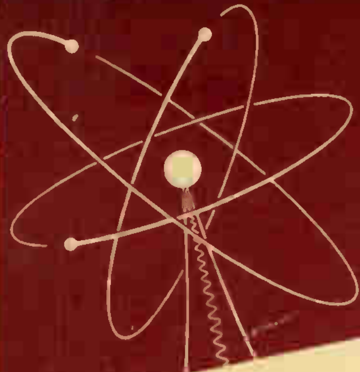


ELECTRONS

Lesson AEH-1B

DeVRY Technical Institute

4141 W. Belmont Ave., Chicago 41, Illinois

Formerly DeFOREST'S TRAINING, INC.

AEH-1B

ELECTRONS

DeVRY Technical Institute

THE FRONT COVER

To disprove the old saying, "You can't judge a book by its cover", much time and thought have been spent to make these lesson covers attractive, informative, and useful. The rapidly expanding fields of electronics are symbolized at the upper left by the popular diagram of an atom. Here the central nucleus is surrounded by rapidly rotating electrons, the energy of which makes possible all modern applications of electricity and electronics.

The training program includes a number of sections or series of lessons each with a distinctive background color. The title, section code letters, and series number of each lesson are shown in the center, while the code letters and series number appear also as a bar across the fold at the left. The position of this bar is lower on each succeeding lesson so that, when the series is filed with only the folded backs visible, the bars form a diagonal line to indicate proper numerical sequence. Thus, the distinctive color of each series and the bar position provide a convenient index for future reference.

ELECTRONS

Contents

Some people fail because they never begin. More people fail because they never finish. Stick-to-it-iveness wins oftener than genius or luck. You may make mistakes, others may misjudge you. You may be tired and discouraged. But, if you stick, by and by everything and everybody will give way to you.

If you have principles they will do you no good unless you stick to them. If you do not stick to your friends, you don't deserve friends. If you do not stick to your job, you cannot make a success of it and find a better one. In a troubled and anxious time of the Civil War, General Grant said, "I will fight it out on this line if it takes all summer." Let that be your motto.

—Dr. Frank Crane

ELECTRONS

Electronics is the magic of our century.

At the beginning of the 20th century, electric lights and telephones were curious toys. Very few had vision enough to use them. During those years, only brave people ventured with their automobiles onto the city streets, and most of these cars were steam driven or powered by storage batteries. Airplanes meant absolutely nothing to the public.

Home entertainment was provided at that time by player pianos and mechanical type phonographs. There were no radio or television broadcasts. Without electricity in the home, there were no refrigerators, deep freeze units, air-conditioners, vacuum cleaners, automatic toasters, and the many other appliances which we take for granted today. Although Thomas Edison had patented a motion picture camera and projector, there were no movie theatres as we know them now.

Electronics is growing so fast and so big, large numbers of our population are being directly employed by it. The number of radios, over 100,000,000, indicates just how big electronics is today. In fact, from laboratory models, television has grown rapidly to more than 30,000,000 sets in seven years, and now color television is ready to occupy the American home.

Electronic products and equipment are found nearly everywhere. Two-way radiotelephone in trucks, taxis, trains, ships and aircraft are in operation not only in the United States but in many nations throughout the world.

Every day, industry is demanding more electronic instruments. Whether it is a steel mill, an automobile manufacturer, a textile mill, a bakery, a printing plant, or an oil refinery—industry needs electronic equipment to more precisely control quality and speed production.

In fact, practically every type of occupation uses electronic equipment. The doctor, dentist, lawyer, chemist, mechanical engineer, banker, aviator, musician, and dietician all find electronic devices useful in their work.

THE ELECTRONIC TECHNICIAN

The key men in all of this vast growing field are the individuals who understand how the electronic devices work and how to best apply such devices to these increasing needs.

It takes the help of television, radio, and other electronic technicians to produce the equipment in the laboratory. Other equipment is constructed by the technician for a particular need. Once constructed, a large number of technicians are required to properly install it. Finally, no equipment runs indefinitely without maintenance or repair. This need alone employs many thousands of electronic technicians.

THE TECHNICIAN'S DUTIES

Regardless of what type of equipment you will work on, television, radio receivers, transmitters, industrial control devices, or electronic instruments, and no matter which division of the field you may choose to work in, as an electronic technician you must be able to:

1. Understand how the equipment operates.
2. Recognize when it is operating improperly.
3. Determine the portion of the equipment causing the improper operation.
4. Locate and correct the defect within that portion of the equipment.

Although a laborer can follow the shop foreman's assembly line instructions, where a faulty operation appears it takes a technician to determine what construction procedure is at fault, for only a trained technician knows what the good procedures are. Many people can read unpacking instructions, but usually it takes a

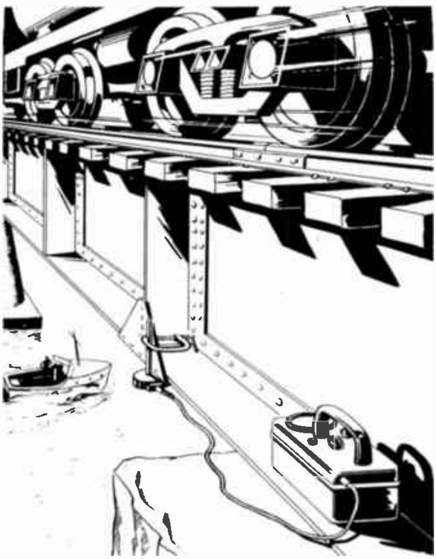
A modern large screen television receiver controls electrons in a variety of ways.
Courtesy Stewart Warner Corp.

skilled technician to adjust the electronic equipment for best operation.

WHAT AN ELECTRONIC TECHNICIAN MUST KNOW

Electronics is the control of electrons. Therefore, to be a good electronic technician, you must first know something about electrons, where they exist, and the nature of the electron that makes control possible. Then you can learn about various parts and how you use them to control the electron. Next you will learn combinations of the parts, which the technician calls "circuits", that are used to get certain effects. Finally you see how these circuits are used in the field of your interest to accomplish the desired results in many different types of equipment.

All of this information is the "basic theory", but your know how as a technician is more than just basic theory. You must be able to understand the language and read graphs, charts, and symbols. Also, you should acquire a "finger skill" so that you can easily and neatly wire up complete circuits or replace a faulty part.



An electronic instrument designed to measure vibration tells whether or not the bridge may be considered safe.
Courtesy The Victoreen Instrument Co.

Every technical field has its own language. Either the every day words do not have an exact enough meaning, or their meaning is too specific to be used in a technical sense. Therefore, to avoid confusion, words are created and adopted by each field so that exact ideas are expressed.

