, then pushing the tube into its socket in the manner shown in Fig. *21F*.

If you have made all connections properly, the meter pointer should move up-scale when the tube is inserted. Read the meter on scale I_M, and record your reading in the first line of Table *17*.

Step 2. To determine the effect of opening the filament circuit in a diode vacuum tube circuit like that shown in Fig. *20A,* disconnect temporarily the lead which comes up through hole *b* and goes to the +1½A terminal, while watching the meter. Note the meter reading when this lead is disconnected, reconnect the lead, then record your observation in Table *17*. Be very careful that the disconnected lead does not touch either the +45 or the +22½ battery terminal, for this would burn out the tube filament instantly. To prevent burning out the tube while changing the wiring, remove the tube from its socket by grasping with one hand and pulling firmly upward, as shown in Fig. *21F*. It is permissible to wiggle the tube sideways a bit by grasping the base, if removal is somewhat difficult at first.

Step 3. To determine the effect of reversing the plate supply voltage in a diode vacuum tube circuit like that shown in Fig. 20A, interchange the wires which are on the —B and +22½ terminals. In other words, the 10″ lead coming from meter terminal *15* should now go to —B, and the 8½″ lead from the —A terminal should now go to the +22½ terminal.

Replace the tube in its socket, note the meter reading on scale I_M, record your result in Table *17*, then remove the tube from its socket again and return the —B and +22½ leads to their original positions as shown in Fig. *21B*.

STEP	NATURE OF MEASUREMENT	YOUR CURRENT READING ON SCALE I_M IN MA.	N.R.I. CURRENT READING ON SCALE I_M IN MA.
1	PLATE CURRENT IN DIODE CIRCUIT OF FIG. 20A WITH 22½ VOLTS ON PLATE	2.2	2.2
2	SAME AS STEP 1, BUT WITH FILAMENT CIRCUIT OPEN	0	0
3	SAME AS STEP 1, BUT WITH REVERSED PLATE VOLTAGE	0	0

Table 17. Record your results for Experiment 17 here.

Discussion: In your regular lessons, you learned that a vacuum tube must have at least two electrodes, a *cathode* and a *plate*. The cathode may be heated indirectly by a filament, as it is in tubes you will receive in later kits, or the filament itself may serve as the cathode, as is the case in the type 1C5GT tube you are now using. The electrons which are emitted by the heated cathode move through the vacuum in the tube to the plate when the plate is made positive with respect to the cathode by applying a suitable d.c. voltage. When a tube has only these two electrodes, it is known as a *diode*.

If a coil or spiral of wire is placed between the cathode and the plate in a tube, we have what is known as a *triode* tube, and the additional electrode is known as the control *grid*.

If another grid is placed between the control grid and the plate, we have a four-electrode tube called a *tetrode;* the added electrode is called the *screen grid.*

Finally, if we place still another wire electrode in the tube, between the screen grid and the plate, we have what is known as a *pentode* tube, and this third added electrode is known as a *suppressor grid.*

In the type 1C5GT tube which you now have, all three of these grids—the control grid, the screen grid and the suppressor grid—are present; your tube is therefore basically a pentode. In your tube, however, no terminal prong is provided for the suppressor grid; this grid is permanently connected to the cathode inside the tube. The suppressor grid in the type 1C5GT tube serves to repel slow-speed electrons which "bounce off" the plate due to secondary emission, thereby forcing them back to the plate.

In this experiment, we are interested only in the behavior of the tube as a diode. We can eliminate the effect of the control grid by connecting it to the cathode (connecting together tube socket terminals *5* and *7* does this), and we can eliminate the effect of the screen grid by connecting it to the plate (connecting together tube socket terminals *3* and *4* does this). Although we cannot change the internal connection of the suppressor grid, we can ignore the effects of this grid for the present, since they are relatively unimportant in this experiment.

By connecting grids to either the cathode or the plate in this manner, any multi-element vacuum tube can be adapted for use as a simple diode.

The fact that you obtain a meter reading for the first step in this experiment shows that electrons will flow through a vacuum tube in the direction from the cathode to the plate when the cathode is heated and the plate is charged positively with respect to the cathode. We know the electrons take this direction because we previously found (Experiment 11) that the meter gives an up-scale deflection when electrons enter the minus terminal of the meter. If you trace around the plate circuit of Fig. *20A* in the direction which makes the electrons enter the minus terminal of the meter, you will find that electron flow is in the direction indicated by arrows, and is therefore from the cathode to the plate through the tube.

The exact value of plate current obtained in Step 1 is not particularly important, and your value will very likely differ considerably from the reading which we obtained. This is perfectly normal, and is due simply to the fact that different tubes, batteries and radio parts will vary considerably in their characteristics. In all measurements which you make in vacuum tube circuits, remember this fact, and do not expect to obtain values which agree closely with the NRI readings.

The important thing for you to recognize is that *your readings should increase when ours do, and your readings should decrease, or drop to zero, when our readings do this.* In other words, your readings should verify basic radio principles by the *manner* in which they increase or decrease, rather than by agreeing with any specific values.

When you disconnect the filament circuit by removing the lead from the +1½A terminal, you interrupt the flow of current through the filament of the tube. As a result, the filament cools to normal room temperature, and ceases emitting electrons. Without electron emission, no electrons can flow to the plate, and consequently the plate current should drop to zero for Step 2.

When you reverse the B battery connections in Step 3, you make the plate negative with respect to the cathode. Under this condition, the plate repels rather than attracts electrons, forcing the emitted electrons to return to the cathode without getting anywhere.

The fact that the meter pointer is at zero with reversed plate voltage also tells that reversing the plate voltage source will *not* reverse the direction of electron flow. If it did, you would observe an off-scale movement of the pointer to the left of zero. Electrons cannot flow in a reverse direction through a vacuum tube because the plate is not heated and cannot emit electrons.

From a technical standpoint, we can consider the cathode-plate path in our vacuum tube to be a resistance. Furthermore, we can consider that the value of this resistance may be either high or low, depending upon the polarity with which the plate voltage supply is connected; with correct polarity as in Step 1, we obtained a definite current value, and with reverse polarity as in Step 3, we obtained no current (no current means that the tube has an infinitely high resistance).

Computing Circuit Current. In the diode vacuum tube circuit of Fig. *20A*, we have a 22.5-volt battery and a 2,000-ohm meter in series with the cathode-plate path through the tube. If this tube path were shorted or if it had zero resistance, the total circuit resistance would be 2,000 ohms and the plate circuit current would be 22.5 divided by 2,000, which is .01125 ampere, or 11.25 ma. Actually, we measure only about 2 ma. of plate current in Step 1 of this experiment; the only way to explain this is by assuming that the tube has resistance.

For computation purposes, let us assume that we obtain a plate current reading of 2 ma. With the aid of Ohm's Law, now we can determine what the resistance of the tube actually is. By dividing 22.5 by .002, we get 11,250 ohms as the total resistance of the plate circuit. Since 2,000 ohms of this is already in the meter, the remainder or 9,250 ohms must be the plate-cathode resistance in this direct current circuit. This resistance is comparatively low, and consequently we can say that the type 1C5GT tube has good conducting ability when its plate is positive with resepct to the cathode. In some specially designed diode rectifier tubes employed in radio receivers, the d.c. resistance value may be as low as 100 ohms.

When the plate was made negative with respect to the cathode, you found that no current flowed. This condition could exist only if the tube had an infinitely large resistance, and behaved like an open circuit.

Practical Extra Information. You already know that an a.c. voltage is equivalent to a repeated and regular reversal in the polarity of a d.c. voltage. Therefore, if an a.c. voltage is employed in the plate circuit of Fig. *20A* in place of the 22.5-volt B battery, the plate will be alternately positive and negative with respect to the cathode.

This experiment shows, however, that current will flow in the plate circuit only when the plate is positive with respect to the cathode. This means that when we apply an a.c. voltage to the plate, we will have a pulsating direct current in the plate circuit, with electrons flowing only in one direction. This is the basic principle of the power packs used in radio receivers to convert alternating current to direct current. In later experiments, you will actually demonstrate this important principle of rectification.

Multi-element vacuum tubes like that which you now have are actually being used as diode tubes in some types of radio equipment. For instance, some manufacturers often use a triode tube as a diode by connecting the control grid to the plate. Also, in emission-type tube testers, all grids of the tube under test are connected automatically to the plate, and the resulting plate current for a diode connection is measured at a suitable plate voltage value. If the tube is in good condition, the measured value of plate current will be normal, and the tube tester will indicate "GOOD."

Instructions for Report Statement No. 17. After you have completed this experiment and studied the discussion, measure the plate current through your diode-connected vacuum tube when there is an 18,000-ohm resistor in the plate circuit. To do this, start with your apparatus arranged just as it was at the end of Step 3 (so all connections are exactly as shown in Figs. *21A* and *21B*). Remove the wire from the +22½ terminal, solder one lead of the 18,000-ohm resistor to this wire by means of a temporary lap or hook joint, then place the other resistor lead on the +22½ terminal after first bending a hook in its end. Insert the tube in its socket, read the meter on scale I_M, and record your result in Report Statement No. 17 as the plate current in ma. when an 18,000-ohm plate load is used. Now remove the tube, disconnect the 18,000-ohm resistor, and reconnect the lead from *15* to the +22½ terminal.

EXPERIMENT 18

Purpose: **To demonstrate that the grid voltage in a vacuum tube has more control over plate current than does the plate voltage.**

Step 1. To determine what happens to the plate current when the plate voltage is increased from 22.5 volts to 45 volts in a single diode vacuum tube circuit, first take a 910 ohm resistor (Part *2-14*) and connect it between meter terminals *16* and *15* to serve as a shunt which will increase the current range of the meter three times, as shown in Fig. *22*. This connection can be made by bending a hook in one resistor lead, tinning the hook liberally, then holding the hook over the soldering lug of meter terminal *16* with one hand while applying the heated soldering iron to the joint with your other hand. Now simply make a soldered lap joint between the other resistor lead and meter terminal lug *15*. You can do this without removing the batteries from the chassis.

With all other connections exactly as they were for Step 1 of Experiment 17 (with the 10-inch lead from terminal *15* going to +22½ as shown in Figs. *21A* and *21B*), insert the tube in its socket, read the meter on scale I_M, and record your reading on the first line of Table *18*. Multiply this reading by 3 to get the plate current value in ma., and record this answer also on the first line of Table *18*.

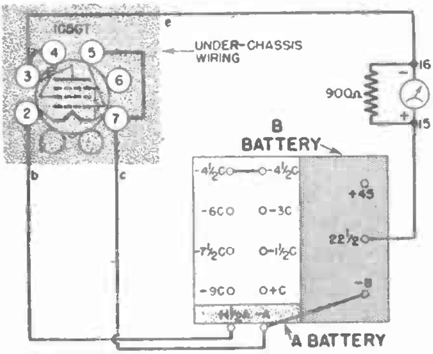


FIG. 22. Semi-pictorial wiring diagram for Step 1 of Experiment 18, in which you charge the plate voltage on a diode tube from 22½ volts to 45 volts and note the effect upon plate current.

Now increase the plate voltage to 45 volts by removing the lead from

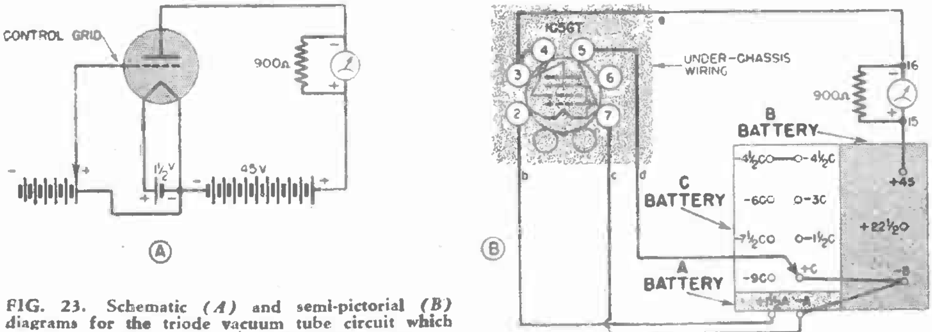


FIG. 23. Schematic *(A)* and semi-pictorial *(B)* diagrams for the triode vacuum tube circuit which you set up for Step 2 of Experiment 18.

STEP	PLATE VOLTAGE IN VOLTS	C BIAS VOLTAGE IN VOLTS	YOUR METER READING ON SCALE I_M	YOUR PLATE CURRENT VALUE IN MA. (METER READING X 3)	N.R.I. METER READING ON SCALE I_M	N.R.I. PLATE CURRENT VALUE IN MA. (METER READING X 3)
1	22.5	0	.8	2.4	.8	2.4
	45	0	2.4	7.2	2.5	7.5
2	45	0	2.5	7.5	2.5	7.5
	45	-4½C	.6	1.8	.6 (C BIAS=-4.5V)	1.8

TABLE 18. Record your results for Experiment 18 here.

the +22½ terminal and placing it on the +45 terminal. There is no need to remove the tube while doing this. Read the meter on scale I_M, record your results (first the meter reading, then the actual current value in ma.) on the second line of Table *18*, then remove the tube from its socket.

Step 2. To determine how much more effective the control grid is than the plate in controlling plate current, connect your type 1C5GT tube as a triode in the circuit shown in Figs. *23A* and *23B*, proceeding as follows:

Turn the chassis over carefully, and unsolder completely the 1¾-inch lead which connects together tube socket terminals *5* and *7*. Save this lead for future use.

Take a 13-inch length of hook-up wire, push it almost completely through chassis hole *d*, and connect the exposed end of this lead to tube socket terminal *5* by means of a soldered temporary hook joint, as shown in Fig. *24*. Do not disturb any other connections under the chassis. Note: If using other makes of batteries, this lead on terminal *5* must be made long enough to reach all terminals on the C battery.

Carefully set the chassis upright again while holding the battery in position, locate the other end of the long lead coming up through hole *d*, and connect it to the +C terminal of your C battery, as shown in Fig. *24B*.

With a 7-inch length of hook-up wire, connect the +C terminal to the —B terminal, as in Fig. *24B*. This wire is purposely made longer than

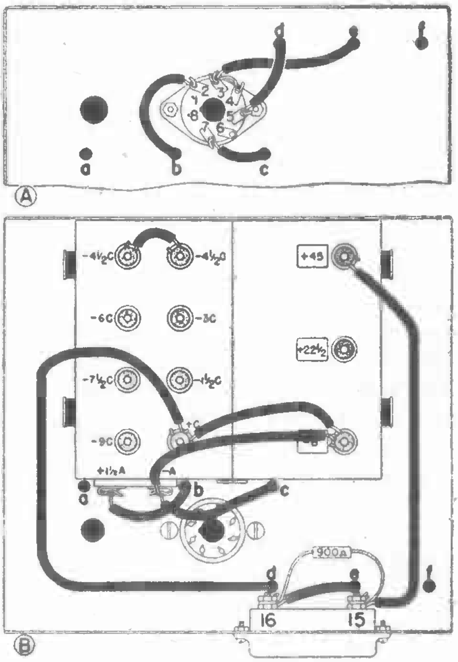


FIG. 24. Connections under the chassis for Step 2 in Experiment 18 should be as shown at *A*. The changes involved are as follows: Remove the lead which connects terminals 5 and 7, then bring a lead through hole *d* and connect it to terminal 5. Connections above the chassis should be changed to those shown at *B*. You now use the C battery terminals for the first time.

necessary, so it can be moved to other terminals later.

You have now duplicated the circuit presented in Fig. *23*. Check your work carefully against the semi-pictorial circuit diagram in Fig. *23B* before proceeding further.

Insert the tube in its socket, read the meter on scale I_M for this condition whereby the plate voltage is 45 volts and the control grid voltage is 0 volts with respect to the cathode, and record your results (first the meter reading, then the actual current in ma.) on the third line in Table *18*.

Now remove the 13-inch lead (the lead coming through hole *d*) from the +C terminal and place it in turn on —1½C, —3C, —4½C, —6C and —7½C until you find the terminal which gives a meter reading *nearest* the first meter reading you obtained in Step 1 (nearest the reading obtained for a plate voltage of 22.5 volts). If one terminal gives too much plate current but the next negative terminal gives too little current, select the terminal which gives nearest the desired plate current. Record on the last line of Table *18* the C bias voltage value as marked on this terminal, the resulting meter reading on scale I_M, and the actual current value in ma. (three times meter reading).

Remove the tube from its socket, but leave all wiring as it is for the present.

Discussion: Since in this experiment we expect to deal with current higher than 3 ma., the first thing we do in Step 1 is place across the meter a 910-ohm shunt resistor which increases the meter range approximately three times.* We then read the meter on scale I_M and multiply each reading by 3 to get the true current value in ma.

In Step 1, you measured the plate current of the diode tube with your meter first for a plate voltage of 22.5 volts, then for a plate voltage of 45 volts. One important fact to remember in these two measurements is that increasing the plate voltage makes the plate current *increase*.

In Step 2, you kept the plate voltage at 45 volts and determined how much voltage was required on the plate current drop to the first current value measured in Step 1 (corresponding to 22.5 volts on the plate).

As Table *18* indicates, we found in the NRI laboratory that it took only about 4.5 volts of change in the control grid voltage (from the zero grid voltage value of the first reading in Step 2 to the —4.5 volt grid voltage value of the second reading in Step 2) to reduce the plate current the same amount as did a 22.5-volt change in the plate voltage (from +45 to +22.5). In other words, we found that 4.5 volts of variation in the control grid voltage had just as much effect upon plate current as did 22.5 volts of variation in the plate voltage.

Considering basic vacuum tube action now, we naturally expect that as we make the grid increasingly more negative with respect to the cathode, it repels electrons more and more. This is exactly what we demonstrated in this experiment—that increasing the negative grid voltage cut down the plate current.

The NRI values indicate that a 4.5-volt change in grid voltage (from

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* Actually, a 910-ohm shunt increases the range of a 2,000-ohm meter 3.2 times, but because of normal deviations in meter characteristics and resistor values during manufacture, we can, for all practical purposes, consider this scale multiplication factor to be 3.

zero to —4.5) had as much effect upon plate current as a 22.5-volt change in plate voltage. We secure the number 5 when we divide 22.5 by 4.5; this indicates that the grid in the tube is five times more effective than the plate in controlling plate current. In technical language, we say that the amplification factor of the tube is 5 for the conditions in the NRI laboratory.

Schematic circuit diagrams tell which terminals are to be connected together. Semi-pictorial and pictorial diagrams also tell *how* these terminals should be connected together for best results (for maximum convenience, minimum wire lengths, or to anticipate possible future changes). The rule to remember is that a group of terminals can be connected together in many different ways, all of which give the same electrical results. Thus, instead of running a lead from +C to —B in Step 2, you would get the same results (though not so convenient a connection) by connecting +C to —A.

Practical Extra Information. The closer the grid is to the cathode in a vacuum tube and the closer the turns of wire in the coiled grid are to each other, the greater is the control which the grid has over plate current.

With an elaboration of the measuring technique employed in this experiment, we can determine quite accurately the amplification factor of any vacuum tube. We would do this by varying the plate voltage enough to cause a convenient change in plate current, then vary the grid voltage exactly enough to cause this same variation in plate current. In each case, we would make accurate measurements of the voltages involved, then divide the plate voltage variation by the grid voltage variation to secure the amplification factor of the tube.

The fact that the grid is a certain number of times more effective than the plate in a vacuum tube means that we can employ the tube to build up the strength of signals. In other words, we can supply a small a.c. voltage to the grid and secure a much larger pulsating plate current which is equivalent to a larger a.c. voltage in series with the d.c. plate voltage. With a coupling condenser or coupling transformer, we can transfer this a.c. voltage alone to another circuit for further amplification or for feeding to a loudspeaker or other device.

It is this superior ability of the grid to control plate current which makes vacuum tubes suitable for use in amplifiers and oscillators. You will learn more about these special vacuum tube circuits later.

Instructions for Report Statement No. 18. Make one additional measurement with the triode vacuum tube circuit of Figs. *23* and *24*. Use a plate voltage of 45 volts and a C bias of —3 volts, with the grid return lead from +C first connected normally to —A (by means of wires going from +C to —B and from —B to —A), then with the grid return lead connected to +1½A, and note what the plate current is in each case. (Here are more detailed instructions: Start with your circuit connected *exactly* as shown in Fig. *24*. Take the lead which comes out of hole *d* and move it from +C to —3C to get a C bias of —3 volts. The grid return lead (going across the battery from +C) is already on —B, and —B is already connected to —A, so read the meter to get the plate current value. Now remove from —B the lead which goes to +C, connect this lead to +1½A so that +C and +1½A are connected, and again read the meter to get the plate current value.)

Turning next to Report Statement No. 18 on the last page, place a check mark after the answer which describes the change you observed in the plate current value when the grid return lead was on +1½A.

From this extra test, you can make your own conclusions as to the importance of placing the grid return lead on a particular filament terminal when working with filament-type tubes such as the 1C5GT. The principles involved are covered in vacuum tube lessons in your fundamental course.

Put the grid return lead back on —B, so that —B is again connected to +C, and removed the tube from its socket. Leave all other wiring as it is until you are ready to start the next experiment.

EXPERIMENT 19

***Purpose:* To demonstrate that a grid in a vacuum tube draws a current when it is positive with respect to the cathode, but does not draw current when negative with respect to the cathode.**

Step 1. To secure plate current reading for different positive and negative values of C bias voltage when your vacuum tube is connected as a triode in the circuit of Fig. *25A*, use the semi-pictorial wiring diagram in Fig. *25B* and the top-of-chassis pictorial diagram in Fig. *26* as your guides for rewiring the vacuum tube circuit for this experiment. Connections under the chassis are left the same as for the previous experiment, and are therefore still as shown in Fig. *24A*.

The changes required above the chassis for this experiment are as follows: Disconnect the 7-inch lead from +C, and connect it to —7½C, so that —7½C is now connected to—B.

Now disconnect from —3C the lead coming up through hole *d*, wind its bare end about twice around one straight lead of the 6.7-megohm resistor (Part *2-11*) as shown in Fig. *26*, and solder this temporary joint. Connect the other lead of this resistor to battery terminal —9C, so as to provide a C bias voltage of —1.5 volts.

Insert the tube in its socket, read your meter on scale I_M, and record your results on the first line of Table *19* as the plate current reading for a —1.5 volt C bias and 6.7 megohm grid circuit resistance. *Note:* Since the 910-ohm shunt is still across the meter, you must multiply each meter reading on scale I_M by 3 to get the

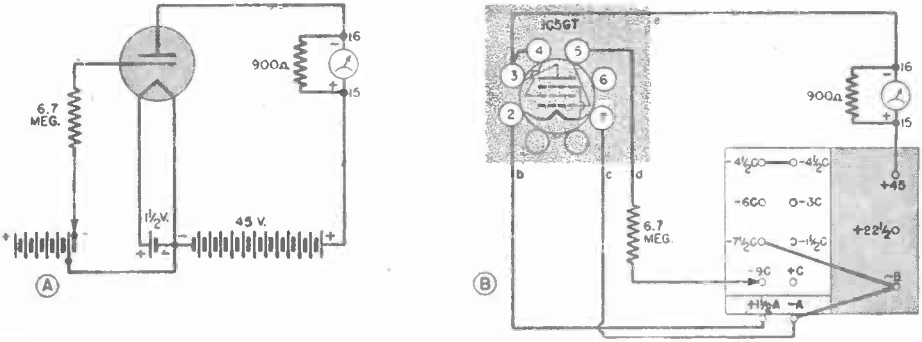

FIG. 25. Schematic *(A)* and semi-pictorial *(B)* diagrams for the triode vacuum tube circuit of Experiment 19. Note: Use the 6.8-megohm resistor sent you as Part 2-11 in place of the 6.7 meg. shown.

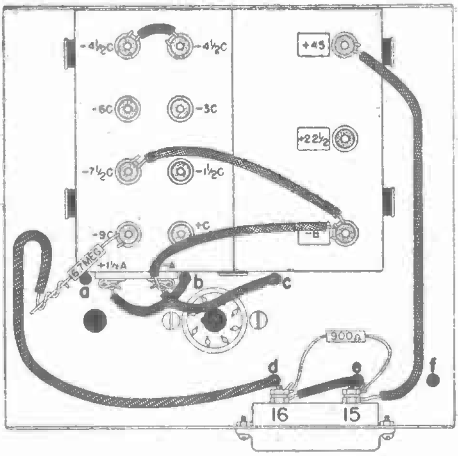

FIG. 26. Connections above the chassis should be modified to appear exactly as shown in this view, before starting to make measurements for Experiment 19.

plate current value in ma. Record the meter reading first in the space provided for this purpose in Table *19*, then multiply the reading by 3 and jot down your answer in the other space provided on the same line in the table.

Now take one of your test leads, attach its alligator clip to one lead of the 6.8-megohm resistor, and touch its test probe to the other resistor lead in the manner shown in Fig. *27*, so as to short out the resistor. Read the meter on scale I_M, and record your results (the meter reading and the current in ma.) on the second line of Table *19* as the plate current for the condition of —1.5 volts C bias and *zero* grid circuit resistance. Remove the test probe and allow it to rest on the table now without touching the chassis or any other part of the circuit, but leave the alligator clip on the other resistor lead.

Remove the lead of the 6.8-megohm resistor from the —9C terminal and connect this lead now to the —7½C terminal without changing any other connections. Read the meter on scale I_M and record your results on the third line of Table *19* as the plate current for zero C bias voltage and a grid circuit resistance of 6.8 megohms.

Now short out the 6.8-megohm re-

C BIAS VOLTAGE IN VOLTS	GRID CIRCUIT RESISTANCE IN MEGOHMS	YOUR METER READING ON SCALE I_M	YOUR PLATE CURRENT VALUE IN MA. (METER READING X 3)	N.R.I. METER READING ON SCALE I_M	N.R.I. PLATE CURRENT VALUE IN MA. (METER READING X 3)
−1.5	6.7	1.7	5.1	1.8	5.4
−1.5	0	1.8	5.4	1.8	5.4
0	6.7	2.4	7.2	2.5	7.5
0	0	2.4	7.2	2.5+	7.5+
+1.5	6.7	2.4+	7.2+	2.7	8.1
+1.5	0	3+	9+	3+	9+
+3	6.7	2.5	7.5	2.7	8.1
+4.5	6.7	2.5	7.5	2.7	8.1

TABLE 19. Record your results for Experiment 19 here. A "+" sign *following* a value indicates that it was slightly *more* than the value given.

1.-1.6

sistor temporarily with the test lead, read the meter on scale I_M, and record your results in Table *19* as the plate current for zero C bias and zero grid circuit resistance. Now remove the short across the resistor.

Remove the lead of the 6.8-megohm resistor from the —7½C terminal and place this resistor lead on the —6C terminal. Read the meter on scale I_M, record your results in Table *19* as the plate current for +1.5 volts C bias and a grid circuit resistance of 6.7 megohms.

FIG. 27. Method of using a test lead to short out temporarily the grid resistor employed in Experiment 19.

Now short the resistor with the test lead, read the meter on scale I_M, and record your results in Table *19* as the plate current for +1.5 volts C bias and zero grid current resistance. Now remove the test lead entirely from your circuit, since it will no longer be used in this experiment.

Remove the lead of the 6.8-megohm resistor from the —6C terminal, and place this lead on the —4½C terminal. Read the meter on scale I_M, and record your results in Table *19* as the plate current for +3 volts C bias and 6.8 megohms grid circuit resistance. The resistor should not be shorted when this C bias voltage is used because this would make the meter read off-scale.

Remove the lead of the 6.8-megohm resistor from the —4½C terminal and place this lead on the —3C terminal. Read the meter on scale I_M, and record your results in Table *19* as the plate current for 4.5 volts C bias and 6.7 megohms grid circuit resistance. Now remove the vacuum tube from its socket.

Discussion: For your first measurement, in this experiment, you make the grid 1.5 volts negative with respect to the cathode by connecting the cathode (filament) to the —7½C terminal of the C battery and by connecting the grid to the —9C terminal, which it 1.5 volts negative with respect to the —7½C terminal. (Instead of saying that the grid is 1.5 volts negative with respect to the cathode, technicians commonly say that they are using a *—1.5 volt C bias,* or a grid voltage of —1.5 volts.)

When the grid is made negative in this manner, it repels rather than attracts electrons, and consequently there is no electron flow in the grid circuit. You proved this by shorting the grid circuit resistance; if grid current did exist, it would flow through the grid resistor and produce across this resistor a voltage drop. Shorting of the resistor would remove this voltage drop from the grid circuit and change the resultant voltage on the grid, making the plate current change.

You found, however, that shorting

of the grid resistor did not noticeably affect the plate current as indicated by the meter; this means that no grid current was flowing in your circuit. Actually, the grid-cathode path in a tube acts as an infinitely high resistance when a negative C bias is used, just as does the plate-cathode path when the plate is made negative with respect to the cathode (you proved this latter statement in Step 3 of Experiment 17).

Careful inspection of your circuit when you connect the resistor lead to the —7½C terminal will show you that now both the grid and the cathode of your tube are connected to the same terminal. This means that you are employing zero C bias, and the grid is therefore at cathode potential. Under this condition, the grid neither attracts nor repels electrons, and again we would expect that there would be no appreciable amount of grid circuit current. We obtain a higher plate current reading for zero bias than for —1.5 volts bias, simply because more electrons can get through the grid wires to the plate when the grid is no longer repelling them.

When using zero C bias, you again find that shorting the grid resistor has no great effect upon the meter reading. This proves definitely that there is no appreciable amount of grid circuit current flowing.*

When you make the grid 1.5 volts positive with respect to the cathode by connecting the resistor lead to the —6C terminal (this terminal is 1.5 volts positive with respect to the —7½C terminal to which the cathode is connected), the grid attracts some of the electrons which are emitted from the cathode. Those electrons which reach the grid travel through the 6.8-megohm grid circuit resistor in their way to the C bias battery, developing across this resistor a voltage drop which acts in series with that provided by the C bias battery but is of opposite polarity.

In other words, the voltage drop across the resistor neutralizes the voltage provided by the C bias battery, reducing the positive C bias value which is actually acting on the grid. As a result, the grid-cathode path through the tube does not get the full voltage provided by the C battery when the resistor is in the circuit. Cutting out the grid resistor proves this fact, for with the resistor removed, the meter reading increases noticeably.

Increasing the positive C bias to 3 volts, with the 6.8-megohm resistor in the grid circuit, does not give any more plate current than did a +1.5 volt C bias. The reason for this is simply that making the grid more positive in this manner causes it to attract more electrons, and the resulting increase in electron flow through the grid resistor increases the voltage drop across this resistor and completely neutralizes the increase in C bias voltage. We secure the same

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* You may note a slight increase in the meter reading when shorting the resistor while using zero bias. This is due chiefly to a contact potential which exists between dissimilar metals in the grid circuit and in the grid lead inside the tube; this contact potential makes the grid slightly positive with respect to the cathode when the grid resistor is shorted out. Another reason for the increase is the fact that some electrons will be headed straight for grid wires and will hit these wires. When the grid resistor is present, these electrons travel through it and develop across it a small negative C bias. Shorting the resistor shorts out this bias, thus making the grid swing a small amount more positive.

On the other hand, you may note a slight decrease in the meter reading due to gas in the tube or to dirt between tube terminals. If wiping the tube base and tube socket with a cloth has no effect, continue with your experiments. Small decreases (or increases) in the meter reading can be overlooked.

effect with a +4.5 volt C bias; in other words, all positive C bias voltages give essentially the same plate current reading when the 6.8-megohm resistor is in the circuit.

Of course, removing the resistor would allow the full voltage of the C battery to be applied to the grid; we cannot do this for the +3 and +4.5 volt bias values, however, because the resulting plate current would be way higher than the range of our meter, and would possibly damage the meter and the tube.

Practical Extra Information. In some radio circuits, both positive and negative C bias voltages are applied to the grid. There is no objection to this practice as long as the vacuum tube is designed to handle high plate current values and the grid circuit is so designed that it will not distort the radio signal. Whenever the grid circuit draws current, the source of grid voltage must supply a certain amount of power.

As a general rule, the control grids of the vacuum tubes employed in radio receivers are seldom driven positive, and therefore grid current is seldom present. An exception to this occurs in the case of certain power output tubes, which are intentionally driven positive to obtain increased audio output power.

Another exception occurs in the case of oscillator circuits; here the grid often is purposely allowed to become positive, but the circuit itself is so designed that it introduces automatically a negative bias which keeps the plate current down to a safe and useful value. This is done simply by employing the proper value of grid resistor, for as you learned in this experiment, a grid resistor can develop a voltage which will counteract an applied positive voltage on the grid. We will use this same grid resistor scheme in the NRI Tester as a precaution against damage to the tube and meter in the event that the grid of the tube is accidentally driven positive.

Instructions for Report Statement No. 19. After completing this experiment and studying the discussion, take one additional reading. With your apparatus set up as it was for the last measurement in this experiment (with the 6.8-megohm grid resistance in the circuit, a plate voltage of 45 volts, and a C bias of +4.5 volts obtained by having the grid resistor lead on —3C while —B is connected to —7½C), reduce the plate voltage from 45 volts to 22.5 volts by moving the plate lead (the lead which goes to meter terminal *15*) from +45 to +22½. Read the meter on scale I_M and record the value in Report Statement No. 19, then multiply your value by 3 to get the actual plate current in ma. for 22.5 volts on the plate, and record this also in the report statement. Finally, pull out the tube.

EXPERIMENT 20

Purpose. **To secure data and prepare graphs which will show the grid voltage-plate current characteristics of your type 1C5GT vacuum tube when connected as a triode and when connected as a pentode under three different sets of operating conditions.**

Step 1. To secure the E_g-I_p characteristic curve for your tube when operated as a triode with a plate voltage of 45 volts, reconnect the tube and battery into the circuit shown in Fig. *23.* The connections are shown in pictorial form in Fig. *24,* but by now you should be able to follow semi-pictorial diagrams like that in Fig. *23B* and depend upon the photographs and pictorial diagrams only for checking purposes. For the first reading, set the C bias at —9 volts by placing on terminal —9C the lead which comes from chassis hole *d* (this lead is shown on +C in Fig. *23B).* Read the meter on scale I_M, and record your results (both the meter reading and the actual current in ma., which is three times the meter reading) on the first line of Table *20A* as the plate current for a C bias voltage of —9 volts.

Move the control grid lead (the one coming from hole *d)* in turn to —7½C, —6C, —4½C, —3C, —1½C and +C, read the meter on scale I_M in each case, and record the meter readings and the actual current values on the correct lines in Table *20A.* Since the cathode of the tube is connected to +C in this case, the battery markings are also the C bias voltages, with +C giving zero C bias voltage because the cathode is also connected to +C. In other words, when the lead from *d* is connected to —4½C, you are using a C bias voltage of —4.5 volts.

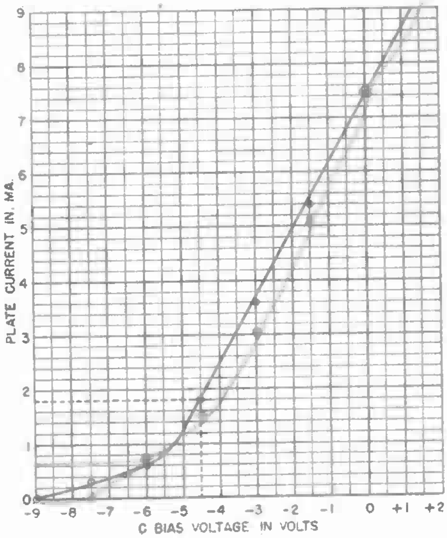
To secure a positive C bias voltage of 1.5 volts, remove from +C the lead which goes to —B, and connect this lead instead to —1½C, so —B and —1½C are now connected together. Leave the control grid lead on +C. Read the meter on scale I_M, and record your result in Table *20A* as the plate current for a bias voltage of +1.5 volts.

You now have meter readings for C bias voltages ranging from —9 volts to +1.5 volts in 1.5-volt steps. Plot these values on Graph *20A* to secure the E_g-I_p characteristic curve for your tube when used as a triode. Do this in the following manner for each measured value:

Locate on the vertical scale at the

C BIAS VOLTAGE IN VOLTS	YOUR METER READING ON SCALE I_M	YOUR PLATE CURRENT IN MA.	N.R.I. METER READING ON SCALE I_M	N.R.I. PLATE CURRENT IN MA.
−9	0	0	0	0
−7.5	0+	0+	.1	.3
−6	2.5	7.5	.2	.6
−4.5	[illegible]	1.5	.6	1.8
−3	1	3	1.2	3.6
−1.5	1.7	5.1	1.8	5.4
0	2.5	7.5	2.5	7.5
+1.5	3+	9+	3+	9+

TABLE 20A. Record your results for Step 1 of Experiment 20 here. Corresponding values which were obtained in the NRI laboratory, along with the curve representing these values on the graph at the right, are presented here merely for comparison purposes. Your own values may be different.



GRAPH 20A. Plot on this graph the results you obtain in Step 1 of Experiment 20, and connect the points together to give a smooth curve. This will then be the characteristic curve of your type 1C5GT tube when operated as a triode with a plate voltage of 45 volts and no plate load.

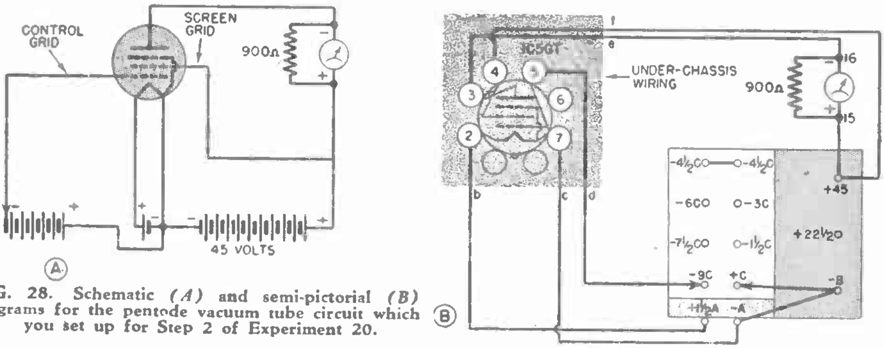


FIG. 28. Schematic (*A*) and semi-pictorial (*B*) diagrams for the pentode vacuum tube circuit which you set up for Step 2 of Experiment 20.

left the measured plate current value in milliamperes. Draw a light horizontal pencil line across the entire graph, passing through this current value on the scale. Now locate on the horizontal scale at the bottom of the graph the C bias voltage which gave you that current value, and draw a vertical pencil line upward from this C bias value. Where the two lines intersect, make a dot with your pencil. This dot now represents the current reading obtained for the C bias voltage in question.

In the same manner, plot on this graph each other reading which you obtained in Step 1. After you have plotted a few values, you will find that you can trace along the horizontal and vertical lines with your pencil and place the dots in their correct positions without actually drawing in the horizontal and vertical pencil lines. Finally, draw a smooth freehand curve which passes through or near the dots which you placed on the graph.

To illustrate this process of plotting values on a graph, we have plotted with small circles connected by a thin solid line the results obtained in the NRI laboratory for this experiment. The horizontal and vertical lines for one point, corresponding to a C bias voltage of 4.5 volts and our plate current reading of 1.8 ma., are indicated as dash-dash lines to show you how they are used to locate a point on the graph. *You are not expected to get the same values or the same curve.*

Step 2. To secure the E_g-I_p characteristic curve for your pentode tube when operated in the circuit shown in

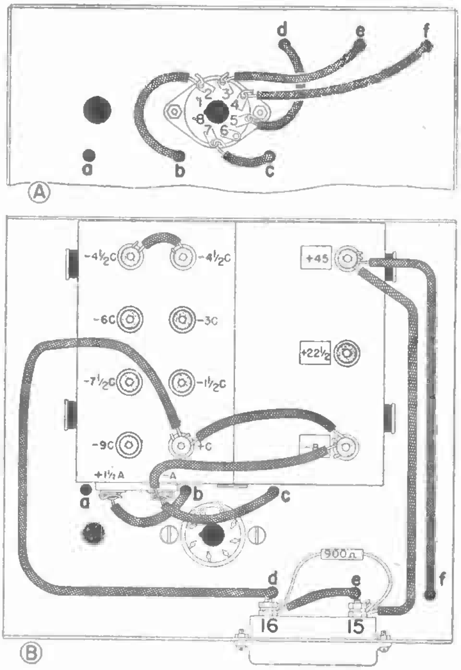


FIG. 29. Connections under the chassis for Step 2 of Experiment 20 should be as shown at *A*. Since the parts under the chassis are now wired according to Fig. *24*, simply remove the wire which connected terminals *3* and *4*, and run a wire through chassis hole *f* to terminal *4*. Battery connections are shown at *B*. Note that while the grid lead is shown + C, the first measurement is made with a bias of —9 volts. See Fig. *28*.

28A, so that 45 volts is applied directly to the screen grid and the same 45 volts is applied to the plate through the 2,000-ohm meter shunted by the 910-ohm resistor, remove the tube from its socket and change the wiring of your circuit in accordance with the semi-pictorial diagram in Fig. *28B*. This will make the wiring appear as shown in Figs. *29A* and *29B*. Only two changes are necessary under the chassis; the bare wire which connected tube socket terminals *3* and *4* is removed, and a 14-inch long wire is brought through hole *f* and connected to tube socket terminal *4* by means of a soldered temporary hook joint. Above the chassis, the changes involved are connecting to the +45 battery terminal the wire which comes up through hole *f*, and moving the lead on —1½C back to +C.

For the first reading, place the control grid lead (coming up from hole *d)* on terminal —9C. Insert the tube in its socket, read the meter on scale I_M, and record your results in Table *20B* as the plate current for a C bias voltage of —9 volts. (Remember that the meter readings on scale I_M must be multiplied by 3 to get the current in ma. when the 910-ohm shunt resistor is being used across the meter.)

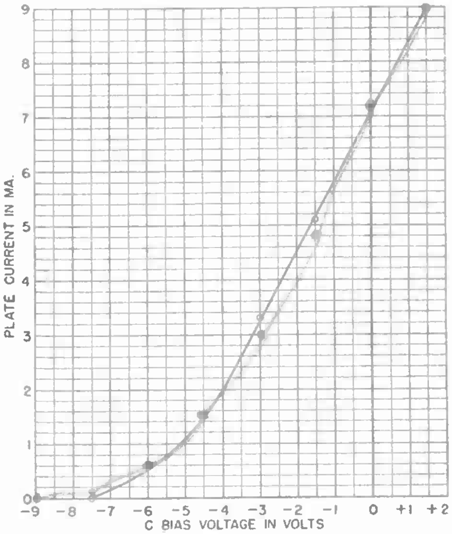
Move the control grid lead (coming through hole *d)* in turn to —7½C, —6C, —4½C, —3C, —1½C and +C; read the meter in each case and record your results in Table *20B*. The value marked on the battery terminal will be the C bias voltage in these cases, since the cathode is connected to +C.

To secure a C bias of +1.5 volts, connect now to +C the wire from hole *d*. Remove from +C the lead which goes to —B, and connnect this 7-inch lead instead to —1½C. Read the meter on scale I_M, and record your results in Table *20B*.

Plot your results for Step 2 on

C BIAS VOLTAGE IN VOLTS	YOUR METER READING ON SCALE I_M	YOUR PLATE CURRENT IN MA.	N.R.I. METER READING ON SCALE I_M	N.R.I. PLATE CURRENT IN MA.
-9	0	0	0	0
-7.5	.1	.3	0	0
-6	.2	.6	.2	.6
-4.5	.5	1.5	.5	1.5
-3	1	3	1.1	3.3
-1.5	1.6	4.8	1.7	5.1
0	2.4	7.2	2.4	7.2
+1.5	3.0	9.0	3.0	9.0

TABLE 20B. Record your results for Step 2 of Experiment 20 here. Remember that your own values are not expected to be the same as the NRI values given here for comparison purposes.



GRAPH 20B. Plot on this graph the results you obtain in Step 2 of Experiment 20, and connect the points together to give a smooth curve. This will then be the characteristic curve of your type 1C5GT tube when operated as a pentode with plate and screen grid voltages of 45 volts; no plate load.

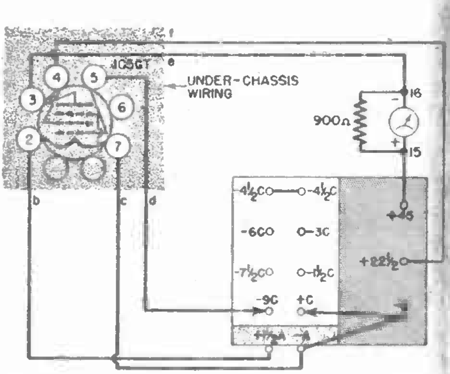


FIG. 30. Semi-pictorial wiring diagram showing all connections for Step 3 of Experiment 20. The only changes required to make your set-up coincide with this are moving of the screen grid lead (coming through hole *f*) from +45 to +22½, and returning to +C the lead coming from —B.

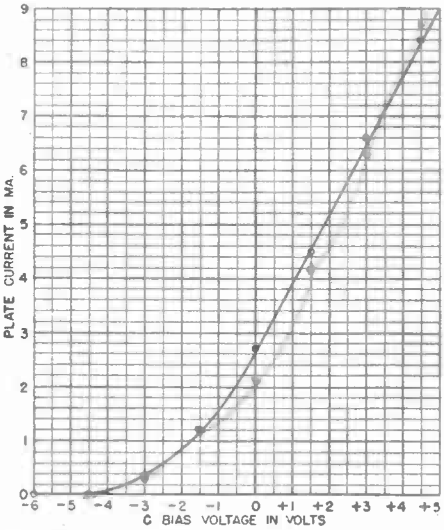
Graph *20B*, then draw a smooth curve passing through or near your points.

Step 3. To determine the effect of a lower screen grid voltage value upon the E_g*-*I_p *characteristic curve of a pentode tube being operated with a plate voltage of 45 volts,* move the screen grid lead (coming up through hole *f*) from the +45 terminal to the +22½ terminal of the battery, as in Fig. *30*. Reconnect back to +C the lead now on —1½C, as shown in Fig. *30*, repeat each measurement indicated in Step 2, and record your results in Table *20C*. Make two additional measurements; first use a C bias of +3 volts by moving from —1½C to —3C the 7-inch lead which goes to —B, while leaving the hole *d* lead on +C. Next, use a C bias of +4.5 volts by moving from —3C to —4.5C the 7-inch lead which goes to —B, leaving the hole *d* lead still on +C.

Step 4. To determine the effect of a plate load resistance upon the E_g*-*I_p *characteristic curve of a pentode tube when operated with plate and screen grid voltages of 45 volts as indicated in the circuit of Fig. 31A,* connect an 18,000-ohm resistor in series with the meter as indicated in Fig. *31B*. This is done by using ter-

C BIAS VOLTAGE IN VOLTS	YOUR METER READING ON SCALE I_M	YOUR PLATE CURRENT IN MA.	N.R.I. METER READING ON SCALE I_M	N.R.I. PLATE CURRENT IN MA.
−9	0	0	0	0
−7.5	0	0	0	0
−6	0	0	0	0
−4.5	0	6	0	0
−3	.1	.3	.1	.3
−1.5	.4	1.2	.4	1.2
0	.7	2.1	.9	2.7
+1.5	1.4	4.2	1.5	4.5
+3	2.1	6.3	2.2	6.6
+4.5	2.9	8.7	2.8	8.4

TABLE 20C. Record your results for Step 3 of Experiment 20 here. Remember that your own values are not expected to be the same as the NRI values given here for comparison purposes.



GRAPH 20C. Plot on this graph the results you obtain in Step 3 of Experiment 20, and connect the points together to give a smooth curve. This will be the characteristic curve of your type 1C5GT tube when operated as a pentode with a plate voltage of 45, a screen grid voltage of 22.5, and no plate load.

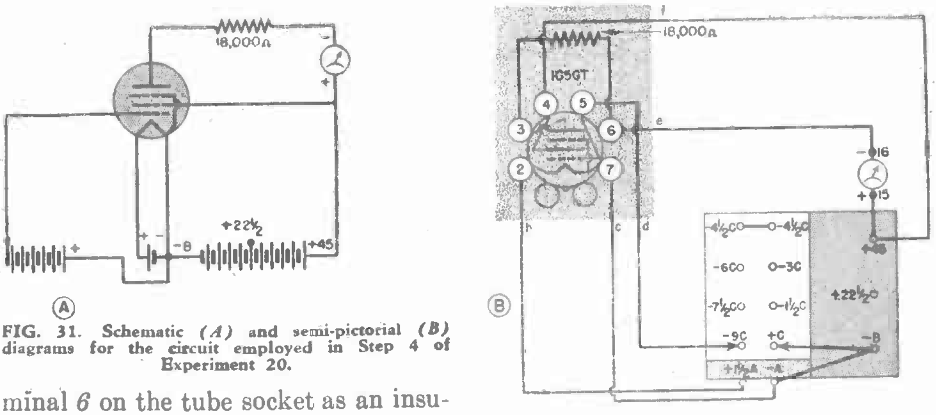


FIG. 31. Schematic *(A)* and semi-pictorial *(B)* diagrams for the circuit employed in Step 4 of Experiment 20.

minal *6* on the tube socket as an insulated support for one resistor lead. The actual connections under the socket are shown in Fig. *32;* observe that the wire coming through hole *e* has been moved from terminal *3* to terminal *6*, and the 18,000-ohm resistor has been connected between terminals *3* and *6* by means of temporary hook joints. Now disconnect the 910-ohm shunt resistor from meter terminals *15* and *16* so that the meter will read current values in ma. directly on scale I_M. Vary the C bias voltage value from —9 volts to +4.5 volts in 1.5-volt steps by following exactly the same procedure employed in Steps 2 and 3, and read the meter on scale I_M in each case. Record your results in Table *20D*, and plot the results on Graph *20D*.

Step 5. Prepare the parts for assembly of the NRI Tester by removing the vacuum tube from its socket, disconnecting all battery leads, then untying the black lace and removing *the entire group* of batteries all at once. Next, unsolder the leads on the meter terminals, unsolder all connections to the tube socket, then pull the leads out through the holes in the chassis. Straighten out the hooks at the ends of wires only when necessary to pull the wire through a hole, for you will usually have to form the hooks again when using the wire later. Separate the panel from the chassis by removing the three screws at the bottom of the panel, but leave the meter and jack strip mounted on the panel, and leave the tube socket on the chassis. Remove surplus solder from the meter terminal lugs, but do not remove these lugs. Remove surplus solder from the tube socket lugs; if difficulty is encountered in doing this, remove the socket temporarily from the chassis so you can shake or tap off the surplus solder from each lug in turn without getting it into the prong holes.

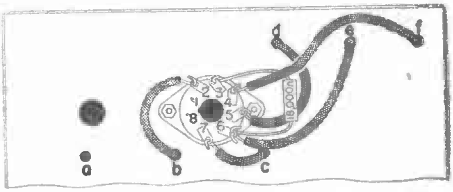


FIG. 32. Connections under the chassis for Step 4 of Experiment 20 should be as shown here. To make your circuit conform with this, move the plate lead (coming through hole *e)* from terminal *3* to terminal *6*, and connect an 18,000-ohm resistor between terminals *3* and *6*.

Discussion: First of all, you should realize that the variations which occur normally in vacuum tubes and radio parts during manufacture make it practically impossible for you to secure exactly the same values and the same curves which we secured in the

NRI laboratory. Our values and our curves are shown merely for comparison purposes and to illustrate the procedure for plotting this type of data on graphs. You can be sure your work is entirely satisfactory if you secure merely the same general shape or slant of curves, but remember that even this shape or slant can vary considerably from that shown on a particular graph.

One thing which you should realize after performing this experiment is that the plate current does *not* always increase *uniformly* with changes in grid voltage. In other words, as the negative bias on the grid is reduced, the plate current will increase faster than it did when working with highly negative grid bias values, and the curve will tend to bend upward. Study your curves carefully, giving particular attention to the grid bias values at which the curves bend upward.

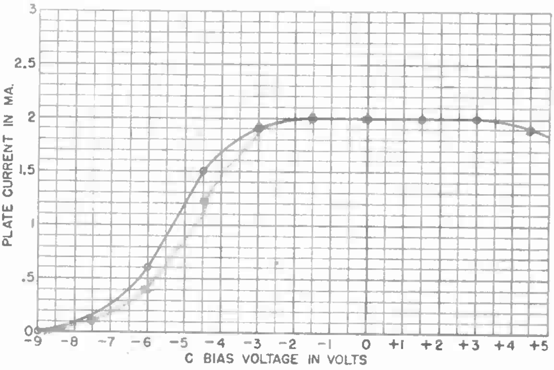
In Step 1 you take readings of plate current for various positive and negative C bias values while your type 1C5GT tube is connected as a triode without a plate load resistance. When you plot your values on Graph *20A* and connect the points together, you secure a curve which contains all of the information present in Table *20A*.

In addition, however, the curve which you draw can give you hundreds of other plate current values for C bias voltages in between the values at which you made measurements. Thus, if you wanted to find out what the plate current would be for a C bias voltage of —4 volts, you would simply trace upward from —4 on the horizontal scale until you came to the curve, then trace horizontally to the left from that point on the curve and read the value of plate current where you intersect the vertical scale of current.

It is this characteristic of a graph, wherein you can estimate in-between

C BIAS VOLTAGE IN VOLTS	YOUR PLATE CURRENT IN MA. (READ DIRECTLY ON SCALE I_M)	N.R.I. PLATE CURRENT IN MA (READ DIRECTLY ON SCALE I_M)
−9	0	0
−7.5	.1	.1
−6	.4	.6
−4.5	1.3	1.5
−3	1.9	1.9
−1.5	2	2
0	2	2
+1.5	2	2
+3	2	2
+4.5	1.9	1.9

TABLE 20D (left). Record your results for Step 4 of Experiment 20 here. Reemmber that your own values are not expected to be the same as the NRI values given here for comparison purposes.



GRAPH 20D (above). Plot on this graph the results you obtain in Step 4 of Experiment 20, and connect the points together to give a smooth curve. This will be the characteristic curve of your type 1C5GT tube when operated as a pentode with a plate voltage of 45 volts, a screen grid voltage of 45 volts, and an 18,000-ohm plate load.

values with accuracy, which makes graphs so valuable in radio work.

When you connect your tube as a pentode in Step 2, with 45 volts on both the plate and screen grid, you would naturally expect to secure a slightly different characteristic curve than for triode operation. The curves in Graphs *20A* and *20B* resemble each other quite closely under the conditions of this experiment, with only minor differences in corresponding values, but these triode and pentode characteristics of the 1C5GT tube may differ considerably under other operating conditions.

Reducing the screen grid voltage on your pentode tube to 22.5 volts lessens the effectiveness of the screen grid, with the result that the E_g-I_p characteristics are altered considerably. The NRI curve in Graph *20C* differs quite appreciably from the previous two curves, as you can readily see by comparing them. The curve which you obtained for Step 3 should likewise differ from the previous curves in that it is shifted to the right on your graph with respect to values on the horizontal scale. The shape of the curve is still essentially the same as for Steps 1 and 2.

In Step 4, the 18,000-ohm resistor is placed in the plate circuit to limit plate current and duplicate more closely the actual operating conditions under which this tube would be used. The 900-ohm meter shunt is removed to improve the accuracy of readings, since the plate load resistor will limit the meter current to values considerably below the full-scale value of 3 ma. Now you secure a radically different characteristic curve, with a somewhat flat top. This curve is actually more useful to a radio man than the preceding three curves, for it more nearly represents actual conditions under which vacuum tubes are operated in radio circuits.

Instructions for Report Statement No. 20. To show the importance of graphs for giving operating values *in between* those actually measured for a vacuum tube, refer to your own characteristic curve for the type 1C5GT tube operating as a pentode with no plate load (this is Graph *20C* on page 50), and determine the plate current for a C bias of —1 volt. Do this by locating the —1 point on the horizontal scale, tracing vertically upward from this until you intersect your own curve, then tracing horizontally to the left from the intersection so you can read the plate current value in ma. on the vertical scale. Record the value in Report Statement No. 20 on the last page, and send in the page for grading.

IMPORTANT

These instructions may save you unnecessary trouble.

Send in your Report Statement for grading as soon as you finish Experiment 20.

DO NOT BUILD the NRI Tester until you have received a *passing grade* (A, B, or C) for this work. This will avoid the necessity of dismantling the tester in order to repeat any of the experiments for which you didn't get the right answers.

How To Assemble the NRI Tester

THE NRI Tester which you are now ready to build *(provided you have obtained a passing grade on Experiments 11-20)* is a complete and modern test meter designed to meet the requirements of professional radio servicemen for many years to come. This instrument, when assembled and calibrated according to the instructions given in this manual, will allow you to make many different measurements in radio circuits.

Actually, the NRI Tester is a combination vacuum tube voltmeter and multimeter which provides at least eighteen separate and distinct ranges. You will be able to measure a.c. voltages up to 550 volts in four ranges, d.c. voltages up to 450 volts in four ranges, direct current values up to 45 milliamperes in two ranges, resistance values up to 100 megohms in four ranges, and output measurements of radio receivers in four ranges.

Later, you will be provided with a headphone which can be plugged into the NRI Tester; with this combination you can listen to the quality and strength of audio signals anywhere in a radio receiver, thereby speeding up the location of defects which are causing distortion.

The sensitivity of the voltmeter ranges in the NRI Tester is quite high in comparison to that of other testers being used for service work. A sensitivity of 1,000 ohms-per-volt is considered satisfactory for most radio service work, but each d.c. voltage range in your NRI Tester has a sensitivity better than 20,000 ohms-per-volt. (Actually, on one range of your instrument, the sensitivity is well over 2,000,000 ohms-per-volt.) As a result, you can connect the NRI Tester to high-resistance circuits and make accurate voltage measurements without disturbing circuit conditions appreciably. Many of the measurements which are possible with the NRI Tester could not be made with ordinary meters.

The NRI Tester has been included in your practical demonstration course for several reasons. It gives you an opportunity to assemble a professional-quality test instrument yourself. It allows you to check circuit action and verify the various radio and electrical laws which are studied in your regular course. Finally, it gives you experience in using test instruments.

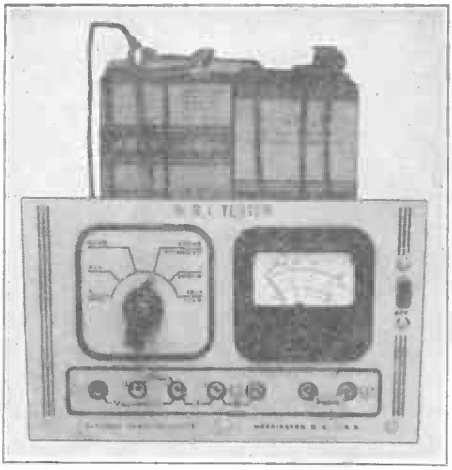


FIG. 33. Your NRI Tester should look like this after you have assembled it according to the simple step-by-step instructions in this manual, if you are using the specified Eveready batteries.

A completely assembled NRI Tester is shown in Fig. *33.* As you can readily see the panel layout is remarkably simple considering the number of uses which the instrument has. At the extreme right on the panel is the switch which turns the instrument on and off. Next to the switch is the special four-scale meter on which all values are read. On the upper left half of the panel is the selector switch, which automatically connects the meter into the test circuit you desire for a particular measurement.

Below the meter and selector switch is the jack strip into which you plug the test leads for various measurements. The two jacks at the extreme right are for the phone which you will receive later; the shorting strip shown in this view is plugged into these two jacks whenever the phone is not used.

Step-by-step instructions for assembling the NRI Tester will now be given. Follow through these instructions slowly and carefully, doing the very best work of which you are capable, for you will want your instrument to show professional workmanship in each and every soldered joint. To make sure you do not miss any steps, place a check mark alongside each completed step as you go along.

Plan to devote a number of evenings to the assembly of this instrument, for the success of the remainder of your practical demonstration course depends entirely upon your assembling this instrument properly. Remember that we are ready to help you with advice whenever you encounter difficulties or have trouble in understanding the instructions.

The complete circuit diagram of the NRI Tester is given in Fig. *34* for reference purposes, and need not be studied at this time.

Instructions for using the NRI Tester will be given progressively in later manuals, as the need arises for the various types of measurements which it makes.

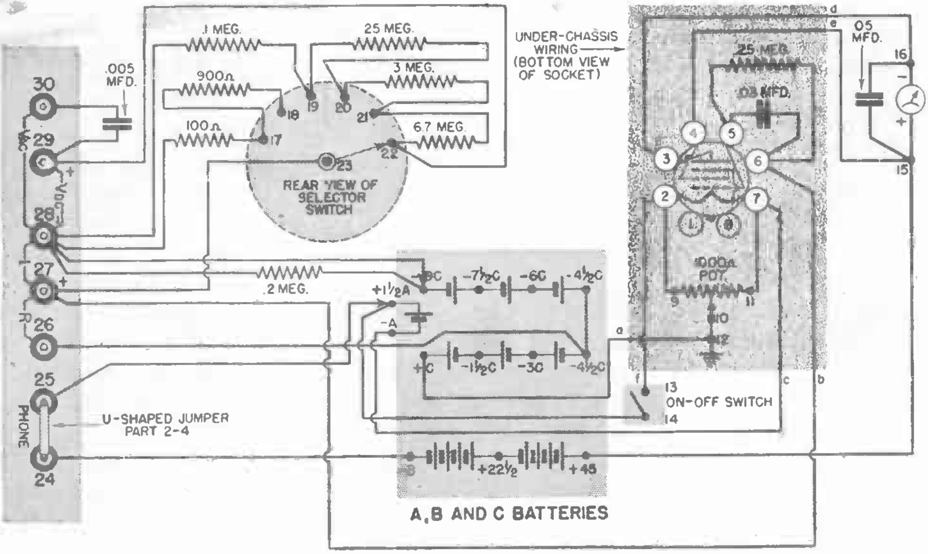


FIG. 34. Circuit diagram of the NRI Tester. This is presented here for reference and checking purposes: you will follow pictorial diagrams and photographs when assembling the unit. to minimize chances for errors. Note: The 6.7, .25, and .2-megohm resistors, and the 900-ohm resistor, shown above have been changed to 6.8, .24, and .22 megohms, and 910 ohms, as previously explained.

Mounting the Parts on the Front Panel

Step 1. To prepare for the preliminary mounting of parts on the panel, place before you the following parts:

Front panel (Part *2-2*) on which you have already mounted (in Experiment 11) the 0-3-ma. milliammeter with two soldering lugs (Parts *1-8A* and *1-8B*) and the 7-jack strip (Part *2-3*), with each terminal on these two parts identified by a number marked on the back of the panel in the manner shown in Fig. *6* in connection with Experiment 11 in this manual.

One ON-OFF power switch (Part *2-5*).

One 6-position rotary selector switch (Part *2-6*).

One bar knob for the selector switch (Part *2-8*).

Two ¼-inch long binder-head machine screws (Part *2-18A*) and two hexagonal nuts (Part *2-18B*).

At this same time, arrange before you the following tools and materials, which will be needed during the assembly of the NRI Tester.

Long-nose pliers.

Side-cutting pliers.

Ordinary pliers.

Medium-size screwdriver.

Small screwdriver.

Twelve-inch ruler.

Soldering iron and holder (Parts *1-1*, *1-2*).

Rosin-core solder (Part *1-3*).

Red push-back hook-up wire (Part *2-17*).

One short length of yellow rubber and cotton-covered wire (Part *1-7F*).

Step 2. Mount the rotary selector switch (Part *2-6*) on the panel in the following manner:

While holding the switch in one hand in the manner shown in Fig. *35*, proceed to bend outward with the thumb of your other hand each of the six soldering lugs located along the outer edge of the switch, until the lugs are flat with relation to the insulating material at the back of the switch. Do not bend the single inside lug. *Do not use pliers for this bending;* the lugs can easily be pushed over with your thumb, if you start from one end of the row of lugs.

Remove the ⅜-inch nut from the shaft of the switch, and push the shaft through panel hole *t* (Fig. *36*) from the rear so that it has the position shown in Fig. *37*. Replace the nut on the shaft which now projects through the front of the panel, and tighten the nut first with your fingers and then with ordinary pliers as shown in Fig. *38*, while using one hand to hold the selector switch in the position shown in Fig. *37* (so that end terminals *17* and *22* on this switch are both the same distance from the top of the panel). Be careful not to let the pliers slip and scratch the panel.

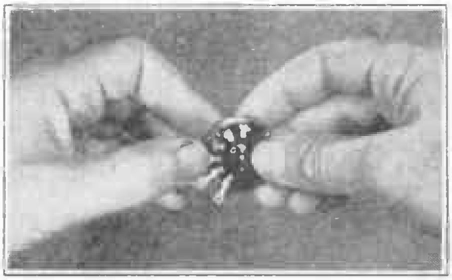


FIG. 35. Method of bending out the soldering lugs on the rotary selector switch (Part *2-6*). Press them outward with your thumb, one at a time, until all the outer lugs point outward like the spokes of a wheel. Do not bend the single center lug.

With a small screwdriver, loosen the set screw which is located in the thick end of the bar knob (Part *2-8*), place this knob over the shaft of the selector switch with the set screw next to the flat portion of the shaft, then tighten this set screw with your small screwdriver while pressing the knob toward the panel.

Rotate the selector switch knob as far as it will go in a counter-clockwise direction, so that the white line on the pointer of the knob is on the panel line marked *V MEG*. If the pointer is not exactly on this line

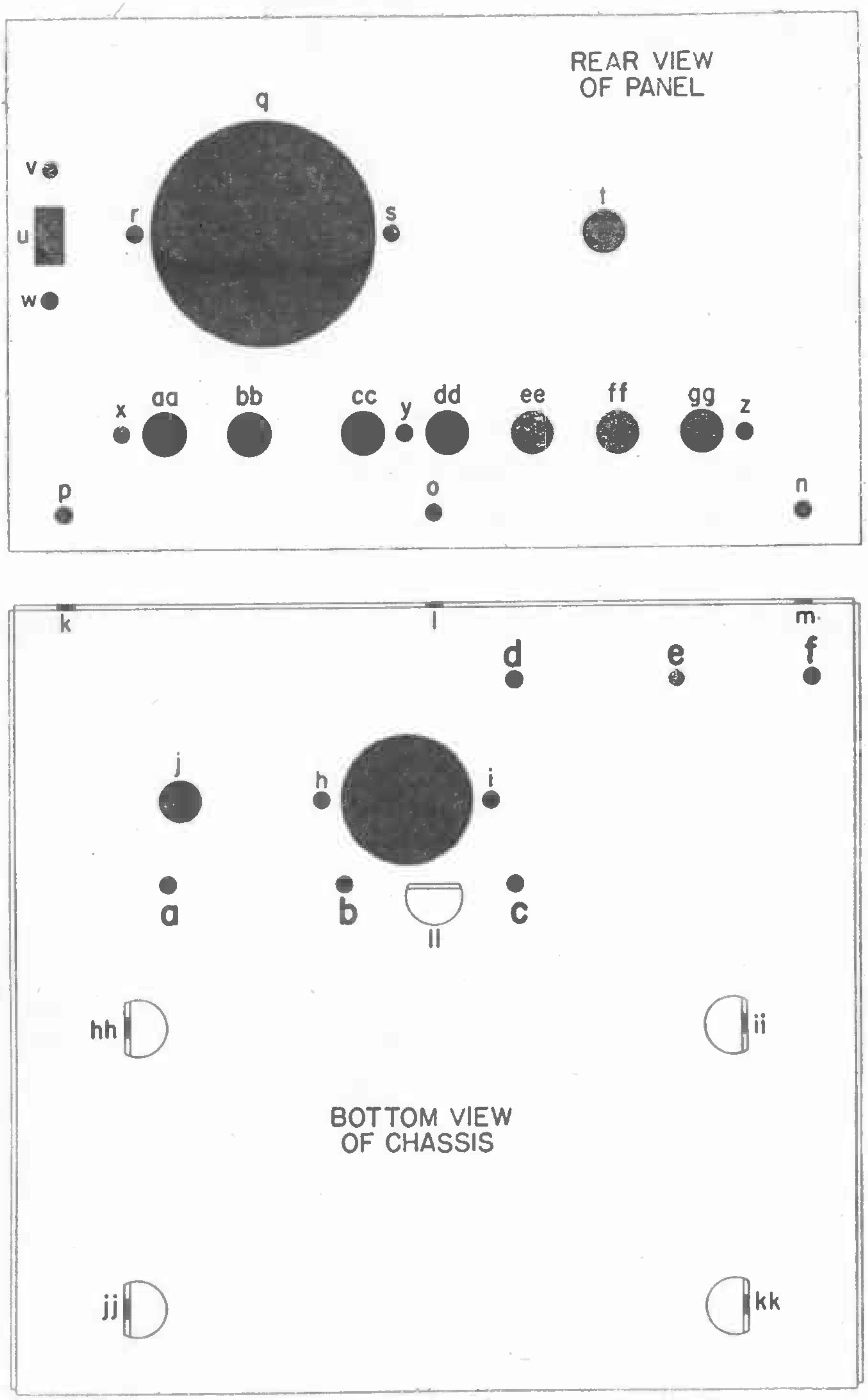


FIG. 36. Rear view of tester panel (above) and bottom view of chassis (below), with all holes identified by letters for convenience in referring to them. The only letters which are to be marked on your parts, however, are those identifying chassis holes, *a*, *b*, *c*, *d*, *e* and *f*. Use these diagrams as your guides for locating the other holes when mounting the parts.

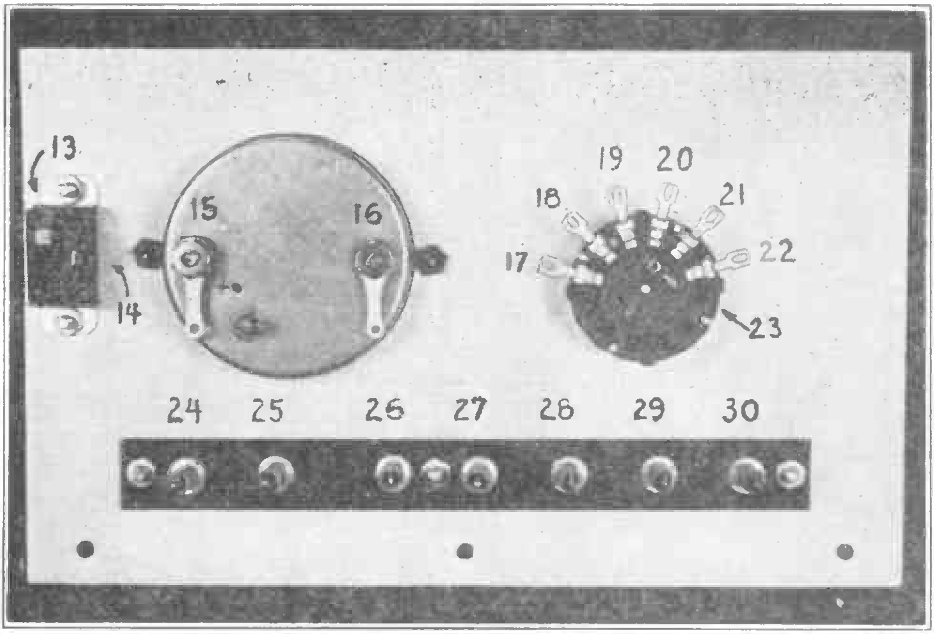


FIG. 37. The back of your tester panel should appear like this after you have mounted the selector switch and ON-OFF switch, as instructed in Steps 2 and 3. (The meter and jack strip were mounted as part of Experiment 11.) Number the various terminals on your own panel by marking them with crayon or pencil as shown in this view. Crayon markings can be wiped off with a cloth if errors in numbering are made.

when looking directly at it with your eyes on a level with the knob, grasp the back of the selector switch with your hand and rotate it firmly but slowly until the pointer is exactly on the line.

✓ *Step 3. Insert the ON-OFF power switch* (Part *2-5*) *in rectangular panel hole u* (Fig. *36*) *from the back of the panel* in the position which places the colored dot next to the panel notation *OFF*. (Flip the switch back and forth to find the dot, for it is visible in only one position of the sliding black button.)

Attach the switch to the panel with two binder - head machine screws (Part *2-18A*) and two hexagonal nuts (Part *2-18B*), with the heads of the screws at the front of the panel. Tighten each screw with a screwdriver while holding its nut with ordinary pliers.

✓ *Step 4. Complete the numbering of the terminals at the back of the panel* in the manner shown in Fig. *37*. Since the terminals for the meter and the jack strip were numbered in a previous experiment, this leaves only

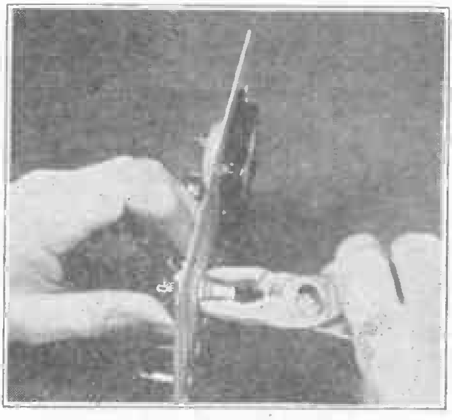


FIG. 38. Method of using ordinary pliers to tighten the nut on the rotary selector switch. Use the same technique for tightening the nut on the 1,000-ohm potentiometer.

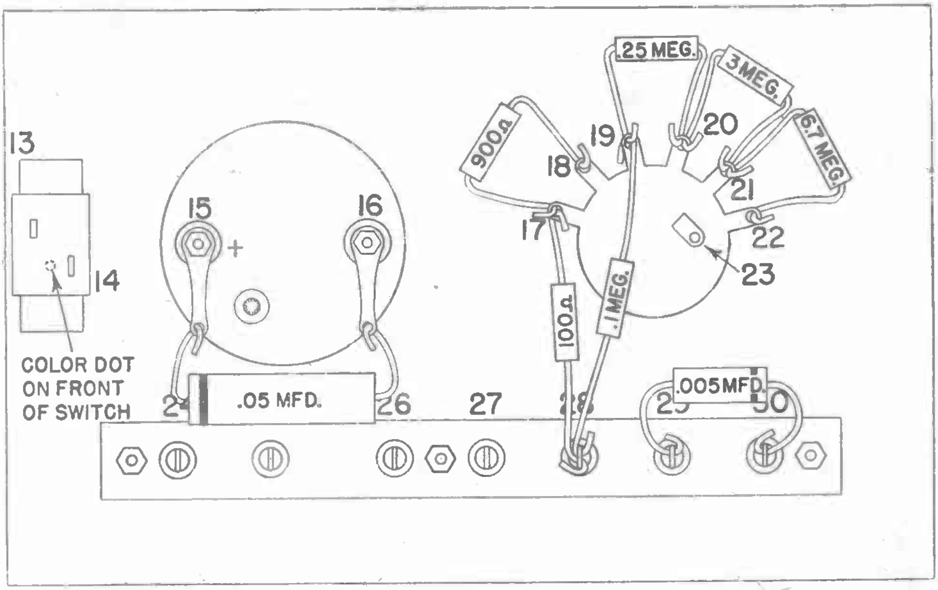


FIG. 39. Rear view of front panel, showing positions of all condensers and resistors. No soldered joints have been made yet. All hook joints should be closed when instructions for this are given in the text.

power switch terminals *13* and *14* and the selector switch terminals *17* to *23* to be numbered. Place these numbers carefully and neatly on the panel, as close as possible to each terminal, with your crayon pencil. Finally, place *on the top* of each jack the identifying number which you have previously placed on the back of the panel above the jack. This will simplify identification of the jacks while working with the panel facing you. Sharpen the crayon with your pocket knife when necessary.

Making Resistor and Condenser Connections on the Panel

✓ *Step 5. Locate and place before you on the table the following parts* from Radio Kits 1RK and 2RK-1:

One .05-mfd. tubular paper condenser (Part *1-13*).

One .24-megohm (240,000 ohms) fixed resistor. (Part *1-14*).

One .1-megohm (100,000 ohms) fixed resistor (Part *1-15*).

One 6.8-megohm fixed resistor (Part *2-11*).

One 3-megohm fixed resistor (Part *2-12*).

One 910-ohm fixed resistor (Part *2-14*).

One 100-ohm fixed resistor (Part *2-15*).

One .005-mfd. tubular paper condenser (Part *2-16*).

One .22-megohm (220,000 ohms) fixed resistor (Part *2-22*).

✓ *Step 6. Connect the .05-mfd. condenser* (Part *1-13*) *between meter terminals 15* and *16* by first shortening the leads with side-cutting pliers so that each lead is now 1 inch long. (Make marks on the leads with crayon after measuring with a ruler, and check each mark carefully before cutting so as not to get a lead too short.) Bend the leads with your fingers to the shapes shown in Fig. *39*, so that the condenser will fit under the meter and its wires will reach to the meter terminal lugs, with the *OUTSIDE FOIL* lead going to the + terminal (*15*). Now bend an open hook in the end of each lead with long-nose pliers, and hook these leads through the holes in lugs *15* and *16* from behind. Close the hooks with long-nose pliers, but do not solder the joints until instructed to do so. In many cases, two or more wires must be placed on a lug prior to soldering.

Step 7. Connect the .005 mfd. condenser (Part *2-16*) *between jack terminals 29 and 30,* by first shortening each condenser lead until it is 1 inch long. Bend the leads with your fingers in the manner shown in Fig. *39*. Insert the end of the *OUTSIDE FOIL* lead into the hole in lug *30,* insert the end of the other condenser lead into the hole in lug *29* from the opposite direction, then bend the leads to form closed hooks, as shown in Fig. *39*.

Step 8. Connect the 910-ohm resistor (Part *2-14*) *between selector switch terminals 17 and 18,* by first shortening each lead so that it is ⅞ inch long. Bend the leads with your fingers to the approximate shapes shown in Fig. *39*. Bend an open hook in each lead with long-nose pliers. Insert the leads in terminal lugs *17* and *18* from behind, then close the hooks and squeeze them just enough so the resistor will support itself above the selector switch, in the position shown in Fig. *39*.

Step 9. Connect a 100-ohm resistor (Part *2-15*) *between selector switch terminal 17 and jack terminal 28,* by first shortening each resistor lead so it is ⅞ inch long. Bend an open hook in one lead with long-nose pliers, hook this lead into the hole in terminal *17* from behind, and close the hook. Now bend a partial hook (a simple right-angle bend) in the other lead so that you can push this lead into the hole in jack terminal *28,* as indicated in Fig. *39,* but do not close the hook yet.

Step 10. Connect the .1-megohm resistor (Part *1-15*) *between selector switch terminal 19 and jack terminal 28,* by first shortening each resistor lead until it is 1¼ inches long. Bend the leads to the shapes shown in *Fig. 39* so that the resistor will be held away from the switch housing, bend an open hook in one lead, hook this through the hole in lug *28* alongside the resistor lead now in that lug, but do not close this hook yet. Now make a right-angle bend in the other lead on a level with the hole in lug *19,* push the lead through this hole from the front, and bend the lead with long-nose pliers to form a closed hook on this lug.

Step 11. Connect the .24-megohm resistor (Part *1-14*) *between selector switch terminals 19 and 20,* by first shortening each lead of this resistor until it is ⅞ inch long. Bend the leads with your fingers to the shapes shown in Fig. *39*. Bend an open hook in the end of each resistor lead. Hook these leads through the holes in lugs *19* and *20* respectively from behind, and squeeze the hooks just enough with long-nose pliers so the resistor will support itself as shown in Fig. *39*.

Step 12. Connect the 3-megohm resistor (Part *2-12*) *between selector switch terminals 20 and 21,* by first shortening each resistor lead until it is ⅞ inch long. Bend the leads as in Fig. *39*. Bend an open hook in the end of each lead. Insert the leads through the holes in lugs *20* and *21* from behind, then squeeze each hook with long-nose pliers. You will now have two leads in lug *20*.

Step 13. Connect the 6.8-megohm resistor (Part *2-11*) *between selector switch terminals 21 and 22,* by first shortening each resistor lead until it is ⅞ inch long. Bend the leads as in Fig. *39*. Bend a hook in the end of

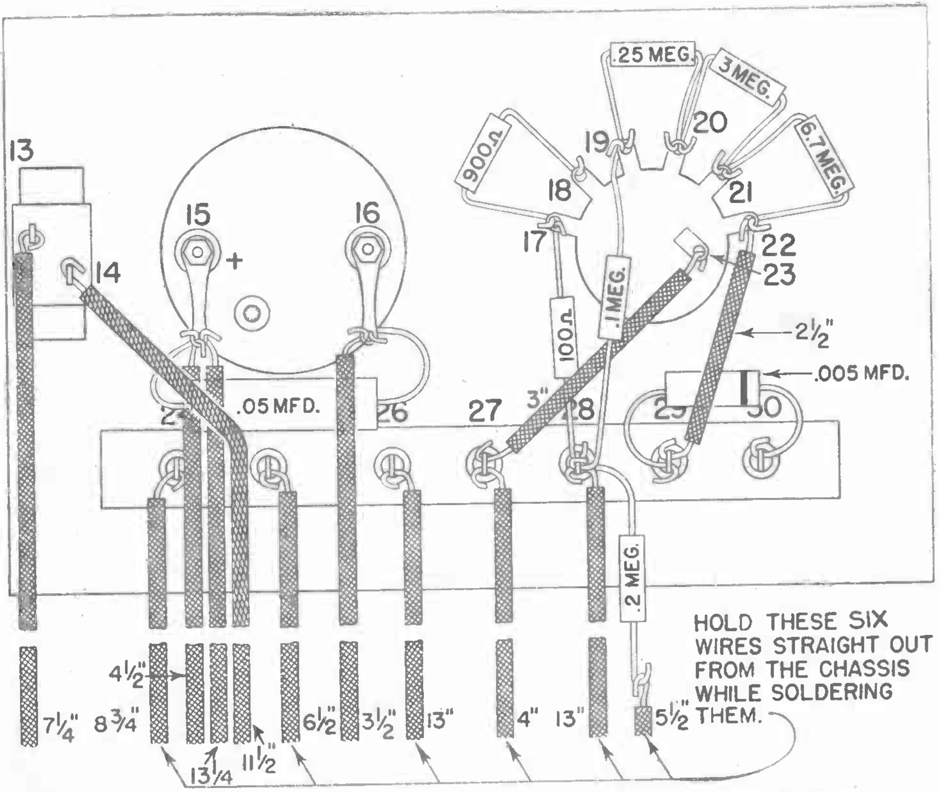


FIG. 40. Rear view of front panel after all leads and parts have been connected with permanent soldered hook joints. The length in inches to which you should cut each piece of hook-up wire is indicated alongside the wire. To save space in this manual and to simplify this diagram, the long leads are shown in shortened form below the panel. Each of the six long jack leads should be held at right angles to the panel while being soldered; these wires can then be bent to the right along the bottom of the panel so they will not interfere with your work. At this stage of the assembly, all joints should have *closed hooks* and be soldered exactly according to the instructions in the text.

each lead. Hook the leads through the holes in lugs *21* and *22* from behind, then squeeze each hook with long-nose pliers. The back of the panel of your NRI Tester should now appear exactly as shown in Fig. *39*.

Completing the Panel Connections

IMPORTANT: Lead lengths specified in these assembly instructions for the NRI Tester are based upon the dimensions of Eveready batteries. Cut your wires to these lengths even when using batteries having other dimensions, because you can easily shorten later any leads which are too long, or replace those few leads which might be too short.

Step 14. Heat your soldering iron now, for you will be using it soon. Cut a 4½-inch length of hook-up wire from the roll furnished you as Part *2-17*, push the insulation back from one end, bend a hook in this end, and insert this hook in the hole in meter lug *15* from behind, alongside the condenser lead already in this hole. Close the hook with pliers while holding the wire straight down along the panel as shown in Fig. *40*.

Now cut a 13¼-inch length of hook-up wire, push the insulation back from one end, bend a hook in that end, and insert this hook also in the hole in meter terminal lug *15*. Hold this wire straight down along the panel parallel to the other wire, then squeeze all three hooks which are in this lug. Solder this joint, using rosin-core solder. After the solder has hardened, push the insulation back toward the lug on each wire. Get the habit of pushing the insulation over exposed wire like this whenever using push-back wire.

Be sure to bend the lug away from the meter case so that there is at least a ¼-inch clearance between the joint and the case.

Step 15. Cut a 3½-inch length of hook-up wire, connect one end of it to meter lug *16* by means of a hook joint, squeeze the hook tight while holding the wire straight down along the panel as shown in Fig. *40,* then solder this joint. Finally, push the insulation on the wire up toward the joint if any wire is exposed below the joint, and bend the lug out ¼ inch.

Step 16. To connect together selector switch terminal 23 and jack terminal 27, cut a 3-inch length of hook-up wire, make a permanent hook joint with one end of this wire at terminal *23,* and solder this joint. Form a hook joint with the other end of the wire on terminal *27,* but do not solder this yet.

Step 17. Cut a 4-inch length of the stranded tinned rubber and cotton insulated wire (Part *1-7F,* left over from the first ten experiments), remove the insulation from both ends for a distance of about ¼ inch, then connect one end of it to jack terminal *27* with a permanent hook joint. Hold the wire perpendicular to the panel, and squeeze the hooks on both wires at this lug so the 4-inch wire will stand upright by itself when the panel is lying on the table, and solder the joint. (It is necessary to use the *1-7F* wire here because its rubber insulation prevents leakage.)

Step 18. Cut a 13-inch length of hook-up wire, form a hook in one end, and insert this hook in the hole in terminal *28* alongside the two hooks already there. Next, take the .22 megohm resistor (Part *2-22,* color-coded red, black and yellow on a brown body color), and connect a 5½-inch length of hook-up wire to the end of one resistor lead by means of a permanent soldered hook joint so as to lengthen this lead. Shorten the other resistor lead to a length of 1 inch, bend a hook in the end of this lead, and insert this hook also in the hole in terminal *28.* There should now be four leads in the hole in this terminal. Hold the 13-inch wire and the resistor straight out from the panel, squeeze each of the four hooks together with pliers, then solder this joint. Push the insulation on the wire toward the joint, then bend the 13-inch wire and the resistor lead to the right along the panel. (Take a glance at Fig. *42* now to see how the wires are bent to the right so they will be out of the way until needed again. Do not make sharp bends; keep each bend at least an inch away from its joint. Figure *40* merely shows the points to which the wires should be connected on the panel; it does *not* show the correct positions of those wires which extend below the panel and are left unconnected now.)