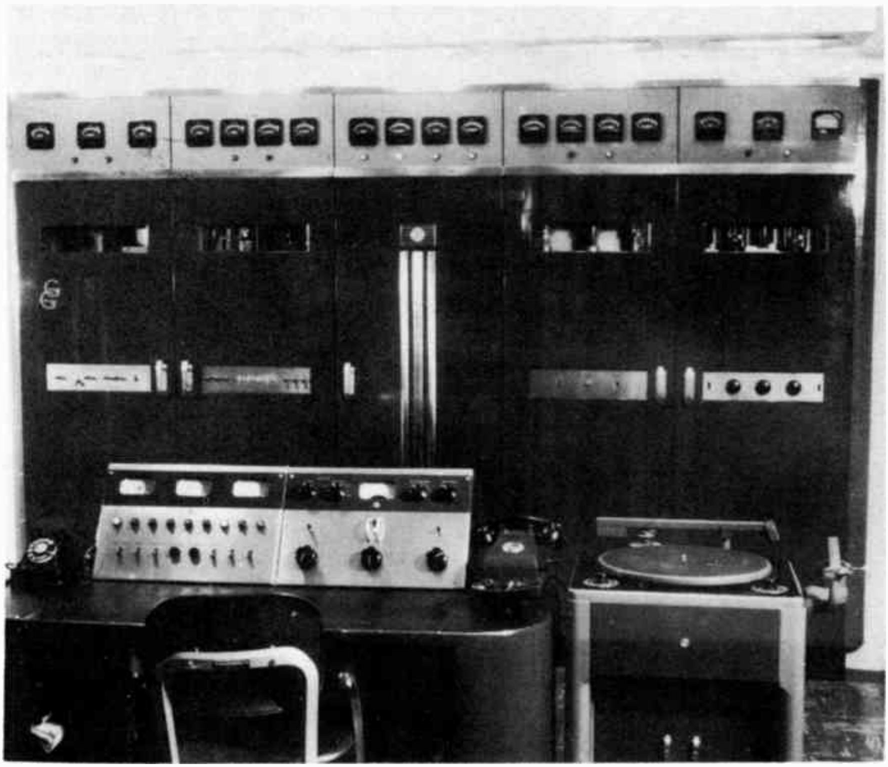
It is a mighty poor carpenter who does not understand the meanings of terms like "saw horse", "riser", "off plumb", and "countersink". Just as handicapped is the electronic technician who doesn't know the meaning of "ohm", "transformer", "oscillator", or "rectifier". Each needs his technical language—language which you will learn as you advance in your training program.

Again referring to a good carpenter, he needs to understand drawings and architectural blue prints. Not to be able to understand these would be a serious handicap. Although it might be possible to replace them with a long, wordy description, it is much easier for him when he understands the purpose of each symbol used on the blue print.

The same holds true for the electronic technician. The diagrams are a very valuable aid when learning how the various circuits are connected, but far more important, once you are active in the electronics field you will refer to them daily for easy to locate and accurate information regarding the particular model of equipment with which you are working.

Just as the proper manner to hold a chisel or use a saw are little finger skills expected of a carpenter, the correct use of a soldering iron or a meter or the skilled use of long nose pliers and diagonal cutters are needed by electronic technicians. Aside from the basic theory, these little skills do distinguish the successful technician from the sloppy workman.

Finally, there are tricks to every trade. Electronics is no exception. Once the basic theory is understood and finger skills are acquired along with the language and diagram reading abilities, the technician develops procedures which enable him to construct, maintain and locate defects with a minimum of time and effort. In fact, once he has carefully devel-



A variety of electric and electron equipment found at a broadcast station.
Courtesy WBAP—Fort Worth, Texas

oped this technique it seems to the onlooker that the technician uses magic. It looks so easy.

YOUR TECHNICAL TRAINING

In fact it is easy when learned one step at a time. That is just how this training program works. In each successive lesson, we describe the electrons, their nature, various parts and how these control electrons, useful combinations

Life tests are being run on these television picture tubes. They are periodically checked by a technician.
Courtesy General Electric Company

of these parts, and finally how these combinations are used in a specific piece of equipment.

At the same time you will find out what each symbol is for, learn what each term means, and gain experience in reading diagrams and graphs. Also you will acquire good experience in your laboratory projects. Not only are you becoming skillful in handling your tools, but you will work with circuits and discover what factors determines their proper or improper operation.

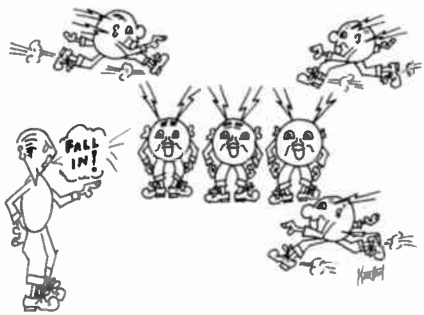
Finally, these lessons describe just how to use this knowledge most effectively in your work and with a minimum number of steps. With these techniques you will be an electronic technician capable of taking decisive steps rather than be a tinkerer stumbling along.

ELECTRONS

But first things must come first. Since all electronic equipment controls electrons, just what is an electron?

Before we tell you what these electrons are and do, you ought to take a look about you. The walls, floor, tables, chairs, etc. all about you are all material objects. You can see and feel them. Yet, someone might ask you, "What are these materials made of?"

All materials are made of tiny particles called **molecules**, which are invisible to the naked eye. It has been proven experimentally by a number of people and accepted by the rest of the world. Millions of these particles go to make up a straight pin.



Electronics is the control of electrons.

Furthermore, these tiny invisible particles are composed of **atoms**—all materials are composed of atoms. Of what are atoms made? Well, atoms are made of two things: a nucleus and electrons about the nucleus. Figure 1 at the back of this book illustrates what the atom may look like.

In the atom, most of the space is empty. As shown, the nucleus is at the center, and **electrons** are whirling about it. This arrangement may be likened to our solar system. Like the electrons, the earth and other planets revolve about the sun which forms the nucleus of the system. However, the electrons move much faster than the earth. Their speeds range up to 186,000 miles a second—the speed of light.

When comparing the nucleus and electrons in the atom, although the nucleus is very much smaller than an electron, the electron contributes about as much weight to the atom as does a marble compared to a bowling ball. That is, the electron is ever so much lighter than the very dense nucleus.

When compared to the size of an electron, the distance between the nucleus and the high speed revolving electrons is tremen-

For too small to be seen by the most powerful microscope.

dous. Use the distance between the earth and the sun, some

93,000,000 miles, as the yardstick. The relative distance between the nucleus and the revolving electrons is about the same. This is why the atom is mostly empty space as mentioned.

Yet, through this empty space something normally keeps the electrons from leaving their circular path. Some power or "invisible glue" holds them swinging about the nucleus. This "glue" is somewhat like the force that keeps

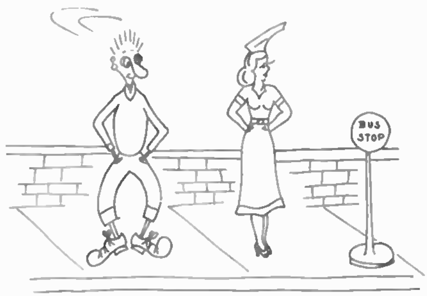
Like chorges repel.

the water in a bucket as it is whirled in a circle.

You'll note six electrons shown in Figure 1. The electrons shaped like a ball are all moving very rapidly about the nucleus. None of the electrons shown bump into each other within an individual atom.

ATOMS

Insofar as anyone knows, all electrons are identical no matter in which atom they appear. That is, electrons in iron atoms are the same as those electrons in gold atoms.



Unlike chorges ....

A question which you may ask now is: why are the various materials so different from each other? To answer this question, we must mention one more thing about atoms. It has been found that the atoms of different materials or substances contain different numbers of electrons. For example, an atom of iron contains 26 electrons, while a gold atom has 79 electrons. An atom of carbon has only 6 electrons, like Fig. 1, and the hydrogen atom is the poorest of all—1 electron. These differences are found in all materials or substances. That is, although all electrons are alike, they can be grouped together in different numbers to form various atoms.

In addition to having its own particular quantity of electrons, each type of atom has a nucleus which is different from that of all other types of atoms. Thus, each material or substance is different because no two kinds of atoms contain the same number of electrons or the same nucleus.

An atom is the smallest unit into which substance or any material can be divided without losing the qualities by which we identify it. If we divide an atom by removing some electrons and part of the nucleus, we have a different material or substance. If we do this to a gold atom, we could get an iron atom. Reverse the process by starting with an iron atom, and adding parts to the nucleus and the proper number of electrons, gold results. However, either process costs a fortune—it requires a tremendous quantity of energy and equipment.

It so happens that there are 100 types of material which can be divided down to atoms. These types of material are called elementary substances, or simply, elements. All of the thousands of other kinds of materials are composed of small particles known as molecules. In turn, these molecules are made up of atoms of two or more of the various elementary substances or elements.

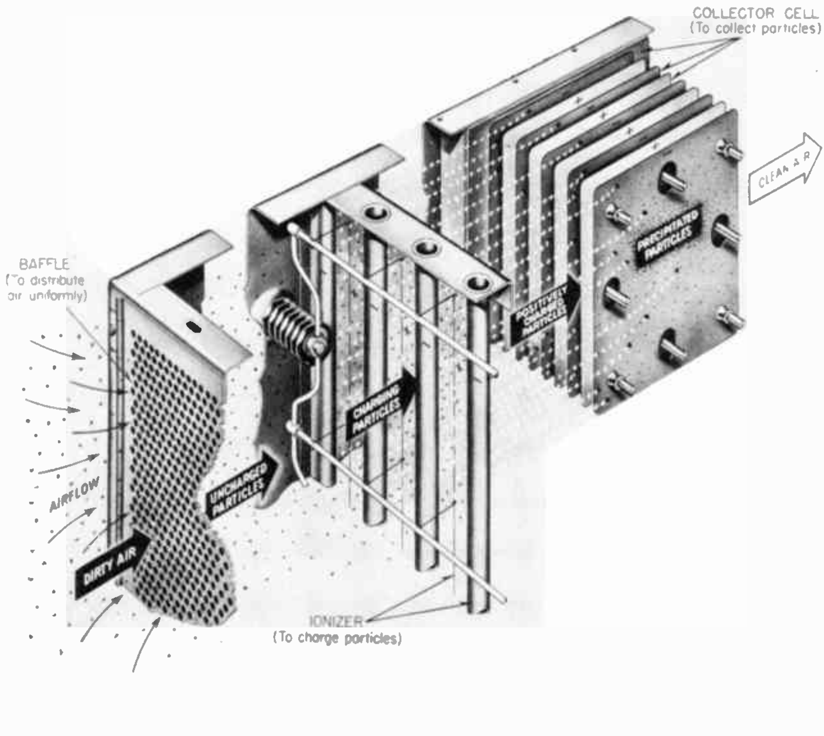
CHARGED PARTICLES

Electrons are small particles of electricity. These particles have a peculiar way of acting toward one another which makes it possible to do the many things that we do with them. If you were to try to bring two electrons close together, you would find that they would resist your action. As soon as you let go of them, they fly away from each other. They resist remaining close together! You would obtain the same results if you tried the experiment with two nuclei from a pair of atoms.

Shown is a table model AM-FM receiver, one of 100,000,000 radios in the United States.
Courtesy Motorola, Inc.

However, if you brought an electron just near enough to a nucleus, you might notice them pulling toward one another. When you let them go, they would fly together. From these actions, you could decide that LIKE PARTICLES OF ELECTRICITY REPEL each other, whereas UNLIKE PARTICLES ATTRACT.

Because of the way they act, electrons and nuclei are considered to be different kinds of electricity. To distinguish between them, we say that a nucleus is POSITIVE electricity, and an electron is NEGATIVE electricity.



This air cleaner makes use of the fact that when electrons are removed from atoms on dirt particles, the positive dirt atoms are attracted by the negative plates in the collector cell.

Courtesy Westinghouse Electric Corp.

In any normal atom, the positive nucleus exactly balances the negative electrons which the atom contains, and its attraction holds them in the atom. Therefore, a normal atom is neither positive nor negative—it is said to be NEUTRAL.

However, when the negative electricity in a normal atom is decreased by removing one or more electrons without disturbing the nucleus, then the atom is no longer neutral. The atom contains more positive than negative electricity. On the other hand, when electrons are added to a normal atom by some means, again a condition of unbalance is produced and the atom has an excess of negative electricity.

POSITIVE ATOMS are deficient in electrons; NEGATIVE ATOMS contain an excess of electrons. These charged atoms also play an important part in the operation of electronic equipment.

When electrons are removed from the atoms of an object, the object then has more positive than negative electricity. The entire object is said to be positive. If electrons are added to give an object an oversupply of negative electricity, then the object is said to be negative.

Just like the electrons and nuclei, negative and positive objects attract each other. This attraction can be observed by means of an ordinary pocket comb and some tiny scraps of paper. Run a comb through your hair a few times, or rub it on woolen clothing, then touch it to small scraps of paper. Usually, the bits of paper will cling to the comb and may be lifted as shown in Figure 2.

The friction caused by rubbing two objects together rubs more electrons off of one material onto the other. Hence, one is charged positive and the other negative.

This little demonstration has an interesting feature. When the comb is charged negative, as it is brought close to the bits of paper it repels a few electrons out of the paper into the surface below. This leaves the paper positive which is then attracted to the negative comb.

On the other hand, if the comb is positive, it attracts electrons out of the surface into the paper. Since these excess electrons charge the paper negative, it is again attracted to the positive comb.

The fact that neutral atoms can be converted into positive and negative charged atoms is very important. The comb and the bits of paper illustrate the generation of both kinds of charges. This is evidence that there are such charges. By no means is this the only evidence, but it is something anyone can try.

Now we know that electrons are found in the small particles of all matter called atoms. Moreover these electrons have very important characteristics: they always have the same negative charge and they are always attracted by positive and repelled by negative charges.