Step 19. Connect together terminals 22 and 29 by taking a 2½-inch length of hook-up wire, connecting one end to terminal *29* and connecting the other end to terminal *22* with permanent hook joints. Solder the joints at terminals *22* and *29.*

Step 20. Solder the joints at terminals 17, 18, 19, 20, 21 and 30 in turn, without placing any additional wires on these joints.

Step 21. Cut a 7¼-inch length of hook-up wire and solder one end of it *to power switch terminal 13 by means of a permanent hook joint,* while holding the wire parallel to the panel as shown in Fig. *40.*

Step 22. Cut an 11½-inch length of hook-up wire and solder one end of it to power switch terminal *14* by means of a permanent hook joint while holding the wire parallel to the panel and bending it as shown in Fig. *40.*

Step 23. Cut a 6½-inch length of hook-up wire, attach it to jack terminal *25* by means of a permanent hook joint, hold the wire straight out from the panel, squeeze the hook together so the wire will stay there, then solder this joint on lug *25.* Push the insulation back, then bend the wire to the right.

Step 24. Cut an 8¾-inch length of hook-up wire, attach it to jack terminal *24* by means of a permanent hook joint, hold the wire straight out from the panel, squeeze the hook together so the wire will stay there, then solder the joint. Push the insulation back over the wire, then bend the wire to the right.

Step 25. Cut a 13-inch length of hook-up wire, attach one end of it to terminal *26* by means of a permanent hook joint, hold the wire straight out from the panel, squeeze the hook together so the wire will stay up, then solder the joint. Push the insulation back over the wire, then bend the wire to the right.

You have now completed all wiring which is to go on the panel of the NRI Tester.

Making Chassis Connections

Step 26. Set the completed front panel aside for the time being, and place before you the following parts from Radio Kits 1RK and 2RK-1.

Metal Chassis (Part *1-11*) on which you mounted (in Experiment 9) the octal-type tube socket (Part *1-10*).

1,000-ohm potentiometer (Part *2-7*).

One 13/16-inch long soldering lug (Part *1-8C*).

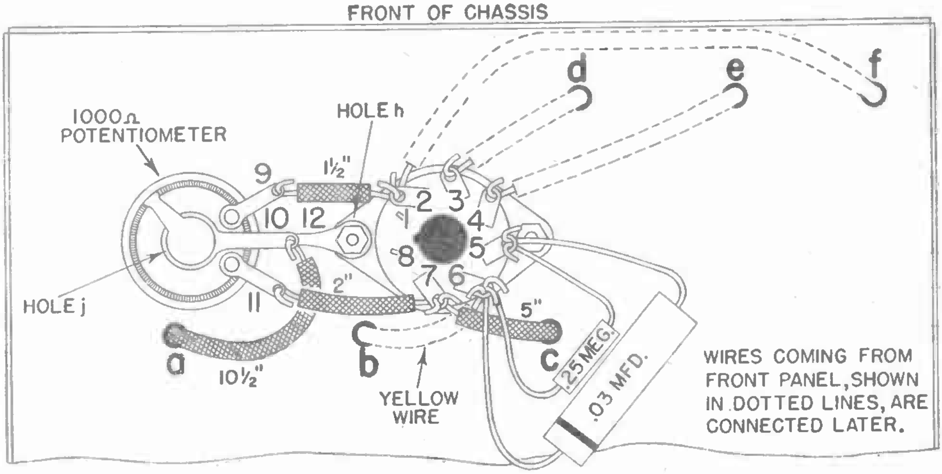
.24-megohm fixed resistor (Part *2-13*).

.03-mfd. tubular paper condenser (Part *1-12*).

45-inch length of black lace (Part *2-20*).

One grid cap clip (Part *2-21*).

Step 27. To mount the 1,000-ohm potentiometer (Part *2-7*) *on the chassis,* first remove the ⅜-inch hexagonal nut from the potentiometer shaft, in-



WIRES COMING FROM FRONT PANEL, SHOWN IN DOTTED LINES, ARE CONNECTED LATER.

FIG. 41. Bottom view of chassis, showing preliminary assembly of leads and wires. After the chassis is bolted to the panel, four wires from the panel will be run through holes *b, d, e* and *f* and connected to terminals *6, 3, 4* and *2,* respectively, as indicated by the dotted lines.

sert the shaft through chassis hole *j* (Fig. *41*) from the bottom, and replace the nut on the shaft which now projects from the top of the chassis. Hold the potentiometer with one hand in the position shown in Fig. *41,* so that the middle soldering lug of the potentiometer is in line with the mounting bolts of the tube socket, and tighten the nut with ordinary pliers exactly as you tightened the nut on the selector switch shaft.

✓ *Step 28. Remove the nut from that tube socket mounting screw which is closest to the potentiometer* (in hole *h*) without removing the screw, place on this screw a 13/16-inch long soldering lug (Part *1-8C*), and replace the nut. Tighten the nut partially with the fingers, bend the soldering lug up from the chassis at right angles, then line up the soldering lug with the middle lug of the potentiometer and tighten the nut finally with pliers and screwdriver.

Now take long-nose pliers and bend the outermost end of this lug back toward the chassis again so that it lies right over the center lug of the potentiometer, with the hole in lug *1-8C* coinciding with the slot in lug *10* of the potentiometer.

Mark the number *12* on the chassis alongside the lug which you have just bolted to the chassis, as shown in Fig. *41*. Identify the potentiometer terminal lugs by numbers *9, 10* and *11* marked on the chassis near the lugs, as shown in Fig. *41*.

✓ *Step 29. Cut a 10½-inch length of hook-up wire,* push one end through chassis hole *a* from the top of the chassis, form an open hook in the end, insert this hook through the slot of lug *10* and the soldering hole in lug *12* (which now coincide), close the hook with long-nose pliers, then solder this joint so that lugs *10, 12* and the 10½-inch length of wire all form a single secure joint.

✓ *Step 30. Connect potentiometer terminal 11 to tube socket terminal 7* with a 2-inch length of hook-up wire, by forming permanent hook joints. Solder the joint at terminal 11, but do not solder the joint at *7* yet.

✓ *Step 31. Cut a 5-inch length of hook-up wire,* push one end through hole *c* from the top of the chassis, and connect this end to tube socket terminal *7* by means of a permanent hook joint. Now solder the joint at terminal *7*.

✓ *Step 32. Connect potentiometer terminal 9 to tube socket terminal 2* with a 1½-inch length of hook-up wire, using permanent hook joints. Solder terminal *9,* but do not solder terminal *2* yet.

✓ *Step 33. Connect the .24-megohm resistor* (Part *2-13*) *between tube socket terminals 5 and 6,* by first shortening the resistor leads so that each is ¾-inch long. Bend the leads with your fingers to the shapes shown in Fig. *41*. Bend a hook in the end of each lead with long-nose pliers. Hook the leads through the holes in terminal lugs *5* and *6* from underneath, then close the hooks with long-nose pliers. Do not solder these joints yet.

✓ *Step 34. Connect the .03-mfd. condenser* (Part *1-12*) *between tube socket terminals 5 and 6*, with the *outer foil* lead going to *6*, by first shortening the leads so that each is 1¼-inch long. Bend the leads as shown in Fig. *41* and form an open hook in the end of each with long-nose pliers. Hook the leads through the holes in terminals *5* and *6*, and close the hooks with long-nose pliers. Now solder the joints at terminal *5,* but do not solder terminal *6* yet. Adjust the leads now with your fingers and pliers so that the resistor and

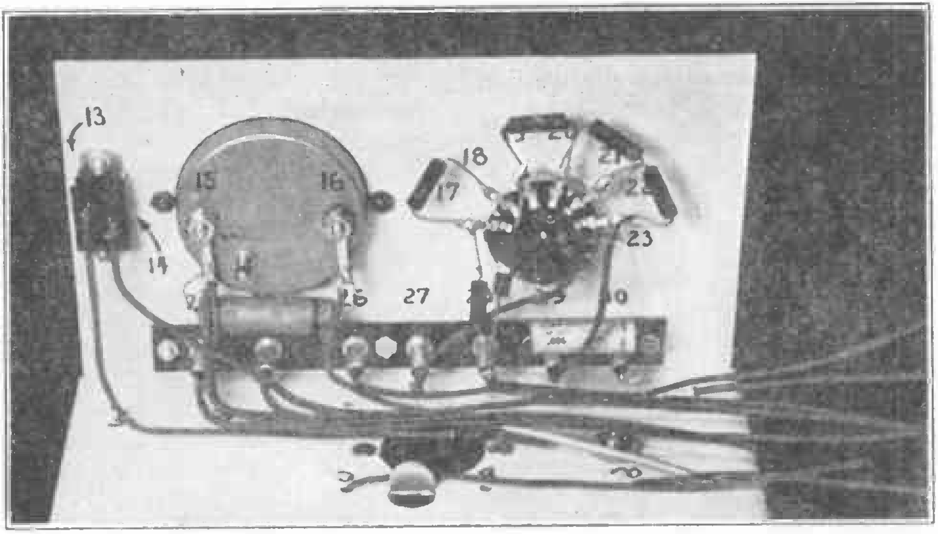


FIG. 42. Rear view of NRI Tester after the panel is fastened to the chassis. Note that the leads have been temporarily bent off the chassis to the right to permit placing the battery block on the chassis between the five tabs. The position of the *OUTSIDE FOIL* lead of the condenser connected between meter terminals *15* and *16* does not matter, since neither meter terminal is grounded.

condenser are both self-supporting about ⅛-inch away from the metal chassis.

You have now completed the wiring underneath the chassis as much as you can before final assembly. The bottom of the chassis should now appear as shown in Fig. *41*. Two wires will be projecting up through the top of the chassis, through holes *a* and *c* respectively.

✓*Step 35. Fasten the panel to the chassis now with the three remaining binder-head machine screws* (Part *1-9A*) *and three hexagonal nuts* (Part *1-9B* just as you did in Step 2 of Experiment 11, after first bending the projecting wires temporarily out of the way. Insert the screws one after another, placing a nut on each and tightening loosely with the fingers while the chassis is in the position shown in Fig. *5*. Now align the panel neatly with respect to the chassis, and tighten the screws permanently with screwdriver and ordinary pliers. At this stage in the assembly process, your NRI Tester should appear as shown in Fig. *42*.

✓*Step 36. Locate the panel wire which you connected to terminal 13 of the power switch, and push this wire through chassis hole f* (directly under terminal *13*). Connect to socket terminal *2* with a permanent hook joint the wire which projects underneath the chassis through hole *f*. Solder terminal *2* now (there should be two wires on this terminal).

✓*Step 37. Locate the 4½-inch wire which is soldered to meter terminal 15, and push the free end of this wire through chassis hole e,* which is almost directly under this meter terminal. Underneath the chassis, connect to tube socket terminal *4* by means of a permanent hook joint the wire which is now projecting through hole *e*, and solder this connection to terminal *4*.

✓*Step 38. Locate the 3½-inch wire which is connected to meter terminal 16, push it through chassis hole d* (directly under this meter terminal), then turn the chassis over and connect to tube socket terminal *3* by means of a permanent hook joint the wire which is now projecting under the chassis through hole *d.* Solder this joint on terminal *3* now.

Step 39. Locate the 4-inch wire 1-7F which is connected to jack terminal 27, and push it through hole b. When you have pulled the wire through, shape the wire neatly with your fingers above the chassis so that it goes around the tube socket. Now turn the chassis over and connect to tube socket terminal *6,* by means of a permanent hook joint, the wire *1-7F* which projects underneath the chassis through hole *b.* Close the hook with long-nose pliers, then solder terminal *6.*

Step 40. Locate the U-shaped shorting piece made from heavy wire (Part *2-4*)*, and push this piece all the way into the two jacks marked PHONE at the front of the panel.* This piece can be seen in the view of the completed NRI Tester (Fig *33*). Do not remove this piece until you receive instructions for doing so in connection with the use of a headphone unit.

Mounting the Batteries

Step 41. Replace the group of batteries on top of the chassis exactly as shown in Fig. *19B,* and tie them in position with the black lace just as you did before. Be sure that the terminal identification card is in position and the two —4½C terminals are connected together *exactly as shown in Fig. 19D.* You can readily thread the black lace under the card when tying down the batteries.

Step 42. Locate the wire which projects through hole c and push the insulation back from its end about half an inch. Bend this end downward and insert its end in the spring clip of the —A terminal, then form the wire neatly with your fingers so it has the position shown in Fig. *43.*

Step 43. Locate the wire which comes up through chassis hole a, bring it straight up to the top of the C batteries, bend it sharply toward the +C terminal along the top of the batteries, then push back the insulation and connect this wire to the +C terminal. Adjust the position of the wire now so it is as shown in Fig. *43.* This position keeps the wire at least a quarter inch away from the +1½A terminal.

Step 44. Locate the wire which is attached to one lead of the .22-megohm resistor (the other lead of this resistor is on jack terminal *28*), bring this wire diagonally upward to the —9C terminal, connect the wire to —9C with a *closed* hook, and tighten the knurled nut on this terminal. Now straighten out any bends in the wire or the resistor leads, so this lead has the position shown in Fig. *43.*

NOTE: Whenever you connect a wire to a screw terminal, always bend the hook in the wire in a clockwise direction. Since a nut is tightened by turning it in a clockwise direction also, tightening of the nut will tend to close the hook in the wire rather than open it. Hooks which are bent in the opposite direction (counter-clockwise) will sometimes spread apart and fall off when the nut is tightened, hence this is to be avoided.

Step 45. Locate the wire which comes directly from jack terminal 28, and solder the grid clip (Part *2-21*) to the end of this lead with a permanent soldered hook joint, as shown at the upper right in Fig. *43.* This clip will be called the *calibrating clip.* Now run this lead down along the chassis from jack *28* to the left front corner of the A battery (near chassis hole *a*), then bring the wire straight

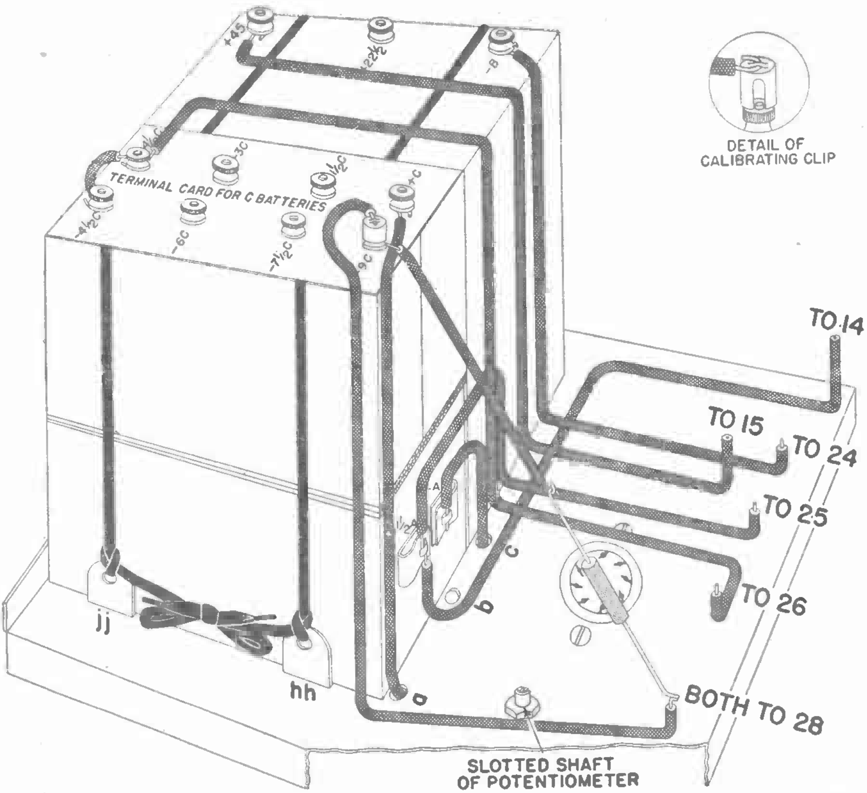


FIG. 43. Battery connections for the NRI Tester when using the specified Eveready batteries. WARNING: DO NOT LET METER TERMINAL *15* OR THE +45 TERMINAL OF THE BATTERY COME IN CONTACT WITH THE CHASSIS OR WITH ANY OTHER BATTERY TERMINAL, BECAUSE AN ACCIDENTAL CONNECTION OF THIS NATURE MAY BURN OUT THE TUBE OR THE POTENTIOMETER, OR BOTH.

up along the front left corner of the battery group. At the top, form a loop in the rest of the wire as shown in Fig. *43*, and push the calibrating clip over the knurled nut on terminal —9C.

If the calibrating clip fits loosely, squeeze it together a bit with pliers or your fingers to get a snug fit. The extra loop of wire is required because the calibrating clip will at times be moved to terminals —7½C, —6C or —4½C.

Step 46. Locate the wire which comes from jack terminal 26, press it down along the chassis up to the B battery, bring it straight up the side of the B battery, bend it over the top edge, run straight back along the top almost to the back corner, then make a right-angle bend toward the —4½C terminal, and connect the wire to the right-hand —4½C terminal exactly as shown in Fig. *43*. Tighten the knurled nuts on terminals —6C and —7½C at this time.

Step 47. Locate the wire which comes from terminal 25, bring this wire straight back along the chassis, straight up along the side of the B battery to a point about 2 inches above the chassis, bend at right angles to the left, then bend downward at a point directly over the +1½A terminal, and connect the wire to the +1½A terminal.

✓*Step 48. Locate the wire which comes from power switch terminal 14* and bring the wire straight down to the chassis, back along the chassis to the B battery, along the chassis just in front of the batteries, then up to the +1½A terminal, and connect to this terminal.

✓*Step 49. Locate the 13¼-inch wire which comes from meter terminal 15,* bring it straight down from this meter terminal to the chassis, make a right-angle bend there and bring it straight back along the chassis to the B battery, then make another right-angle bend and bring it up along the side of the B battery. Bend the wire at right angles over the front top edge of the battery block, run it straight back along the top of the B battery, push back the insulation, connect the wire to the +45 terminal, then adjust its position as shown in Fig. *43*.

Step 50. Locate the wire which comes from jack terminal 24, bring it back along the chassis to the B battery, then make a right-angle bend and bring it up along the side of the battery. At the top, bend the wire over and connect it to the —B terminal as shown in Fig. *43*.

You have now completed the battery connections for the NRI Tester. Go over all connections and push the insulation toward the joints whenever possible, to cover as much exposed wire as you can and thus minimize chances for accidental short circuits. When using the specified Eveready batteries, your completed tester should now appear essentially as shown in Fig. *44*.

Checking the Connections

✓*Step 51. Having completed the assembly and wiring of the NRI Tester, you are now ready to check the accuracy and completeness of your connections* by means of the complete circuit diagram given in Fig. *34*. This checking procedure is an important part of any radio assembly job, so go through it slowly and carefully. *Place a check mark (√) in the space provided for this purpose after each step in the following checking procedure,* when you are certain that the connections called for in that step are correct.

Tube socket terminal *2* should have two leads, one going to poteniometer terminal *9* and the other going through chassis hole *f* to *ON-OFF* switch terminal *13*. ☑

Tube socket terminal *3* should have one lead, going through chassis hole *d* to meter terminal *16*. ☑

Tube socket terminal *4* should have one lead, going through chassis hole *e* to meter terminal *15*. ☑

Tube socket terminal *5* should have two leads, one from a .03-mfd. condenser and the other from a .24-megohm resistor. ☑

Tube socket terminal *6* should have three leads, one from a .03-mfd. condenser, another from a .24-megohm resistor, and a yellow lead going through chassis hole *b* to jack terminal *27*. ☑

Tube socket terminal *7* should have two leads, one going to potentiometer terminal *11*, and the other going through chassis hole *c* to the —A terminal of the battery block. ☑

Terminal *10*, the middle lug of the potentiometer, should be grounded to soldering lug *12* which is bolted to the chassis, and should have a lead going through hole *a* to the +C terminal on the battery. ☑

Terminal *14* on the *ON-OFF* switch should have one lead, going to the +1½A battery terminal. ☑

Terminal *15* on the meter should have three leads, one from a .05-mfd. condenser, one going to +45, and one going through chassis hole *e* to tube socket terminal *4*. ☑

Terminal *16* on the meter should have two leads, one from a .05-mfd. condenser and the other going through chassis hole *d* to tube socket terminal *3*. ☑

Selector switch terminal *17* should have two leads, one from a 100-ohm resistor and the other from a 910-ohm resistor. ☑

Terminal *18* should have one lead, from a 910-ohm resistor. ☑

Terminal *19* should have two leads, one from a .1-megohm resistor and the other from a .24-megohm resistor. ☐

Terminal *20* should have two leads, one from a .24-megohm resistor and the other from a 3-megohm resistor. ✓

Terminal *21* should have two leads, one from a 3-megohm resistor and the other from a 6.8-megohm resistor. ☑

Terminal *22* should have two leads, one from a 6.8-megohm resistor and the other going to jack terminal *29*. ☑

Terminal *23*, the central terminal on the selector switch, should have one lead, going to jack *27*. ☑

Jack terminal *24* should have one lead, going to —B. ✓

Jack terminal *25* should have one lead, going to +1½A. ☑

Terminal *26* should have one lead, going to —4½C. ✓

Terminal *27* should have two leads, one going to selector switch terminal *23* and the other (a yellow lead) going through chassis hole *b* to tube socket terminal *6*. ☐

Terminal *28* should have four leads, one from a .1-megohm resistor, one from a .22-megohm resistor, one from a 100-ohm resistor, and one going to the calibrating clip which should now be on terminal —9C. ☐

Terminal *29* should have two leads, one from a .005-mfd. condenser and the other going to selector switch terminal *22*. ☑

Terminal *30* should have one lead, from a .005-mfd. condenser. ☐

The U-shaped shorting piece should be in the phone jacks (connecting together jack terminals *24* and *25*.) ☑

Calibrating the NRI Tester

Step 52. Place the assembled NRI Tester on the table in front of you, with the panel facing you. Set the selector switch to the *100 × V* line on the panel (the selector switch is at this position in Fig. *33*.) Set the power switch to the *OFF* position by pushing the black slide *down*.

Insert the vacuum tube in its socket on the tester chassis; do this by placing the aligning key of the tube gently in the corresponding hole in the socket, then rotating the tube until you can feel that the projecting pin on one side of this key is in the corresponding groove in the center hole of the socket. Now push the tube firmly into the socket until the tube base is resting on top of the socket. There should be no movement of the meter pointer yet.

Step 53. Turn on the tester switch by pushing the button on this switch upward toward the position marked *ON*. The colored dot under the button of this switch will now be visible. You will probably note a small movement of the meter pointer to the right when this is done.

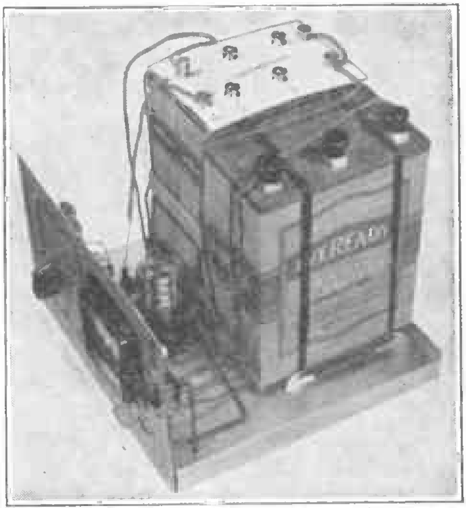


FIG. 44. Completed NRI Tester, as it appears when the specified Eveready batteries are used.

CAUTION: If you are interrupted while calibrating the NRI Tester, be sure to push this switch *OFF* in order to conserve the battery life. Energy is drawn from the batteries whenever this switch is *ON*.

Step 54. With the tester still turned on, adjust the zero-correcting knob at the back of the meter until the pointer is at *0* on the *DC* scale (the scale directly above scale I_M), while tapping the top of the meter lightly with a finger to overcome bearing friction. *DON'T USE PLIERS* to turn the zero-correcting knob, because the pliers may touch meter terminal *15* and burn out both the tube and potentiometer.

Step 55. Remove the calibrating clip from battery terminal —9C, and place it on battery terminal —7½C (this calibrating clip is on the lead which goes to jack terminal *28*). Now adjust the 1,000-ohm potentiometer on the chassis (Part *2-7*) with a screwdriver while tapping the top of the meter lightly with a finger, until the meter pointer is at 1.5 on the *DC* scale.

Important: ALWAYS USE THE *DC* SCALE DURING CALIBRATION. The I_M scale is needed only when the meter is used by itself as it was in previous experiments; this I_M scale is no longer needed now that the meter is in the *NRI* Tester circuit.

Step 56. Remove the clip from terminal —7½C and place it back on —9C. Readjust the zero-correcting knob at the back of the meter until the pointer is at *0* on the *DC* scale.

Step 57. Place the clip on terminal —7½C, and readjust the potentiometer until the meter pointer is at *1.5* on the *DC* scale.

Step 58. Continue this sequence of adjustments until you attain the desired condition whereby the meter pointer is at *0* when the clip is on terminal *—9C,* and the meter pointer is at *1.5* on the *DC* scale when the clip is on terminal *—7½C.* (Three repetitions of this procedure should give an accurate calibration.) This completes the calibration procedure, so your NRI Tester is now ready for use.

Step 59. Place the clip permanently on the —9C terminal of the battery, turn off your completed and calibrated NRI Tester by pushing the switch button downward to the position marked *OFF,* then place the tester aside until you receive further instructions for its use in Manual 3RK.

The greatest hazard to battery life lies in leaving the tester turned on overnight or for several hours at a time when not using it. Whenever you leave the tester, *make sure* the switch is *OFF*.

Completely remove both test leads from the input jacks whenever you finish with the tester to avoid accidentally exhausting the C battery.

The meter pointer may drop *below zero* when you turn the tester off, but this action is unimportant and can be neglected. The pointer will move up to zero again when you turn on the tester and tap the panel.

Supplementary Calibrating Instructions

Variations in tube characteristics and battery voltages may make it impossible for you to calibrate your NRI Tester as described in Steps 54-58. If your tester has been assembled correctly and contains no defective parts, the following information and instructions should help you secure the desired condition described in Step 58.

High-Emission Tube. Although the manufacture of vacuum tubes is a highly developed art, it is extremely difficult to make exactly identical tubes by mass production methods. The tubes which are made for the NRI Tester are carefully processed and selected, but can still vary considerably in their characteristics. As a result, you may find that the tube which is sent you for use in your NRI Tester will not permit the normal adjustment specified in Step *58*. To be more specific, the tube which you receive may have higher cathode emission than normal, with the result that you will be unable to bring the meter reading *down to 1.5* on the *DC* scale by adjusting the potentiometer while the calibrating clip is on the *—7½C terminal*. This condition will occur only with a new battery, and is remedied by lowering the plate voltage on the tube temporarily in the manner described in the next step.

Step 60. To reduce the effective plate voltage by 1½ volts, connect the cathode lead to —A instead of to *+1½A*. To do this, remove from the *+1½A* terminal the lead which goes to jack terminal *25*, and connect this lead to the —A terminal, so that there are now two leads on —A and only one lead on *+1½A*. After changing the wiring as instructed in this step, repeat the calibrating procedure set forth in Steps 55 to 59.

Remember that when the B battery ages sufficiently, it will drop in voltage and make it necessary for you to restore the original connection.

Run-Down B Battery. As the B battery ages and its voltage drops, you eventually reach the condition in which the plate voltage on the tube is too low to permit a calibration according to Step 58. In other words, you will find it impossible to bring the meter reading *up to 1.5* on the *DC* scale by adjusting the potentiometer. As a rule, this condition will not occur for several months if you follow the instructions given in later manuals for the use of the NRI Tester and turn on the tester only while you are actually making measurements. When the condition occurs, you can still use your batteries for a considerable period of time by lowering the C bias 1½ volts in the simple manner described in the next step (Step 61).

New Tube. Occasionally, a new tube will give the same condition as a partly run-down B battery, wherein it is impossible to bring the meter reading *up to 1.5* during calibration. The procedure in Step 61 will take care of this also.

Step 61. To reduce the effective negative C bias voltage 1½ volts, locate the wire which comes up through chassis hole *a*, and move it from the +C terminal to the —1½C terminal. The calibrating procedure set forth in Steps 55 to 59 should now be repeated.

Of course, none of the above procedures will correct for defective parts, incorrect connections, or incomplete soldering. If you still fail to obtain a satisfactory calibration, locate in the list below the type of trouble you have encountered and then read the information, and carry out the instructions given concerning it.

1. No reading, Step 55. No reading with the switch ON, even with the calibrating wire on —7½C, may be due to a defective ON-OFF switch, poor connections at the A or B battery terminals, a defective tube (open filament), or a defective (open) meter. Make sure the nuts on the ON-OFF switch do not restrict the movement of the sliding portion of the switch, check the tester thoroughly for loose connections and incorrect wiring, and then have a reliable radio dealer test the tube and check the meter for continuity.

2. Full-Scale Deflection for Step 53. A full-scale deflection of the meter pointer as soon as the tester is turned on is usually due to insufficient grid bias. Carefully inspect your C batteries to make sure they are interconnected *exactly* as instructed on pages *28-31*, and illustrated in Fig. *19*. You should also check to see that all connections to the C batteries are secure. Have the C batteries checked by a reliable radio dealer. If they check O.K., look for an open or a ground in the grid circuit.

The full-scale deflection could also be caused by a defective tube, so have it checked carefully in a tube tester.

Note. If you have to replace the tube, don't use anything but a type 1C5 (GT or GT/G) as this is the only tube that will work satisfactorily in the NRI Tester. *The 1A5 and 1Q5 tubes so often used as substitutes for the 1C5 in radio receivers will not work in your NRI Tester.*

3. Full-Scale Deflection for Step 50. A full-scale deflection as soon as the B battery is connected into the circuit, and before the tube is plugged into its socket, indicates a ground in that portion of the plate circuit between meter terminal *16* and plate terminal *3* of the tube socket. *Disconnect the B battery immediately* or it will quickly become exhausted, and the meter may burn out. Check the bottom of the tube socket, and remove all excess solder. Be sure that the insulation on the wire going up to meter terminal *16* through hole *d* keeps this plate lead from touching the chassis. If no ground is apparent, the meter itself is probably grounded. Write to us and we will tell you how to clear up this type of trouble.

4. Meter Won't Come Down to 1.5. This type of trouble is usually due to insufficient bias. If you cannot correct the trouble as described in Supplementary Calibration Step 60, have the C battery voltage checked. If one of the C batteries is low, replace it, and make sure that Jacks *26* and *28* are not grounded in any way.

5. Meter Won't Go Up to 1.5. This type of trouble can be caused by a low A battery as well as a low B battery and defective tube. Therefore, if Supplementary Calibration Step 61 and a new tube fail to bring the meter pointer up to 1.5, have the A battery checked. Replace it if the voltage is less than 1.2 volts under a 100-milliampere load.

Step-by-step operating instructions are given in later Manuals.

1.1
21
11

Important

Do not discard any of the parts supplied to you in NRI radio kits until you have completed your Course. All the parts left over after assembling the NRI Tester will be used in later experiments.

If you write to NRI regarding the complete tester, please refer to it as the *NRI Tester for Experiments.*

INSTRUCTIONS FOR PERFORMING RADIO EXPERIMENTS 21 TO 30

3 RK-1

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

A COURSE IN PRACTICAL DEMONSTRATIONS OF RADIO FUNDAMENTALS

THE UNKNOWN FUTURE OF RADIO

In the short period of approximately twenty years, radio has brought innumerable benefits to mankind. Continents have been drawn together, new cultural avenues have been opened up to rich and poor alike, entertainment has been brought to shut-ins, advertising methods have been revolutionized, and education of large audiences has been made possible.

But these are only a few of radio's achievements. Twenty-four hours a day in city or country, during hurricanes, floods and disasters on land or sea, radio brings help to those in distress. In the air, radio beam highways guide airplanes safely along their routes through storm, fog and darkness.

With 110,000,000 listeners and with hundreds of millions of dollars being spent yearly to provide programs, radio ranks first in American life. From breakfast to bedtime, broadcast band and short-wave stations alike pour forth entertainment, news, education and advertising, for all who own radio receivers and want to listen.

And yet today is only the beginning. Short-wave radio uses are expanding rapidly. Television, frequency modulation and electronic musical instruments are all taking on commercial status. Soon these and many more new services will be bringing even more startling marvels of sound and sight into American homes.

Yes, we have seen only the beginning of radio. Its unknown future for the years ahead is by far radio's greatest asset. And radio's future is *your future.*

J. E. Smith.

NATIONAL RADIO INSTITUTE
WASHINGTON, D.C.

1947 Edition

THIS EXPERIMENTAL MANUAL IS A PART OF THE
N. R. I. COURSE WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

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Instructions for Performing Radio Experiments 21 to 30

Introduction

A PRACTICAL radio circuit consists of one or more sources of e.m.f. and one or more radio parts like resistors, coils and condensers. In every radio circuit, no matter how simple or how complex it may be, the distribution of voltages and currents is quite definite and is governed by three simple electrical laws. In the early lessons of your fundamental course, you learned that these three basic laws are: *1. Ohm's Law; 2. Kirchhoff's Current Law; 3. Kirchhoff's Voltage Law.*

To appreciate the actions which take place in a radio receiver, radio transmitter or other radio device, it is essential that you have a clear understanding of these three laws. In this manual, therefore, you will make a number of practical demonstrations which will illustrate each of these laws and convince you of their reliability.

The three basic electrical laws can be applied to any radio circuit whatsoever. With a.c. circuits, however, capacitive reactance and inductive reactance must be taken into account along with resistance. For this reason, it is convenient to use two forms of each law, one for d.c. circuits and the other for a.c. circuits. The laws are given below for reference purposes.

Ohm's Law for D.C. Circuits. The current (*I*) flowing through a d.c. circuit is directly proportional to the voltage (*E*) acting in the circuit, and is inversely proportional * to the *resistance* (*R*) of the circuit. Formula: $I = E \div R$.

Ohm's Law for A.C. Circuits. The current (*I*) flowing through an a.c. circuit is directly proportional to the voltage (*E*) acting in the circuit, and is inversely proportional to the *impedance* (Z) of the circuit. Formula: $I = E \div Z$.

Kirchhoff's Current Law for D.C. Circuits. In any d.c. circuit, the *arithmetical* sum of the currents flowing to a point in the circuit is equal to the *arithmetical* sum of the currents flowing away from that point.

Kirchhoff's Current Law for A.C. Circuits. In any a.c. circuit, the *vector* sum of the currents flowing to a point in the circuit is equal to the *vector* sum of the currents flowing away from that point.

Kirchhoff's Voltage Law for D.C. Circuits. In any d.c. circuit, the *arithmetical* sum of the voltage sources acting in any one complete electron path is equal to the *arithmetical* sum of the voltage drops in that electron path.

Kirchhoff's Voltage Law for A.C. Circuits. In any a.c. circuit, the *vector* sum of the voltage sources acting in any one complete electron path is equal to the *vector* sum of the voltage drops in that electron path.

Observe that the only difference between the d.c. and a.c. forms of Kirchhoff's two laws is the fact that we consider *arithmetical* sums in d.c. circuits (we add the voltage and current values together directly while taking their signs into account), while in a.c. circuits we must consider *vector* sums of the currents or voltages under consideration (we must consider phase relationships when combining the voltages or currents).

In d.c. circuits, resistance is the only thing which offers opposition to electron flow; voltage drops across resistors and currents through resistors are always in phase with each other, and hence voltage values or current values can be added or subtracted directly in d.c. circuits.

In a.c. circuits, we have inductive reactance and capacitive reactance

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* Inversely proportional means that an *increase* in one quantity causes a corresponding proportional *decrease* in another quantity.

offering opposition to electron flow along with resistance, and consequently the currents in various parts of the circuit will have a definite *phase* relationship with each other. Likewise, the a.c. voltages under consideration will have a definite *phase* relationship with each other, making it necessary that we consider phase relationships by combining the values vectorially.

Purpose of Experiments in This Manual. Ohm's Law and Kirchhoff's Laws together constitute the foundation of all electrical and radio circuits. Without these three laws, engineers would be unable to design circuits or locate faults in circuits. Therefore, as a prospective Radiotrician you must have a clear understanding of how voltages and currents distribute themselves in circuits according to these laws. You must know, for example, what current changes are to be expected when a voltage, a resistance or a reactance is increased or decreased in value.

Complete failures of coils, condensers, resistors and circuit connections, as well as partial changes in the electrical values of these parts, are common everyday radio defects. Once you are familiar with the fundamental laws applying to radio circuits, you will be able to predict the effects which these failures will have upon circuits, and will therefore be able to locate defective parts very rapidly.

Briefly, then, the purpose of the next ten experiments (21 through 30) in your practical demonstration course is *to show you how Ohm's Law and Kirchhoff's Laws govern circuit behavior in radio equipment.* In these experiments, you will learn to use the N.R.I. Tester which you constructed after completing Experiment 20, and you will secure additional experience in reading schematic circuit diagrams.

Contents of Radio Kit 3RK-1

The parts included in your Radio Kit 3RK-1 are illustrated in Fig. *1*, and listed in the caption underneath. Check off on this list the parts which you receive, to be sure you have all of them. Do not destroy any of these parts until you have completed your entire N.R.I. course, for many of the parts will be used over and over again in later experiments.

IMPORTANT: If any part in your Radio Kit 3RK-1 is obviously defective or has been damaged during shipment, please return it to the Institute *immediately* for replacement.

INSTRUCTIONS FOR EACH EXPERIMENT

1. **Read the entire experiment, giving particular attention to the discussion.**
2. **Perform each step of the experiment and record your results.**
3. **Study the discussion and analyze your results.**
4. **Answer the report statement for the experiment. It will always be on the last page of the manual.**

EXPERIMENT 21

***Purpose:* 1. To show that d.c. voltage sources add when connected in series aiding; 2. To show that d.c. voltage sources subtract when connected in series bucking; 3. To show that d.c. voltage sources which are equal in value remain unchanged when connected in parallel.**

Step 1. To learn how to read the DC scale, study carefully the exact-size reproductions of this scale in Fig. *2*, where examples of readings for four different pointer positions are given. Observe that the scale reads from 0 to 4.5, with numerical values on the scale being read in much the same way as the values on scale I_M were read in previous experiments. When the pointer is directly on a numbered

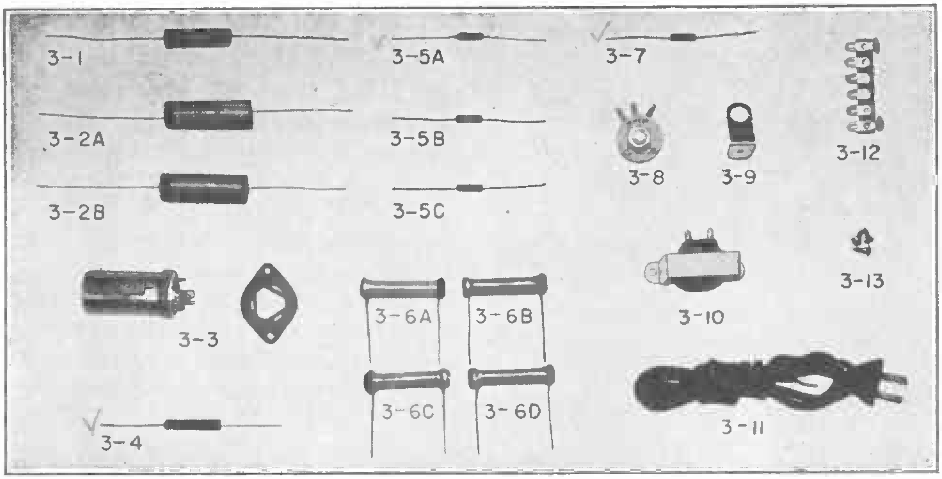

Fig. 1. The parts included in Radio Kit 3RK-1 are pictured above, and are identified in the list below. Some resistors may have a better tolerance (a lower percentage tolerance) than that indicated here.

Part No.	*Description*
3-1	One .05-mfd., 400-volt paper condenser.
3-2A	One .25-mfd., 400-volt paper condenser.
3-2B	One .25-mfd., 400-volt paper condenser. Same as Part *3-2A*.
3-3	One dual 10-10-mfd., 450 working volt electrolytic condenser.
3-3A	(At right of Part *3-3* in Fig. *1*). Bakelite mounting wafer for electrolytic condenser.
3-4	One 200-ohm, 1-watt resistor with 10% tolerance (color-coded red, black, brown and silver).
3-5A	One 1,000-ohm, ½-watt resistor with 10% tolerance (color-coded brown, black, red and silver).
3-5B	One 1,000-ohm, ½-watt resistor with 10% tolerance (color-coded brown, black, red and silver).
3-5C	One 1,000-ohm, ½-watt resistor with 10% tolerance (color-coded brown, black, red and silver). Parts *3-5A*, *3-5B* and *3-5C* are identical.
3-6A	One 40,000-ohm, 3-watt resistor with 20% tolerance (color-coded yellow, black and orange).
3-6B	One 40,000-ohm, 3-watt resistor with 20% tolerance (color-coded yellow, black and orange).
3-6C	One 40,000-ohm, 3-watt resistor with 20% tolerance (color-coded yellow, black and orange).
3-6D	One 40,000-ohm, 3-watt resistor with 20% tolerance (color-coded yellow, black and orange). Parts *3-6A*, *3-6B*, *3-6C* and *3-6D* are identical.
3-7	One 1-megohm, ½-watt resistor with 10% tolerance (color-coded brown, black, green and silver).
3-8	One 1,000-ohm wire-wound potentiometer.
3-9	Mounting bracket for potentiometer.
3-10	One 10-henry choke coil with 25-ma. current rating.
3-11	One 5-foot power line cord with attached outlet plug. (Students who do not have power line facilities will use this cord for storage battery connections.)
3-12	One 6-lug terminal strip with four of the lugs insulated.
3-13	Three ⅜-inch No. 6 round-head wood screws.

You should have the following parts left over from Radio Kits 1RK and 2RK after you have performed the first twenty experiments and assembled the N.R.I. Tester.

Part No.	*Description*
1-1	One 55-watt electric soldering iron (or Part *1-1A*, a plain soldering iron).
1-2	One soldering iron holder.
1-3	Remainder of roll of rosin-core solder.
1-16	One 18,000-ohm, ½-watt resistor (color-coded brown, gray, orange and silver).
2-17	Remainder of roll of red push-back hook-up wire.
2-19A & 2-19B	Eight tinned copper strips, now mounted on the four 1.5-volt flashlight cells which you obtained yourself.
	Miscellaneous pieces of various types of hook-up wire, soldering lugs, and small amounts of plain solder, acid-core solder and paste flux.
	Assembled N.R.I. Tester with test leads.
	All tools which were specified in the previous experiments and which were to be obtained by you.