It is this important action that is used in every piece of electronic equipment, whether it is your car radio or television receiver or a huge electronic "brain" mentioned so often in the newspapers. In the next lesson, we use these facts to describe our first method of controlling electrons.

IMPORTANT DEFINITIONS

In this and the following lessons, the important new words are introduced with **boldface** type in the text and are listed in the back of the lesson for handy reference. As an aid in pronouncing the words, a system of re-spelling is used. In this system, a particular sound is represented by a group of letters, the pronunciation of which closely resembles that of the required sound.

For example, "radio" may be re-spelled as (RAY di oh), "pilot" as (PIGH lught) and DeVry as (Dee VRIGH). To show the accented parts of the words, two methods are employed. The main accent is shown by CAPITALIZING the part to be stressed, as in (RAY di oh). When two parts of the word are to be accented, the capitalized part shows where the main stress should be placed and the *italics* show where the secondary stress should be placed. An example of a double accented word is "anybody", which is re-spelled as (EN i *bah* di).

In addition to the letters of the alphabet, two additional marks often are employed: the colon (:) and the apostrophe ('). The colon is used to change the sound of double-o from that of the word foot (foot) to that of the word food (foo:d). In many words, such as lemon, about, and circuit, the unaccented vowels (o, a, and u respectively) often are pronounced as though they were spelled uh, and therefore, this term is used to represent those vowels in the respelling system. Frequently, an apostrophe (') is used to represent the "uh" sound as in (LEM 'n) or TEL i vizh 'n).

ATOM—A small particle which contains electrons and a nucleus, which is a positively charged center.

ELECTRON—(i LEK trahn)—an extremely small particle which is contained in the atoms of all materials and is negatively charged.

MOLECULE—A particle which contains one or more atoms. Various combinations of atoms in the molecule go to make up all materials in the world as we know them.

STUDENT NOTES

1- Electronics is the control of Electrons.

2- All Electrons are Identical.

3- No two Kinds of ~~C~~ Atom contains the same number of Electrons, or the same nucleus.

Atoms

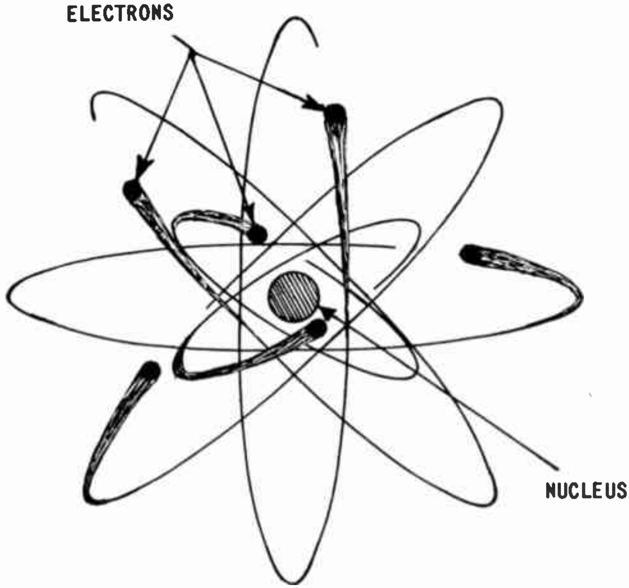
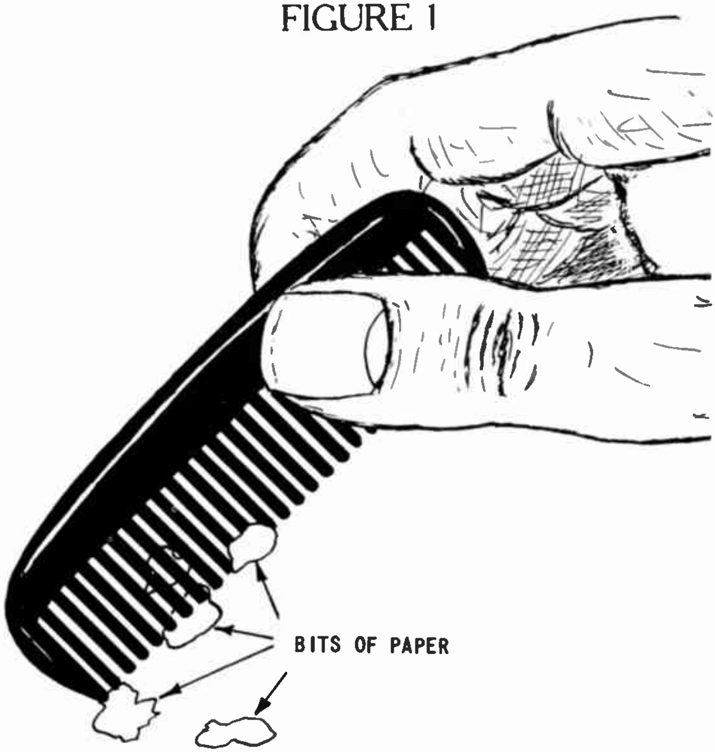


FIGURE 1



AEH-1

FIGURE 2

AEI

FROM OUR *Director's* NOTEBOOK

LET'S GO

You have now embarked on a new journey that will take you well into the inner realms of Radio and Electronics. The ease and speed with which you reach your goal, will depend upon how you pull on the oars. A steady and constant pull will get you there more quickly and more smoothly, than a few sudden jerks now and then with free drifting in between.

And just as it takes so many strokes of the oars to reach the end, just so a prescribed number of lessons must be completed. Most rapid progress can be made not by trying to do too much at one time and getting tuckered out, but by following a definite schedule and doing a certain number of pages every day—it's that steady pull on the oars that counts.

By knowing more and being able to do your work better, you will quickly make yourself worth more to the world and to your community, and it won't take the world long to find that out.

Merit is the one straight road to success. The man who is successful is the man who is useful. Ability and capacity always find opportunity. They never remain undiscovered, because they are sought by too many who are anxious to use them.

We are sure you'll enjoy the trip, and here's wishing you a happy arrival at the port of opportunities in Electronics.

Yours for success,

W. C. DeVry

DIRECTOR

PRINTED IN U.S.A.

1-3

BASIC CIRCUITS

Lesson AEH-3A

DeVRY Technical Institute
4141 W. Belmont Ave., Chicago 41, Illinois
Formerly DeFOREST'S TRAINING, INC.

AEH-3A

BASIC CIRCUITS

ELECTRONS AID PAINTERS

Step into a modern paint shop. In a constant procession, articles to be painted are carried by conveyor hooks into the spray booth where, from spray guns, a mist of paint surrounds the object and settles in a fine, even coat. No need to rotate the object or move the spray guns, yet no spots are missed and very little paint is wasted on the spray booth walls.

This magic is the work of static electricity. Electronic equipment has placed opposite electric charges on the paint mist and the object. Opposite charges attract each other, therefore the charged mist is pulled to the object.

Static electricity is used also to produce pile in fabrics, control smoke and soot, filter dust from air, separate a metal from its ore, and in many similar applications.

BASIC CIRCUITS

Contents

Thank God every morning when you get up that you have something to do that day which must be done, whether you like it or not. Being required to work, and forced to do your best, will breed in you temperance and self-control, diligence and strength of will, cheerfulness and content, and a hundred virtues which the idle never know.

—Charles Kingsley

BASIC CIRCUITS

Although a variety of equipment is used in the broad field of electronics, every piece of this equipment is made up of electric circuits. This is true no matter whether it is a radio, television receiver, transmitter, radar gear, or electronic control equipment. Fortunately, although these circuits may differ widely in their mechanical construction, electrically they are either series circuits, parallel circuits, or a combination of these two.

Three basic items make up an electric circuit. (1) A voltage source must supply the needed electric current. (2) There must be the parts, or components, to which this current is supplied. (3) Wires are needed to provide a current path from the source to each part needing current and back again to the source.

The difference in series and parallel circuits is the manner in which the parts are connected to the source by the wires, and this difference can best be described by using examples.

A SERIES WATER SYSTEM

Figure 1 is a water system that illustrates the important features of a series electric circuit. It includes a pump, two narrow pipes or tubes that the water must be forced through, and the necessary connecting pipes.

With the entire system filled with water, and the pump working, the water is circulating through the system. For our purposes, we will assume the pipe itself has no friction or opposition to the water flow, but the narrowed pipe sections or tubes do oppose the water flow. Water is pumped from the pump outlet in the direction of the arrow through the connecting pipe to Tube #1. Tube #1 offers an opposition to the water in that it has a narrow section through which the water must flow.

Continuing the water flow through Tube #1 and through a section of the connecting pipe, it comes to Tube #2. Again the narrow pipe offers opposition to the water. Having passed through Tube #2, the water returns by a pipe to the pump as indicated by the arrow. The number of gallons of water leaving the pump must be the same as that entering the pump. There is no other place for the water to go. In fact, every place in this system has the same number of gallons of water flowing past it each minute. The total pressure produced by the pump is not applied across Tube #1 nor across Tube #2, but across both.

From this description, the series water system of Figure 1 shows three important features. These are:

(1) There is only one possible path from the pump outlet back to the intake.

(2) The amount of water flow is the same at every point in the system.

(3) The total pressure of the pump is applied across all of the tubes.

A SERIES CIRCUIT

Figure 2 is a photograph of an electric circuit. The flashlight type battery corresponds to the pump, the connecting wires correspond to the connecting pipes, and the two resistors correspond to Tubes #1 and 2 of Figure 1.

Figure 3 is a picture diagram of the circuit shown in Figure 2. Note that the parts of Figure 2 are drawn in Figure 3 as rough outlines. Also, the parts of Figure 2 are shown in their exact location in Figure 3. Connection joints of the parts are indicated by twisted lines. These connections are, in the case of Figure 2 soldered connections. In other cases, they may be connected, by small mechanical clamps. Not only are the electric connections shown but also the path of the physical wires and the location of the actual parts.

Figure 4 is the schematic diagram of the circuit pictured in Figure 3. Since there are two resistors in the circuit, some way must be found to talk about one or the other. Therefore, each resistor has a "1" or a "2" added to the right and lower than the letter symbol R which is read "R sub-one" for R_1 and "R sub-two" for R_2. This is referred to as SUBSCRIPT NOTATION. When needed, subscripts also are used for the other letter symbols in these diagrams such as I_1, I_2, E_1, E_2, etc.

Note the graphic symbol for the voltage source in Figure 4. There is only one short line and one long line and it is called a cell. One or more cells used as a voltage source in an electric circuit is called a battery.

Battery E supplies current from the negative terminal (short line) through the wire to R_1, through R_1, then R_2, and through the wire to the positive terminal (long line). The current through R_1 is the same as that through R_2, which is the same amount as that leaving and entering battery E. Thus, in a **series circuit**, there is only one possible path for the current and the current is the same in each part of the circuit. Minus "−" and plus "+" signs are used across R_1 and R_2 to indicate the direction of current through them. They are used also as an aid to determine the polarity of the voltage across each resistor. Part of the battery

Many parallel circuits are found in electron instruments such as this AM/FM radio-phono combination console.

Courtesy RCA

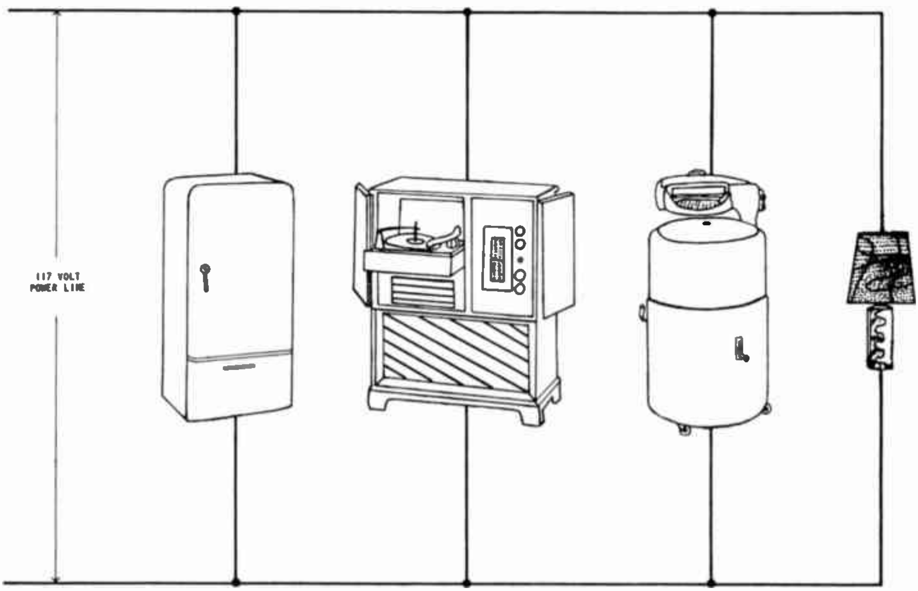
voltage is across R_1, and part across R_2.

For voltage, any reference point can be used. For instance, with the "−" of R_1 as the reference point, the voltage across R_1 is "+" or positive. Likewise using the "+" of R_2 as the reference, the voltage across R_2 is "−" or negative. When the positive side of R_1 is chosen as the reference, the voltage across R_1 is negative, while with the positive side of R_2 as the reference, the voltage across R_2 is negative.

The battery voltage can be stated in the same way. Using the minus side of the battery as the reference point, the battery voltage is positive. Or, using the positive side of the battery as the reference, the battery voltage is negative. However, where polarity is not important, the voltage is stated as a number and no mention is made to either negative or positive.

What is the polarity of the voltage across R_1 and R_2 together? The answer is in what we've already said about R_1 and R_2 separately. Using the "−" side of R_1 as the reference, the voltage across R_1 is positive. The "−" to "+" indicates the direction of the current. Since the current through R_2 is in the same direction, the current is in the same direction from the "−" of R_1 to the "+" of R_2.