STEP	NATURE OF MEASUREMENT	YOUR VALUE IN VOLTS	N.R.I. VALUE IN VOLTS
3	VOLTAGE OF CELL A	1.5+	1.5
	VOLTAGE OF CELL B	1.5+	1.5
	VOLTAGE OF CELL C	1.5	1.5
	VOLTAGE OF CELL D	1.5	1.5
4	VOLTAGE OF CELL A	1.5	1.5
	VOLTAGE OF CELLS A+B	3.0	3.0
	VOLTAGE OF CELLS A+B+C	4.5	4.5
	VOLTAGE OF CELLS A+B+C+D	6.3	6.0
5	VOLTAGE OF CELLS A+B+C−D	2.8	3.0
	VOLTAGE OF CELLS B+C−D	1.5	1.5
	VOLTAGE OF CELLS C−D	0	0
6	VOLTAGE OF CELLS A+B−C−D	0 ✓	0 ✓
	VOLTAGE OF CELLS A+B−C	1.6 ✓	1.5 ✓
	VOLTAGE OF CELLS B−C	0 ✓	0 ✓
	VOLTAGE OF CELLS B−C−D	1.5 ✓	1.5 ✓
8	CELLS A,B,C AND D IN PARALLEL	1.5	1.5
9	CELLS A,B,C AND D IN SERIES-PARALLEL	2.9	3.0
10	CELLS A,B,C AND D IN SERIES-PARALLEL	2.9	3.0

TABLE 21. Record your results here for Experiment 21. The check mark (✓) indicates that each of the readings obtained for Step 7 in the N.R.I. laboratory was the same as the corresponding reading for Step 6.

line, read the number above that line. When the pointer is on a short line between two numbered lines, read a value halfway between the values of the two adjacent numbered lines.

Step 2. Check the calibration of your N.R.I. Tester as instructed in the last section of Manual 2RK, and recalibrate if necessary. Be sure to remove both test leads from the jacks on the N.R.I. Tester panel during a check-up of calibration and during the recalibration procedure, and set the selector switch to *100 × V* during calibration. Do not touch any terminals or leads behind the panel with your fingers during calibration, for body capacity, the resistance of the body (around 100,000 ohms), and hum voltage pick-up by the body can cause errors in calibration.

In the future, check the calibration of the N.R.I. Tester the first time you use the instrument each day. Additional checks can be made quickly at any time if you suspect an error in calibration.*

IMPORTANT: Overloading of the meter will appear to destroy the zero calibration of the N.R.I. Tester, but this is merely a temporary effect which will be corrected automatically if the next measurement you make will give nearly a full-scale reading. However, you can correct the calibration shift yourself by removing the calibrating clip from the —9C battery terminal, touching it momentarily to a terminal 4½ volts less negative

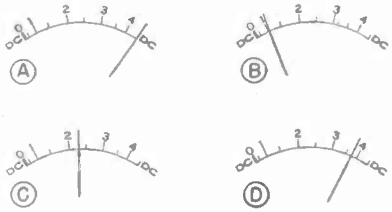

FIG. 2. Actual-size reproductions of the *DC* scale on the meter of the N.R.I. Tester, with examples showing how to read this scale at four different pointer positions. The readings are as follows: *A*—4.5; *B*—1.1; *C*—2.3; *D*—3.75.

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* If you write to N.R.I. regarding this tester, please refer to it as the *N.R.I Tester for Experiments.*

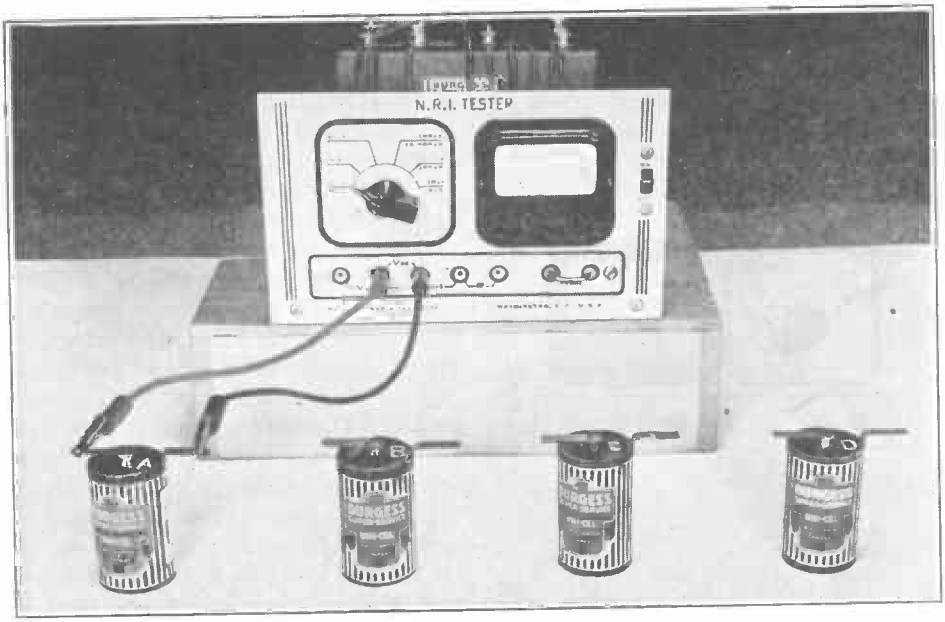

FIG. 3. Method of using the N.R.I. Tester to measure the volumes of inidividual dry cells. This set-up is used in Step 3 of Experiment 21. The test leads were shortened for this photograph in order to make them show more clearly, but *do not shorten your own test leads.* Placing the N.R.I. Tester on a box makes it easier to read the meter accurately.

(—4½C), then replacing the clip on its original terminal. This restores the iron vane in the meter to its normal non-magnetized state.

Step 3. Place before you the four flashlight cells on which you have previously placed terminal strips. Place before you also the N.R.I. Tester, with its panel and meter facing you. Plug the red probe into the $+V_{DC}$ jack, plug the black probe into the $-V_{DC}$ jack, and set the selector switch to *V* as shown in Fig. *3*, so that your N.R.I. Tester will serve as a 0 to 4.5-volt d.c. voltmeter and will read values in volts directly on the *DC* scale.

With your metal-marking crayon, mark your four cells *A*, *B*, *C* and *D* respectively, as shown in Fig. *3*.

Place the red clip on the + (center) terminal of cell *A*, place the black clip on the — terminal of this cell, turn on the N. R. I. Tester, read the meter on the *DC* scale, and record your result in Table *21* as the voltage of cell *A* in volts. In the same manner, measure the voltage of each of the other cells, and record their values in Table *21*.

WARNING

Do not allow the alligator test clips to remain in contact with the panel or chassis of the N.R.I. Tester for any period of time, for this may short-circuit the C battery and drain it in a few minutes, even if the switch on the tester panel is *OFF*.

Get the habit of pulling out the test probes whenever you put the N.R.I. Tester away or leave it for any reason, to prevent the clips from touching the chassis accidentally.

Step 4. To measure the voltages of cells when connected in series-aiding, connect your four cells together in series-aiding exactly as shown in Fig. *4*, so that the — terminal of cell *A* goes to the + terminal of cell *B*, the — terminal of *B* goes to the + of *C*, and the — of C goes to the + of D. Since the cell terminals were previously tinned, simply overlap the terminals which are to be connected together, then apply the heated soldering iron to the uppermost terminal. Rotate the selector switch one notch to the right, to setting $3 \times V$, without moving the probes. Your N. R. I. Tester is now serving as a 0 to 13.5-volt d.c. voltmeter, and you will have to multiply each reading on the *DC* scale by 3 to get the actual value of the voltage being measured.

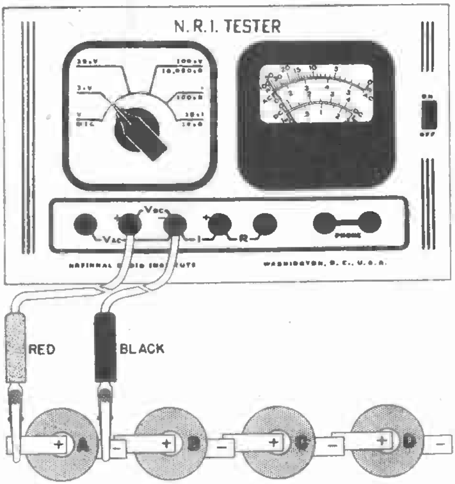

FIG. 4. This diagram illustrates how voltage measurements are made on a group of four flashlight cells connected in series-aiding for Step 4 of Experiment 21.

Place the red clip on the + terminal of cell A, place the black clip on the — terminal of cell A, read the meter on the *DC* scale, multiply the reading by 3, and record the result in Table *21* as the voltage of cell A. (For reasons explained in the discussion, do not expect this reading to check exactly with the first reading taken in Step 3.)

Move the black clip to the — terminal of cell B, leave the red clip on the + terminal of cell A, read the meter on the *DC* scale, multiply the reading by *3*, and record your result as the voltage of cells $A + B$.

Place the black clip on the — terminal of cell C, read the meter on the *DC* scale, multiply the reading by 3, and record your result in Table *21* as the voltage of cells $A + B + C$.

Move the black clip to the — terminal of cell D, read the meter on the *DC* scale, multiply the reading by 3, and record your result in Table *21* as the voltage of cells $A + B + C + D$.

Step 5. To measure voltages when four cells are connected together in series with three aiding and one bucking, as shown in Fig. *5*, first disconnect cell D from the group. Now turn cell D around so that its — terminal is in contact with the — terminal of cell C, and solder these two terminals together. Place the red clip on the + terminal of cell A, place the black clip on the + terminal of cell D, change the selector switch to setting V, read the meter on the *DC* scale, and record this reading in Table *21* as the voltage of cells $A + B + C - D$.

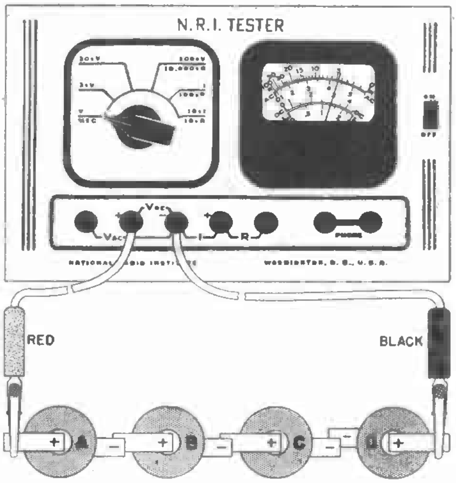

FIG. 5. Method of connecting four flashlight cells in series with three aiding and one bucking, with the V range of the N.R.I. Tester being used to check voltages. This measurement is made in Step 5 of Experiment 21.

Move the red clip to the — terminal of cell A, read the meter on the *DC* scale, and record your reading as the voltage of cells $B + C - D$.

Move the red clip to the − terminal of cell B, read the meter on the *DC* scale, and record your reading as the voltage of cells $C - D$.

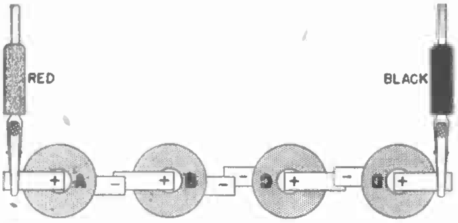

FIG. 6. Cell connections and test clip positions for Step 6 of Experiment 21.

Step 6. To make voltage measurements on four cells connected in series, with two cells aiding and two cells bucking, unsolder the terminals of cell C from the others in this group, turn this cell around so that its − terminal is on the − terminal of cell B, then solder the cell terminals into position again as shown in Fig. *6*. Place the red clip on the + terminal of A, place the black clip on the + terminal of D, read the meter on the *DC* scale, and record your reading as the voltage of cells $A + B - C - D$.

Move the black clip to the + terminal of cell C, read the meter, and record your result in Table *21* as the voltage of cells $A + B - C$.

Now move the red clip to the + terminal of cell B, read the meter, and record your result as the voltage of cells $B - C$.

Move the black clip back to the + terminal of cell D. You will now get a zero or a downscale reading, indicating improper polarity of connections, so reverse the positions of the red and black clips; that is, place the black clip on the − terminal of cell A, and place the red clip on the + terminal of cell D. Read the meter and record your result in Table *21* as the voltage of cells $B - C - D$.

Step 7. Take a short length of red hook-up wire and connect the + terminal of cell B to the + terminal of cell C by means of temporary soldered lap joints. Take another length of hook-up wire and connect the + terminal of cell A to the + terminal of cell D by means of temporary soldered lap joints, as shown in Fig. 7. If you notice a spark when making either of these connections, check the polarity of battery connections against the diagram in Fig. 7. There should be no sparks if connections are made properly.

Now repeat each of the *measurements* called for in Step 6, to see if these two wire connections affect any of the voltage values. Make a small check mark after each of the readings for Step 6 in Table *21* which are still the same. Finally, remove the two wires and disconnect the four cells.

Step 8. To measure the voltage provided by four cells connected in parallel, first place the four flashlight cells side by side in the manner shown in Fig *8*. Cut a 6-inch length of hook-up wire and remove all insulation from it, then place this bare tinned copper wire over the + terminals of the four cells as shown in Fig. *8*, and solder the wire to each terminal. In the same manner, take another 6-inch length of bare tinned

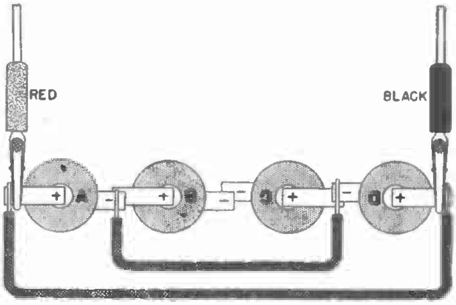

FIG. 7. Cell connections and test clip positions for Step 7 of Experiment 21.

copper wire and connect together the — terminals of the four cells. Place the red clip on any + terminal, place the black clip on any — terminal, and measure the voltage of these four cells in parallel with the *V* range of your N.R.I. Tester. Read the meter on the *DC* scale, and record your result in Table *21* as the voltage of four cells in parallel.

TOLERANCES OF RADIO PARTS

It is important to realize that any practical radio measurement will be affected by variations in the apparatus used in the circuit. When we calculate a value in mathematics, it is possible to obtain an answer that is so accurate it can be considered perfect. Measurements, on the other hand, depend upon the tolerances of parts, the characteristics of the measuring device and the ability to read scales closely.

Radio parts vary as much as 20% from the rated value in many cases, yet are considered satisfactory. (The standard tolerance is actually 20% in the case of resistors; thus, a resistor rated at 100 ohms may have any value from 80 ohms to 120 ohms.)

Therefore, do not expect to obtain exactly the calculated or N.R.I. values. You are using your own tester and parts, and the values of these parts can be quite different from the values of the parts used at N.R.I. without exceeding normal tolerances.

Obviously, there is little use in trying to make your readings extremely accurate, when radio parts are not exact in the first place. This is a practical fact, and you will find that the same condition exists in radio receivers and transmitters.

Step 9. To measure the voltage of parallel pairs of cells connected in series, cut each of the bare wires in Fig. *8* at its mid-point, then move down the cell groups including *C* and *D*, and connect the + terminal of *C* to the — terminal of *B* by means of a lap joint, as shown in Fig. *9*. Place the black clip on the — terminal of cell *D*, place the red clip on the + terminal of cell *A*, read the meter on the *DC* scale, and record your result as the voltage of four cells connected in series-parallel according to Fig. *9* Now disconnect these four cells.

Step 10. To measure the voltage of four cells connected together in series-parallel, first connect cells *A* and *B* in series aiding, as shown in Fig. *10*. Next, connect cells *C* and *D* in series aiding also. Now connect these two series groups of cells in parallel in the manner shown in Fig. *10*, by using two 1½-inch lengths of bare tinned copper wire. (You can cut these lengths from the bare wire prepared for Steps 8 and 9.) Place the red clip on the + terminal of cell *A*, place the black clip on the — terminal of cell *B*, and read the meter on the *DC* scale. Record your result in Table *21* as the voltage of four cells connected in series-parallel.

Discussion: A dry cell delivers essentially 1.5 volts by itself when new. When the test leads of the N. R. I. Tester are plugged into the V_{DC} jacks, and the selector switch is set at position *V*, you can read the voltage of a dry cell directly in volts on the *DC* scale of the meter.

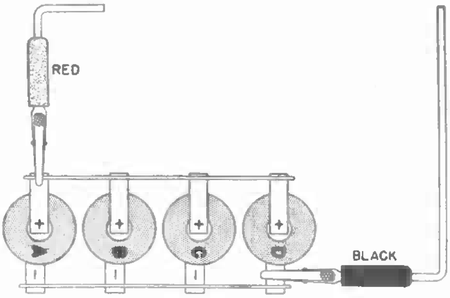

FIG. 8. Cell connections and test clip positions for Step 8 of Experiment 21.

There are four d.c. voltage ranges in all: V; $3 \times V$; $30 \times V$; $100 \times V$. In each case, you first read the meter on the *DC* scale, then multiply this reading by the factor indicated at the setting of the selector switch. Thus, when you place the selector switch at the *3×V* setting for one step in this experiment, you must read the meter on the *DC* scale, and multiply the value by 3 to get the actual voltage in volts.

This system for securing a number of different voltage ranges with only one meter is identical with that employed in the professional multimeters used by radio servicemen and radio engineers. After using an instrument a few times, these men find themselves able to multiply meter readings by the correct factors mentally and secure voltage values for the higher ranges almost as readily as when using a direct-reading range.

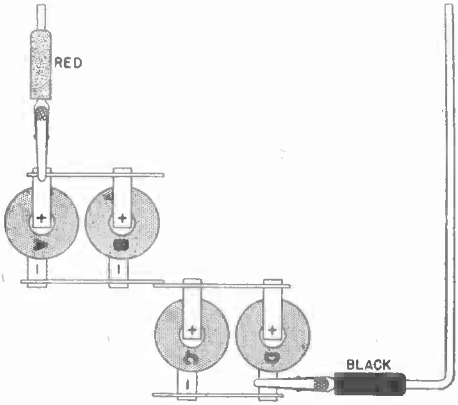

FIG. 9. Cell connections and test clip positions for Step 9 of Experiment 21, in which two parallel-connected pairs of dry cells are connected in series.

In the case of ranges which have multiplying factors of 10, 100, 1,000 or 10,000, it is a simple matter to add the indicated number of zeros to the meter reading. When the multiplying factor is 3 or 30, actual multiplication is required.

A good habit to form is that of turning the N. R. I. Tester on only while you are actually reading the meter. If you keep the power switch *OFF* during the preliminary set-ups and in between experiments, you will greatly increase the useful life of the batteries in the N. R. I. Tester.

In Step 3, you measure the voltage of each of the four flashlight cells with the N. R. I. Tester connected as a 0-4.5-volt d.c. voltmeter. Under this condition, your instrument has a sensitivity of 2,233,000 ohms-per-volt, which is exceptionally good for a d.c. voltmeter. If the four flashlight cells are new and all have the same dates stamped on them, they should all have essentially the same terminal voltages.

In Step 4, you use the *3×V* range for the first time, with your N. R. I. Tester serving as a 0-13.5-volt d.c. voltmeter under this condition. This means that you must multiply the reading on the *DC* scale by 3 to get the actual voltage each time. Naturally, you cannot read the voltage of a single cell as accurately with this range as you could with the *V* range, so do not expect your first reading to check too closely with the readings in Step 3.

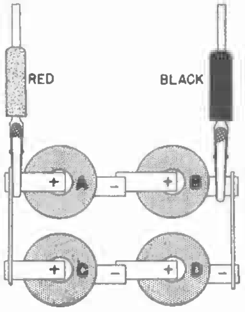

FIG. 10. Cell connections and test clip positions for Step 10 of Experiment 21, in which two series-connected pairs of dry cells are connected in parallel.

In Step 4, you connect the four cells in series-aiding, which means that unlike terminals of adjacent cells are connected together (— to +). Careful study of the voltage values which you obtained should indicate that the voltages of the individual cells add together when the cells are connected in series-aiding.

When connections to one of the cells are reversed as in Step 5, this cell is actually bucking the voltage of one of the other cells. Cells *C* and *D* in Fig. *5* can thus be considered to buck each other, so that there is essentially zero voltage between the positive terminals of these cells. As a result, voltage measurement across all four cells as shown in Fig. *5* should indicate the same voltage you obtained previously for cells *A* and *B* connected in series aiding. Likewise, when you connect the red clip to the + terminal of cell *B*, you should measure only the voltage of cell *B*. When the red clip is on the + terminal of cell *C*, the reading should be zero because these two cells buck each other.

When four cells are connected in series according to Step 6, so that cells *C* and *D* are connected with opposite polarity to that of cells *A* and *B*, we have the condition where one group of two series-connected cells is bucking the other group of two series-connected cells. As a result, the voltage across the group of four cells should be essentially zero for the measurement shown in Fig. *6*.

The additional measurements which you make in Step 6 should show you clearly how the voltages of cells in series add or subtract according to the polarity of their connections.

When an unequal number of cells are connected in a series-bucking arrangement, the polarity of the combination will be determined by the polarity of the greater voltage value. In other words, with three cells connected so that one bucks the other two, the polarity of the combination will be the polarity of the two cells which are identically connected. This holds true if the two identically connected cells are separated by the bucking third cell.

Step 7 illustrates clearly the fundamental fact that terminals which are at the same potential (zero voltage between them) can be connected together without affecting circuit conditions. You found in Step 6 that the + terminals of cells *A* and *D* were at zero potential with respect to each other, so in Step 7 you connect these two terminals together with a wire. You found also that the + terminals of cells *B* and *C* were alike in potential, so you connected these two together with another wire. It should be pointed out, however, that the + terminals of *B* and *C* are *not* at the same potential as the + terminals of *A* and *D*. In other words, a measurement between these two pairs of terminals would indicate a voltage, and this would be the voltage of cell *A*.

In your fundamental course, you learned that when identical voltage sources are connected together in parallel, the resultant voltage of the combination is the same as the voltage of an individual cell. In Step 8, you connect four identical cells in parallel and prove this fact for yourself. The voltage which you obtain for this step should be the same as the voltage for an individual cell.

Cells are connected in parallel when more current is required than can be supplied by a single cell. Four cells are capable of delivering four times as much current as one cell. This means that four cells in parallel will last essentially four times as long as one cell when used in a given circuit. Actually, the 1.5-volt A battery in your N.R.I. Tester contains four small cells connected in parallel.

When you divide the parallel group of four cells into two equal groups in Step 9, each group has a voltage of essentially 1.5 volts. When these groups are connected in series-aiding, you should obtain a voltage equal to that of two cells. With this series-parallel combination, you have a 3-volt battery which is capable of delivering twice the amount of current obtainable from two cells in series.

In Step 10, you set up another type of series-parallel circuit, and find that this gives exactly the same voltage as the circuit of Fig. *9*. Actually, these two series-parallel circuits have exactly the same characteristics, and would be identically the same electrically if the — terminals of cells *A* and *C* are connected together. These terminals are at the same potential, and hence the connection will not affect circuit conditions. Series-parallel circuits are used when both higher current and higher voltage are required than can be supplied by a single cell.

Practical Extra Information. Although the various steps in this experiment are relatively simple and easy to perform, they are of great practical importance. Dry cells connected in series, in parallel, and in various series-parallel combinations are used extensively in radio work.

The dry batteries used for portable radio receivers are a typical example; all of the voltages required for these sets are obtained from combinations of standard 1.5-volt dry cells. The plate circuits of these receivers require high voltages but low currents, and these are provided by large numbers of small 1.5-volt cells connected in series. The grid circuits have even lower current and voltage demands, and consequently the C batteries are also made up of small cells in series. The filament battery, on the other hand, must supply a low voltage but fairly high current, and usually you will find four dry cells connected in parallel for this purpose. A standard 45-volt B battery is made up of thirty 1.5-volt dry cells connected in series.

Dry cells are seldom connected in series-bucking in commercial radio equipment, but this connection is often utilized for experimental work. For example, if you required a voltage of 39 volts but had only a 45-volt B battery and four flashlight cells available, you could connect the four flashlight cells in series to give 6 volts, then connect this 6-volt battery in series-bucking with the 45-volt battery, so that the resulting voltage would be 45 — 6, or 39 volts.

Although we used dry cells as d.c. voltage sources in this experiment, the various rules and laws which were demonstrated will apply also to other d.c. voltage sources, such as d.c. generators.

Instructions for Report Statement No. 21. In the discussion of Step 9, it was pointed out that the series-parallel circuit shown in Fig. *10* had exactly the same characteristics as the series-parallel circuit of Fig. *9*; furthermore, you learned that these two circuits could be made the same *electrically* by connecting the minus terminals of Cells *A* and *C* together. (Any two points in a circuit can be connected together without affecting circuit conditions if the potential difference between those two points is zero.)

For this report statement, you are asked to prove that the — terminals of cells *A* and *C* in Fig. *10* are at the same potential. Do this by connecting the cells as shown in Fig. *10*, then place the red clip on the — terminal of cell *A*, and place the black clip on the — terminal of cell *C*. Measure the voltage between these points with the *V* range of the N. R. I. Tester, turn to the last page and make a check mark in Report Statement No. 21 after the voltage value which you obtained.

EXPERIMENT 22

***Purpose:* To demonstrate that Kirchhoff's Voltage Law holds true in a simple d.c. circuit.**

Step 1. Set up a simple series circuit consisting of four 1.5-volt dry cells and three 1,000-ohm resistors, as shown in Fig. *11A*.

The actual arrangement of these parts can be as shown in Fig. *11B,* in which the four flashlight cells are connected in series aiding. Connect resistor R_1 to the — terminal of cell *D* by means of a soldered lap joint. Connect resistors R_1, R_2 and R_3 together by means of temporary soldered hook joints.

Connect the right-hand terminal of R_3 to the + terminal of cell *A* with a suitable length of red hook-up wire, using a lap joint on the cell terminal and a soldered hook joint on the resistor lead. Set the N. R. I. Tester to measure d.c. voltages on the *V* range (set the selector switch to *V*, plug the red probe into the $+V_{DC}$ jack, and plug the black probe into the $-V_{DC}$ jack).

To prove Kirchhoff's Voltage Law, you will now measure the voltage across each part in this simple d.c. circuit, by starting with cell *A* and moving from part to part in the direction of electron flow. (Since electrons flow out of the — terminal of a voltage source, they will flow from the — terminal of *A* to the + terminal of *B* and continue in this direction through the circuit, as indicated by the arrows in the schematic diagram of Fig. *11A*.)

To prove Kirchhoff's Voltage Law, we must arbitrarily assume that a voltage having a given polarity (direction) in the circuit under consideration is a + value, and that a voltage having the opposite polarity is a — value. For the circuit of Fig. *11A*, we will assume that voltages having the same polarity as the dry cells are + values.

Place the red clip on the + terminal of cell *A*, and place the black clip on the — terminal of cell *A,* as shown in Fig. *11B*. Read the meter on the *DC* scale and record the value in Table *22* as the voltage of cell *A*. Place a + sign ahead of this value.

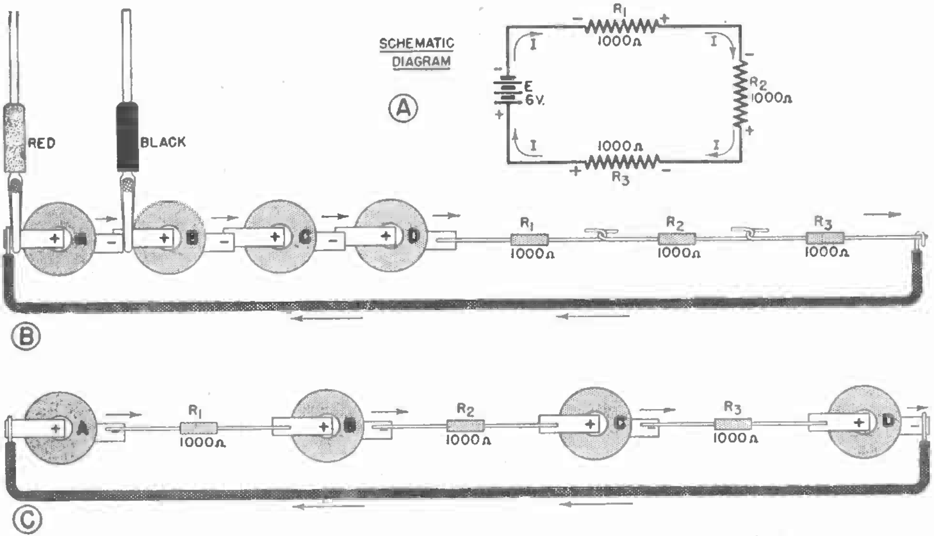

FIG. 11. Semi-pictorial and schematic circuit diagrams for Experiment 22. Arrows indicate the direction of electron flow in each case.

Now remove both clips at once, and move the clips to the terminals of the next part (cell *B*) without changing their relative positions. If an up-scale reading is secured, record it as a + value; if the meter reads backward, reverse the positions of the clips and record the reading as a — value. Remember that all other readings obtained with this reversed position of the clips must be recorded as negative values.

Here is another guide for determining the sign of a measured value in this circuit. Use a + sign when the black clip is ahead as you move in the direction of electron flow, and use a — sign when the red clip is ahead.

Move the red and black clips together around the circuit in the direction of electron flow until you have measured the voltage across each part and recorded it in Table *22*. Now, add together the + values first, then add together all the — values. The total of + values should be essentially equal to the total of — values if Kirchhoff's Voltage Law holds true for this d.c. circuit (they will seldom be exactly equal because all readings taken with meters are subject to normal variations).

Step 2. To show that Kirchhoff's Voltage Law holds true regardless of the positions of the resistors and cells in a simple d.c. circuit, rearrange your resistors and cells in the manner shown in Fig. *11C*. Following the same procedure outlined in Step 1, measure the voltage across each part in the circuit and record its value in the spaces provided for this purpose in Table *22*. When you have done this, break the circuit by unsoldering the red wire from the — terminal of cell *D*.

Add your measured values as described in Step 1 to check the accuracy of Kirchhoff's Voltage Law. Remember that natural inaccuracies in measuring and reading make an exact check almost impossible.

Dry cells are supplying energy whenever connected into a complete circuit. Therefore, if you stop making measurements for study purposes or any other reason while working with batteries, always break the circuit by unsoldering a lead from one cell terminal. You can easily reconnect this lead when you are ready to begin measurements again.

Discussion: In this experiment, you learned for yourself the exact nature of a voltage drop across a resistor. You know that the same current is flowing through all parts of your simple series circuit when it is completed. This flow of electrons through a resistor develops across the resistor a voltage, with the value of the voltage being determined by Ohm's Law (voltage = current × resistance).

Because your N. R. I. Tester is a

STEP 1			STEP 2		
PART BEING MEASURED	YOUR VOLTAGE IN VOLTS	N.R.I. VOLTAGE IN VOLTS	PART BEING MEASURED	YOUR VOLTAGE IN VOLTS	N.R.I. VOLTAGE IN VOLTS
A	+1.5	+1.5	A	+1.5	+1.5
B	+1.5	+1.5	R_1	-2.0	-2.0
C	+1.5	+1.5	B	+1.5	+1.5
D	+1.5	+1.5	R_2	-2.1	-2.0
R_1	-2.0	-2.0	C	+1.5	+1.5
R_2	-2.1	-2.0	R_3	-2.1	-2.1
R_3	-2.1	-2.1	D	+1.5	+1.5

I
+5.5
-6.2
II
+6.0
-6.2

TABLE 22. **Record your results here for Experiment 22.**

polarity-indicating device when connected as a d.c. voltmeter, you are able to determine the polarity of each voltage measured in this series circuit. In other words, whenever you secure an up-scale reading on the voltmeter, you know that the red clip of your meter is connected to the + terminal of the part whose voltage you are measuring.

One thing you should realize from this experiment is that a voltage drop produced across a part by the flow of current through it always has opposite polarity to that of the voltage source which is forcing that current through the circuit.

In Step 1, you find that each dry cell provides essentially 1.5 volts, with all four dry cells having the same polarity. This means that you have a voltage source of 6 volts in your circuit. Measurement of the individual voltages across the resistors shows a voltage of essentially 2 volts across each resistor. The resistors all have the same polarity, and this is opposite to the polarity of the dry cells. The three resistors thus have a combined voltage drop of essentially 6 volts, which is equal to the combined voltage of your source. If your results agree fairly closely with these values, you have proved the accuracy of Kirchhoff's Voltage Law for a d.c. circuit.

This experiment also allows you to determine for yourself the direction in which electrons flow through a resistor. You know the direction in which electrons flow in this complete circuit, for you learned in your fundamental course that electrons always come out the — terminal of a voltage source, and flow through the circuit toward the + terminal of the source. Since you know the direction of electron flow in your circuit and since you know the polarity of each voltage drop through your measurements (this polarity is as indicated in the schematic diagram in Fig. *11A*), you arrive at the basic radio fact that *the resistor terminal at which electrons enter is negative*, and *the resistor terminal which electrons leave is positive.*

Thus, if you know the polarity of the voltage drop across a resistor, you can immediately specify the direction in which electrons are flowing through that resistor. Conversely, if you know the direction in which electrons are flowing through a resistor, you can specify the polarity of the voltage drop developed across that resistor.

Resistor values of 1,000 ohms were chosen for this experiment because this particular value allows you to determine the current flowing through the resistor without going to the trouble of making a current measurement. It so happens that the current value in milliamperes flowing through a 1,000-ohm resistor is exactly equal to the voltage in volts across that resistor. This means that if you measure a voltage drop of 2 volts across 1,000-ohm resistor R_1, you have a current of 2 ma. flowing through that resistor. This relationship beteen current and voltage holds true only for a 1,000-ohm resistor, as you can readily verify by means of Ohm's Law.[*]

Step 2 verifies Kirchhoff's Voltage Law in much the same manner as does Step 1, and also demonstrates in a convincing manner the basic fact that in a series circuit, the current through the circuit and the voltage across individual parts in the circuit remain

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[*] $E = I \times R$; when R is in ohms and E is in volts, I is in amperes in this equation. Dividing current in milliamperes by 1,000 gives current in amperes, so we can say that $E = \frac{I_{ma}}{1,000} \times R$; since R is 1,000, the formula becomes $E = \frac{I_{ma}}{1,000} \times 1,000$. Cancelling now gives $E = I_{ma}$.

exactly the same regardless of the positions of the parts in the circuit.

Once you understand clearly the simple basic facts presented in this experiment, and realize that Kirchhoff's Voltage Law must hold true for any simple d.c. series circuit, you will have taken a tremendous step toward complete mastery of fundamental radio principles.

Instructions for Report Statement No. 22. You learned in this experiment and in your regular course that the sum of the voltage sources acting in any given circuit must equal the sum of the voltage drops in that circuit, according to Kirchhoff's Voltage Law. Under this condition, the voltage which you would measure between any two points in a circuit would be the difference between the voltage source values and the voltage drop values existing between these two points. For this report statement, you will make a measurement which proves the preceding statement.

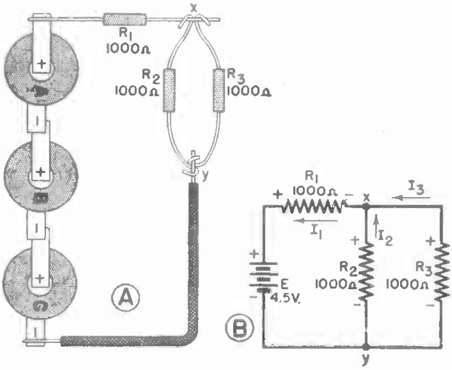

FIG. 12. Semi-pictorial and schematic circuit diagrams for Experiment 23.

Reconnect the red lead to the — terminal of Cell *D* in Fig. *11C,* then use your N. R. I. Tester to measure the voltage between the + terminal of cell *A* and the — terminal of cell *B.* To make this measurement, place the red clip of the N. R. I. Tester on the + terminal of cell *A*, and place the black clip on the — terminal of cell *B*. After measuring the voltage between these two points, turn to the last page and place a check mark after the voltage value which is closest to that which you measured.

Finally, turn off the N. R. I. Tester, then disconnect your circuit (Fig. *11C*) completely by unsoldering the resistors and the length of red hook-up wire.

EXPERIMENT 23

***Purpose:* To demonstrate that Kirchhoff's Voltage and Current Laws hold true for a complex d.c. circuit having a single voltage source.**

Step 1. After checking the calibration of your N. R. I. Tester (this is necessary only if this is the first experiment you are doing today), *set up the complex d.c. circuit shown in Figs. 12A and 12B,* by first connecting flashlight cells *A, B* and *C* in series aiding.

Connect one lead of resistor R_1 to the + terminal of cell *A* by means of a soldered lap joint. Connect a length of red hook-up wire to the — terminal of cell *C* with a soldered lap joint. Bend a hook in each end of the other two 1,000-ohm resistors (R_2 and R_3), then connect these two resistors in parallel between the free end of the hook-up wire and the free lead of R_1 with temporary soldered hook joints, as shown in Fig *12A*.

To prove that Kirchhoff's Voltage Law holds true for the closed circuit consisting of voltage source *E*, resistor R_1 and resistor R_2 in Fig. *12B*, use the N. R. I. Tester as a 0-4.5-volt d.c. voltmeter (the *V* range) to measure the voltage across each part of this closed circuit. Do this by measuring the source voltage first; place the red clip on the + terminal of *A*, place the black clip on the — terminal of *C*, read the meter, and record your result in Table *23*.

Now move your two test clips together around this circuit in the direction of electron flow. This means that you will next measure the voltage across R_2, by placing the black clip on its upper lead (at point x), and placing the red clip on its lower lead. Naturally, this makes the meter read down-scale since the voltage across R_2 is a voltage drop; therefore, reverse the positions of the test clips, read the meter, and record your result with a — sign ahead of it in the proper space in Table *23*.

Measure the voltage drop across R_1 and record its value in Table *23*.

Finally, measure the voltage drop across resistor R_3 and record its value in Table *23*, then unsolder joint y (Fig. *12A*) so as to prepare for the next experiment and at the same time open the circuit.

Since the voltage value measured across a 1,000-ohm resistor corresponds to the current value in ma. through the resistor, you will not have to record current values separately.

Discussion: The measurements which you make in this experiment will verify both of Kirchhoff's Laws for d.c. circuits. Let us first consider the voltage law.

The 4.5-volt voltage source, resistor R_1 and resistor R_2 form one complete circuit. If the measured value of the source voltage is essentially equal to the sum of the voltage drops across R_1 and R_2, you have confirmed Kirchhoff's Voltage Law for this circuit.

The other complete circuit around which Kirchhoff's Law should hold true is that consisting of E, R_3 and R_1. Add together arithmetically the values which you obtained for these resistors; if they add up to the source voltage, you have performed the experiment correctly.

Kirchhoff's Current Law says that the currents flowing to a given point in a circuit must be equal to the currents flowing away from that point. In other words, currents I_2 and I_3 in Fig. *12B* should add up to the value of current I_1. (The arrows on this diagram indicate the direction of electron flow; current flow is considered to be in the opposite direction. Either electron flow or current flow can be employed, provided you use the same one all through a series of calculations.)

NATURE OF MEASUREMENT	YOUR VOLTAGE IN VOLTS	N.R.I. VOLTAGE IN VOLTS
VOLTAGE ACROSS SOURCE	+4.4	+4.5
VOLTAGE ACROSS R_2 (SAME AS I_2 IN MA.)	-1.5	-1.5
VOLTAGE ACROSS R_1 (SAME AS I_1 IN MA.)	-2.8	-3.0
VOLTAGE ACROSS R_3 (SAME AS I_3 IN MA.)	-1.4	-1.5

TABLE 23. Record your results here for Experiment 23.

If the value which you obtained by adding currents I_2 and I_3 is essentially equal to current I_1, you have verified Kirchhoff's Current Law. Thus, adding N. R. I. values of 1.5 and 1.5 for I_2 and I_3 gives 3.0 ma., which is the same as the recorded N. R. I. value of 3.0 for I_1.

Note that the same voltage drops were measured across R_2 and R_3; this proves conclusively that parts connected in parallel all have the same voltage across them.

Instructions for Report Statement No. 23. Radio men sometimes find it necessary to measure the voltage of a source having terminals which cannot be reached conveniently without disconnecting a lot of apparatus. Sometimes it is a physical impossibility to measure the source voltage at its source; measurement of the induced voltage in a transformer is one example. In a situation like this, the practical radio man will break the circuit at some point and measure the voltage between the terminals thus provided. The voltage measured in this manner will be essentially equal to the source voltage if the voltmeter resistance is many times higher than any resistance in the circuit under consideration, and this condition is almost always true when using a vacuum tube voltmeter such as the N. R. I. Tester.

For this experiment, you will duplicate a practical voltage measurement like this by placing the black clip of the N. R. I. Tester on the red lead which you unsoldered from joint y in Fig. *12*, placing the red clip on either one or both of the resistor leads which formerly went to joint y, and measuring the voltage with the V range of the N. R. I. Tester. After doing this, turn to the last page and make a check mark after the voltage value which is closest to that which you measured.

EXPERIMENT 24

Purpose: **To demonstrate that Kirchhoff's Voltage and Current Laws hold true in a circuit which has more than one source of e.m.f.**

Step 1. Starting with the circuit of Fig. 12A, insert 1.5-volt dry cell D in series with resistor R_3 in such a manner that your set-up now appears as shown in Fig. *13A*. The schematic circuit will now have the form shown in Fig. *13B*, with the + terminal of E_1 (dry cell D) going to one lead of R_3, and with the − terminal of this cell going to the − terminal of cell C.

Considering first the closed circuit consisting of E, R_1 and R_2, move completely around this circuit with your 0-4.5-volt d.c. voltmeter and measure the voltage across each part. Remember that when recording the voltage values in Table *24*, you are to place a + sign ahead of any value having the same polarity as battery E, and a − sign whenever a voltage has the opposite polarity. The set-up for measuring the voltage across R_1 is shown in Fig. *13C*.

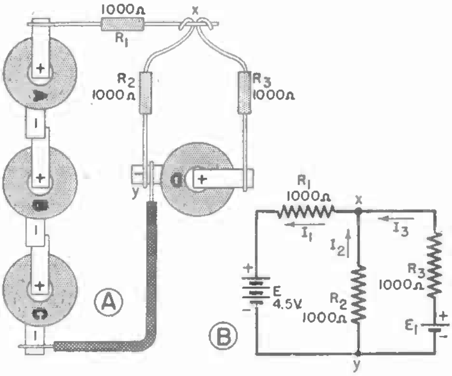

FIG. 13. Semi-pictorial and schematic circuit diagrams for Experiment 24.

Considering next the closed circuit consisting of E, E_1, R_3 and R_1, measure the voltage across each part in the same manner, and record in Table *24* the voltages measured for E_1 and R_3. You will find that the voltage across E_1 is opposite in polarity to that of E, and you will therefore have to place a − sign ahead of the measured value for E_1. You do not have to record the voltages for E and R_1 again, since you have already measured these.

Step 2. To check Kirchhoff's Voltage Law for the closed circuit consisting of E_1, R_3 and R_2, measure the voltage across each part while moving in the same direction around the circuit, giving a + sign to voltages having the polarity of E_1. Record your measured values on the last three lines in Table *24*.

Now unsolder the two leads from the — terminal of cell *D* (Fig. *13A*) and separate these leads, so as to prevent the dry cells from discharging.

Discussion: In each of the three complete circuits in which you made measurements for Steps 1 and 2, the source voltage (the sum of the source voltages in circuit $E - E_1 - R_3 - R_1$) should be approximately equal to the voltage drops when + and — signs are taken into account, for Kirchhoff's Voltage Laws hold true.

Thus, in circuit $E - R_1 - R_2$, the N. R. I. source value of +4.5 is equal to the sum of —2.5 and —2.0.

In circuit $E\text{-}R_1\text{-}R_3\text{-}E_1$, the source voltages of +4.5 and —1.5 buck each other, leaving a source voltage of 3 volts in this circuit, which is equal to the sum of the —2.5 and —.5 volt voltage drops.