The current direction could have been indicated originally with just the "−" of R_1 and the "+" of R_2. Now the voltage across both R_1 and R_2, with the "−" of R_1 as the reference, is positive. Using the "+" of R_2 as the reference point, the voltage across R_1 and R_2 is negative. In brief, it is the reference point selected that determines the polarity of the voltage.



As illustrated graphically, the wiring system in a home is arranged so that the various facilities operate in parallel. Thus each is independent of the others.

Note that the battery "+" side is connected directly to the "+" side of R_2. For the same reason, since the wire symbol does not indicate resistance, the "−" side of the battery is connected directly to the "−" side of R_1. The polarity of the battery voltage is the same as the polarity of the voltage across both R_1 and R_2. In fact, the battery voltage E is the sum of the voltages across R_1 and R_2.

In Figure 4, the current passes through R_2 from the "−" side of R_2 to the "+" side, through the wire, through E, through the wire to R_1 from "−" to the "+" side of R_1. Since the direction of the current is determined by the battery polarity, it doesn't matter at which point in the circuit the description of the complete path is started. There is the same current everywhere in the circuit. The current entering the resistor is the same amount leaving the resistor.

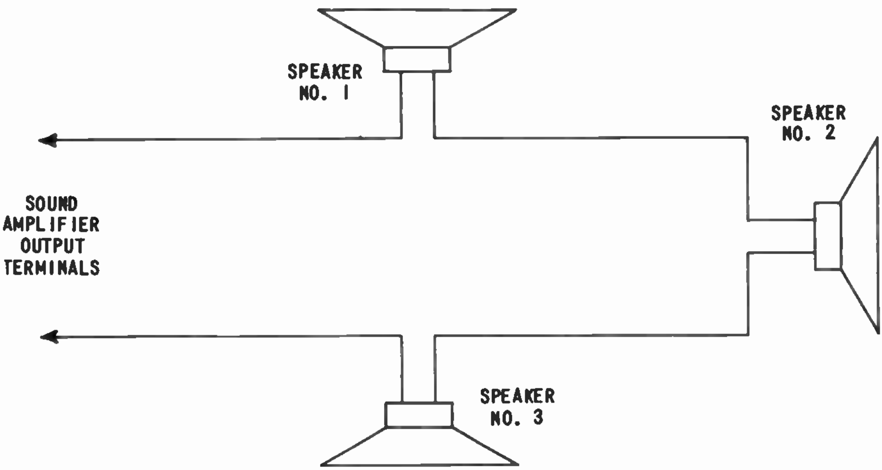
A series circuit can be made up of any number of cells, batteries, and resistors. To be IN SERIES means that the SAME CURRENT must pass through each part since there is only one path. Therefore, in Figure 4, R_1 and R_2 are in series.

Series circuits have three important features:

1. *There is only one possible current path.*

2. *The current is the same at each point in the circuit.*

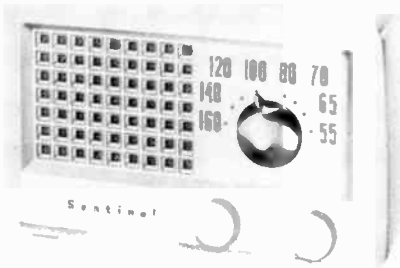
3. *Only part of the applied voltage is across each resistor.*



For some applications, speakers are connected in series across the output terminals of the sound installation to provide adequate sound coverage.

A PARALLEL WATER SYSTEM

The series circuit of Figures 2, 3, and 4 are not the only way in which two or more resistors can



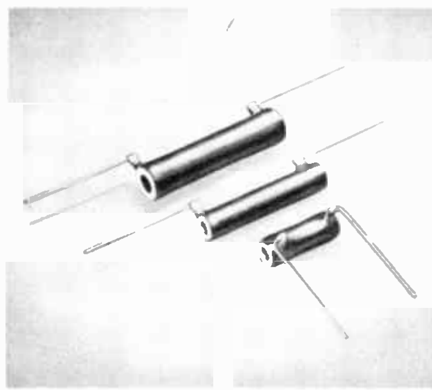
A popular type of radio receiver. In small units such as these, the various components must be arranged carefully to permit the necessary parallel and series connections.
Courtesy Sentinel Radio Corp.

be connected. Another method is called a parallel circuit. To illustrate the action of this electric circuit, a parallel water system is pictured in Figure 5. A pump and two narrowed pipes or tubes are connected together, but this time the tubes are not in series with each other.

Let us assume the system is completely filled with water, the pump is operating and water is flowing through the entire system, and that the connecting pipe offers little or no friction to the flow of water.

All the water is flowing from the pump through the outlet pipe A in the direction of the arrow. The length of the outlet pipe is from the pump to the Junction B leading to Tube #1 and Tube #2. Upon reaching this junction, the water divides, some of it goes through a pipe to Tube #1 and the rest goes through the pipe to #2. The water flowing from these Tubes combines at Junction C, of intake Pipe D and all the water returns to the pump through Pipe D. The same amount of water leaving the pump by Pipe A returns through Pipe D. Assuming the pipes have no friction, the entire pressure of the pump is across each tube but only part of the total water flow passes through each.

The important features of this parallel water system are: (1)



Wire wound resistors covered with a ceramic type insulation material.
Courtesy Ohmite Mfg. Co.

there is more than one possible path for the water, (2) only part of the total water passes through each tube although the same amount of water returns to the pump that leaves, (3) the entire pressure of the pump is applied across the tube in each separate water path.

Electron equipment such as this television receiver contains a large number of components, many of which form series circuits.
Courtesy Hallicrafters

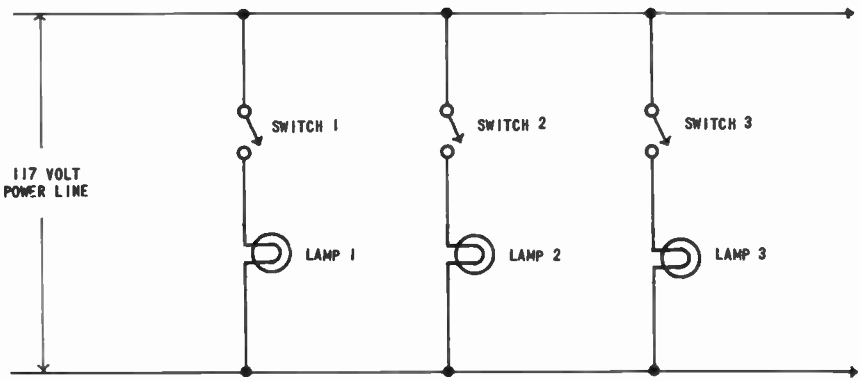
A PARALLEL CIRCUIT

Figure 6 is a photograph of a basic parallel electric circuit. A battery takes the place of the pump and two resistors serve the same purpose as the Tubes of Figure 5. The connecting wire replaces the connecting pipes.