In circuit $E_1\text{-}R_3\text{-}R_2$, the source voltage of +1.5 volts is equal to the algebraic sum (the numerical difference) of +.5 and —2.0, which is —1.5 volts. These values indicate that resistor R_2 is actually transferring into circuit $E_1\text{-}R_3\text{-}R_2$ a portion of the larger voltage source *E*, and cell E_1 is bucking out part of this voltage available across R_2. The difference, or .5 volts, appears across and sends current through R_3.

Before you can apply Kirchhoff's Current Law, you must determine the direction of electron flow through each resistor. You can do this very easily if you mark the polarity of each resistor on the schematic circuit diagram in Fig. *13B*. Do this as you make each voltage measurement. The direction of electron flow will then be from — to + through each resistor. You should find that the directions are as indicated by the arrows in Fig. *13B*. This means that currents I_2 *and* I_3 are flowing toward point *x*, and current I_1 is flowing away from this point. If the sum of I_2 and I_3 is essentially equal to I_1, you know that currents flowing to this point are equal to currents flowing away from the point, and you have proved Kirchhoff's Current Law.

Since 1000-ohm resistors are used, the current in ma. through a resistor will be the same as the voltage in volts across that resistor. Adding the N. R. I. values of 2.0 and .5 for I_2 and I_3 gives 2.5 ma., which is equal to the N. R. I. value of 2.5 ma. for I_1, thus verifying Kirchhoff's Current Law.

STEP	NATURE OF MEASUREMENT	YOUR VOLTAGE IN VOLTS	N.R.I. VOLTAGE IN VOLTS
1	VOLTAGE ACROSS E	+4.5	+4.5
	VOLTAGE ACROSS R_1 (SAME AS I_1 IN MA.)	-2.4	-2.5
	VOLTAGE ACROSS R_2 (SAME AS I_2 IN MA.)	-2.0	-2.0
	VOLTAGE ACROSS R_3 (SAME AS I_3 IN MA.)	-.4	-.5
	VOLTAGE ACROSS E_1	-1.5	-1.5
2	VOLTAGE ACROSS E_1	+1.5	+1.5
	VOLTAGE ACROSS R_3	+.3	+.5
	VOLTAGE ACROSS R_2	-2.0	-2.0

TABLE 24. **Record your results here for Experiment 24.**

Practical Extra Information. The voltage drop produced by the flow of current through a resistor is widely used in radio. Perhaps the most common example is that of the cathode resistor in a vacuum tube circuit; the flow of plate-cathode current through this resistor develops across the resistor a voltage drop which is usually made to serve as the C bias voltage for the tube. Voltage drops across resistors are also used for automatic volume control purposes, for frequency-correcting purposes, for preventing undesirable oscillation, for protection against overloads, and for many similar purposes which will be studied in detail in the experiments which follow and in your regular course.

A voltage drop across a resistor is sometimes considered as a secondary source of voltage when used in many of the applications just mentioned. Actually, the resistor in question is not a true voltage source, but is merely transferring a true source voltage (produced by a dry cell or power pack) from one circuit to another.

FIG. 13C. This photographic illustration shows the parts connected for Step 1 of Experiment 24, with the N.R.I. Tester connected to measure the voltage across R_1.

Instructions for Report Statement No. 24. If you reverse the polarity of either of the voltage sources employed in the circuit of Fig. *13*, circuit conditions will change.

For Report Statement No. 24, you will prove this by reversing the connections of cell *D* in Fig. *13* in the following manner: Unsolder the lead of R_3 from the + terminal of cell *D*. Turn the cell around, and solder the free lead of R_3 to the — terminal of this cell. Solder the red wire and the free lead of R_2 to the + terminal of cell *D*. You should now have the circuit of Fig. *13A* with the terminals of cell *D* reversed. After doing this, measure the voltage across R_3 with the N. R. I. Tester, and compare your measured value with that obtained across R_3 in Step 1. (When comparing these voltages, consider only the voltage values, without regard for + and — signs.) Now turn to the last page and check the answer which describes your result.

EXPERIMENT 25

Purpose: **To demonstrate that a definite period of time is required to charge or discharge a condenser through a resistance.**

Step 1. To charge a .5-mfd. capacity through a 10-megohm resistance, first connect the two .25-mfd. tubular paper condensers (Parts *3-2A* and *3-2B*) in parallel to secure a combined capacity of .5 mfd., using temporary soldered connections as shown in Fig. *14*. Touch the leads of the two parallel-connected condensers together to discharge the condensers. Now bend the condenser leads so they can be inserted in the two *R* jacks on the N. R. I. Tester panel. Set the selector switch at *V*, turn on the N. R. I. Tester, and insert the .5-mfd. capacity into the *R* jacks while watching the meter. The schematic circuit for this set-up appears in Fig. *16A*. The pointer should rise rapidly to 4.5 volts, then return gradually to nearly 0; estimate the length of time it takes for the pointer to return from 4.5 to 1.5 on the *DC* scale, and record the value in Table *25,* but leave the condensers in the jacks for about two minutes, until the pointer comes to rest near zero.

You can estimate the time in seconds simply by counting at a normal speaking rate as follows: One hundred and one, one hundred and two, one hundred and three, etc. Each phrase will then be approximately equal to one second. If you practice counting first while watching the second hand of your watch or clock, you can do this very accurately.

STEP	NATURE OF MEASUREMENT	YOUR TIME IN SECONDS	N.R.I. TIME IN SECONDS	COMPUTED TIME CONSTANT IN SEC.
1	CHARGING .5 MFD. WITH 4.5 V. THRU 10 MEG.	7	6	5
2	DISCHARGING .5 MFD. THRU 10 MEG.	7	6	5
3	DISCHARGING .5 MFD. THRU .9 MEG.	LESS THAN 1 sec.	less than 1 SEC.	.45

TABLE 25. Record your results here for Experiment 25.

Do not touch the condenser leads while making this measurement; grasp the paper sleeves of the condensers with your fingers to hold them into the jacks, for otherwise the resistance of your body will give confusing readings.

Step 2. To observe how the voltage varies across a .5-mfd. capacity while it is being charged directly by a 4.5-volt d.c. source, touch the leads of the two parallel-connected .25-mfd. condensers together to discharge the condensers, then insert the leads in the V_{DC} jacks on the N. R. I. Tester panel. Attach the alligator clip of the red test lead to the condenser lead which is in the + V_{DC} jack, and attach the black alligator clip to the condenser lead which is in the $-V_{DC}$ jack. Turn on the N. R. I. Tester, leaving the selector switch at *V*.

Using three of the flashlight cells connected in series aiding as the 4.5-volt d.c. source, hold the red probe on the + terminal of the cell group with one hand, and hold the black probe on the — terminal of the cell group, as shown in Fig. *15,* so as to secure the circuit shown in Fig. *16B*. When the meter pointer has come to rest at about 4.5 on the *DC* scale, remove the probes from the battery terminals, estimate the time required for the meter pointer to drop down to 1.5 on the *DC* scale, record your value in Table *25,* and turn off the Tester.

If you wish to repeat this experiment for any reason, discharge the condensers by shorting their leads with a screwdriver before starting the experiment again.

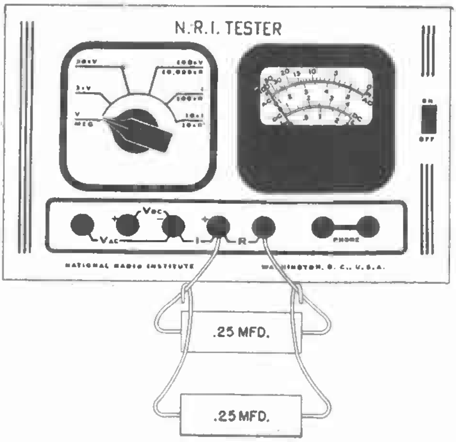

FIG. 14. Method of charging a .5-mfd. capacity for Step 1 of Experiment 25. (Two .25-mfd. condensers in parallel have a combined capacity of .5 mfd.)

Step 3. Connect the 1-megohm resistor (Part *3-7*) *in parallel with the .5-mfd. capacity as indicated in Fig. 16C, by using temporary soldered hook or lap joints,* and repeat the entire procedure set forth in Step 2. Again try to estimate the time re-

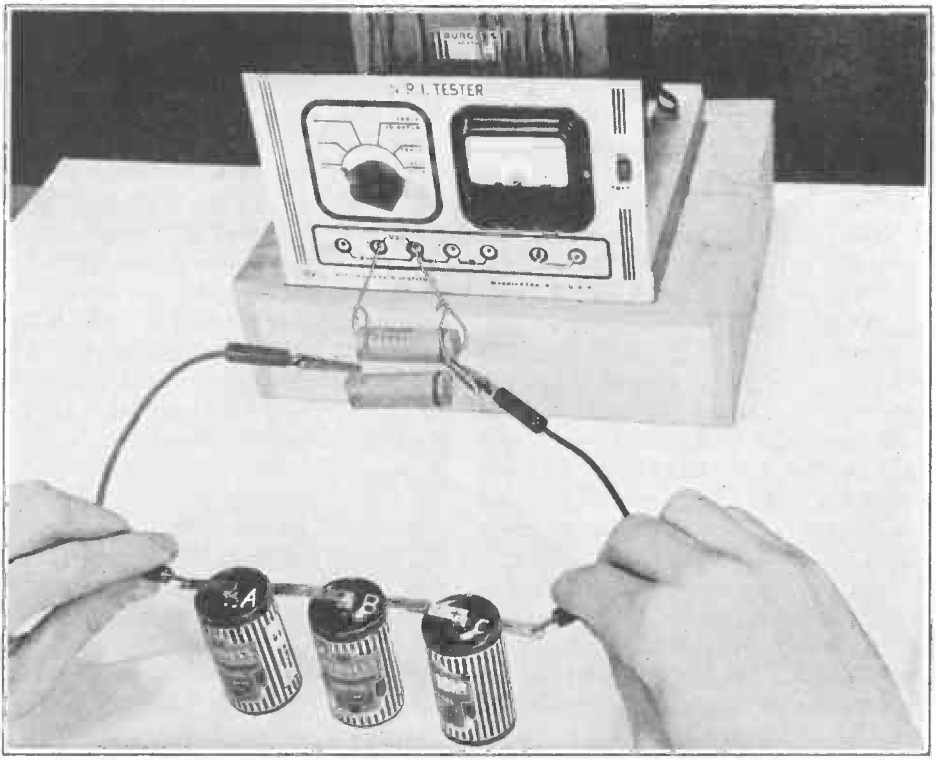

FIG. 15. Photographic illustration showing how apparatus is set up for Step 2 of Experiment 25.

quired for the pointer to drop from 4.5 to 1.5; if the pointer drops too fast for you to estimate the time, simply record in Table *25* the fact that the time was less than one second.

Now remove the test leads, remove the condenser-resistor combination from the V_{DC} jacks, and separate the condensers and resistor by unsoldering.

Discussion: When the .5-mfd. capacity is connected to the *R* jacks, the schematic circuit diagram for the set-up is as shown in Fig. *16A,* in which a 4.5-volt d.c. source (a portion of the battery system of the N. R. I. Tester) is charging the condenser through a 10-megohm resistor in the N. R. I. Tester. The meter and the vacuum tube in the N. R. I. Tester together measure the voltage developed across the 10-megohm resistor by the condenser charging current. When voltage is first applied to the condenser, the meter immediately swings to 4.5 on the *DC* scale, and therefore indictates the full voltage of the 4.5-volt d.c. source.

After reaching 4.5, the meter pointer immediately begins moving

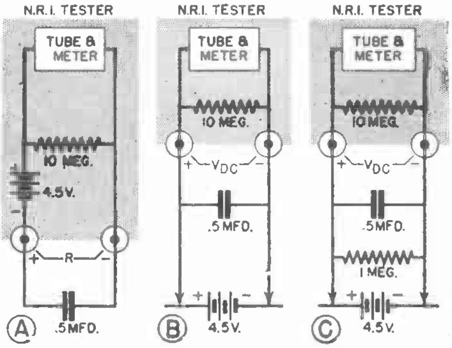

FIG 16. Schematic circuit diagrams for Experiment 25.

down scale, rather rapidly at first and then more slowly. The pointer drops in this manner because the condenser acquires a back e.m.f. (a voltage drop) as it charges. As the voltage drop increases across the condenser, the voltage drop across the resistor reduces correspondingly because the source voltage of 4.5 volts must divide itself between these two parts according to Kirchhoff's Voltage Law.

It is a fundamental radio fact that the rate at which a condenser charges depends only upon the value of the condenser and upon the value of the resistor through which the charging current flows. Furthermore, multiplying the resistance value in megohms by the capacity value in microfarads gives a time value in seconds which is known as the *time constant* of the condenser-resistance combination. During charging of a condenser, this time constant will be the time in seconds required for the condenser to charge up to 63% of its final voltage.

In our case, 63% of 4.5 volts is 2.85 volts. Subtracting this value of 2.85 volts from the total available voltage of 4.5 volts leaves 1.65 volts as the voltage across the 10-megohm resistor at the end of the time constant period. Estimating the time it takes for the voltage across the 10-megohm resistor to drop to 1.5 volts is close enough.

According to theory, the time constant for a .5-mfd. condenser and a 10-megohm resistor is 10 x .5, or 5 seconds. The time which you estimate and record in Table *25* should therefore be about five seconds.

After the pointer passes below 1.5, it will still take several minutes before it comes to rest. The pointer will not drop entirely to zero, for the condenser has a leakage resistance value (somewhere around 100 megohms) which may allow some current to flow through the circuit even when the condenser is fully charged. Tap the meter housing lightly to overcome bearing friction when the pointer is near zero.

In Step 2, you use an external d.c. voltage source of 4.5 volts and connect it directly to the condenser, with the N. R. I. Tester connected across the condenser leads to measure the condenser voltage, as shown in the schematic diagram in Fig. *16C*. When you hold the probes across the 4.5-volt d.c. source, this voltage is applied to the condenser in parallel with the 10-megohm resistance of the N. R. I. Tester. The meter therefore indicates the full d.c. source voltage of 4.5 volts for as long as you hold the probes on the batteries. After the condenser was fully charged, you removed the probes from the battery terminals. This allowed the condenser to discharge through the 10-megohm input resistance of the N. R. I. Tester.

In the case of discharge, the time constant is the time in seconds required for the condenser to discharge until its voltage is 37% of its original charged voltage. In other words, when the condenser voltage drops to .37 x 4.5, or to 1.65 volts, the end of the time constant period is reached.

In Step 2, you are actually measuring the voltage across the condenser, because the meter, the 10-megohm resistor and the condenser are all in parallel. Theoretically, therefore, it will take the time constant value of about five seconds for the condenser to discharge from 4.5 volts to 1.5 volts in Step 2. If your estimate is within a few seconds of this value, you can consider that you have performed this experiment satisfactorily.

Shunting the 1-megohm resistor across the .5-mfd. condenser lowers the 10-megohm N. R. I. Tester input resistance to about .9 megohm, since these two resistors are now in parallel.

This means that the condenser will discharge through .9 megohm when the external voltage source is removed. The time constant for .9 megohm and .5 mfd. is about .45 second; this means that the condenser voltage will drop to 1.5 volts in about half a second after the voltage source is removed. As you observed, this short time is very hard to estimate accurately; it is sufficient simply to say the time was less than one second.

Practical Extra Information. The basic radio fact which you have just observed, wherein a condenser employed in series with a resistor in a d.c. circuit requires a certain amount of time to charge and to discharge, has many practical applications in modern radio receiver circuits. Perhaps the best known of these applications is the automatic volume control circuit, which you take up in your regular lessons; here, the time delay characteristics of the resistor and condenser control the speed with which the a.v.c. system responds to changes in signal strength. Fast a.v.c. action is desirable in order to keep the volume essentially constant during periods when stations are fading in and out rapidly and during tuning from one station to another, but a.v.c. action must not be so fast that it responds to audio variations. The time constant employed must be a compromise between these two conditions.

Instructions for Report Statement No. 25. In this experiment, you showed that decreasing the resistance value in the discharging circuit of a condenser will reduce the time constant of the circuit. It can also be shown that decreasing the capacity of the condenser without changing the resistance reduces the time constant.

For Report Statement No. 25, you will prove the preceding statement by reducing the capacity to .125 mfd. and discharging this through the 10-megohm input resistance of the N. R. I. Tester.

To carry out this experiment, connect the two .25-mfd. condensers in series by soldering a lead of one condenser temporarily to a lead of the other condenser; this gives you a combined capacity of .125 mfd. between the two free leads of this condenser group. Push one free condenser lead into the $+V_{DC}$ jack of the N. R. I. Tester, and push the other free condenser lead into the $-V_{DC}$ jack. With the selector switch still at *V*, turn on the tester, then charge the .125-mfd. capacity with a 4.5-volt d.c. source (use your two test leads and the three dry cells in series for this purpose; connect the + terminal of the cell group to the condenser lead in the $+V_{DC}$ jack with the red test lead, and connect the — terminal of the cell group to the condenser lead which is in the $-V_{DC}$ jack). Remove the charging source. Estimate the number of seconds it takes for the meter pointer to drop from 4.5 volts down to 1.5 volts on the *DC* scale while discharging through the 10-megohm resistance of the N. R. I. Tester, turn to the last page, and place a check mark after the result you obtain. 3

EXPERIMENT 26

***Purpose:* To demonstrate that direct current will flow through a coil, and to prove that the d.c. voltage drop produced across a coil by current flow depends solely upon the value of the direct current flowing and the d.c. resistance of the coils.**

To demonstrate that direct current will not flow through a paper condenser.

To demonstrate that direct current will flow through an electrolytic condenser, and to show that the value of the current will change when the polarity of the condenser connection is reversed.

Step 1. To study the characteristics of a coil in a direct current circuit, set up a series circuit like that shown in Figs. *17A* and *17B*, consist-

STEP	NATURE OF MEASUREMENT	YOUR VALUE IN VOLTS	N.R.I. VALUE IN VOLTS
1	ACROSS COIL	.5	.9
	ACROSS 1000Ω	3.4	3.7
2	ACROSS 200Ω	.3	.7
	ACROSS 1000Ω	3.4	3.9
3	ACROSS 1000Ω	0	0
	ACROSS .25 MFD.	4.2	4.5
4	RESISTANCE OF .25 MFD. COND.	R= 40 MEG.	R= 100 MEG.
5	ACROSS 40,000Ω	0	.1
6	ACROSS 40,000Ω	.9	1.7

TABLE 26. Record your results here for Experiments 26.

ing of flashlight cells *A*, *B* and *C*, the 10-henry choke coil (Part *3-10*), and one 1,000-ohm resistor (Part *3-5A*). With your N.R. I. Tester set for use as a 0-4-5-volt d.c. voltmeter (range *V*, with the test leads in the V_{DC} jacks), measure the voltage across the choke coil and across the resistor, and record each value in Table *26*. As soon as you have finished, open the circuit by disconnecting one coil lead, and turn off the N. R. I. Tester.

Step 2. To demonstrate that a coil in a d.c. circuit acts exactly like a resistor having the same ohmic value as the coil, replace the 10-henry choke coil with a 200-ohm resistor (Part *3-4*) and complete the series circuit connection so that your set-up corresponds to the circuit diagram in Fig. *18.* Now repeat the measurements of Step 1, measuring the voltage across each part in turn to see if the resistor gives circuit values the same as were obtained for the coil. Record your results in Table *26*. Open the circuit and turn off the N. R. I. Tester as soon as you have finished measurements.

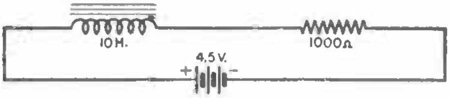

FIG. 17A. Schematic circuit diagram for Step 1 of Experiment 26.

FIG. 17B. Method of measuring the voltage across the 1,000-ohm resistor in the coil-resistor circuit which you set up for Step 1 of Experiment 26.

A 200-ohm resistor is used in place of the coil, because the coil has a d.c. resistance of about 200 ohms.

Step 3. To study the behavior of a paper condenser in a d.c. circuit, connect the three cells in series with the 1,000-ohm resistor (Part *3-5A*) and the .25-mfd. paper condenser (Part *3-2A*), as shown in Fig. *19*. Measure the voltage across the resistor and the condenser, and record your results in Table *26*. Open the circuit and turn off the N.R.I. Tester.

Step 4. To confirm the results obtained in Step 3, measure the resistance of your .25-mfd. condenser by using the highest resistance range of the N.R.I. Tester.

Before making a resistance measurement with the N.R.I. Tester, it is necessary to adjust the ohmmeter to zero. Set the selector switch to *MEG.*, short the *R* jacks so as to give zero external resistance (by plugging the test probes into these jacks and placing one test clip on the other clip), then adjust the potentiometer with a screwdriver until the pointer is at zero at the right-hand end of the *R* (top) scale.

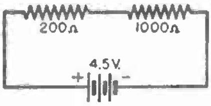

FIG. 18. Schematic circuit diagram for Step 2 of Experiment 26.

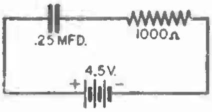

FIG. 19. Schematic circuit diagram for Step 3 of Experiment 26.

After making the ohmmeter zero adjustment, leaving the selector switch set at *MEG.*, remove the test leads, then insert the condenser leads in the *R* jacks as shown in Fig. *20*, while watching the meter pointer. Do not touch the condenser leads with your fingers while doing this. Hold the condenser in this position until the meter pointer has come to rest definitely. Tap the top of the meter lightly with your finger to make sure the pointer has reached its final position, then read the meter on the *R* scale and record your reading in Table *26* as the resistance of the .25-mfd. condenser in megohms.

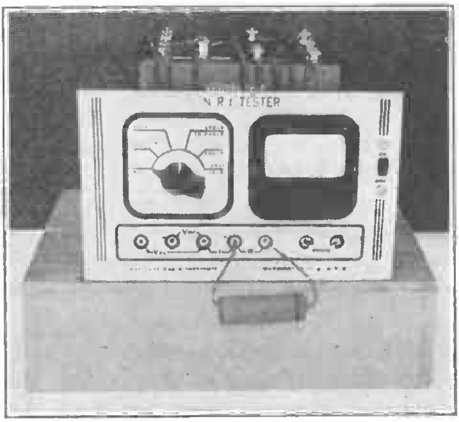

FIG. 20. Method of measuring the resistance of a .25-mfd. condenser with the N.R.I. Tester. Resistances up to 100 megohms can be measured with the N.R.I. Tester in this manner when the selector switch is set at *MEG.*

When the selector switch of the N.R.I. Tester is set at *MEG.*, and the *R* jacks are being used, your instrument is serving as a 0-100-megohm ohmmeter, and its indications are read directly in megohms on the *R* scale at the top of the meter.

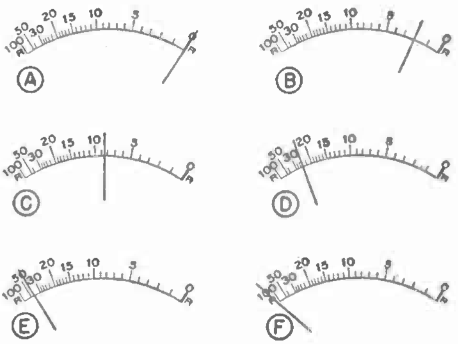

FIG. 21. Examples illustrating how to read the *R* scale on the meter of your N.R.I. Tester. The readings are as follows: *A*—0; *B*—2.0; *C*—8.5; *D*—24; *E*—40; *F*—INFINITY.

You should have no difficulty in reading the *R* scale after your experience with the *DC* scale and scale I_M. The only thing you should watch for is the fact that this scale reads from right to left. Between 0 and 20 on this scale, each small division represents 1. Between 20 and 30, each small division represents 2.

Readings for six different positions of the pointer on the *R* scale are indicated in Fig. *21*. Study each one of these carefully until you are certain you know how to read this scale, for you will use the ohmmeter scale extensively in your practical demonstration course and in actual radio work.

After completing resistance measurements, be sure to restore the original calibration. This can be done in a moment, simply by moving the calibrating clip to its calibrating position on —7½C and readjusting the potentiometer to give a meter reading of 1.5 on the *DC* scale, then returning the clip to —9C.

Step 5. To determine how an electrolytic condenser behaves in a d.c. circuit, connect one section of the dual 10-mfd. electrolytic condenser (Part *3-3*) in series with a 40,000-ohm resistor (Part 3-6A) and a series-connected group of three flashlight cells, as shown in Figs. *22A* and *22B*.

Correct connections for the electrolytic condenser are shown in Fig. *22B*. Observe that the three outside lugs, two with holes and one without, are all a part of the metal housing of the condenser; internally, this housing is connected to the — terminals of both 10-mfd. electrolytic condenser sections. The two terminal lugs in the center, one having a triangular cut-out alongside it in the fiber base, and the other having a square cut-out in the base, are the + terminals of the condenser sections.

Since both sections are of the same value in this particular dual unit, it does not matter which central lug you use for the + terminal of your electrolytic condenser. Of course, you can use either of the outer lugs for the negative terminal, since they are connected together anyway through the housing.

Observe that the negative terminal of the electrolytic condenser is connected to the negative terminal of the cell group in the circuit of Fig. *22B*. This is the correct method of connecting an electrolytic condenser to a circuit in which d.c. voltage is present.

With the N. R. I. Tester being used as a 0-4.5-volt d.c. voltmeter, measure the voltage across the 40,000-ohm resistor and record your value in Table *26*.

Step 6. Reverse the connections to the electrolytic condenser in the circuit of Fig. 22A, so that the + terminal of the condenser now goes to the — terminal of the cell group. Again measure the voltage across the 40,000-ohm resistor, and record your result in Table *26*.

Discussion: The resistance of the coil which you used in Step 1 is about 200 ohms (230 ohms to be exact, but we can consider this to be 200 ohms for all practical purposes). Adding 200 ohms to 1,000 ohms (the resistor value) gives a total circuit resistance of 1,200 ohms. We know that three dry cells connected in series aiding give a voltage of 4.5 volts, so we can easily determine the circuit current by means of Ohm's Law. The formula to be used is: $I = E \div R$; dividing 4.5 by 1,200 gives .00375 ampere, and this is equal to 3.75 ma.

Your measurement for Step 1 should confirm the 3.75-ma. value for the circuit current. You will recall that the voltage measured across a 1,000-ohm resistor corresponds to the current through that resistor in ma.; therefore, if you measured approximately 3.75 volts across the 1,000-ohm resistor, you know that you performed the experiment correctly.

A current of 3.75 ma. flowing through the 200-ohm coil will develop across this coil resistance a voltage of 200 × .00375, or .75 volt. If the voltage which you measured across the coil was approximately ¾ of a volt, you have confirmed the basic fact that a coil acts exactly like a resistance in a d.c. circuit. In other words, the only thing which limits the flow of current through a coil is the resistance of the wire used in winding the coil.

A coil is intended primarily for use in a.c. circuits, for there it has a reactance which opposes the flow of alternating current.

Step 2 shows even more convincingly the resistive nature of a coil in a d.c. circuit. This time, the resistor which replaced the coil in your circuit has about the same ohmic value as the coil. Therefore, your measured voltage values across the 200 and 1,000-ohm resistors should be essentially the same as in Step 1.

When the voltage across the condenser is measured in Step 3, you find that it is equal to the source voltage of 4.5 volts. Actually, the voltage is zero at the start, and builds up gradually to this final value as the condenser becomes charged.

When you measure the resistance of the .25-mfd. condenser in Step 4, you encounter the same charging phenomenon at first. The meter swings upscale, then gradually swings back to the left. You must wait until the pointer has stopped moving before taking a reading. If your condenser is in good condition, it will have a resistance above 50 megohms.

The one type of condenser which has a fairly low resistance is the electrolytic condenser. Between the plates of an electrolytic condenser is a paste or liquid which has considerably lower resistance than the mica, paper or air used between the plates in other condensers. Furthermore, an electrolytic condenser will allow more direct current to flow in one direction than in the other. This is why you must always consider polarity when connecting an electrolytic condenser.

The correct polarity for an electrolytic condenser is always such that the — terminal of the condenser goes to the — terminal of the voltage source; this is the connection we use in Step 5. The voltage measured across the 40,000-ohm resistor is an indication of the amount of current flowing through the condenser. We are not concerned with the exact current value at present, even though we could compute it by means of Ohm's Law. The important thing is to compare the measured voltage in Step 5 with the measured voltage in Step 6. You should obtain a higher voltage in Step 6, indicating that a higher value of direct current flows through an electrolytic condenser when it is improperly connected.

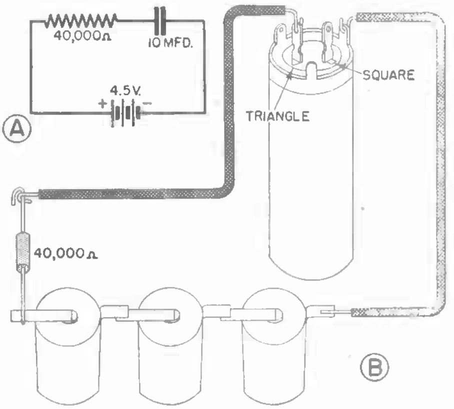

FIG. 22. Schematic (*A*) and semi-pictorial (*B*) circuit diagrams for Step 5 of Experiment 26.

Practical Extra Information. Your results in Steps 5 and 6 indicate that an electrolytic condenser has a definite resistance, and that this resistance is lower for an improper connection than for the correct polarity of connections. Since an electrolytic condenser is primarily intended for use as a capacitance, it is desirable to keep direct current through it at a minimum. With improper polarity of connections, excessive current through the condenser causes it to overheat and destroy itself.

Instructions for Report Statement No. 26. Radio servicemen frequently find it necessary to make continuity tests in order to determine whether a complete d.c. circuit exists between any two points in a piece of radio apparatus. Resistances of various parts in a circuit must also be checked to determine whether any part is shorted or open. In many circuits, the part which is to be tested may be shunted by a paper condenser. You have proved that a paper condenser will not conduct direct current once it is charged; this means that you can ignore the presence of a paper condenser across a part if you know that the condenser is in good condition. In practical radio work, you can seldom be sure that a condenser is in good condition, so it is best to disconnect shunt condensers when making continuity tests.

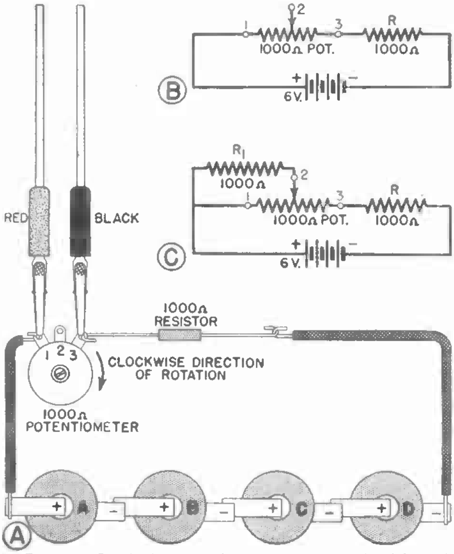

FIG. 23. Semi-pictorial (*A*) and schematic (*B* and *C*) circuit diagrams for Experiment 27.

For this report statement, make an additional test of this statement by setting up the circuit of Fig. *18*, connecting a .25-mfd. condenser across the 200-ohm resistor, and measuring again the d.c. voltage across the 1,000-ohm resistor. Compare the measured voltage value with that obtained originally for this circuit set-up, then turn to the last page and place a check mark after the answer you obtain.

EXPERIMENT 27

Purpose: **To show that during no-load conditions the voltages across various parts of a voltage divider will divide exactly according to resistance; to show that application of a load across a part of the voltage divider affects the division of voltages.**

Step 1. To set up a simple voltage divider circuit, connect together in series the four flashlight cells, the 1,000-ohm potentiometer (Part *3-8*) and the 1,000-ohm resistor *R* (Part *3-5A*) according to the semi-pictorial wiring diagram in Fig *23A,* so that you will have the circuit represented by the schematic diagram in Fig. *23B.* Use temporary soldered joints throughout. The potentiometer and the 1,000-ohm resistor can be placed on the table, and connected to the group of four cells with lengths of hook-up wire as shown. Number the potentiometer lugs *1, 2* and *3* as indicated in Fig. *23A,* by writing on the fiber base of the potentiometer alongside each lug.

Measure the voltage drop across the potentiometer by placing the red clip on terminal *1,* and placing the black clip on terminal *3,* as shown in Fig. *23A.* Set the selector switch at *V,* plug the test probes into the V_{DC} jacks (remember that the red probe goes into the + jack), turn on the N. R. I. Tester, read the meter on the *DC* scale, and record the value in Table *27* as the voltage in volts across the 1,000-ohm potentiometer.

Now measure the voltage across the 1,000-ohm resistor *R* and record its value in Table *27.*

Step 2. To demonstrate how the potentiometer can provide a variable voltage, measure the voltage between movable terminal *2* and fixed terminal *1* on the potentiometer while rotating the potentiometer shaft from one ex-

STEP	NATURE OF MEASUREMENT	YOUR VOLTAGE IN VOLTS	N.R.I. VOLTAGE IN VOLTS
1	VOLTAGE ACROSS 1000Ω POT.	2.9	2.9
	VOLTAGE ACROSS 1000Ω RES. R	2.9	3.1
2	VOLTAGE AT 0 ROTATION	0	0
	VOLTAGE AT ¼ ROTATION	.5	.6
	VOLTAGE AT ½ ROTATION	1.2	1.4
	VOLTAGE AT ¾ ROTATION	2.1	2.1
	VOLTAGE AT FULL ROTATION	2.8	2.9
4	VOLTAGE ACROSS 1000Ω POT.	2.1	2.1
	VOLTAGE ACROSS 1000Ω RES. R	3.6	3.9
	VOLTAGE AT 0 ROTATION	0	0
	VOLTAGE AT ¼ ROTATION	1	.5
	VOLTAGE AT ½ ROTATION	1.2	1.1
	VOLTAGE AT ¾ ROTATION	1.5	1.4
	VOLTAGE AT FULL ROTATION	2.1	2.1

TABLE 27. Record your results here for Experiment 27.

treme to the other. Do this by placing the red clip on terminal *1* and the black clip on terminal *2* (terminal *2* goes to the movable contact, as you can readily see by studying the construction of the potentiometer). The potentiometer has a slotted shaft, which can readily be rotated by inserting a screwdriver in the slot. After rotating the potentiometer back and forth a few times to see how the meter pointer behaves, rotate the potentiometer to the extreme clockwise position, read the voltage on the *DC* scale of the meter, and record it in Table *27* as the voltage for zero rotation. Now rotate the potentiometer through approximately ¼ of its complete movement, read the voltage again, and record it in Table *27* as the voltage for ¼ rotation. Repeat for ½, ¾ and full rotation of the potentiometer, recording the voltage in Table *27* each time.

Step 3. To prove that rotation of the movable contact of the potentiometer has no effect upon the voltage across the potentiometer when there is no load, connect the 0-4.5-volt d.c. voltage range of the N. R. I. Tester across the potentiometer (to terminals *1* and *3*) and watch the meter while you rotate the potentiometer shaft back and forth.

Step 4. To study the action of your voltage divider circuit under loaded conditions, connect a 1,000-ohm resistor R_1 (Part *3-5B*) between terminals *1* and *2* of the potentiometer by means of temporary soldered hook joints, as indicated in the schematic circuit diagram in Fig. *23C*, so that this resistor will serve as a load across one section of the potentiometer. Rotate the potentiometer shaft to its extreme counter-clockwise position, so that R_1 is in parallel with the entire resistance of the potentiometer, then repeat each of the measurements and tests called for in Steps 1 and 2 and record your results in Table *27*. Now disconnect one battery lead to open up the circuit and conserve battery life.

Discussion: Theoretically, the voltages which you measure across the 1,000-ohm resistor and 1,000-ohm potentiometer in Step 1 should be equal; actually, they may not be equal for the reason that manufacturing tolerances may make the values of these two parts higher or lower than 1,000 ohms. Therefore, with the 6-volt d.c. source, you should obtain somewhere around 3 volts across each of these parts. In other words, resistances of equal value connected in series will divide a voltage in half.

With essentially 3 volts across the entire potentiometer, you would expect to secure half of this value, or 1.5 volts, when the movable arm is at the halfway position in Step 2. Likewise, at the ¼ and ¾ positions, you would expect approximately .75 volt and 2.25 volts respectively. If you secure approximately these values in Step 2, you can consider your work as satisfactory.

Step 2 thus shows that the varying voltage obtainable from a potentiometer is proportional to the resistance across which the voltage is obtained when there is no load connected across this resistance. This method for obtaining a variable voltage is widely used in radio receivers for providing a control over volume.

Varying the position of the movable arm of the potentiometer in Step 3 has no effect upon the voltage across the potentiometer, simply because nothing is connected to the movable arm.

When you connect a 1,000-ohm load between the movable terminal and one end terminal of the potentiometer in Step 4, and rotate the potentiometer to its extreme counter-clockwise position, this 1,000-ohm load is in parallel with the full 1,000 ohms of the potentiometer. Two equal resistors in parallel always give a combined value equal to half that of one resistor, and consequently the resistance between terminals *1* and *3* in your circuit is now 500 ohms. The voltage drop across this 500 ohms should be only half the voltage drop across the 1,000-ohm fixed resistor; if you measured about twice as much voltage across resistor *R* as across the potentiometer, you verified this fact.

When the potentiometer arm is in its mid-position, you have the 1,000-ohm load shunted across half of the potentiometer resistance, which is 500 ohms. A 1,000-ohm resistor in parallel with a 500-ohm resistor gives a resultant or combined resistance of 333 ohms,* and this 333-ohm resistance acts in series with the remaining 500-ohm section of the potentiometer and the 1,000-ohm fixed resistor to give a total circuit resistance of 1,833 ohms. By means of Ohm's Law now, it is possible to compute what the voltage drop should be across each section of this circuit.

Computation. To find the circuit current, divide 6 by 1,833. This gives approximately .0033 ampere. To obtain the voltage drop across any section, we simply multiply this current value by the resistance of that section. Thus, the voltage drop across 1,000-ohm resistor *R* will be approximately 1,000 × .0033, or 3.3 volts. Across the unloaded 500-ohm section of the potentiometer, the drop should be 500 × .0033, or about 1.6 volts. Across the loaded section of the potentiometer (across R_1), the drop should be 333 x .0033, or about 1.1 volts, when the arm is at the mid-position. If you measured approximately this last value of 1.1 volts for the ½-rotation position in Step 4, you can consider your work satisfactory. Observe that you get less voltage across the loaded section of the potentiometer than across the unloaded section; this shows that the presence of the load disturbs the normal distribution of voltages in a voltage divider circuit.

Practical Extra Information. The important fact to remember in connection with Step 4 is that for a given setting of the potentiometer arm, the voltage will be less with a load than without a load. Furthermore, the lower the ohmic value of the load, the lower will be the voltage obtained. However, adjusting the potentiom-

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* The method of calculating this combined resistance of two resistors in parallel is given here for students who are interested:

$$R = \frac{R_1 \times R_2}{R_1 + R_2} \qquad R = \frac{1{,}000 \times 500}{1{,}000 + 500}$$

$$R = \frac{500{,}000}{1{,}500} \qquad R = 333 \text{ ohms}$$

eter will compensate for increased load and give the required voltage in most circuits.

In the voltage divider circuits of radio receivers, fixed resistors are generally used in place of potentiometers. This is possible because the value of the load across each resistor section is known, and its effect upon the voltage can be calculated by the set designer and compensated for.

Instructions for Report Statement No. 27. In the variable voltage divider circuit shown in Fig. *23B*, the fixed 1,000-ohm resistor serves the purpose of reducing the maximum voltage obtainable across the potentiometer. You will encounter this series resistor quite often in radio circuits, for oftentimes the source has a far higher voltage than can safely be applied directly to the terminals of the potentiometer.

For this report statement, make an additional measurement to determine whether a change in the value of the fixed 1,000-ohm resistor will have any effect upon the voltage provided by the potentiometer. To do this, connect the N. R. I. Tester to measure the voltage between terminals *1* and *2* of the potentiometer, complete the battery circuit which was previously disconnected to conserve battery life, adjust the potentiometer until the N. R. I. Tester indicates the voltage of 2 volts, then take your other 1,000-ohm resistor and shunt it temporarily across the 1,000-ohm resistor already in the circuit so as to reduce this series resistance to 500 ohms. Note the change in the N. R. I. Tester reading, then turn to the last page and place a check mark after the answer in Report Statement No. 27 which describes your result.

EXPERIMENT 28

Purpose: **To show that coils and condensers offer a definite amount of opposition to the flow of current in an a.c. circuit.**

Step 1. To set up a power supply circuit which will give you a 5-volt

A. C. EXPERIMENTS

If you do not have 110 to 120-volt, 50 to 60-cycle a.c. power in your home or in the place where you plan to carry out future experiments in this practical demonstration course, you are temporarily excused from performing the a.c. experiments (28, 29 and 30). This applies also to students who have only 25 or 40-cycle power.

Read these experiments carefully, however, giving especial study to the discussions so that you understand the basic principles involved, but do not answer the last three questions in the report statements at the present time. In the margin alongside Report Statements 28, 29 and 30 on the last page, write in pencil the words *"NO A.C. POWER,"* and send in this last page for grading. Your grade for Manual 3RK will be based upon the seven experiments which you have performed. In the next assignment, you will be provided with special instructions for carrying out three similar a.c. experiments and future experiments requiring a.c. power.

If you *have 115-volt, 50 or 60 cycle a.c. power* in your home, you are expected to perform the following three experiments and answer *all ten* of the report statements.

a.c. voltage when it is connected to the 115-volt a.c. line, first secure a scrap piece of wood which is at least ½ inch thick and at least 5 inches wide and 7 inches long. Take the six-lug terminal strip (Part *3-12*) and mount it on this board with two of the ⅜-inch No. 6 round-head wood screws (Part *3-13*) in approximately the position shown in Fig. *24*.

Take the mounting bracket for the potentiometer (Part *3-9*) and mount it on your wood baseboard with the remaining ⅜-inch wood screw in approximately the position shown in Fig. *24*.

Mount the 1,000-ohm wire-wound potentiometer (Part *3-8*) on its mounting bracket by removing the hexagonal nut from the potentiometer shaft, inserting this threaded shaft through the large hole in the bracket from behind, replacing the nut on the shaft, and tightening the nut with ordinary pliers while holding the potentiometer so that its three terminal lugs are at the top (the correct position of the potentiometer is shown in Fig. *24*).