Figure 7 is a pictorial diagram of the circuit in Figure 6. Again the parts are drawn in outline just as for the series circuit. E is the battery, R_1 represents the inside resistor, and R_2 represents the outside resistor shown in the photograph of Figure 6. Soldered joints of Figure 6 are represented by twisted lines in Figure 7.

Figure 8 is the schematic diagram of the circuit in Figure 6. The two lines joined by a dot indicates that the wires are connected together. Physically, the schematic diagram of Figure 8 does not tell where the connection is made as in a wiring diagram, but only that there is one. When the dot is omitted and the wires cross each other, no connection is indicated. These are the practices in all the lessons. In fact, all symbols used in our texts are those adopted by the Institute of Radio Engineers (IRE) and the American Standards Association (ASA).

Battery voltage E causes the total current I_T to leave the negative terminal through wire A to the junction of the wires leading to R_1 and R_2. At this point, the current divides into two parts, I_1 and I_2, but the battery voltage E across the circuit remains the same. Current I_1 passes through R_1 while current I_2 passes through R_2. Having passed through these resistors, I_1 and I_2 unite at the junction of the two connecting wires to become I_T then the total current returns to the positive

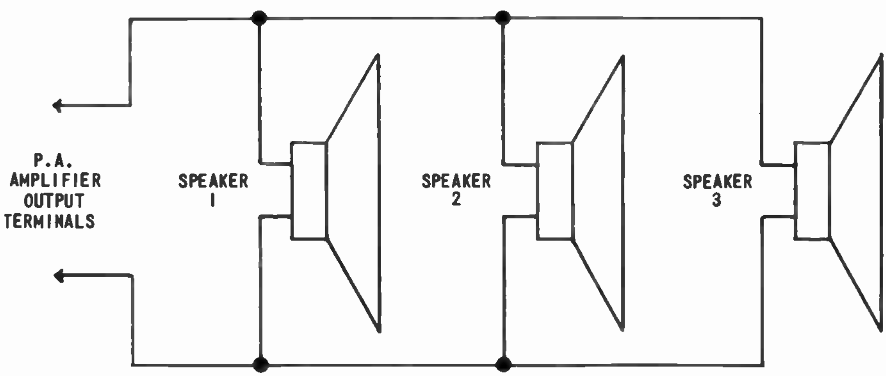


Electric lamps form separate branches of a parallel circuit in house wiring. In each branch a switch permits the associated lamp to be turned on or off independently of the others.

terminal of E through Wire D. Thus, the current leaving and entering the battery is exactly the same as the total of I_1 and I_2 or I_T. All parallel circuits like Figure 8 have more than one current path.

Again, the minus "$-$" and "$+$" signs are drawn near each of the resistors to indicate the direction of current through them. Also, they indicate the polarity of the voltage across each resistor.

In the circuit of Figure 8, the battery voltage E is applied across resistor R_1, and also across R_2. That is, the "$-$" side of the battery is connected directly to "$-$" side of resistors R_1 and R_2 and the "$+$" side of the battery is



In many sound system installations such as a public address (P.A.) system, often several loudspeakers are connected in parallel to provide adequate sound distribution.

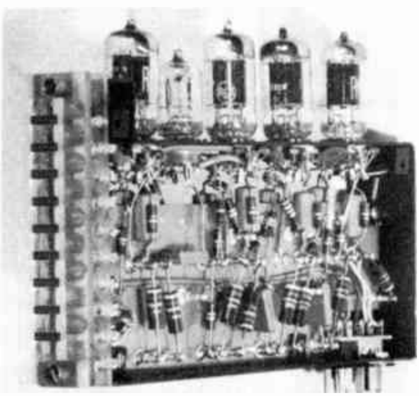
connected directly to the "+" side of resistors R_1 and R_2. Since there is no appreciable decrease of voltage due to the connecting wires, THE FULL BATTERY VOLTAGE E IS ACROSS R_1 AND ACROSS R_2.

In a parallel circuit, the important features are:

(1) There is more than one current path.

(2) The total current is the sum of the currents through each of the branches.

(3) The total applied voltage is across each branch.



Inside view of one section of a nuclear research instrument. Notice the short, direct wiring that makes circuit tracing a relatively easy job.

Courtesy Tracerlab Inc.

There are two main differences between a parallel and a series circuit: These are:

(1) In a parallel circuit, the current divides into separate paths and the total current is the sum of the currents in each path. In a series circuit, there is only one path and so the current is the same throughout the entire circuit.

(2) In a parallel circuit, the applied voltage is across each resistor. In a series circuit, only part of the applied voltage is across each of the resistors in series.

TRACING CIRCUITS

In troubleshooting a circuit, it may be necessary to draw a schematic and a pictorial or wiring diagram of the current paths. A wiring diagram shows the exact physical location of the circuit parts and wires. Sometimes it is valuable to draw the wiring diagram first and then to draw the schematic from it. Then the wiring diagram is used to locate the trouble indicated by your knowledge of the circuit operation obtained with the aid of the schematic.

Suppose a schematic was drawn of a circuit which appeared as in Figure 4. We can redraw it so that the battery E is shown on the right and the resistors are shown on the left. However, in a redrawn schematic, the same connecting points must be observed, otherwise the two circuits no longer are electrically identical. The schematic diagram shows only the electric connections; it does not show the mechanical layout of the parts.

BUILDING CIRCUITS

Quite often the reverse procedure is desired. Figure 8 may be the schematic of a practical circuit. From it Figure 7 is drawn to show the actual layout for the circuit. In the drawing, the cell and the two resistors R_1 and R_2 may even be drawn to the same size as the physical dimensions and the wires of Figure 7 may show the actual length. Then by placing the parts in the positions drawn, a neat circuit can be wired for use.

A good practice to observe in building circuits is to wire components following the direction of the current. Start from the "–" of the voltage source and wire the components in position until the "+" of the voltage source is reached.

CURRENT IN ELECTRIC CIRCUITS

In an electric circuit, the current passes from the negative terminal of the battery through the resistors and returns to the positive terminal of the battery. This is true in all electric circuits: series or parallel. What determines the current in these circuits is the applied voltage and the resistance of the circuit. Once these factors are known the total current can be determined.

In fact, the current, voltage, and resistance are related to each other. This relationship is described in the next lesson by using the basic circuits just explained.

IMPORTANT DEFINITIONS

PARALLEL CIRCUIT—[PAR uh lel SER kut]—a circuit with more than one current path.

SERIES CIRCUIT—[SEE reez SER kut]—a circuit with two or more parts having only one current path.

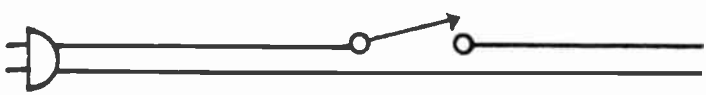
SUBSCRIPT NOTATION—numbers shown at lower right of a symbol, as R_1.