Assemble your a.c. power supply circuit on the baseboard according to the schematic circuit diagram in Fig. *25A* by making the connections exactly as shown in Fig. *25B,* in the following order:

a. Number each of the lugs on the terminal strip in the manner shown in Fig. *25B* by placing the numbers on the baseboard directly under the respective lugs, and using either pencil, ink or crayon for marking purposes. The potentiometer terminals will already be numbered *1, 2* and *3* from the previous experiment.

b. Connect the 1,000-ohm resistor (Part *3-5A*) to terminals *4* and *5* by means of temporary hook joints, but solder the joint at terminal *4* only.

c. With a suitable length of hook-up wire, connect potentiometer terminal *1* to terminal *7*, but solder only the joint at terminal *1*.

d. With a suitable length of hook-up wire, connect potentiometer terminal *2* to terminal *6*, soldering both joints this time.

e. With a suitable length of hook-up wire, connect potentiometer terminal *3* to terminal *5*, but solder only terminal *3*.

f. Take the four 40,000-ohm resistors (Parts *3-6A*, *3-6B*, *3-6C* and *3-6D*) and connect them all together in parallel, with 3-inch lengths of hook-up wire serving as the leads for the group, in the manner shown in Fig. *25B*. This can be done by cutting away or pushing back the insulation for about 1 inch from the end of a 3-inch length of hook-up wire, winding this bare end of the hook-up wire

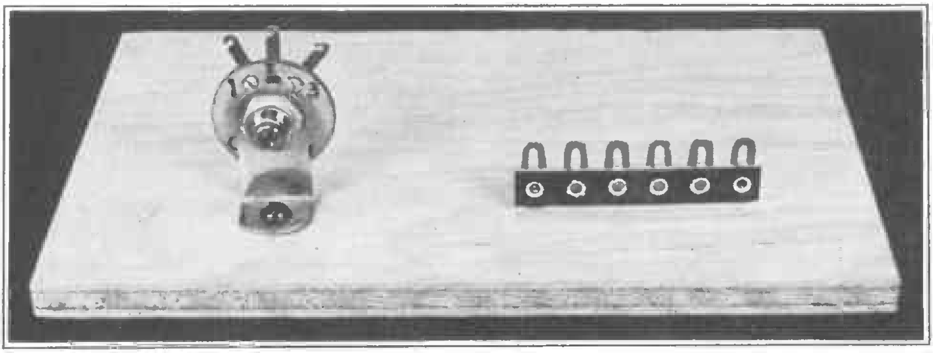


FIG. 24. For Step 1 of Experiment 28, mount the terminal strip and the potentiometer bracket in approximately the positions shown here, on a wooden base-board approximately 5" wide, 7" long and ½" thick.

several times around the group of four resistor leads, then applying solder to the joint liberally so that it flows between all of the resistor leads. Do the same for the other group of four resistor leads. Now connect one of the leads for this resistor group to terminal *7*, and connect the other lead to terminal *9*, but solder only terminal *7* at this time. Four 40,000-ohm resistors in parallel give a combined resistance of 10,000 ohms.

g. Take the 5-foot length of power line cord with attached plug (Part *3-11*), twist the bare ends if they have become untwisted, connect one lead of this cord to terminal *9* by means of a temporary hook joint, and connect the other lead of this cord to terminal *5* in the same way. Solder both joints.

h. Check all connections carefully against the semi-pictorial wiring diagram in Fig. *25B*, for a single mistake here may result in your blowing the house fuse when you plug this circuit into the power line. Be sure that there are no wires or lumps of solder shorting together adjacent lugs on the terminal strip.

Step 2. To become familiar with the reading of the AC scale on the meter of the N. R. I. Tester, study carefully the actual-size reproductions of this scale in Fig. *26*. An analysis of the four examples which are given should enable you to read this scale at any position of the pointer, for the *AC* scale is read in essentially the same way as the *DC* scale.

The *AC* scale on your meter is used for all four of the a.c. voltage ranges: V, $3 \times V$, $30 \times V$ and $100 \times V$. When using the V range, read the voltage in volts directly on this scale. When using the $3 \times V$ range, multiply the reading on the *AC* scale by 3. When using the $30 \times V$ range, multiply the reading by 30. When using the $100 \times V$ range, multiply the reading by 100.

Step 3. To measure the voltages which are present across various parts of an a.c. voltage divider circuit when there is no load, first set the N. R. I. Tester to measure the highest a.c. voltage which you will encounter. This will be the 115-volt a.c. line voltage, so set the selector switch to $30 \times V$. Plug the red probe into the left-hand V_{AC} jack (terminal *30*), and plug the black probe into the $-V_{AC}$ jack (terminal *28*), which is *THIRD* from the left.

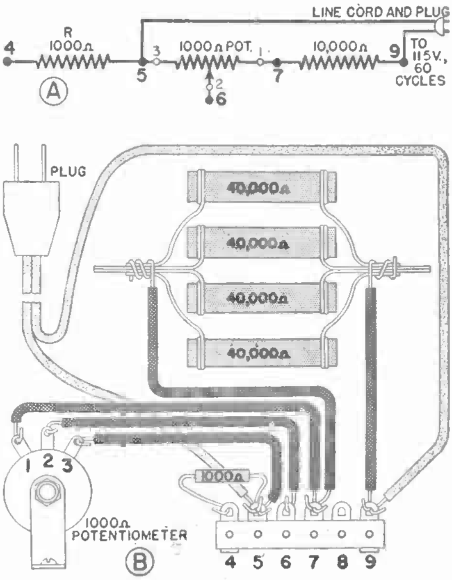


FIG. 25. Schematic (*A*) and semi-pictorial (*B*) circuit diagrams for the a.c. power supply source which you set up in Step 1 of Experiment 28.

CAUTION: It is extremely important that you perform all a.c. experiments on an insulated bench or table. An ordinary wooden table is ideal, as also is a wooden table covered with linoleum or oilcloth, but a porcelain-top table is unsatisfactory because the porcelain is applied to a metal base. A.C. experiments should be performed at a location where you are out of reach of any grounded objects such as a radiator, water pipe, gas pipe, metal electric conduit, outlet boxes, or damp concrete basement floors. If your experiments must be done in a basement, any inexpensive rug or piece of linoleum placed on the floor will eliminate the shock hazard from this source.

The most important precaution for you to observe, however, is never to touch a terminal at which a.c. line voltage may exist, if you can possibly avoid doing this. As an added precaution, use only one hand while working with electrical apparatus with the power on. If you should accidentally touch a high-voltage terminal with one hand, and no part of your body is grounded, there will be no danger of shock.

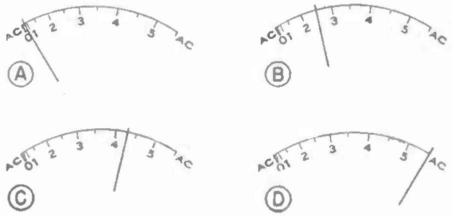


FIG. 26. To illustrate how the *AC* scale on the meter of the N.R.I. Tester is read, readings corresponding to four different positions of the pointer are given in these examples. The readings are as follows: *A*—.5V; *B*—2.5V; *C*—4.3V; *D*—5.5V.

Safety Rules for A.C. Circuits

Disconnect your equipment from the a.c. line at all times except when actually making a test or reading.

Do not allow any part of your body to come in contact with a grounded object while working with a.c. equipment.

Whenever it is necessary for you to handle equipment while power is on, use only one hand for this purpose. Many engineers keep the unused hand in their pocket to avoid using it unconsciously, such as for grabbing a part which may be falling over.

Always connect the black clip of the N. R. I. Tester to the a.c. terminal which is nearer to ground potential whenever making a voltage measurement. Observing this precaution may prevent you from getting a shock when you touch the panel or chassis of the N. R. I. Tester. When you do not know which of the a.c. terminals is grounded, measure between each of them and a ground wire; the one which gives a voltage reading to ground will be hot, so the other will be grounded.

To locate the terminal of your a.c. voltage divider which is nearer to ground potential, place the black clip on a ground wire going to any convenient ground such as a water pipe, and place the red clip on terminal *9*. Insert the power cord plug in the a.c. outlet, note the meter reading on the *AC* scale, then reverse the position of the plug in the outlet and again note the meter reading. In one position the reading should be essentially zero, and in the other position the reading should be almost 4 on the *AC* scale, indicating a voltage of about 4 × 30, or 120 volts since the *30* × *V* range is used.

The plug position which gives a reading near 4 is the safest position, so make a crayon mark both on the plug and on the outlet so that you will *always* replace the plug in this position during the next three experiments. This plug position makes terminal *9* hot, so *do not touch this terminal* (or the resistor leads on it) while power is on.

Read the meter on the *AC* scale while the plug is in the safest position, multiply the reading by 30, and record your result in Table *28* as the voltage in volts between terminal *9* and ground. Now pull out the plug.

Move the red clip to terminal *5*, leave the black clip on the ground wire, leave the N. R. I. Tester just as it is, then insert the plug into the wall outlet *in its safest position*.

Read the meter on the *AC* scale, and record your result in Table *28* as the voltage between terminal *5* and ground. Your result should be zero, because terminal *5* is now connected to the power line wire which is grounded at the power plant. Now pull out the plug, remove the black clip from the ground wire, and set aside the ground wire because it is no longer needed.

Now place the black clip on terminal *5*, place the red clip on terminal *9*, set the N. R. I. Tester to *30* × *V*, turn on the tester, insert the plug in the

3.8
30
114.0

3.6
30
108.0

3.4
3
10.2

outlet, read the meter on the *AC* scale, multiply the reading by 30 and record your result in Table *28* as the a. c. line voltage between terminals *5* and *9*. Pull out the plug and turn off the N. R. I. Tester.

Measure the a.c. voltage across the 10,000-ohm resistor (the four 40,000-ohm resistors in parallel are equivalent to one 10,000-ohm resistor, and will therefore be referred to as a 10,000-ohm resistor during these experiments), by placing the back clip on terminal *7* (this is closer to ground than terminal *9*) and placing the red clip on terminal *9*. Turn on the N.R.I. Tester, insert the plug in the outlet, read the meter on the *AC* scale, multiply the result by 30, and record it in Table *28* as the voltage existing between terminals *7* and *9*. Pull out the plug and turn off the N. R. I. Tester.

Measure the voltage across the 1,000-ohm potentiometer by placing the black clip on terminal *5*, placing the red clip on terminal *7*, turning on the N. R. I. Tester with the selector switch still at *30*× *V*, and inserting the plug into the outlet. Read the meter on the *AC* scale and multiply the result by 30; if this result is below 16.5 volts (the maximum value on the next lower *AC* scale), rotate the selector switch in *3*× *V*. Read the meter again on the *AC* scale, multiply the reading by 3 this time, and record it in Table *28* as the voltage in volts between terminals *5* and *7*. Pull out the plug and turn off the N. R. I. Tester.

Step 4. To adjust the voltage between terminals 5 and 6 to 5 volts, place the black clip on *5*, and place the red clip on *6*. Set the N. R. I. Tester to the *3*× *V* range, turn on the switch, insert the power cord plug in an outlet, then rotate the potentiometer with a screwdriver until the meter pointer is approximately at 1.75 on the *AC* scale (corresponding to 5 volts on this scale). This value is safely within the next lower range of your meter, so change the selector switch to the *V* range and make a more accurate adjustment of the potentiometer to give meter reading of 5 on the *AC* scale. Pull out the plug and turn off the N. R. I. Tester, without changing the potentiometer setting.

Step 5. To measure voltage and current values for a 1,000-ohm resistor (R_1) *which is connected between terminals 4 and 6 of the a.c. voltage divider to give the circuit shown in Fig. 27A,* take one of your 1,000-ohm resistors (Part *3-5B*), shape the leads

STEP	NATURE OF MEASUREMENT	YOUR VALUE IN VOLTS	N.R.I. VALUE IN VOLTS
3	VOLTAGE BETWEEN 9 AND GROUND	114	120
	VOLTAGE BETWEEN 5 AND GROUND	0	0
	VOLTAGE BETWEEN TERMINALS 5 AND 9	114	120
	VOLTAGE BETWEEN TERMINALS 7 AND 9	108	108
	VOLTAGE BETWEEN TERMINALS 5 AND 7	10.2	12
5	VOLTAGE ACROSS 1000Ω R_1	2.0	2.4
	VOLTAGE ACROSS R (SAME AS CURRENT IN MA.)	2.1	2.5
6	VOLTAGE ACROSS .5 MFD. C	4.9	4.9
	VOLTAGE ACROSS R (SAME AS CURRENT THRU C IN MA.)	.8	.9
7	VOLTAGE ACROSS 10 MFD. C	2.2	1.9
	VOLTAGE ACROSS R (SAME AS CURRENT THRU C IN MA.)	4.4	4.6
8	VOLTAGE ACROSS 10 HENRY L	4.6	4.7
	VOLTAGE ACROSS R (SAME AS CURRENT THRU L IN MA.)	1.1	.9

TABLE 28. Record your results here for Experiment 28.

so that one will touch terminal *6* when the other is on terminal *4* of the terminal strip mounted on your baseboard, tin the end of each lead liberally with rosin-core solder, apply surplus solder to the tip of your soldering iron, then hold the resistor against these terminals in the manner shown in Fig. *28*, and apply the soldering iron to each resistor lead in turn, long enough to fuse the solder and give a temporary soldered lap joint at each terminal.

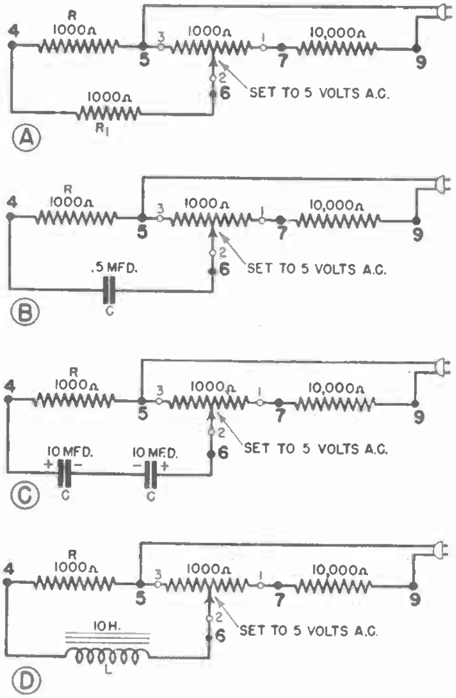


FIG. 27. Schematic circuit diagrams for the circuits which you set up in Steps 5, 6, 7 and 8 in Experiment 28 to determine how resistors, coils and condensers behave in 60-cycle a.c. circuits.

This 1,000-ohm resistor R_1 is now in series with 1,000-ohm resistor *R* previously mounted on the terminal strip between lugs *4* and *5*; resistor *R* provides a convenient means for determining the circuit current when various radio parts are connected between terminals *4* and *6*, for the voltage drop across a 1,000-ohm resistance is equal to the current in milliamperes through that resistance.

Connecting a load between terminals *5* and *6* in this manner will make the voltage between these terminals drop below 5 volts, so readjust this voltage between terminals *5* and *6* to 5 volts in the manner described in Step 4, then pull out the plug.

To measure the voltage across R_1, place the black clip on terminal *4* (this is nearer to ground potential) and place the red clip on terminal *6*. Insert the plug in the outlet, read the meter on the *AC* scale, and record the result in Table *28* as the voltage in volts across 1,000-ohm resistor R_1. Pull out the plug.

To measure the current through R_1, move the red clip to terminal *4*, move the black clip to terminal *5*, reinsert the plug, read the meter on the *AC* scale, and record this value in Table *28* as the voltage in volts across *R*. This will also be the value in ma. of the current through R_1. Pull out the plug, and turn off the N. R. I. Tester.

Step 6. To measure voltage and current values for a .5-mfd. capacity which is connected into an a.c. circuit having a 5-volt a.c. source, first disconnect 1,000-ohm resistor R_1 from terminals *4* and *6*, and remove the N. R. I. Tester clips. Connect a .5-mfd. capacity (two .25-mfd. condensers, Parts *3-2A* and *3-2B*, connected in parallel) to terminals *4* and *6* as indicated in Fig. *27B*. Do this by tinning the condenser leads, holding them against terminals *4* and *6*, and applying the heated soldering iron to fuse the solder and provide secure temporary soldered lap joints, just as you did for resistor R_1 in Step 5.

Adjust the voltage between terminals *5* and *6* to 5 volts again, by placing the black clip on *5* and the red clip on *6*, setting the N. R. I. Tester to the *3* × *V* range, and adjusting the potentiometer roughly to a meter reading of 1.75 on the *AC* scale, then switching to the *V* range and adjusting the potentiometer until the meter reads exactly 5 on the *AC* scale. This is the same adjustment as described in Step 4. Pull out the plug now.

To measure the voltage across capacity *C*, place the black clip on terminal *4* and place the red clip on terminal *6*. Turn on the N. R. I. Tester, leaving it set at the *V* range. Read the meter on the *AC* scale, and record the value in Table *28* as the voltage in volts across .5-mfd. capacity *C*. Pull out the plug.

To measure the current through *C*, place the black clip on terminal *5*, and place the red clip on terminal *4*. Insert the plug in the outlet, read the meter on the AC scale, and record the value in Table *28* as the voltage across *R*. This will also be the value in ma. of current through .5-mfd. capacity *C*. Pull out the plug, turn off the N. R. I. Tester, remove the two test clips, disconnect the .5-mfd. capacity, then separate the two .25-mfd. condensers. Do not straighten out the hooks in the condenser leads yet.

Step 7. To measure voltage and current values for a 10-mfd. electrolytic condenser connected according to the schematic circuit diagram in Fig. 27C, take two 3-inch lengths of red hook-up wire, connect one to each of the center terminal lugs of the dual 10 - 10 - mfd. electrolytic condenser (Part *3-3*), then connect one of these leads to terminal *4* and the other to terminal *6* by means of temporary soldered lap joints. This places the two sections of the condenser in series bucking, with their — terminals connected together internally through the common metal housing of the unit, but gives a resultant capacity which is essentially the same as the capacity of only one active 10-mfd. individual unit; this is true only with electrolytic condensers.

Adjust the potentiometer in the manner described in Steps 4 and 6, so as to give exactly 5 volts a.c. between terminals *5* and *6*, then pull out the plug.

To measure the voltage across the 10-mfd. capacity, place the black clip on *4*, place the red clip on *6*, insert the plug, read the meter on the *AC* scale, and record your result in Table *28* as the voltage in volts across the 10-mfd. capacity *C*. Pull out the plug.

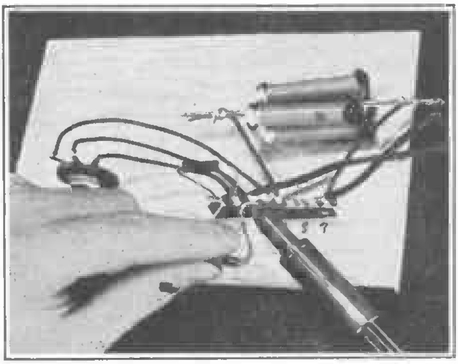


FIG. 28. This illustration shows you how to make a temporary soldered lap joint for the purpose of connecting a radio part temporarily between two terminals. This technique allows you to hold the part with one hand (instead of holding the solder in that hand), and gives a joint which can easily be disconnected.

To measure the current through the 10-mfd. capacity, place the red clip on terminal *4*, place the black clip on terminal *5*, insert the plug, read the meter on the *AC* scale, and record the value in Table *28* as the voltage across *R*. This will also be the current in ma. through the 10-mfd. capacity *C*. Pull out the plug, turn off the N. R. I. Tester, remove the clips, and disconnect the dual 10-10-mfd. condenser from terminals *4* and *6*.

Step 8. To study the action of a coil in an a.c. circuit, take the 10-henry choke coil (Part *3-10*), attach a 3-inch length of hook-up wire to each of its terminal lugs by means of a temporary soldered hook joint, connect one of these leads to terminal *4*, and connect the other lead to terminal *6*, so that you have the circuit arrangement shown in Fig. *27D*.

Adjust the potentiometer as previously described, to give exactly 5 volts a.c., then pull out the plug.

To measure the voltage across coil *L*, place the black clip on *4*, place the red clip on *6*, insert the plug, read the meter on the *AC* scale, and record the result in Table *28* as the voltage in volts across coil *L*. Pull out the plug.

To measure the current through coil *L*, place the black clip on *5*, place the red clip on *4*, insert the plug, read the meter on the *AC* scale, and record the result in Table *28* as the voltage across *R*. This will also be the current in ma. through the 10-henry coil *L*. Pull out the plug, turn off the N. R. I. Tester, remove the clips, then disconnect the coil but leave the two leads connected to the coil terminals. Leave the remainder of the circuit set up for the next experiment.

Discussion: If you have done any previous experimenting or if you have worked at all with a.c. house wiring, you undoubtedly know already that a 110-volt a.c. voltage can give you an unpleasant shock. Furthermore, under certain conditions this voltage can be dangerous. These dangerous conditions are quite easy to avoid, for they depend upon electricity going through your entire body, particularly through the region of the heart.

By keeping all parts of your body away from any grounded metal object and by touching radio apparatus with only one hand whenever there is a possibility that power might be on, you make it impossible for current to find a path through your body. Under these conditions, you can work with 110-volt a.c. voltages with perfect safety.

Every radio man must work extensively with 110-volt a.c. apparatus, so form the proper safety habits right from the start. Safety rules are even more important when working with ordinary a.c. radio receivers; here you encounter stepped-up a.c. voltages approaching 1,000 volts, which are considerably more dangerous than 110 volts, unless these same safety precautions are used.

Study of the schematic circuit diagram in Fig. *25A* will show that you voltage divider consists of a 10,000-ohm resistor and a 1,000-ohm potentiometer connected in series across the a.c. line. This gives a total of 11,000 ohms.

With no load connected across the voltage divider (Step 3), you should find that the voltages divide exactly in proportion to the resistances, just as in the case of the d.c. voltage divider used in the previous experiment. There should be ten times as much voltage across the 10,000-ohm resistor as there is across the 1,000-ohm resistor, and these two voltages should add up to the line voltage. Looking at it another way, the potentiometer resistance is only 1/11 of the total resistance, and consequently the potentiometer voltage should be only 1/11 of the total voltage.

If the line voltage in your case is slightly high, say about 120 volts, the voltage across the 1,000-ohm potentiometer will be about 11 volts. You are thus using this voltage divider to reduce the 120-volt line voltage to 11 volts a.c. for this experiment.

In Step 5, you use a 1,000-ohm resistor R_1 as a load across one section of the potentiometer, with a 1,000-ohm resistor *R* in series with this load for current-measuring purposes. The voltage drop across the 1,000-ohm resistor *R* is exactly equal in value to the current in milliamperes through the load.

When you turn on the power after connecting 1,000-ohm resistor R_1 to terminals *4* and *6*, you will find that the voltage between terminals *5* and *6* is about 1 volt lower than the original no-load value of 5 volts. This proves that the same action holds true for a.c. circuits as for d.c. circuits, wherein the placing of a load across a portion of a voltage divider reduces the voltage available at that portion of the divider.

Actually, in Step 5 you have two 1,000-ohm resistors connected in series across an a.c. voltage of 5 volts (between terminals *5* and *6*). According to Kirchhoff's Voltage Law, the voltages across the two resistors should add up to the 5-volt a.c. voltage available between terminals *5* and *6*. Furthermore, because the resistors are equal in value, the voltages across them should be equal (each should be 2.5 volts). Of course, practical conditions make it unlikely that the voltages will be exactly equal and practical limitations in your measuring instrument make it unlikely that the two measured voltages will add up to exactly 5 volts, but your results should be close enough to the expected values to verify the basic law involved.

If the 1,000-ohm resistor R_1 were shorted out, there would be only 1,000 ohms connected between terminals *5* and *6*, and you would measure the full source voltage across resistor R (between terminals *4* and *5*). This means that 5 ma. would be flowing through this resistor. If you obtain a load current reading of about 2.5 ma. with both the 1,000-ohm resistors serving as load in Step 5, you can say that a resistor has exactly the same current-limiting characteristics in an a.c. circuit as it has in d.c. circuits.

When using the N. R. I. Tester for voltage measurements, make it a practice to estimate first the maximum voltage which could exist between the points across which a measurement is to be made, then set the selector switch to a range which will include this maximum value. If your estimate is high and you find it difficult to read the meter accurately, simply lower the range one step at a time until you can secure a better scale reading.

You may observe that when using the N. R. I. Tester as an a.c. voltmeter on the *V* range, a meter reading can be obtained when only one test clip is connected to an a.c. circuit. This reading is obtained simply because the test leads are picking up stray a.c. energy due to the house wiring.

Even touching your finger to one of the *disconnected* test clips can cause an increase in the meter reading, for then your own body is picking up additional electrical energy, and the N. R. I. Tester is measuring your voltage with respect to the other leads. The distributed capacity between leads is sufficient to complete the circuit through the 10-megohm input resistance of the N. R. I. Tester, but does not affect meter readings at all when both clips are connected.

In Step 6, you have a 1,000-ohm resistor and a .5-mfd. capacity connected in series across the 5-volt a.c. source. When you add together the voltages which you measure across the condenser and the resistor, you will find that they come to considerably more than 5 volts. Kirchhoff's Voltage Law for a.c. circuits says, however, that you cannot add voltages arithmetically in a.c. circuits having condensers or coils. You must add the voltages vectorially, taking phase into account, for the condenser and resistor voltages are 90° out of phase.

When the N. R. I. voltage values

across the condenser and resistor are added together vectorially in the manner shown in Fig. *29A*, the result is about 5 volts. Your values should add vectorially to approximately 5 as well, but remember that exact agreement is seldom possible because of practical conditions.

Adding Voltages Vectorially. For convenience, let 1 inch represent 1 volt on your vector diagram, and use the resistor voltage as your reference vector. Choose a starting point for your diagram (point *S* in Fig. *29A*), then lay out horizontally to the right from this starting point a line (*IR* in Fig. *29A*) having a length which is proportional to the value of the voltage measured across 1,000-ohm resistor ***R***. Place an arrow at the end of this line.

Next, from starting point *S* draw a vector for the voltage across the added part. Since it is a condenser, draw the vector straight down from the reference point, because the voltage across a condenser always lags the voltage across a resistor by 90°.

Having plotted your two vectors for Step 6, add them together by completing the rectangle as indicated with dotted lines in Fig. *29A*, then draw in the diagonal of the rectangle. This diagonal is the resultant vector, representing the sum of the two vectors acting 90° out of phase. Measure the length of this vector in inches; this value will be the resultant voltage in volts, and should be essentially 5 volts.

Electrolytic Condenser Characteristics. When two electrolytic condensers are connected in series but with their respective negative terminals tied together, as is done in Step 7, one condenser always retains its desired capacitive properties despite the continual reversal of the a.c. voltage which is applied to the condenser group. In other words, for any given point in the a.c. cycle, one condenser is acting as a true condenser but the other is merely acting as a conductive path. For this reason, the combined capacity of the two electrolytic condensers is only the capacity of one of the units.

As a matter of practical information, this series opposition method of connecting electrolytic condensers is employed in actual practice whenever electrolytics are to be used in a.c. circuits. Otherwise, a single electrolytic unit cannot be used as a condenser in an a.c. circuit.

When Step 7 was carried out in the N. R. I. laboratory, values of 4.6 volts across the resistor and 1.9 volts across the condenser were obtained, as indicated in Table *28*. When these were added together vectorially in the manner shown in Fig. *29B*, a resultant voltage of essentially 5 volts was obtained, giving additional confirmation of Kirchhoff's Voltage Law for a.c. circuits.

Let us compare the relative current-limiting actions of the .5-mfd. and 10-mfd. condensers in this a.c. circuit. We will use the N. R. I. values here for comparison, but you can do the same thing with those values you measured.

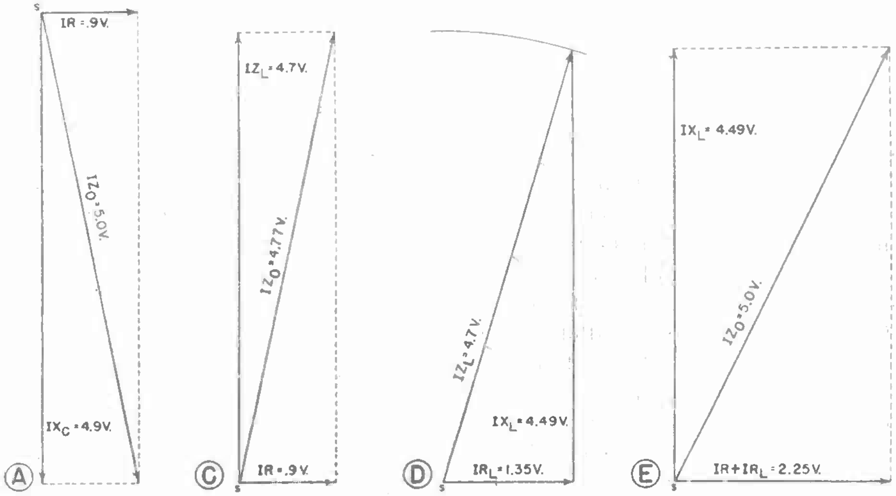
The .5-mfd. condenser gave a current of .9 ma., while the 10-mfd. condenser gave a current of 4.6 ma. This indicates that both condensers serve to limit the value of a.c. current flowing, with the smaller condenser offering more opposition to current flow than did the larger condenser. This is exactly what you would expect from basic electrical principles, for the higher the electrical capacity value of a condenser, the lower is its reactance at a given frequency, and the less it limits current flow.

When the 10-henry choke coil was placed in series with the 1,000-ohm resistor as a load for a 5-volt a.c. source during the performance of Step 8 in the N. R. I. laboratory, a voltage of .9 volt was measured across the 1,000-ohm resistor, and 4.7 volts was measured across the coil. Adding these together vectorially at right angles in the manner shown in Fig. *29C* gives

15
.9
135

only 4.77 volts, which is a bit off from the applied a.c. voltage of 5 volts. The reason for this discrepancy is simply that the coil has considerable resistance, which is completely overlooked in the vector diagram in Fig. *29C*.

Your 10-henry coil has a d.c. resistance of about 200 ohms. When this coil is used in an a.c. circuit, however, certain a.c. losses make the resistance of the coil go up considerably. You will determine this value in the next experiment, but for purposes of clarifying the vector diagram in Fig. *29C*, let us assume that this a.c. resistance is 1,500 ohms.



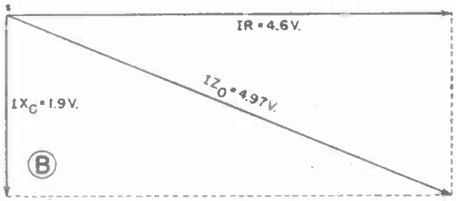


FIG. 29. These vector diagrams, based upon voltage values measured in the N.R.I. laboratory for the various steps of Experiment 28, prove definitely that Kirchhoff's Voltage Law holds true for a.c. circuits. One volt corresponds to ½-inch of vector length on these diagrams.

A voltage of .9 volt across the 1,000-ohm resistor indicates a current of .9 ma. through the circuit. This current flowing through the 1,500-ohm a.c. resistance of the coil gives a resistive voltage drop across the coil of .0009 x 1,500, which is 1.35 volts. Knowing that the total voltage across the coil is 4.7 volts and its resistive component is 1.35 volts, we can use the construction shown in Fig. *29D* to obtain the reactive component of voltage across the coil. Draw horizontal vector IR_L to represent the voltage drop across the a.c. resistance of the coil. swing an arc whose radius is proportional to the measured coil voltage IZ_L, and draw a line vertically upward from the end of IR_L until it intersects the arc. The length of this vertical line will now correspond to IX_L, the reactive component of the coil voltage.

Adding the resistive component of the coil voltage to the voltage drop across the 1,000-ohm resistor gives 1.35+.9, or 2.25 volts. We plot this horizontally in Fig. *29E*, then draw in the reactive component of coil voltage as vector IX_L, at right angles to the first vector. Completing the rectangle now gives vector IZ_0, whose length will be proportional to the total voltage across the coil and resistor combined. For this vector we secure a value of 5 volts, which is correct.

This experiment has shown you quite clearly that we must take phase into account whenever adding voltages in a.c. circuits. You have thus demonstrated for yourself Kirchhoff's important voltage law for a.c. circuits.

Instructions for Report Statement No. 28. In an a.c. circuit, circuit conditions can be changed by shunting any part in the circuit with a resistor, a coil or a condenser, provided that the shunting part has a low enough resistance or impedance. For Report Statement No. 28, you will verify this.

Using the voltage divider circuit shown in Fig. *25,* connect between terminals *4* and *6* an 18,000-ohm resistor (Part *1-16*) and two .25-mfd. condensers, so that you have an 18,000-ohm resistor in parallel with a .5-mfd. capacity. Set the potentiometer to give maximum a.c. voltage (slightly over 10 volts) between terminals *5* and *6,* as measured with the N. R. I. Tester, then pull out the power cord plug. Place the black clip of the N. R. I. Tester on terminal *5,* place the red clip on terminal *4,* insert the plug, and read on the meter 2.1 the voltage across 1000-ohm resistor *R* (use the *V* range). Now pull out the plug, disconnect the two .25-mfd. condensers, insert the plug again, and note the voltage now indicated across 1000-ohm resistor *R.* Turn to the last page and check the answer which describes your result.

EXPERIMENT 29

***Purpose:* To show that when a coil and condenser are connected in series, a resonant effect exists, and one part will partially or totally cancel the current-limiting effect of the other part; to show that the a.c. resistance of a coil is higher than the d.c. resistance of the coil.**

Step 1. Using the same a.c. voltage-dividing circuit employed in Experiment 28, connect one .25-mfd. condenser (Part *3-2A*) to terminals *4* and *6* by means of temporary soldered lap joints; the circuit is given in Fig. *30A.*

Place the black clip on terminal *5,* place the red clip on terminal *6,* set the selector switch to *3×V,* turn on the N. R. I. Tester, insert the plug in the outlet, and adjust the potentiometer until the meter reads approximately 4 volts (1.3 on the *AC* scale when using the *3×V* range). Now switch to the *V* scale and adjust accurately to 4 volts. (Note the change to 4 volts, as compared to the 5-volt value used in the previous experiment.) Pull out the plug.

To measure the voltage across the

STEP	NATURE OF MEASUREMENT	YOUR VALUE IN VOLTS	N.R.I. VALUE IN VOLTS
1	VOLTAGE ACROSS .25 MFD. C	4.0	4.0
	VOLTAGE ACROSS R (SAME AS CURRENT IN MA.)	.1	.3
2	VOLTAGE ACROSS .25 MFD. C	6.6	5.4
	VOLTAGE ACROSS 10 HENRY L	2.0	2.5
	VOLTAGE ACROSS R (SAME AS CURRENT IN MA.)	1.0	1.0
3	VOLTAGE ACROSS .5 MFD. C	9.9	8.1
	VOLTAGE ACROSS 10 HENRY L	7.1	7.5
	VOLTAGE ACROSS R (SAME AS CURRENT IN MA.)	2.3	1.4
	VOLTAGE ACROSS .55 MFD. C	9.9	7.8
4	VOLTAGE ACROSS .5 MFD. C	7.0	11.4
	VOLTAGE ACROSS 10 HENRY L	15.0	10.5

18.7

TABLE 29. **Record your results here for Experiment 29.**

.25-mfd. condenser, leave the red clip on *6* but move the black clip to terminal *4*. With the N. R. I. Tester still set at *V*, insert the plug, read the meter on the *AC* scale, and record the value in Table *29* as the voltage in volts across .25-mfd. condenser *C*. Pull out the plug.

To measure the current through the .25-mfd. condenser, place the black clip on *5*, place the red clip on *4*, and insert the plug. Read the meter on the *AC* scale and record the value in Table *29* as the voltage in volts across *R* and the current in ma. through *R* and *C*. Pull out the plug.

Step 2. To measure current and voltage values in a series circuit consisting of 1,000-ohm resistor R, 10-henry choke coil L and .25-mfd. condenser C, first disconnect the condenser lead from terminal *4*. Connect this condenser lead to one lead of the 10-henry choke coil (Part *3-10*), and connect the other choke coil lead to terminal *4*, as indicated in the schematic circuit diagram in Fig. *30B*.

Adjust the voltage between terminals *5* and *6* to *4* volts in the manner described in Step 1, then pull out the plug.

To measure the voltage across the .25-mfd. condenser *C*, place the red clip on terminal *6*, and place the black clip on the junction of the condenser and coil leads. With the N. R. I. Tester set to the *3×V* range, insert the plug, read the meter on the *AC* scale, multiply your result by 3, and record the result in Table *29* as the voltage in volts across .25-mfd. condenser *C*. Pull out the plug.

To measure the voltage across coil *L*, move the black clip to terminal *4*, and move the red clip to the junction of the coil and condenser leads. Leaving the N. R. I. Tester set at the *3×V* range, insert the plug, read the meter on the *AC* scale, multiply the value by 3, and record the result in Table *29* as the voltage in volts across 10-henry coil *L*. NOTE: If the voltage reading for the coil on the *3 × V* range is less than 5.5 volts, change over to the *V* range in order to get a more accurate reading.

To measure the current in this series circuit, move the red clip to terminal *4* and move the black clip to terminal *5*. With the N. R. I. Tester set at *V*, read the meter on the *AC* scale and record the results in Table *29* as the voltage in volts across *R* and the current in ma. through the *R-L-C* circuit. Pull out the plug and remove the clips, but do not disturb other parts of the circuit.

4
3.0
12.0

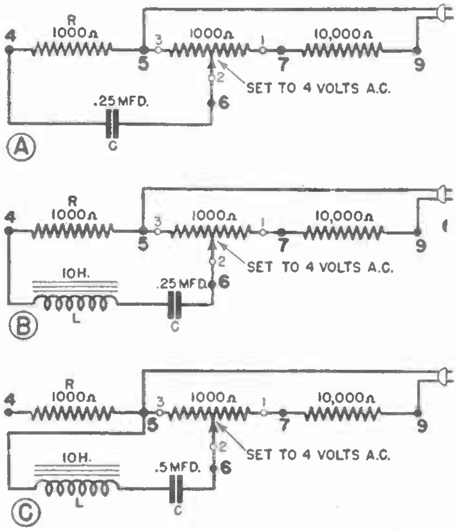


FIG. 30. Schematic circuit diagrams for Experiment 29.

Step 3. In order to repeat Step 2 with the condenser value in the circuit of Fig. 30B increased to .5 mfd., connect the other .25-mfd. condenser (Part *3-2B*) in parallel with the .25-mfd. condenser already in the circuit, using temporary soldered hook joints.

Now insert the plug in the outlet, readjust the voltage between terminals *5* and *6* to 4 volts, and repeat each of the measurements called for in Step 2. Record the results in Table *29*. Be particularly careful to set the voltmeter range first to $3\times V$ for each measurement, lowering to the *V* range only when you are certain the voltage will not overload the meter. Pull out the plug.

As a final measurement in this step, take the .05-mfd. condenser (Part *3-1*) and connect it in parallel with the group of two .25-mfd. condensers, soldering one lead by means of a temporary soldered lap joint to the common junction of the coil and condenser, but leaving the other lead unsoldered. With the red clip on terminal *6* and the black clip on the common junction of the condensers and the coil, and with the N. R. I. Tester set at $3\times V$, insert the plug in the outlet. Grasp the .05-mfd. condenser by its paper housing and press the free lead against terminal *6*. Read the meter on the *AC* scale, multiply the value by 3, and record the value in Table *29* as the voltage in volts across the .55-mfd. capacity. Pull out the plug, turn off the N. R. I. Tester, remove the clips, and unsolder the .05-mfd. condenser completely from the circuit.

Step 4. To remove from your circuit the 1,000-ohm resistor which has been present in the previous steps for current-measuring purposes, disconnect the coil lead from terminal *4* and solder it instead to terminal *5*, as indicated in Fig. *30C*. Adjust the voltage between terminals *5* and *6* to exactly 4 volts in the manner previously described. Pull out the plug, set the selector switch to $30\times V$, leave the red clip on terminal *6*, but move the black clip to the common junction of the condensers and coil. Insert the plug in the outlet, read the meter on the *AC* scale as accurately as possible, multiply the reading by 30, and record the result in Table *29* as the voltage across the .5-mfd. condenser. Pull out the plug.

The meter reading will be very low, below 1 on the scale, indicating a voltage value somewhere between 15 and 30 volts. You cannot estimate the value very accurately at this end of the scale, but can make a much more accurate reading on the $3\times V$ range if the voltage happens to be below the maximum value of 16.5 volts for this range. Therefore, switch to $3\times V$. If the meter pointer swings to the upper end of the scale, read the meter on the *AC* scale, multiply the result by 3, and record it in Table *29* as the voltage for this measurement. If, however, the meter pointer merely vibrates around *0* when you switch to the $3\times V$ range, or reads slightly backward, do not attempt to get a more accurate reading. (It is a characteristic of the N. R. I. Tester to vibrate near *0* when overloaded on any of the *AC* voltage ranges. A similar action, usually in the form of a reversed reading, occurs during overloading on any of the *DC* voltage scales. Whenever an overload indication is secured, switch to the next higher range.) Remember that an overload will usually shift the *0* position of the pointer. As previously pointed out, this condition can be corrected simply by touching the calibrating clip momentarily to the —4½C terminal on the battery block.

To measure the voltage across coil *L*, place the black clip on terminal *5*, and place the red clip on the common junction of the coil and condenser leads. Set the N. R. I. Tester to $30\times V$, insert the plug, read the meter on the *AC* scale, and multiply the value by 30. If the value comes out to be close to 16.5 or below this value, see if you can secure a more accurate reading on the $3\times V$ scale. Record your final value in Table *29* as the voltage across coil *L*. Pull out the plug, turn off the N. R. I. Tester, remove the clips, and disconnect the coil and the condenser group, but leave the two .25-mfd. condensers connected together.

Discussion: In Step 1, you have a .25-mfd. condenser connected in series with the 1,000-ohm resistor across the a. c. voltage source of 4 volts. At the power line frequency of 60 cycles, the reactance of a .25-mfd. condenser is 10,600 ohms.*

This is about ten times the ohmic value of the 1,000-ohm resistor, so you should expect to measure about ten times as much voltage drop across the condenser as you do across the resistor.

In the N. R. I. laboratory, the voltage across *C* was just about 4 volts. The voltage across the resistor was very low and difficult to read, with the estimated reading being .3 volt. If these voltages are added together vectorially, taking into account the fact that they are at right angles (90° out of phase), the resultant voltage across *R* and *C* together will still be about 4 volts, the source voltage. In other words, the circuit is essentially capacitive. The circuit current was about .3 ma. in this case.

The insertion of a 10-henry coil in series with the condenser and resistor to give the circuit shown in Fig. *30B*, while keeping the a.c. source voltage at 4 volts, will make both the circuit current and the condenser voltage go up. The fact that circuit current goes up is proof that the total impedance of the circuit has been lowered.

Now we obtain more voltage across the condenser than we have available at the source. From your fundamental course you learned, however, that the voltages across a coil and a condenser in a series circuit are 180° out of phase; this means that the combined voltage across them is the *difference* between their numerical values. The reason the current goes up is simply because the inductive reactance of the coil cancels out part of the capacitive reactance of the condenser, thereby lowering the total impedance in the circuit.

.4
3
.120
9
30
0

When the capacity in the circuit of Fig. *30B* is increased to .5 mfd. in Step 3, you will find that the coil, condenser and resistor voltages go up considerably. Coil and condenser voltages will be almost equal, indicating a condition very nearly approaching resonance. The difference between the coil and condenser voltages, when added vectorially to the resistor voltage, should presumably equal the source voltage of 4 volts. In the case of the N. R. I. values, however, adding the difference value of .6 volt at right angles to the resistor voltage of 1.4 volts does not give a value anywhere near 4 volts. We can be reasonably sure that this discrepancy is due to the a.c. resistance of the coil; furthermore, the voltage drop due to the a.c. resistance must be quite large.

It is possible to make measurements from which both the a.c. resistance of the coil and the Q factor of the coil can be computed. You do this by connecting the coil to a known a.c. voltage source in series with a condenser whose value will bring about the approximate condition of series resonance. Under this condition, the condenser and the coil both have maximum voltage values. The ratio of the coil voltage to the supply voltage is then the Q factor of the coil at the frequency used for the test (60 cycles in our case) and for the current value

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*The formula used for determining this reactance value is: $X_C = \frac{1{,}000{,}000}{6.28 \times f \times C}$, where X_C is the reactance in ohms, *f* is the frequency in cycles and *C* is the capacity in mfd.

flowing through the coil in the case of iron-core coils.

Knowing the Q factor, you can compute the a.c. coil resistance simply by dividing the reactance of the coil by the Q factor. This formula is correct for series resonant circuits, because at resonance the voltage of the source is dropped entirely in the coil resistance, and the a.c. resistance value therefore determines what the circuit current will be.

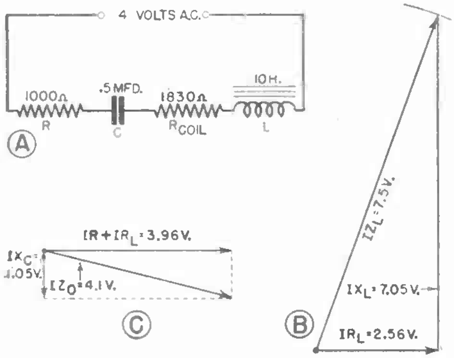

FIG. 31. Equivalent simplified circuit diagram corresponding to Fig. *30B*, and vector diagrams which prove that Kirchhoff's Voltage Law for a.c. circuits holds true in this particular circuit when tested out with the values obtained in the N.R.I. laboratory. One volt on these diagrams corresponds to ¼-inch of vector length.

As an example illustrating how the computations are made, we will use the values measured in the N. R. I. laboratory. We can assume that .5 mfd. tunes the coil essentially to resonance, particularly if the addition of the .05-mfd. condenser in Step 3 made the condenser voltage drop. We know that at resonance, the reactances of the coil and condenser are equal. We do not know the coil reactance because the inductance of this coil varies with the amount of current flowing through the coil (the rated value of 10 henrys applies only when rated current of 25 milliamperes is flowing). Therefore, we can compute the condenser reactance and assume that the choke will also have this reactance.

At 60 cycles, a .5-mfd. condenser has a reactance of about 5,300 ohms, so this will be used as our coil reactance value.

The measured N. R. I. voltage value across the choke coil in Step 3 was 7.5 volts. The supply voltage for the series resonant circuit is not 4 volts, however, because there is a drop of 1.4 volts across the 1000-ohm series resistor *R*. Subtracting 1.4 from 4 gives 2.6 volts actually acting on the coil and condenser.

Remembering that Q factor is equal to coil voltage divided by the *actual* supply voltage, we divide 7.5 by 2.6, and get 2.9 as the Q factor for the coil only. Now, dividing the coil reactance of 5,300 ohms by this Q factor value of 2.9 gives 1830 ohms as the a.c. resistance of the coil at 60 cycles.

Knowing the a.c. resistance value, we can use the values for Step 3 and see if we can make Kirchhoff's Voltage Law for a.c. circuits check in this case. The circuit diagram in Fig. *31A*, in which the a.c. resistance of the coil is separated from the coil inductance, will help you to understand this circuit.

To calculate the voltage drop across the a.c. resistance of the coil, multiply the a.c. resistance value by the circuit current value obtained in Step 3; 1830 x .0014, which is approximately 2.56 volts.

Next, we must find the true voltage drop across the inductance of the coil. The drop across the a.c. resistance of the coil is 2.56 volts, and the total coil impedance drop obtained in Step 3 is 7.5 volts. We draw a horizontal vector for 2.56 volts, then swing an arc having a radius proportional to 7.5 volts, and draw a line vertically upward from the end of the 2.56-volt vector until it intersects the arc, as shown in Fig. *31B*. The length of this vertical line will now be proportional to the voltage drop across the inductive reactance of the coil. Using the values measured at N.R.I., this drop came out to be 7.05 volts.

The resultant drop across the reactances in this circuit will be the difference between 8.1 and 7.05, or 1.05 volts. If we add this reactance drop at right angles to the total drop of 3.96 volts (2.56 + 1.4) across the 1,000-ohm resistor and the a.c. resistance of the coil in the manner shown in Fig. *31C*, we secure a resultant voltage vector which is just about 4 volts. Again we have confirmed Kirchhoff's Voltage Law for a.c. circuits.

This experiment has established the fact that in a series circuit, the reactances of a coil and a condenser cancel each other partially or completely. Furthermore, this experiment has proved definitely that the a.c. resistance of a coil is greater than its d.c. resistance. Finally, the experiment has shown that when a coil and condenser are connected in series, the combined reactance will be less than the largest individual reactance.

Instructions for Report Statement No. 29. An important principle to remember in connection with resonant circuits is that a change in the applied voltage does not affect the conditions of resonance.

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With your parts connected according to the circuit shown in Fig *30C*, adjust the potentiometer until the a.c. voltage as measured between terminals *5* and *6* is 4 volts, then measure the voltage across condenser *C* while observing the safety precautions emphasized in previous a.c. experiments. Make a note of the voltage value observed, then readjust the voltage between terminals *5* and *6* to 2 volts, which is half of 4 volts, and measure again the voltage across condenser *C*. Compare the two voltage values measured across *C*, then turn to the last page and place a check mark after the answer which applies to your observation.

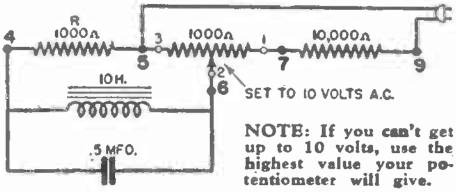
If the voltage across any part of the resonant circuit (such as across the condenser) drops proportionately when you reduce the source voltage to half its value, you have proved the statement brought forth above.

EXPERIMENT 30

Purpose: **To show that the combined reactance of a coil and condenser connected in parallel in an a.c. circuit is higher than that of the lowest reactance in the combination.**

Step 1. With the a.c. voltage divider used in Experiments 28 and 29, connect the 10-henry coil between terminals *4* and *6* to give the same circuit arrangement as is shown in Fig. *27D*. Set the N. R. I. Tester to *3×V*, place the black clip on terminal *5*, place the red clip on terminal *6*, insert the plug in the outlet, turn on the tester, and adjust the potentiometer until you have 10 volts between terminals *5* and *6*, as indicated by a reading of 3.3 on the *AC* scale. Pull out the plug.

Place the black clip on terminal *5*, place the red clip on terminal *4*, insert the plug, and note the meter reading with the N. R. I. Tester set at *3×V*. If the actual voltage indication is below 5.5 volts, change to the *V* range to secure a more accurate reading. Record your final value as the current in ma. through *R* and *L*, then pull out the plug.



NOTE: If you can't get up to 10 volts, use the highest value your potentiometer will give.

FIG. 32. Schematic circuit diagram for Step 2 of Experiment 30.

Step 2. Place a .5-mfd. condenser in parallel with the coil as shown in Fig. 32 (use the two .25-mfd. condensers, Parts *3-2A* and *3-2B*, which you previously connected in parallel to give .5 mfd.). Use temporary soldered lap joints to terminals *4* and *6* for this purpose. Readjust the voltage between terminals *5* and *6* to 10 volts in the manner specified in Step 1, then pull out the plug. Place the black clip on terminal *5*, place the red clip on terminal *4*, leave the N. R. I. Tester set at the *V* range, turn on the N. R. I. Tester, reinsert the plug, read the meter on the *AC* scale, and record the result in Table *30* as the current in ma. through *R, L* and *C*. Pull out the plug, and turn off the Tester.

STEP	NATURE OF MEASUREMENT	YOUR VALUE IN MA.	N.R.I. VALUE IN MA.
1	CURRENT THRU R AND L	2.5	1.7
2	CURRENT THRU R, L AND C	.5	.5

TABLE 30. **Record your results here for Experiment 30.**

Discussion: In this experiment, you measure the current first through a 10-henry inductance having a reactance of approximately 5,300 ohms at 60 cycles, then through a parallel circuit consisting of the inductance and a .5-mfd. capacity which likewise has an impedance of 5,300 ohms. If you performed this experiment correctly, you should find that the mere shunting of the coil with this condenser serves to reduce the circuit current to 1/3 of the value for the coil alone. The parallel coil-condenser combination must therefore have a reactance of about 3 times the 5,300-ohm value for the coil alone, or 15,900 ohms.

The currents through the coil and the condenser are 180° out of phase, and therefore the total current drawn by these two parts must be equal to the difference between the currents through the individual parts.

The important fact for you to remember in connection with this experiment is that when a coil is shunted by a condenser, the combined impedance is greater than the lowest reactance.

Instructions for Report Statement No. 30. Suppose we repeated this experiment with a large condenser shunted across the choke coil, so that the condenser impedance is much lower than the coil impedance. Would the fundamental rule presented in this experiment still hold true? You can easily check this by making the following additional measurements.

Starting with your apparatus connected according to the circuit of Fig. *32*, disconnect both the 10-henry coil and the .5-mfd. condenser from terminals *4* and *6*, then connect to these same terminals a 10-mfd. capacity (your dual 10-10-mfd. condenser connected for a.c. operation, as was done in Step 7 of Experiment 28). Adjust the voltage between terminals *5* and *6* to 5 volts a.c., then measure the a.c. voltage across 1000-ohm resistor *R* (between terminals *4* and *5*). Remember that this voltage value is also the current in ma.; the higher this current, the lower is the impedance 4.5
between terminals *4* and *6*.

Now connect to terminals *4* and *6* the 10-henry choke coil, so it is in parallel with the 10-mfd. capacity, and measure again the a.c. voltage 4.2
across 1000-ohm resistor *R*. Check your answer in Report Statement No. 30. Pull out the plug, turn off the N. R. I. Tester, then disconnect the voltage divider.

IMPORTANT: Do not discard any of the parts supplied to you in N. R. I. radio kits before you have completed your course. The parts will be used again in later experiments.

PHOTOELECTRIC CONTROL CIRCUITS WITH RELAYS

25X-1

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

REFERENCE TEXT

FOR YOUR REFERENCE LIBRARY

This reference book will prove very valuable should you ever have occasion to deal with photoelectric apparatus, for it contains explanations of the operating principles and characteristics of basic electronic circuits. Each circuit has been carefully selected to show certain fundamental principles which, once understood, can be utilized in designing many other useful circuits of the same general type.

Electronic tubes such as the well-known General Electric Thyratron and the Westinghouse Grid-Glow tubes are being used more and more in industry today; you will find in this text much reference material on this particular subject.

NPC10M748 1948 Edition Printed in U. S. A.

PHOTOELECTRIC CONTROL CIRCUITS WITH RELAYS

Types of Relays

YOUR study of light-sensitive cells has shown that these "electric eyes" change their electrical characteristics when the light on them changes. Thus, light causes a photoconductive cell to change its resistance, this change being converted into either a current or voltage change by the cell circuit; a photovoltaic cell actually produces an e.m.f. directly, which is generally used to cause a current change in an electrical circuit; a photoemissive cell controls the electron flow in its circuit, thereby producing changes in voltage and current. Now, the current changes are quite small—several milliamperes at most, and usually of the order of microamperes. To control electrical apparatus with light-sensitive cells, it is usually necessary to build up these comparatively small current changes in some manner.

In most practical control circuits, the impulse or electrical power change originating at the photoelectric cell actuates an electromagnetic relay whose contacts either open or close the circuit to the device which is to be controlled by changes in light. The greater the current required by the device, the greater must be the pressure of one relay contact against the other, the larger must be the contacts, and the greater must be the power required to operate the relay. A sensitive relay can be used for small currents, but a husky power relay which has large contacts is needed if heavy currents flow.

Many different schemes for linking the light-sensitive cell with the power relay have been introduced. Electromagnetic relays connected in succession, so the contacts of one control the input to the next, are widely used. For example, a photovoltaic cell may actuate a super-sensitive relay which controls a sensitive relay, and this secondary relay in turn operates the final heavy-duty relay.

Because super-sensitive relays are expensive and require considerable attention, many methods have been developed to eliminate their use. A voltage change in the cell circuit can be amplified sufficiently by one or more vacuum tube amplifiers to operate sensitive or heavy-duty relays. The voltage change originating at the cell can also be applied between the grid and the cathode of a gas triode (such as a "grid-glow" or a Thyratron tube), and a heavy-duty power relay can be inserted in the plate circuit of the gas triode. In many cases the device being controlled can be connected directly into the plate circuit of the gaseous tube, in place of the power relay.

Thus, you may find between the light-sensitive cell and the controlled device either an amplifier (containing one or more gaseous or vacuum type amplifier tubes), an electromagnetic relay, or a combination of the two. The intervening circuits may impart special characteristics to the complete photoelectric control unit. In general, however, the final action is to open or close the circuit at the desired time interval after the light on the cell has changed by a certain definite amount.

Choosing Relays. In selecting a relay for a particular application, certain fundamental facts must be considered. How much current is required to make the relay contacts close? This current is called the *pull-up* current of the relay. At what value of current will the relay contacts open? This is called the *drop-out* current. Other important factors are: How long does it take after the current or voltage reaches the pull-up value before the contacts close completely? How much time elapses, after the relay current is reduced to the drop-out value, before the contacts are opened? Where rapid counting or fast action is required, fast relays are used; for certain jobs, such as illumination control applications, extremely slow relays are needed; where light changes on the cell are small, the difference between pull-up and drop-out currents must be small. The nature of the power supplied to the relay circuit must be considered for relays are generally designed for either d.c. or a.c. use, but not for both (D.C. relays are usually more sensitive than a.c. relays.) The ohmic value of the relay coil is another important factor, for the voltage drop across the coil must be considered in the design of the control circuit.

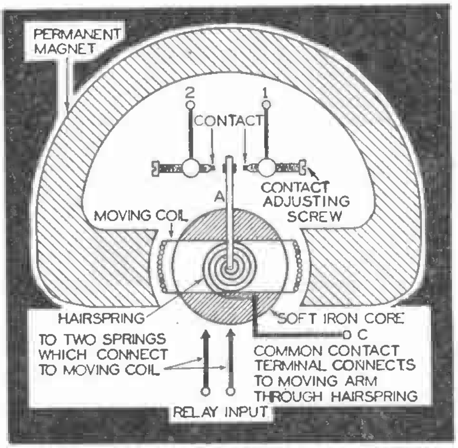


FIG. 1. A super-sensitive relay is basically similar to a moving-coil type meter; in fact, it is frequently called a meter-type relay.

Other factors affecting the choice of a relay are the current, the voltage, and the nature of the load in the circuit being controlled. The contacts must be able to carry and break the current through the circuit without serious arcing or sparking. The voltage must not be so high that current will jump across the contacts when they are open. When the load is inductive, the amount of current which can be carried is reduced unless anti-sparking filters are used. Even then, the high surge voltage produced by breaking an inductive circuit may cause arcing across the contacts if they are too close to one another in their open position.

Now that you know what the important characteristics of a relay are, let's make a detailed study of the various types of relays used for photoelectric and electronic control systems.

SUPER-SENSITIVE RELAYS

From a practical viewpoint, super-sensitive electromagnetic relays are really modified moving coil type microammeters, with platinum-iridium contacts mounted on the moving pointer, and with adjustable contacts (one on each side of the pointer) mounted on the meter scale. Platinum-iridium contacts are used because this alloy does not oxidize or tarnish in air, and resists the pitting (eroding) action of the current.

The basic arrangement of a typical super-sensitive relay is shown in Fig. *1*. The two moving coil terminals are connected into the controlling circuit (light-sensitive cell circuit), and the remaining three terminals, going to contacts *1* and *2* and to pointer *A*, are for the controlled circuit. An increase in current through the relay coil will send arm *A* to contacts *1* or *2*, depending on the direction of current flow in the coil circuit. The sensitivity of this relay depends on the strength of the permanent magnet, the number of turns on the coil, and the spring restoring torque (twist), just as with ordinary meter movements. Units which will make contact on currents as low as 5 microamperes are obtainable.

► One commercial form of this relay, the Weston meter-type relay, is shown in Fig. *2*. The minimum current required to close the contacts is 15 microamperes, and the contacts are rated to handle up to 200 milliamperes (non-inductive load) at 6 volts.

► A super-sensitive relay of this type can be used in the following three ways:

I. With *no current* flowing through the relay coil, arm *A* (Fig. *1*) is set midway between contacts *1* and *2*, so a positive current (a current flowing in such a direction that it causes the pointer to swing clockwise) will move arm *A* to contact *1* and a negative current (making the pointer swing counter-clockwise) will move the arm to contact *2*. The closer together the contacts are placed, the smaller is the current required to move the arm over to one of the fixed contacts.

II. Arm *A* is made to center itself halfway between contacts *1* and *2* for a *definite value* of coil current, making contact with *1* when the current exceeds this value and making contact with *2* when the current falls below this mid-value. Moving contacts *1* and *2* closer together gives relay action for smaller changes in current.

III. Arm *A* is set to make contact with *2* for all coil currents from zero up to a certain definite value in the relay range; currents above this value then move the arm over to contact *1*. The reverse of this action is also possible.

Courtesy Weston Electrical Inst. Co.

FIG. 2. The Weston model 534 meter-type relay, capable of operating on coil currents as low as 15 microamperes.

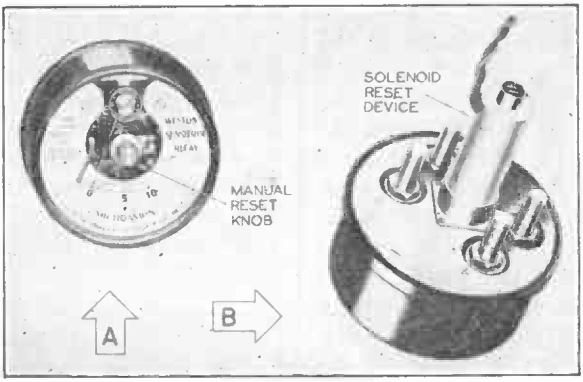
► The speed of operation of meter type relays can be increased by moving the fixed contacts closer together.

Only small currents and voltages, usually not over 200 milliamperes at 6 volts, can be controlled where fast operation is desired. There must be no appreciable inductance in the contact circuit which would cause serious arcing.

Any current or voltage range for the moving coil of the relay can be obtained by using shunts and multipliers. Super-sensitive relays having ranges below 200 microamperes can be connected directly across dry or wet type photo-voltaic cells, or placed in series with a battery across photoconductive cells. The contacts of the relay are usually connected through a 4.5- to 6-volt battery to the coil of a sensitive relay, which may in turn actuate a power relay.

The extremely high sensitivity of the meter type (super-sensitive) relay is offset by a number of disadvantages. There is a tendency for the contacts to "chatter," or open and close repeatedly, when the actuating coil current is just about enough to make or break a contact. This results in arcing, faulty operation of the relay, and eventual destruction of the contacts. To overcome this chattering without depriving the relay of its low current pull-up value, the Weston Electrical Instrument Corporation has introduced their so-called *Sensitrol* relay, shown in Fig. *3A*.

The basic construction of this relay is like that shown in Fig. *1*, except that a small soft iron piece or "rider" replaces the contact points on moving arm *A*, and a small but powerful permanent magnet replaces the contact at *1*. When the arm swings over to the right it is snapped up against the face of the magnet, making a solid contact. External force must be applied to the pointer to free the rider from the magnet and break the contact. This can be done in either of two ways: by turning the reset knob in the center of the relay, which pushes the pointer back to its no-current position, or by using a solenoid (electromagnet) to reset the pointer electrically. The solenoid type Sensitrol is pictured in Fig. *3B*.



Courtesy Weston Electrical Inst. Co.

FIG. 3. The Sensitrol relay. The type at A has a manual reset knob, while the one at B is reset magnetically.

Sensitrol relays can be obtained in many different types, to open or close a circuit on either an increase or a decrease in current. These relays usually are used for installations where repeated or continuous control is unnecessary, such as in locations where an attendant can reset the relay after each closing. However, time relays can be used in conjunction with the solenoid type Sensitrol to reset the relay automatically. Although the apparatus required is quite expensive, it gives the only practical solution to certain types of control problems.

SENSITIVE RELAYS

Relays of the sensitive type require currents of from .5 to 3.0 milliamperes for their operation. This type of relay is used in the plate circuit of a vacuum tube amplifier whose grid is connected to the control element (light-sensitive cell, thermostat, beat-frequency oscillator, etc.), and also in circuits where it is controlled by the contacts of a super-sensitive relay.

Fig. *4* shows the construction of a typical sensitive relay. In general, a sensitive relay consists of a soft iron armature, pivoted at one end, which is attracted to the iron core of an electromagnet when the required current is passed through the electromagnet coil. Contacts are placed on the free end of the armature.

The electromagnet consists of a large number of turns of No. 30 to No. 40 B. & S. gauge enamelled or insulated copper wire, wound on a bobbin which slips over one leg of a U-shaped core. These coils are designed to have the greatest number of ampere-turns for a given operating voltage and current. The weaker the rated pull-up current of the relay, the greater must be the number of turns on the coil; increasing the turns means increasing the resistance of the coil. Relay coils have resistances varying from 1 to 10,000 ohms, depending upon the operating current. Sensitive relays for photoelectric work ordinarily have resistances of from 1,000 to 8,000 ohms.

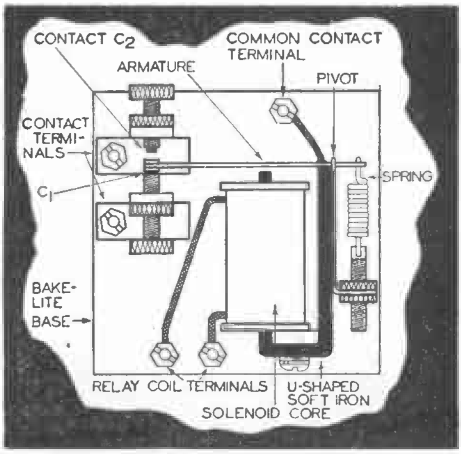
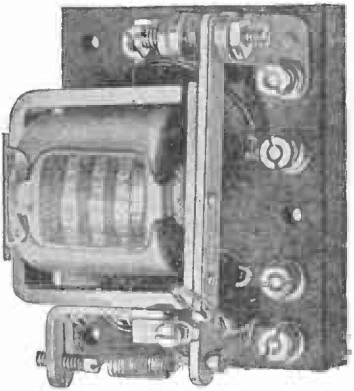


FIG. 4. A typical sensitive relay. The "common contact" terminal connects to the armature.

Relay coils generally are rated according to the power in watts required to pull up the armature and close the contacts. This wattage rating allows relays of different voltage and current ratings to be compared as to sensitivity.

Pivoted at one end of the U-shaped core (Fig. *4*) is the soft iron armature which is attracted to the U-shaped core when the solenoid is excited with sufficient current. The armature is normally held against contact C_2 by the action of the spring; when the pull-up current value passes through the coil the armature is pulled up against C_1. Thus, by making the proper connections to contacts C_1 and C_2, the opening and closing of one circuit can be controlled by the relay, or two separate circuits can be controlled.

It is important that the armature and the core of the relay coil be made of material which will not retain its magnetism when the current falls below the pull-up value. Therefore, special alloys of iron with silicon are used; they change their magnetism as the magnetizing current changes and lose practically all magnetism when the current drops to zero. These alloys have a high permeability, which means that they produce a large magnetic attraction for low values of ampere turns. The lower the electrical power required to pull up the armature, the more sensitive is the relay. Notice that one end of the armature (in Fig. *4*) rests against one of the poles of the U-shaped core; this reduces the reluctance of the magnetic circuit, giving greater sensitivity.



Courtesy Struthers-Dunn, Inc.

FIG. 5. The Dunco CXB51 sensitive relay, which can be obtained with coils of various voltage and current ratings.

► The armature must be properly balanced so it will move freely without wasting any of the attractive force, if maximum sensitivity is to be obtained. The electrical connection to the armature is ordinarily made at some point on the U-shaped core, with current passing through the pivot and out along the armature to the double contacts. Pigtails (flexible leads) are sometimes used to bridge the pivot and give a more dependable electrical connection. Sensitive relays of this type will handle about 2 amperes at 110 volts a.c. or ¼ ampere at 110 volts d.c., provided that the loads are non-inductive. (When there is an inductive load, less current can be handled. However, placing a condenser or a condenser-resistor filter across the contacts reduces the sparking and allows currents more nearly the rated values.) A typical sensitive relay is shown in Fig. *5*.

The Telephone Relay. Another type of sensitive relay, shown in Fig. *6*, is commonly known as a *telephone type relay*, because it is widely used in telephone circuits. The coil of this relay is about 3 inches long and 1 inch in diameter, and has a cylindrical soft iron core. At one end of the core, a rectangular soft iron armature is so pivoted that it is attracted to the core when current flows through the coil. There are no contacts on the armature. Instead, there is an armature lever which has an insulated bushing at its tip. When the armature pulls up, this lever pushes against spring steel blades on which the contacts are mounted; these contact blades can be arranged either to open or close circuits when the relay operates. The blades are very similar to those used on plug-in telephone jacks. Any number of combinations of make-and-break circuits is possible. A few of the fundamental contact possibilities are shown in Fig. *6*. When the armature button moves in the direction of the arrow, the indicated "make-and-break" or "open-and-close" action takes place.

The telephone relay is an extremely flexible device. With certain modifications it can be adapted to any practical speed or function. It will pull up in .02 to .05 seconds and drop out in the same time. A residual magnetism screw, set into the armature to prevent it from sticking to the core when coil current is zero, can be adjusted to reduce the movement of the armature and thus speed up its action. This screw, of course, must be made of non-magnetic material.

The drop-out time of the telephone relay can be increased by preventing a rapid decrease in magnetic flux through the core. For instance, a medium speed relay is obtained by placing a copper sleeve over the iron core (between the coil and the core). A slow speed relay is obtained when a heavy copper washer is slipped over the end of the core. The thickness of the washer determines the speed of operation of the relay. The principle of mutual induction explains why relays can be slowed up in this way; the copper washer or sleeve is really a single turn coil of low resistance, mutually coupled magnetically (by the core) to the relay coil. The thicker the washer, the lower its resistance and the longer it can prevent a change in the flux through the core.

► Super-sensitive relays are generally of the fast type. However, sensitive relays are made with fast, medium, and slow operating speeds. Fast, sensitive relays are recommended for use in the plate circuit of a vacuum tube.

► The most dependable relays have a drop-out current which is about one-half the pull-up current; this gives a relay differential (ratio of drop-out current to pull-up current) of 50%. Designing them this way provides a more positive action, particularly when small current variations are present. Once the relay closes, it is held firmly closed until the current falls to the drop-out value. Relays with differentials of 15% to 25% are available, but these usually require more frequent attention. They operate on small differences in exciting current, but this low differential makes for a less positive relay with a tendency to chatter.

A.C. and D.C. Operation. The sensitive relay can be used in a.c. or pulsating d.c. current control circuits if certain precautions are observed. It is often an advantage to use a.c. if it is possible to do so, for a.c. voltages are almost always easier to obtain in the exact values required, whereas batteries change in voltage and require constant replacement.

A telephone relay (designed specifically for d.c. use) may be used in the plate circuit of a tube which is rectifying a.c., provided a condenser is

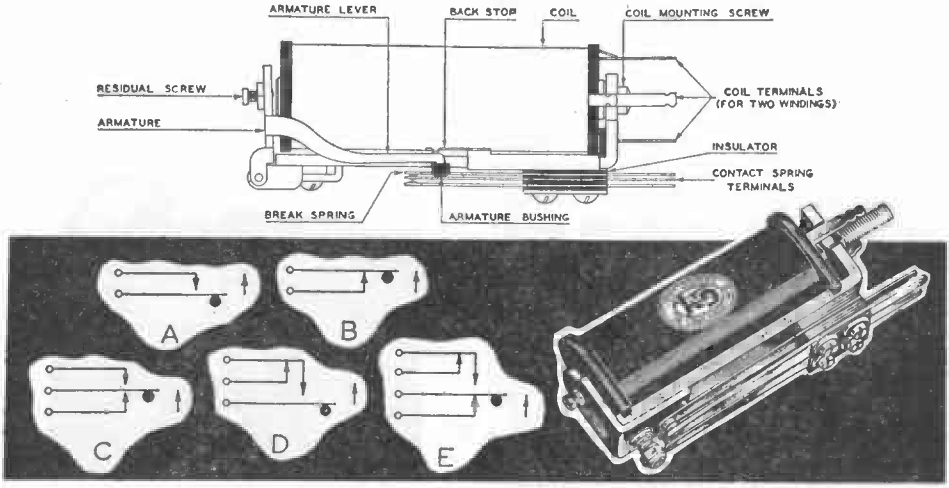


FIG. 6. The telephone-type relay, so named because it is widely used in telephone work as well as in electronic control apparatus. Almost any contact arrangement is available; several are shown here. These basic contact arrangements are: A—make; B—break; C—break before make; D—make before break; E—break and make before break. A "make" arrangement closes a circuit when the relay is energized, while a "break" style opens a circuit.

shunted across the relay coil. The condenser and the coil then act as a filter to smooth out the pulsations in the current. The lower the coil resistance, the larger must be the condenser capacity to prevent contact chatter. Always use the smallest capacity which will prevent chatter. A 2-mfd. condenser is about correct for a 5,000-ohm relay coil.

► Special types of relays are available for use in a.c. circuits. These are generally less sensitive than d.c. types, for power is lost because of *eddy currents* and *hysteresis*. The cores and armatures of some a.c. relays are made up of very thin sheets of silicon iron, like audio transformers, while other types use solid cores having one or more slots along one side to reduce eddy currents. To help prevent chattering, the mass (weight and shape) of the moving armature, and the spring tension are made such that the moving system has a vibration period which is less than the frequency of the exciting current. As an additional check on chattering, that pole of the core which faces the armature has a split end, in which is imbedded a heavy copper ring, called a "shading" ring or coil; this is shown in Fig. 7. This ring acts like a short-circuited secondary winding, its induced current producing a flux which holds the armature down during that part of the cycle when the current (and the main flux) drops to zero. All these factors tend to make a.c. relays less sensitive and more expensive than d.c. types.

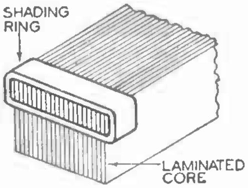


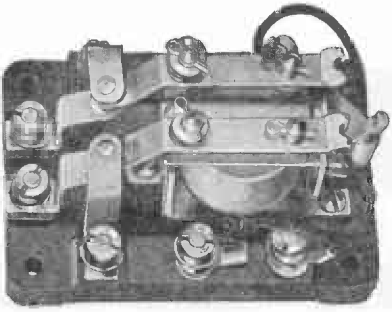
FIG. 7. In order to prevent chatter when relays are operated on a.c., a heavy copper shading ring, like that shown here, is forced into a slot cut into that end of the laminated iron core which faces the armature.

HEAVY-DUTY OR POWER RELAYS

When the power that is to be turned on or off by a relay exceeds 200 watts a.c. or 25 watts d.c. (the maximum values which can be handled by the *average* sensitive relay) a power relay, controlled by a sensitive relay, is generally used to handle it.

The coil of a power relay requires a d.c. input power of about 2 watts, in general, for satisfactory control of up to 1,000 watts a.c.; if a 100-volt d.c. source is used to excite the power relay coil, the operating or pull-up current (I = P/E) will be 2 ÷ 100 or .02 ampere (20 milliamperes). The resistance of the relay coil (R = E/I) should therefore be 100 ÷ .02 or 5,000 ohms in this case. The required resistance for any relay coil can be figured in this manner. Generally, a.c. relays require a higher power input than d.c. relays.

The principle of operation of the power relay is essentially like that of the sensitive relay. The same precautions are taken to prevent chatter on



Courtesy Struthers-Dunn, Inc.

FIG. 8. Dunco midget heavy-duty relay (Type CDBX1), having two contact blades mounted on the clapper type armature to give double-pole double-throw operation.

power relays designed for a.c. excitation. A typical power relay (also called an auxiliary relay) is shown in Fig. *8*. It has a rectangular clapper type armature pivoted in front of an electromagnet. The clapper carries one or more contact arms which move between fixed contacts. The one shown is a double-pole, double-throw switching relay: one circuit closes when the relay pulls up, the other closes when the relay drops out. A large number of make-and-break combinations are possible. In circuits where a supersensitive relay controls a sensitive relay which, in turn, actuates the power relay, the first two relays are essentially simple make-and-break types, which the power relay furnishes the desired switching (often quite complex).

Another form of power relay, one which can apply heavy contact pressures, makes use of the suction or minimum reluctance action of a magnetic circuit. A diagram of such a relay is shown in Fig. *9*. When a.c. or d.c. is fed to the relay coil, the armature has a tendency to take a position which will make the reluctance of the magnetic circuit a minimum (by making the air gap between the armature and the poles as small as possible). Thus, when the relay coil is actuated, the armature takes the position shown by the dotted lines and the contact arm moves from *B* to *C*.

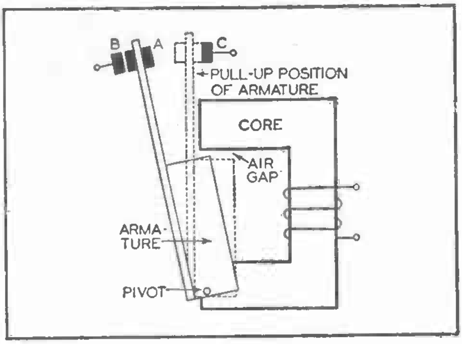
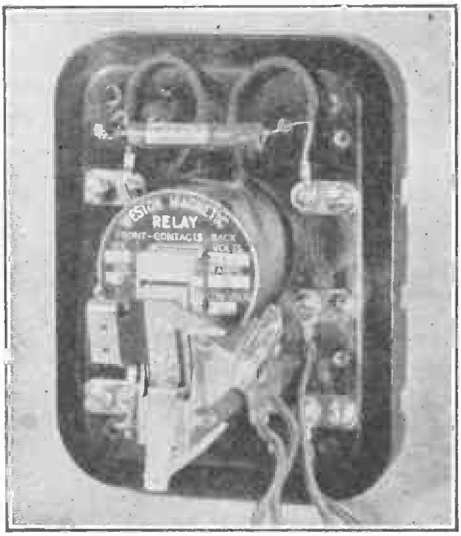


FIG. 9. Diagram illustrating the principle of operation of the minimum reluctance type of power relay. Dotted lines show pull-up position of armature.



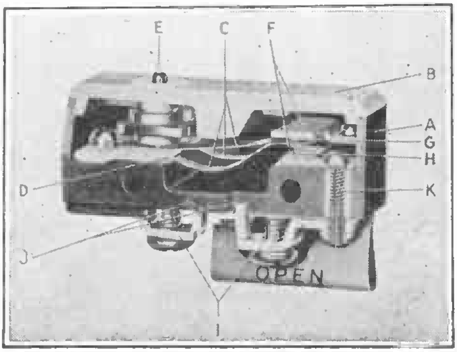
Courtesy Weston Electrical Inst. Co.

This power relay uses mercury tube switches instead of air contacts. As many as four separate mercury switches may be mounted on the relay, which is of the minimum reluctance type.

Both sensitive and power type relays can be made with a small latch or mechanical lock which will hold the armature in position once it has been attracted to the core. Relays with this device are known as *latch-in relays;* they must be released either mechanically (by pushing on the latch) or by an auxiliary electromagnet whose armature is attached to the latch. Latch-in type relays are useful when the relay-actuating current is an impulse (produced by pushing a button or interrupting a light beam) which must keep mechanisms in operation until the desired condition has been reached. The latch can then be released by some type of limit switch, opening the relay in readiness for another control operation. For example, when an intruder passes through a light beam, the photocell, through its relays, can be made to ring a bell continuously until the owner of the establishment releases the latch-in relay.

SPECIAL RELAYS

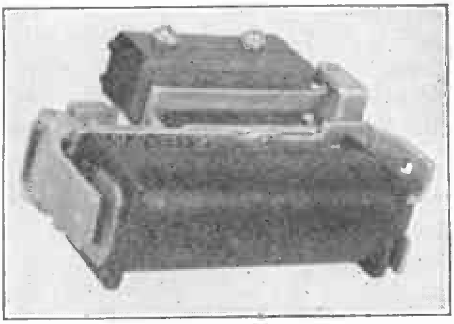
Although unique control arrangements can be obtained by using sensitive and auxiliary relays together, the use of combinations of relays in this way is not entirely satisfactory in many cases, for each relay is a potential cause of failure of the entire system. The ideal relay is one sensitive enough to operate on extremely low power inputs, yet capable of controlling large amounts of power. The Micro Switch and the mercury type contacts, when used on ordinary sensitive relays, closely approximate the ideal relay.



Courtesy Micro Switch Corp.

FIG. 10. A cut-away view of a Micro Switch. A slight pressure on the plunger (E) either opens or closes the contacts, depending on the contact arrangement. The parts shown and labeled are: A—part of the case or enclosure; B—the top of the unit; C—the spring arms; D—the anchoring blocks for the ends of the curved springs; E—the plunger which actuates the switch; F—the fixed contact faces; G—the movable contact; H—not a part, but the distance the contact must travel to touch the lower face; I—the terminals; J—the terminal anchors; K—a feedthrough screw which ties the contact to a terminal.

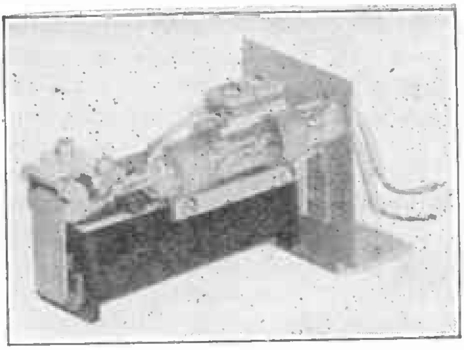
A Micro Switch is shown in Fig. *10*. This switch operates with a snap when a pressure greater than 14 ounces is applied to the operating plunger, and releases with the same snap action when the pressure is reduced to about 4 ounces. The actual travel of the plunger is approximately .0004 to .002 inch. The moving contact is attached to one flat spring and two curved springs. The flat spring produces a downward force on the moving contact, while the curved springs produce an upward force on it. In the normal position, the downward force of the flat spring is slightly greater than the upward force of the curved springs. However, when the flat spring is depressed by the plunger, its force on the contact is decreased, and the lower springs bring the contact up to the fixed contact with a snap. Switches of this type are available in a number of simple make-and-break combinations.



Courtesy Automatic Electric Co.

A combination of a telephone-type relay and a Micro Switch. The relay operates the plunger of the Micro Switch.

Vacuum contacts are used extensively on relay installations where sparking at contacts may cause an ex-



Courtesy Automatic Electric Co.

FIG. 11. Vacuum contact switch mounted on telephone-type sensitive relay. Insulated knob on armature at left presses against glass lever which extends into the glass vacuum tube and operates the contacts which are inside.

plosion and fire. Reasonably large currents can be controlled with a sensitive relay and the special vacuum contact shown in Fig. *11*. The contact points, mounted in a glass tube from which all the gas has been evacuated, are operated by a glass lever which acts through a flexible seal, lifting the movable contact. Since the contacts are in a vacuum, in which there is no gas to cause ionization or arcing, only a small gap is required between them. The contacts therefore have a long life. As much as 6 amperes at 220 volts a.c. or d.c. can be controlled by the unit shown, regardless of whether the load is inductive or resistive, and as many as 40 make-and-break operations per second can be made.

Mercury Contact Switches. If you place a quantity of mercury on a flat sheet of glass you will observe that the mercury remains in a globule and that the slightest tilt to the glass will cause the mercury to move. This characteristic, together with the fact that mercury is a metal and therefore a good electrical conductor, has resulted in the *mercury contact switch.* A quantity of mercury is placed in a small capsule-shaped glass tube having two (or more) contact wires sealed into the glass. The tube is sealed after air is pumped out; an inert gas is sometimes placed in the tube after evacuation, to prolong its life. When the switch is tilted as shown in Fig. *12,* the mercury makes contact with only one wire or electrode, but in a level position the globule of mercury spreads out over both electrodes, closing the circuit between them. If both electrodes are placed at one end of the tube, tilting the switch in that direction will close the circuit. Many other arrangements of two and more contacts are possible. Mercury tube switches are available in many different types, some with mercury-to-metal contacts and others where the mercury pools themselves form the contacts; some require large, others require small angles of tilt. Switches which must carry large amounts of power in general require more mercury, heavier contacts, a larger angle of tilt, and larger forces to cause the tilt.

Mercury tube switches can be mounted on sensitive or low powered relays, in combinations capable of controlling up to several kilowatts of power. As many mercury tube switches can be attached to a relay as are required for the control operations, when the desired contacts cannot be made by a single switch.

Mercury switches have a disadvantage in that they must be mounted

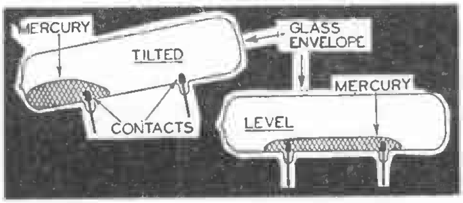


FIG. 12. Tilted and level positions of a simple mercury switch. When the switch is in the level position, a globule of mercury makes electrical connection between the two contacts.

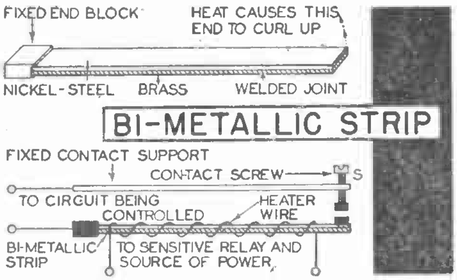


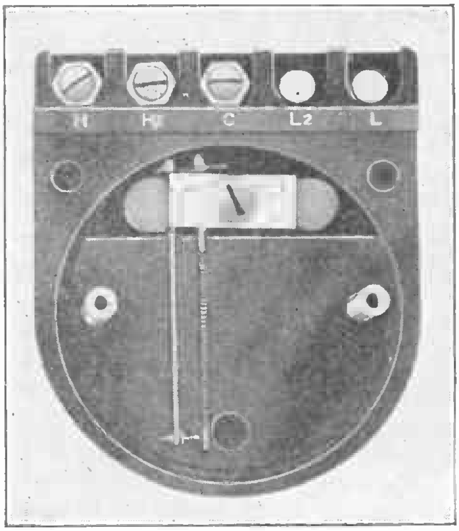
FIG. 13. Basic principles of the bi-metallic strip type time delay relay are illustrated here. The four connections are often reduced to three by attaching one heater wire to the bi-metallic strip.

"level" and cannot be used in places where they would be subject to jarring. The vacuum switch is better for these cases.

Time Delay Relays. Quite often a relay is needed which will not close its contacts for a definite interval of time (5 seconds to 3 minutes) after the coil is energized. For example, a time delay relay is needed in certain illumination control systems. Here a single photocell is made to operate two sensitive relays, one of which turns on lights when room illumination drops below the desired value, and the other turns off the room lights when the photocell "sees" too much light. Clearly, steps must be taken to prevent either small clouds that momentarily hide the sun or passing objects from flashing the lights on and off. The usual solution is to use the sensitive relays to control time delay relays, which, in turn, control the light circuits. These time delay relays require current for a definite period of time before their contacts close.

Most time delay relays are heat-operated mechanisms. The control current supplied to one passes through a resistance wire, and the heat developed causes some mechanical motion which is used to close or open contacts. Usually, this motion is produced by a *bi-metallic strip* (a thermostat). If a nickel-steel strip and a hard brass strip are welded together, as in Fig. *13A,* and one end is firmly anchored, a very positive motion will be obtained when heat is applied to the device. For a given temperature increase, the brass increases in length 18 times more than the nickel-steel; the strip must therefore curl upward to allow the brass to stretch. This bi-metallic strip can be heated by sending current through a coil of resistance wire wound around it. If contacts are placed on the free end of the strip and fixed contacts mounted on either side, the strip can be used to open or close a circuit. The time required to make contact can be changed by adjusting the positions of the fixed contacts. The contact is usually mounted on an adjusting screw, as at *S.*

Figure *13B* shows a simple but effective time delay relay requiring about 6 volts of d.c. or a.c. for its operation and intended for use with a



Courtesy Weston Electrical Inst. Co.

A time delay relay with the cover removed. The heater coil operates from 6 volts d.c.

sensitive relay. The time delay contacts will handle about 25 watts a.c. (¼ ampere at 110 volts). If more power is to be handled, a heavy-duty relay must follow the time delay relay. This relay always requires 60 seconds for a complete make-and-break operation, but it can be adjusted to make contact in an interval varying from 15 to 45 seconds.

Care and Adjustment of Magnetic Relays

Prevention of Sparking at Contacts. To obtain long contact life from relays, sparking must be reduced to a minimum. The most effective protection for a super-sensitive relay, where sparking is especially serious, is to connect a condenser C and a resistor R in series across the relay contacts, as shown in Fig. *14A*. The time constant of the combination of R and C should be much lower than the speed of the relay (R in ohms times C in mfd. gives time in microseconds; divide by 1,000,000 to get time in seconds). In general, a 1 mfd. condenser in series with a 100-ohm resistor will be satisfactory. In a.c. circuits the reactance of the condenser must be sufficiently high (the capacity low) so current passing through the condenser will not operate the power relay or other device being controlled by the contacts. The condenser should have a working voltage of at least 400 volts for circuits using 110 volts or less.

When the relay contacts are connected into the coil circuit of another relay, it is wise to shunt the coil of the second relay with a resistor like R_S in Fig. *14B* whose resistance is at least five times the coil resistance, so that it will not appreciably raise the pull-up current. This resistor tends to neutralize the inductance of the relay coil and lessen the tendency towards sparking at the contacts which are in series with that relay coil.

Cleaning Contacts. To begin with, relays exposed to the air should be kept in dust-proof housings or at least partially protected from dust, chemical fumes, and foreign particles. Relays should be cleaned regularly with an air bellows or air pressure line. All contacts and moving parts should be cleaned with carbon tetrachloride (Carbona). When flat type contacts become pitted or corroded, they should be filed flat and bright by placing a thin file (such as that used in cleaning automobile distributor contacts, or a jeweler's file) between the contacts, squeezing the contacts together and slowly drawing out the file, repeating the process as often as nec-

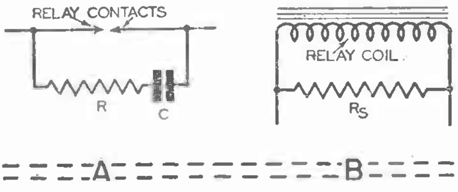


FIG. 14. Spark filters. The R-C filter A will tend to prevent sparking at the relay contacts. The resistor across the relay coil at B will reduce relay contact sparking when the relay is used to control the coil current.

essary. When the contacts are shaped (rounded or cylindrical) they should be polished with fine "crocus" cloth. Never oil or grease the moving parts of relays, for they are designed to give free action without a lubricant. These instructions apply only to sensitive and power relays; super-sensitive relays must be handled just as carefully as meters.

Adjusting Relay Contacts. All relays come from the manufacturer properly adjusted for pull-up and drop-out current. Tampering with the adjustments should be avoided, but if adjustments are necessary, the following general rules, which deal specifically with sensitive relays, will be helpful:

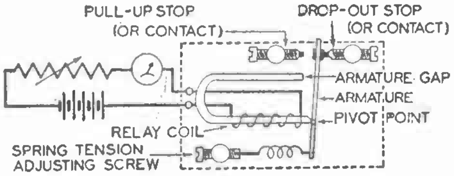


FIG. 15. A test circuit used to send an adjustable current through the relay coil of a sensitive relay. This circuit is necessary in order to adjust the relay properly.

1. Connect the relay in the test circuit, shown in Fig. *15*, which is capable of supplying enough direct current to operate the relay. With a current near the pull-up current flowing through the coil, loosen the spring tension screw, then adjust the pull-up stop (this is also the pull-up contact in most cases) so the gap (called the armature gap) between the armature and the soft iron core or pole piece is about .002". If there is a copper cap or copper stud in the pole piece (to prevent the armature from sticking), adjust for zero air gap, being certain that good contact is being made between the armature and the pull-up contact.

2. Reduce the coil current to the desired *drop-out* value and gradually increase the spring tension until the armature drops out.

3. Turn out the drop-out stop, adjust the current to the desired *pull-up* value, then slowly turn in the drop-out stop, bringing the armature nearer to the coil core, until the armature pulls up. The relay is now properly adjusted for the desired pull-up and drop-out currents.

Check the adjustments by varying the current back and forth to the drop-out and pull-up values, to be sure the relay operates properly. If the armature drops out sluggishly, increase the armature gap and repeat adjustments *2* and *3*. If the armature pulls up sluggishly, turn in the drop-out stop a little more.

► Always adjust the relay in the position in which it is to be used. A relay may be adjusted just as easily in its final operating circuit, following the procedure given above while using operating conditions for pull-up and drop-out currents.

Ordering Relays. In ordering relays or getting a quotation as to cost, you must decide first upon the type (meter, sensitive, power, mercury contact, etc.) and the manufacturer, after studying the catalogs of different relay manufacturers. You will find that each type of relay can be secured in a number of different voltage and current ratings. In most cases, it is best to let the manufacturer use his own judgment in making the final choice. When you write to a manufacturer, always supply at least the following information:

1. Catalog number and name of the type of relay you desire.
2. Pull-up and drop-out current (or voltage) values required.
3. Whether the exciting current will be a.c. or d.c.

4. Contact arrangements desired.
5. Power to be handled by contacts (voltage and current); whether a.c. or d.c. power is used, and whether or not load is inductive.
6. Speed of pull-up and drop-out, or time for one complete operation (if important in your case).
7. Special information as to how relay will be used.

Photoelectric Controls Using Only Relays

Inasmuch as a super-sensitive relay will operate on currents below ¼ milliampere—currents which photovoltaic and photoconductive cells will produce with normal changes of light—these cells may be connected directly to super-sensitive relays. Photoemissive cells, however, are not suitable for direct connection to a relay, as the safe current which they can pass is generally insufficient for relay actuation.

While some photoconductive cells will pass enough current to actuate a *sensitive* relay directly, the photovoltaic cell (which can supply ample current for a *super-sensitive* relay) is the only type of cell which is used *commercially* to operate a relay directly. The current outputs of the photoemissive and photoconductive cells are first amplified by vacuum or gaseous tubes in practical *commercial* equipment.

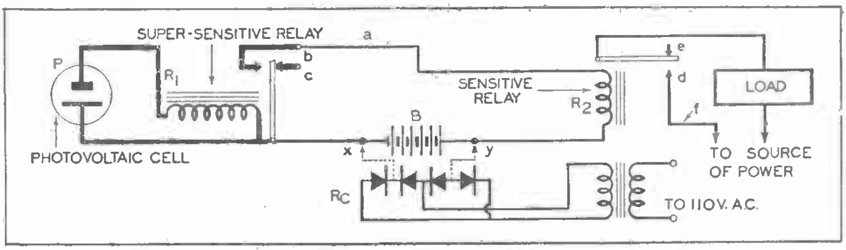


FIG. 16. Typical photovoltaic cell circuit using two relays.

The simplicity of the connections between a photovoltaic cell and a relay is best demonstrated by the circuit shown by the heavy lines in Fig. *16*. *P* is a Weston Photronic Cell and R_1 is any one of the 0-200 microampere super-sensitive (or meter type) relays. The contacts of relay R_1 control the exciting current to relay R_2, which can be either an ordinary sensitive relay or one with micro-contacts, vacuum, or mercury contacts. When the control circuit is to be on intermittently and only for short intervals, the battery *B* may be used, but a.c. should be used if the control circuit is to operate frequently. If the sensitive relay is of the d.c. type, a voltage step-down transformer and a full-wave rectifier can be used to permit operation on a.c.; if relay R_2 is of the a.c. type, a step-down transformer is all you need. Simply remove battery *B* and connect the rectifier unit or the step-down transformer to points *x* and *y*. In the circuit shown in Fig. *16*, the supersensitive relay operates when light falls on P; this relay closes the circuit to relay R_2, and its contacts close the circuit to the load. If illumination on P is to disconnect the load from the power source, connect lead f to contact e instead of to d. If interruption of a light beam directed on P is to actuate relay R_2, connect lead a to contact c instead of b. Should a time delay be desired in the control, the super-sensitive relay can be connected to a time delay relay, which in turn can actuate a power relay.

Only your imagination plus a knowledge of the relays available is needed to develop any desired type of photoelectric control, using this basic circuit.

For example, you could use the circuit in Fig. *16* as an illumination control by putting P near the window of an office and connecting R_2 to a power relay which controls the office lights. As long as the light on P is sufficient, R_1 and R_2 will remain actuated, but if the illumination drops below the desired level these relays will drop out. The power relay, controlled by R_2, will then turn on the lights. For this arrangement, R_2 should be a time delay relay so momentary light changes will not make the lights go on and off (or a time delay relay can be inserted between R_2 and the power relay, if you prefer).

The circuit could also be used to count moving objects if you arranged a light beam so that it falls on P, and replace R_2 with an electromagnetic counter. Then an object passing through the light beam will cause R_1 to drop out and so operate the counter.

Recommendations. A photovoltaic cell delivers its largest current when its terminals are shorted. In selecting a relay which is to have a given pull-up current rating, that which has the lowest coil resistance will give best results. When the illumination on the photovoltaic cell is too low to give relay operation, use two or more cells in parallel to get the current output required by the super-sensitive relay. In figuring the speed of a relay system, *add* the speeds of the individual relays; the more relays used, the slower the system will be.

Vacuum Tube Amplifiers for Sensitive Relay Operation

The necessity of continually cleaning the contacts of a meter-type relay and the high initial cost of the device are two factors influencing the choice between photovoltaic cells and the other two types of cells for a particular photoelectric control job. In a good many cases, control engineers have a decided preference for a vacuum tube amplifier connected between the light-sensitive cell and a sensitive relay. To be sure, the amplifier tube must be replaced periodically (the estimated life of the average tube is the equivalent of 1,000 hours of continuous use), and power must be supplied constantly. When these features are not objectionable, then rugged, positive, and reliable controls are possible. Photoemissive cells of the gas type and photoconductive cells are generally used.

The basic circuits are of three types: *1,* the *rise* and *fall* type, where the photoelectric cell causes the vacuum tube plate current to rise or fall in value; *2,* the *impulse* type, where a rapid change in light is converted into an electrical impulse causing quick positive relay action; *3,* the *light differential circuit,* where the vacuum tube amplifier operates the relay when light falling on one photoelectric cell differs from that falling on another cell. The amplifier tubes generally used have maximum operating values of 2 to 12 milliamperes. In many cases, these values can be reduced more than 50 per cent, giving longer tube life if sufficiently sensitive relays can be used. When the light change is too small to actuate a relay through a single vacuum tube stage, two or more direct coupled amplifiers may be employed in cascade.

RISE AND FALL CIRCUITS

Forward Type. If the current in the plate circuit of the vacuum tube rises when the illumination on the cell is *increased,* we have what is commonly called a *forward* circuit. Fig. *17A* shows a simple practical forward circuit which can be used with a selenium cell. Fig. *17B* is a forward circuit for a photoemissive cell.

To operate these circuits, the potentiometer K_1 is adjusted, with illumination removed from the cell, until the relay armature drops out and makes contact with *L* (this is the armature position for low or drop-out current). Now, when the cell is illu-

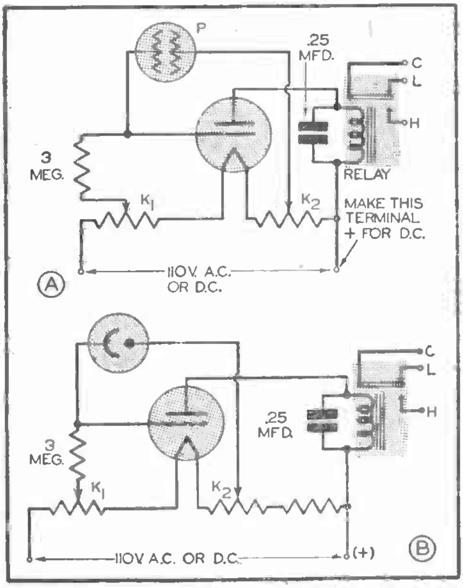


FIG. 17. Forward photocell circuits. A selenium cell is used at A, while B is for a photoemissive cell.

minated normally, the resistance of the cell reduces in value. This causes an increased current flow through the 3-megohm resistor. The positive pulsations on a.c. (or the normal drops on d.c.) make the grid end of this resistor positive. The grid, originally highly negative, thus becomes more positive with respect to the cathode, plate current increases, and the relay pulls up. Potentiometer K_2 should be adjusted so that just enough plate current will flow to make the pull-up contact pressure strong enough to prevent chattering.

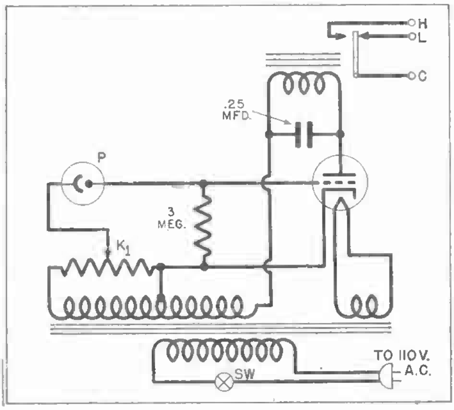


FIG. 18. A reverse circuit for a photoemissive cell.

The negative half of the a.c. cycle is ignored, as the tube does not pass current when the plate is negative. Thus, the average *positive* value across the 3-megohm resistor sets the pull-up point.

The control action of this circuit, then, is that the relay pulls up when one level of illumination is reached and drops out when the illumination drops below another (lower) level. If the illumination is high at first, then decreases, the relay will remain pulled up until the drop-out level is reached. Conversely, if the illumination is low at first, then increases, the relay will remain out until the pull-up level of illumination is reached.

► If the photoemissive cell (used in Fig. *17B*) is a gas type, it should never be operated at a peak voltage greater than that recommended for the cell used, and a resistance of at least one megohm should be in series with the cell to limit the current in case the voltage is accidentally exceeded. (Note that a 3-megohm resistor serves for this purpose in Fig. *17B*.) To increase its life, the photoconductive cell (Fig. *17A*) should be operated at the minimum voltage which will give satisfactory control.

► In general, in a forward circuit, the C bias voltage (controlled by K_1) is varied to cause drop-out at the desired minimum value of illumination, and the cell excitation voltage (controlled by K_2) is adjusted to give relay pull-up with the desired maximum value of illumination, if the control circuit is to work between definite limits of light values. Only the grid bias control (K_1) is needed in circuits where light is completely cut off to secure the control operation. Here, either the light beam intensity or the relay contacts can be adjusted to vary the value of illumination which actuates the relay.

► If the load is connected to terminals *C* and *H* in Fig. *17B,* a reduction or interruption of the light will open the load circuit; if it is connected to terminals *C* and *L,* light reduction or cut-off will connect the load to its supply. The circuit to use depends on whether the load circuit is to be turned on or turned off when the light is reduced or cut off. In both cases the relay armature is pulled up as illumination on the cell increases, so this is still a forward circuit, even though a reversed action is obtained.

Reverse Circuit. When the control unit is to be in operation for long periods of time, and the cell is illuminated the greater part of the time, the amplifier tube is passing maximum current most of the time and its life is consequently shortened. A control circuit can be designed in which illumination on the light-sensitive cell produces a low plate current, so that a reduction in light causes the plate current to increase and actuate the relay. This *reverse circuit,* as it is called (where the relay closes when light is *decreased*), gives longer amplifier tube life and consequently less attention need be given the unit. Such a circuit using a photoemissive cell, is shown in Fig. *18*; a photoconductive cell can be used also in this circuit.

The variable arm of potentiometer K_1 in Fig. *18* is adjusted so the relay drops out when maximum light is on the cell. The photocell current passing through the 3-megohm grid leak places a high negative bias on the amplifier tube. (The a.c. supply for the photocell is out of phase with that for the tube plate so *negative* pulses are applied to the grid at the time the plate is positive.) This bias is varied by the potentiometer to get the desired minimum value of plate current. When the light is reduced or cut off, little or no cell current flows through the grid leak. The grid bias becomes practically zero, raising the plate current and pulling up the relay armature. If the load circuit is now connected to *H* and *C,* light cut-off connects the load to its supply; if the *L* and *C* terminals are used, light cut-off disconnects the load from its supply.

► You can easily tell whether a vacuum tube amplifier control circuit is of the forward or reverse type. In a *forward* circuit the photoelectric cell connects between the *grid* and a point more *positive* than the cathode; in a *reverse* circuit the cell connects between the grid and a point more *negative* than the cathode. Figs. *17A* and *17B* are forward circuits; Fig. *18* is a reverse circuit.

► The circuits used in Fig. *17* employ low-drain battery type tubes (such as the 30 1G4, etc.) even on a.c. The resulting low-power requirements and the absence of a power transformer make for an economical, light-weight and small unit. However, the use of a power transformer, as in Fig. *18,* is desirable as a wider variety of voltages is available, and the transformer isolates the unit from the power line. Tubes such as the 27, 56, 6C5, 6J5, etc., can be used. Incidentally, the circuit in Fig. *18* can be made either the forward or the reverse type by using separate windings on the power transformer and by making the proper polarity connections.

IMPULSE CONTROL CIRCUITS

The principal objection to circuits of the forward and reverse types using *photoconductive* cells is that they are rather insensitive to small changes in illumination. Where simple, rapid off-on light conditions exist, this objection may be eliminated by employing a circuit which utilizes the charge and discharge ability of a condenser.

A simple *impulse* or so-called *trigger* circuit, using a selenium (photoconductive cell is shown in Fig. *19.* A photoemissive cell can be used as well, provided its anode is connected to the potentiometer arm. The unique feature of this circuit is that the grid of the amplifying tube is blocked by a condenser, so that there is no d.c. path back to the cathode. When the cell is illuminated with *any* steady light value, the plate current is a definite value which is fixed by the potential of the floating grid.

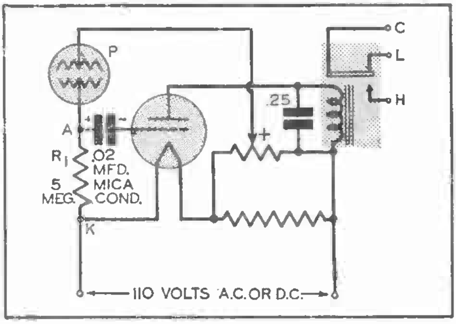


FIG. 19. One form of the impulse circuit, using a selenium cell. The relay, normally closed, drops out when illumination on the cell is cut off suddenly. The relay remains pulled up for all constant values of illumination, and pulls up by itself at a definite time after each interruption of light.

The impulse circuit operates in this manner: Assume that the cell is illuminated, current therefore flows through it, making point *A* positive with respect to the cathode *K*. The grid in this tube, under these conditions, is what is known as a "floating" or "free" grid, because no source of voltage is connected directly to it. A floating grid always has a zero, or slightly negative, potential with respect to the cathode. The reason for this is that a floating grid is struck by some of the electrons in the plate current, and retains them (since they have no place to go). Eventually, this process will build up a negative charge on the floating grid, making its potential about zero with respect to the cathode. Once this happens, very few more electrons strike the grid, because they are repelled by the electrons already on it. The floating grid therefore stays at about cathode potential once it has reached it.

Since point *A* is considerably above cathode potential, and the grid is at cathode potential, a potential difference (voltage) exists across the grid condenser. This makes the condenser charge up with the polarity shown in Fig. *19.* As long as the illumination on the cell stays constant, this condenser voltage has no effect on the tube plate current. The grid stays at about zero potential, and a rather high plate current flows.

However, a marked effect is produced if the light on the cell is cut off quickly. The cell current then drops rapidly bringing point *A* down almost to cathode potential at once. The charge on the condenser cannot disappear quickly, so the voltage on the condenser remains. This immediately makes the grid (which is connected to the negative end of the condenser) considerably negative with respect to the potential of the cathode, for the positive end of the condenser is now at about cathode potential. Plate current therefore decreases considerably, dropping out the relay. The charge on the condenser gradually leaks off, and the grid "floats" again: plate current then rises, and the relay picks up. When light comes on again, the condenser recharges, and the circuit returns to its initial condition.

An increase in the light on the cell will have no effect on the relay, since it will cause no change in the tube plate current. The only effect the light increase has is that it increases the cell current, and so raises point *A* higher above the cathode in potential. This, in turn, raises the voltage across the condenser, which means that the "trigger" action of the circuit will be stronger (the negative bias of the grid will be greater) when light is cut off. We can produce this stronger trigger action by moving the potentiometer arm nearer the plus end: doing so increases the voltage across the cell, increasing the current through it and producing the same effect as an increase in light.

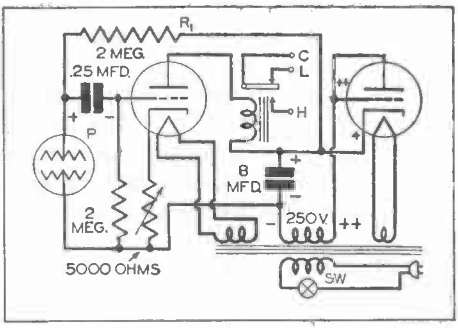


FIG. 20. Another form of impulse circuit, which uses an extra tube to secure d.c. operating voltages. Here the relay pulls up only when light on the cell is suddenly interrupted, and drops out automatically in a definite time interval. Current flows through the tube circuits only during the half of each cycle for which polarity is as indicated.

A gradual decrease in the light on the cell will not cause this trigger action, because the charge on the condenser will have time to leak off while the potential of point *A* is going down, and no negative bias will be placed on the grid. To sum up: Our trigger circuit works only if the light on the cell is cut off quickly. An increase in light at any speed or a slow decrease, will not affect the plate current of the tube, and the relay will remain in its pull-up position. The relay always returns to its pull-up position shortly after it drops out, even if the cell is not illuminated again.

► A more practical impulse circuit which insures long cell and tube life and strong, positive trigger action is shown in the circuit of Fig. *20*. As d.c. is supplied by the rectifier, the grid condenser may have a large capacity. With normal light on the cell the 5,000-ohm cathode variable resistor is adjusted to give a negative bias to the grid, so the relay drops out.

With normal light the cell resistance is low, the voltage drop across the cell is consequently low, and the .25 mfd. condenser receives only a low charge. When the light is cut off the cell resistance rises, there is a larger voltage drop across the cell, the + terminal of the condenser becomes more positive, and electrons flow up through the 2-megohm grid leak to make the — terminal of the condenser correspondingly more negative. These electrons flowing through the grid leak produce in it a voltage drop which reduces the negative bias to zero or even swings the grid positive, and plate current rises, actuating the relay.

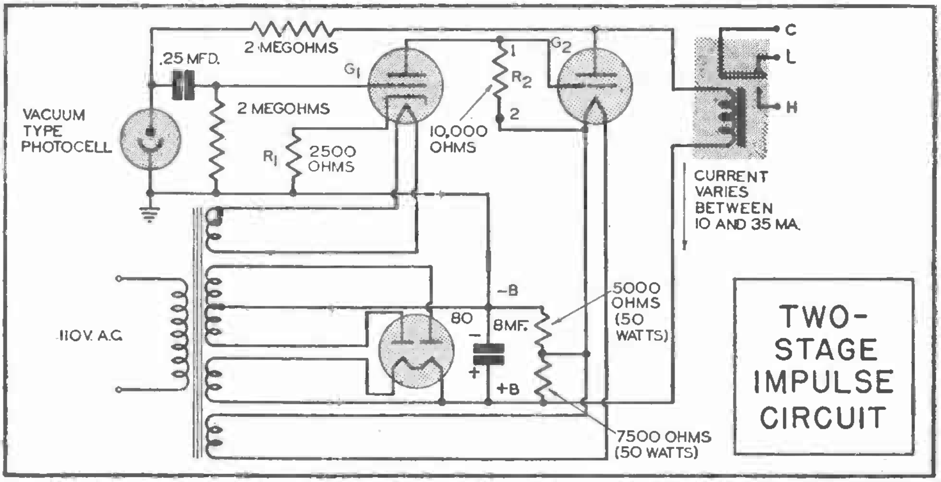


FIG. 21. This diagram shows a two-stage amplifier in an impulse circuit.

When the condenser becomes charged fully (the time required depends on the time constant of the charging circuit) the grid leak current reduces to zero, restoring the normal high negative bias, and the relay drops out. When the cell light comes on again the cell resistance drops, and the fully charged condenser partly discharges through the C bias circuit, driving the grid more negative but, as the relay has already dropped out, no further relay action takes place.

In any of these impulse circuits, increases in resistance of the selenium cell with age and use can be offset by increasing the ohmic value of the grid leak resistor.

Two or More Amplifier Stages. Where the change in light is small, sufficient change in current for relay operation can be obtained by adding a second vacuum tube amplifier. With normal light change, the use of a second amplifying stage permits the direct use of a heavy duty relay. As the variation in light is generally not a cyclic change, but is irregular in its occurrence, direct coupled amplifiers are needed. Impulses or slow current changes thus are relayed through the amplifying circuits.

A typical two-stage direct-coupled photocell control circuit is given in Fig. *21*. A photoemissive cell is shown, but a photoconductive cell may be used just as well. The circuit is shown operating a heavy-duty relay. If small light changes are used for control, the power tube is replaced with a high-mu triode voltage amplifier tube which feeds into a sensitive relay, and the operating voltages are adjusted for the new tube. Although an impulse or trigger type input circuit is shown, a forward or reverse photocell connection can be used with good results. A gas cell can be used by lowering the excitation voltage; a tap on the voltage supply divider resistance will give the required low voltage.

This circuit works in the following manner. Grid G_1 is biased negatively by resistor R_1; grid G_2 is biased negatively by the plate voltage drop in resistor R_2 (terminal *1* is nearer ground or $B-$ potential than is terminal *2*). With normal light on the photocell, the plate current of the second tube is large enough to keep the relay pulled up. When the light to the photocell is cut off, grid G_1 becomes more positive, increasing the plate current of the 27 tube (this impulse circuit is practically the same as that in Fig. *20*). This plate current increase causes the voltage drop across resistor R_2 to increase, driving the grid of the second tube more negative. The plate current of the second tube drops, releasing the armature of the relay. As the power tube plate current will drop from about 35 ma. to 10 ma., a heavy-duty relay may be used. A more sensitive circuit can be designed by using a screen grid tube in place of the triode in the first stage.

LIGHT DIFFERENTIAL CIRCUITS

Quite often a circuit is desired which will respond to a difference in light from two light sources. Color matching of liquids (such as dyes) is a typical case. In color matching, two beams of light, each of the same color content and intensity, are used. One beam is sent through a standard solution, the other through a sample of the solution being compared with the standard; then both beams are allowed to fall on photocells connected in a control circuit. This circuit is so arranged that any difference in the two beams caused by their passing through the solutions will actuate a meter or start some control operation.

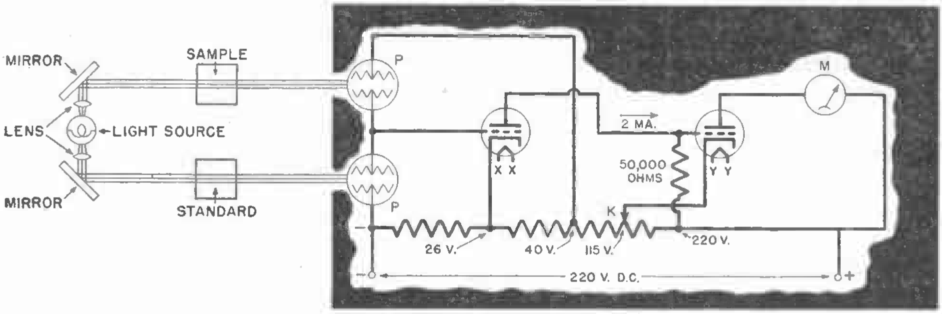


FIG. 22. A light differential circuit.

A typical light differential circuit is shown in Fig. *22*, where the light of a single lamp is split by two lenses, making two light beams. Each beam is reflected from a mirror, one beam being directed through a glass container holding the standard liquid, the other beam passing through the glass container in which is the liquid whose color or density is being compared. The beam emerging from each container is viewed by a photoelectric cell, which can be either of the emissive or conductive type.

With both containers removed, the arm of potentiometer *K* is adjusted until meter *M* reads mid-scale. When the standard and sample products are introduced into the light paths, any difference in the light transmitted to the cells shows up as a deviation of the meter from mid-scale. A darker sample causes deflection in one direction, while a lighter sample causes a deflection in the opposite direction. A relay is used sometimes in place of the meter to give a desired control operation when the two solutions differ in characteristics by a specific amount.

Gas Tubes for Direct Power Relay Actuation

A heavy-duty or power relay can be operated directly from a single amplifier tube circuit without using any sensitive relays, provided that the amplifier tube is of the gas or vapor type.

When triode amplifier tubes have gas in their envelopes, as in the case of Thyratron tubes, they are no longer suitable for linear amplification, but have properties which are valuable for electronic control circuits. The action of such a tube is briefly this: When the tube is given a definite plate voltage and the grid bias is gradually varied from zero upward to a certain positive value, breakdown occurs and a very large current suddenly starts to flow through the tube. Now, no matter how the grid voltage is varied, the grid has no further control over the plate current. Only the plate voltage determines the amount of plate current, and this voltage must be reduced to about 20 volts before the current stops flowing. Once the plate current is stopped, the anode voltage can be raised to its original value and current will not again flow through the tube until the grid voltage is raised to the "striking" or "firing" potential. The higher the negative grid bias, the higher the plate voltage required before current flows. Likewise if the C bias is reduced or made positive, the required plate voltage will be reduced.

Thus, the tube either passes full plate current or no plate current—there is no in-between value. The sole purpose of the grid voltage is to determine the point at which *plate current starts to flow* for that particular plate voltage. Once started, current can be stopped *only by reducing the plate voltage* below the 20-volt extinction value.

As the removal of plate voltage is necessary to restore the original conditions, some form of interrupter must be used if the supply is d.c. However, the tube is ideal for an a.c. supply, as here the anode voltage must drop to zero during the half-cycle when the plate is negative. Hence, the grid can resume control every half-cycle, if its voltage has fallen below the striking potential.

HOT CATHODE TYPES

Gas triodes and pentodes are designed to have an oxide cathode of large surface so large quantities of electrons can be emitted. (Gas pentodes work exactly like triodes except that the screen grid protects the cathode and reduces the grid current.) The anode voltage is limited to a value which gives a safe current: If this current is exceeded, the cathode emitting surface is bombarded by positive ions and destroyed. Although mercury vapor is used in certain tubes which operate on high voltages and deliver high plate currents, argon, helium, and neon gases are preferred for low voltage and low current tubes; these gases result in tubes which are fairly independent of temperature. Gas tubes are called *Thyratrons* by the General Electric Company (G.E.), and *grid-glow tubes* by the Westinghouse Electric and Manufacturing Company (W.E.&M.). Mercury vapor tubes are made in sizes capable of passing up to hundreds of amperes, but for control purposes ½ ampere tubes are sufficient to control the heaviest power relays needed.

► Grid current will flow in hot cathode gas tubes even when there is no plate current. It is highly important that this grid current shall not flow directly through the light-sensitive cell; the cell current should supplement the normal grid current which is made to flow through a *grid resistor*.

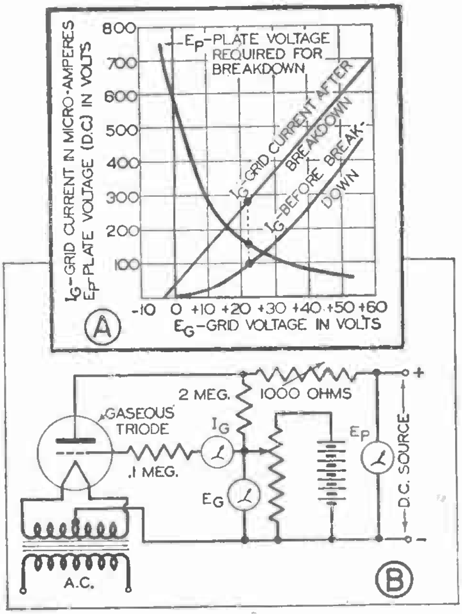


FIG. 23. Characteristic curves of a typical hot-cathode gas filled tube, the Westinghouse type KU-610 grid-glow tube. D.C. starting characteristics for rated anode current are given at A; the test circuit used appears at B.

Figure *23A* shows the characteristics of a typical low-power grid-glow triode tube, in this case the W.E.&.M type KU-610, which has a maximum rated plate current of ¾ ampere. The circuit used to obtain these characteristics is shown in Fig. *23B*. The 1,000-ohm resistor prevents the tube from acting as a short circuit across the load when breakdown occurs and the tube passes current. This resistor is adjusted to give rated plate current. This tube uses neon gas and has a constant anode-cathode drop of about 22 volts when passing current, which means that the 1,000-ohm resistor must waste the remainder of the source voltage. The .1-megohm and 2-megohm resistors serve to stabilize the circuit. Although the tube characteristics shown are for d.c. voltages and currents, they also represent instantaneous values in the case of a.c. power.

► The curves are used as follows: Assume that the tube is to operate at a plate voltage of 110 volts a.c.; the peak voltage is then 110 × 1.41, which equals about 155 volts. Referring to the E_p curve, we find that about + 23 volts on the grid will just allow breakdown of the tube at this plate voltage; any grid voltage *below* +23 volts will not ignite the tube, but if the grid potential ever reaches this value, the gas will ionize. The grid current before breakdown is about 100 ma., and after breakdown it is about 300 ma.

Now, let's see how this tube works in the pratical gas tube relay circuit shown in Fig. *24A*. Although a photoconductive cell of a type which has a low minimum resistance and a large dark-to-light resistance ratio is used here, photoemissive cells can be used also. The connections to the secondary of the transformer are such that when the plate of the KU-610 tube is positive with respect to the cathode (here the filament), the grid is also positive with respect to the cathode. The potentiometer across the 60-volt secondary winding furnishes the grid bias for the tube by varying the potential of the cathode with respect to the grid. With light on the cell, this potentiometer is adjusted so that (on the positive half of the a.c. cycle) the voltage between *P* and *A* minus the voltage drop in R_g

is just below the value which allows the tube to break down. The drop across R_g is caused by the photocell current and the gas tube grid current. Now when the cell is darkened, the cell current drops, the voltage drop in R_g becomes less, and the grid becomes more positive. When the grid becomes positive enough, breakdown occurs and the grid loses control. The plate current rises, actuating the relay.

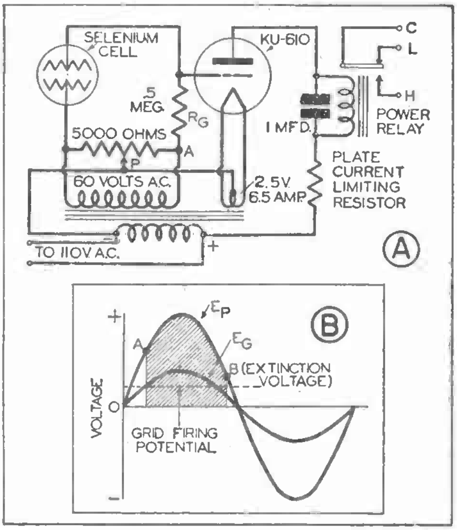


FIG. 24. The circuit at A is a practical photo-conductive cell circuit, using a Westinghouse type KU-610 grid-glow tube to operate a power relay directly. When plate and grid voltages of the grid-glow tube are in phase, plate current passes for that part of a cycle shown shaded at B.

The action is best understood by studying Fig. *24B*, which shows the phase relations between the grid and plate voltages. As the circuit is essentially non-reactive, the grid and the plate voltages can be made to be either entirely in phase or 180° out of phase, simply by reversing connections to the 60-volt winding. The out-of-phase condition is undesirable because, as the plate swings positive, the grid swings negative and too-high plate voltages are required for breakdown or *firing*. With both grid and plate swinging positive simultaneously (in phase), firing occurs at the plate voltage indicated at point *A*, since this is the first point in the cycle at which the plate and grid voltages together allow breakdown. At point *B* the plate voltage is below 22 volts, and so is no longer enough to sustain plate to cathode ionization; the plate current therefore stops. Of course, when the plate and the grid swing negative on the next half of the cycle, no plate current can flow, and the tube is ready for the next cycle of operation. If the cell is dark, then pulses of current will flow on the positive half-cycles as long as this condition remains. However, as soon as the cell is sufficiently illuminated, the grid voltage will fall below the firing potential and current will be cut off.

COLD CATHODE TYPES

A hot cathode is not needed to cause ionization in a tube, as you already know from your study of gaseous rectifier tubes. When a gas such as neon is used, an appreciable tube current can be obtained with a cathode having no electron emitting surface. Ionization of the gas takes place at a voltage depending on the amount and nature of the gas and upon the distance between the anode and the cathode; this ionization results in liberation of the electrons required for the tube current. A grid can be used to control the breakdown or firing voltage. The more negative the grid, the higher the voltage required to start ionization and a flow of current.

The arrangement of the internal elements of a cold cathode grid-glow tube is shown in Fig. *25*. The shield, when connected to the cathode through a 2- to 10-megohm resistor, insures greater uniformity and stability of operation.

The Westinghouse KU-618 is a typical high sensitivity, cold cathode grid-glow tube, which has an anode-to-cathode drop of 180 volts when plate current is flowing. In the basic operating circuit for this tube, shown in Fig. *26*, the tube is connected in series with a relay coil and a 6,000-ohm resistor across the 440-volt secondary winding of the transformer. This current-limiting resistor is used to prevent the tube current from exceeding 100 ma., for excessive currents would destroy the tube.

In actual practice the *A* and *G* terminals of the gas tube are shunted with either a resistor R_A of 10- to 100-megohm value or a 0- to 50-mmfd. variable condenser C_A, while the *G* and *K* terminals are shunted with either a resistor or a condenser (R_K or C_K) of the same value. When resistors are used, it is customary to insert a high ohmic value leak at point *X* to improve stability; the highest value which will give satisfactory operation is used, and may be as much as 250 megohms. The values of R_A and R_K determine the potential of the grid; increasing R_A or lowering R_K makes the grid less positive and prevents the tube from firing. If condensers are used instead of resistors, increasing the impedance of C_A (by lowering its capacity) or decreasing the impedance of C_K makes the grid less positive. A voltage divider made up of a resistor and a condenser can be used if desired. In any case, either a resistor or a condenser is made variable to allow adjustment of the grid potential. As it is inconvenient to secure variable resistors of such high values, one element is usually a variable condenser.

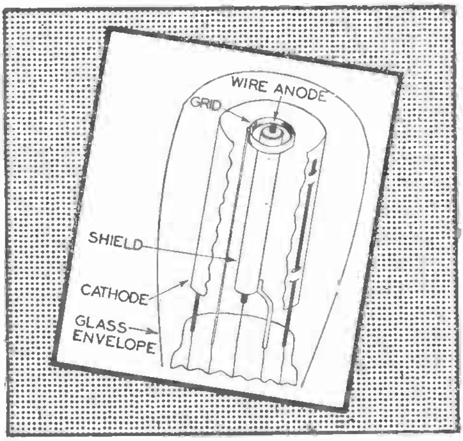


FIG. 25. Cut-away view of a cold-cathode grid-glow tube, showing arrangement of electrodes. The anode is inside a porcelain tube which in turn is surrounded by a metal cylinder, the shield. The grid is simply a thin band or ring of metal surrounding the exposed tip of the anode.

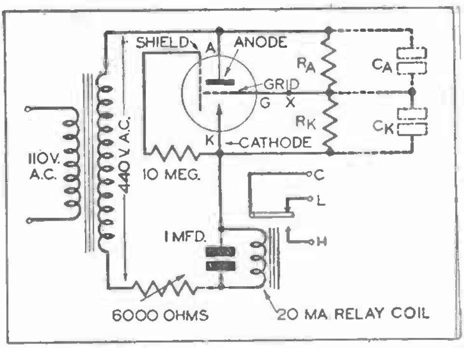


FIG. 26. Basic operating circuit for the Westinghouse KU-618 grid-glow tube. A photo-emissive cell or a photoconductive cell of high resistance can be substituted for either of the resistors or condensers connected to the grid. The arrow in the tube symbol represents the cold cathode.

In actual practice a light-sensitive cell or other device having either a high ohmic resistance or a low capacity that will change in resistance or capacity as a result of the action which is to be controlled is connected in place of one of the resistors (or condensers), and is used as the primary control. The other resistor (or condenser) is made variable to permit adjustment of the point at which control action occurs. This cold cathode glow tube has many electronic control applications.

For a light-sensitive control, vacuum type photoemissive cells are best, as they have large dark resistances (as much as 5,000 megohms), and will operate safely on high excitation voltages (500 volts is a common value for small cells). In one practical circuit a photoemissive cell is connected between the anode and the grid, and a 0-50 mmfd. variable condenser is connected between the grid and the cathode terminals. The condenser is adjusted so the grid-glow tube does not ignite when the cell is dark. Illuminating the cell swings the grid more positive and causes the relay to pull up. When the cell light is cut off, the relay drops out.

► Photoemissive type cells also can be connected between the grid and the cathode. With this connection, the variable condenser is placed between the anode and the grid. The condenser is adjusted so the grid-glow tube does not ignite when the cell is illuminated. Now, the tube will break down and pass current, causing the relay to pull up, only when the cell is darkened.

The anode of the photocell should be connected to the anode of the gas tube when the cell is placed between *A* and *G*. The cell anode should be connected to the grid of the gas tube when the cell is wired to *G* and *K*.

► A light-sensitive control using a cold cathode gas tube has the advantage that no power is used in the control circuit when the control circuit is idle, yet heavy-duty relays can be actuated directly. Note that the power used to feed the filament of a hot cathode gas tube is eliminated. Furthermore, the cold cathode tube is extremely sensitive.

DANGERS OF CRITICISM

If you can't say something good about a person, keep silent. Even when a person asks you outright to criticize, be careful. People often fish for compliments and praise in this indirect way, and criticism is definitely NOT what they want. It's your job then to find something which you can honestly praise. Be frank only when you're absolutely sure that your technical or personal opinion is really wanted.

There's some good in everything, if we'll only look for it. Praising the good, no matter how little it be, will make you a thousand times more popular with people than criticizing even the most serious and glaring faults of others.

A multi-millionaire executive used these words to praise a Pullman porter, *"I wish I could do my job as well as you do yours!"* A thoughtful business man brightened the entire day for an overworked postal clerk during the Christmas rush by commenting justifiably and sincerely, *"I wish I had hair like yours!"* There are even sincere ways to praise an old radio set: *"It was one of the finest sets made in that period,"* or *"That highboy cabinet is certainly a fine piece of furniture."*

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