WORK DIAGRAMS

To do your work properly as an electronic technician, you will have to be able to follow electron circuit diagrams. Also, it will be necessary often to follow the wiring and circuit connections in the electron equipment itself. Occasionally, you will need to sketch your own diagram of some piece of equipment for which no data is available. In fact, as you proceed with your lessons, you will learn that all electron components are represented in diagrams by means of symbols on the order of those illustrated in this lesson. To make a circuit diagram, a technician draws these symbols in any convenient location on a sheet of paper, and then connects their terminals with straight lines. The straight lines represent the wires which connect the actual components in the electron device.

For example, below are schematic symbols of a line cord plug and a switch. Suppose we desire to sketch a diagram of a line cord containing a switch of this type. First, we draw the two symbols, thus:

Then, we add lines to represent the wires of the line cord connecting the plug to the switch.



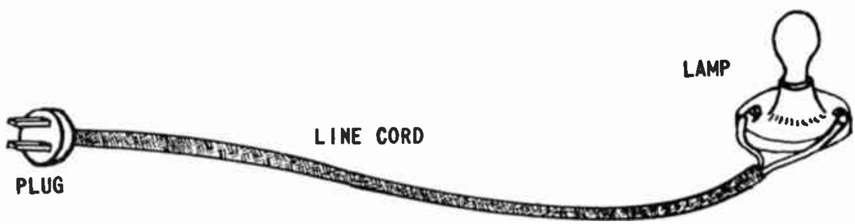
This and following lessons contain problems in circuit study which we call work diagrams. Their purpose is to provide you with practice in following circuit wiring and in drawing diagrams. Also, for practice in reading diagrams, some of the problems ask you to complete pictorial sketches of various equipment by drawing in the

WORK DIAGRAMS—(Cont'd)

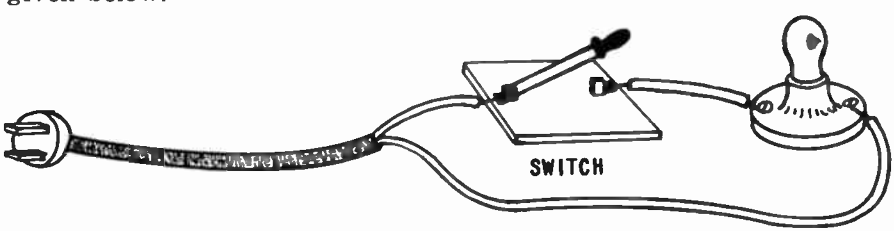
connections indicated in circuit diagrams. To provide a variety of work diagrams, some problems may be concerned with electron equipment which you have not yet studied in the lessons. However, you should be able to follow the connecting wires and sketch the diagrams, regardless, just as you are able to tune in a program on a radio or television receiver whether or not you know how the receiver functions. As you advance in your studies, the operation of all of these units are explained in detail.

In each lesson, when you have completed the work diagrams, check with the solutions which are given on the back of one of the foldout sheets.

1. Draw pencil lines connecting the symbols to form the circuit diagram of the units in the pictorial sketch.

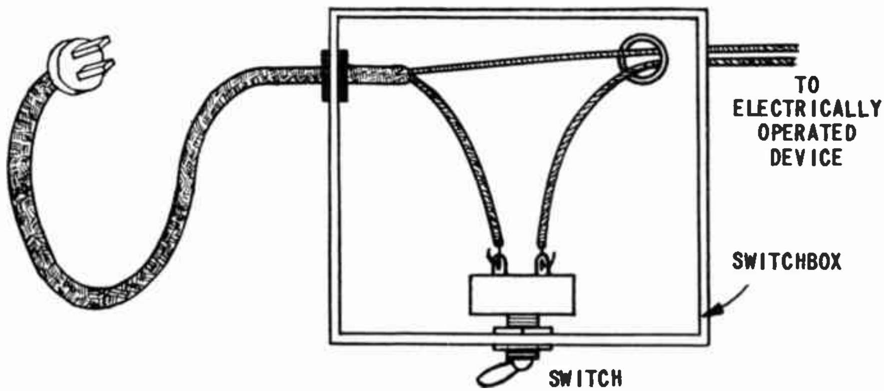


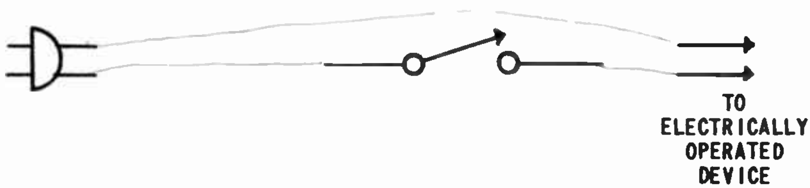
2. This circuit is like that of problem 1, but has a switch in one wire of the line cord. Draw the circuit diagram, using the symbols given below.



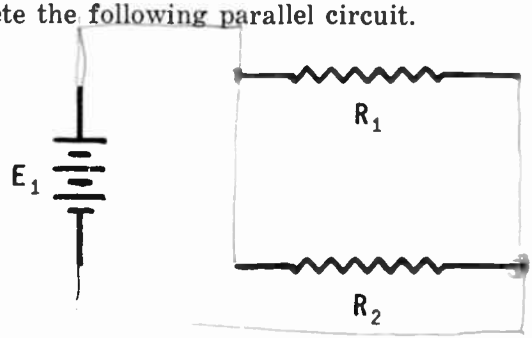
WORK DIAGRAMS—(Cont'd)

3. Sometimes, a switch is mounted in a metal box which serves as a protection. In this example, the wires leave the switchbox to supply current to some electric device which is not included in the drawing. Since the box is not actually part of the electric circuit (does not carry the current), it is not included in the circuit diagram. Draw the diagram.





4. Complete the following parallel circuit.



When you have completed these diagrams, check your work with the solutions given on the back of the foldout sheet.

1- a parallel circuit-
Is a circuit with more than one current path-

2- a Series circuit-
Is a circuit with two or more parts having only one current path.

3- a Subscript notation-
Is a Symbol as R^1.

4- IT. Means Total current-

5.- In a parallel circuit-
the Important Features are;
(a)- There is more than one current Path;
(B)- The total current is the Sum of the currents through each of the Branches
(C)- The total applied Voltage is across each Branch:

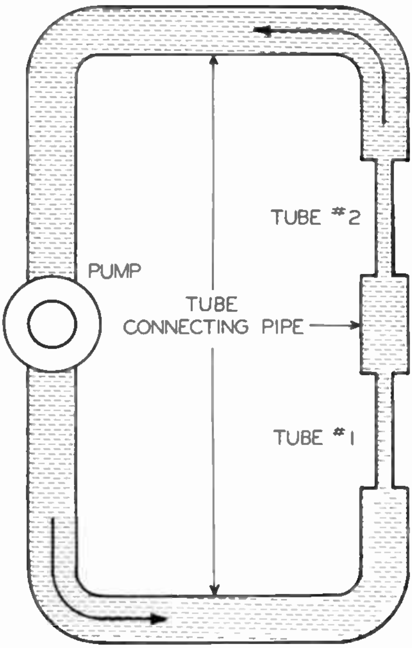


FIGURE 1

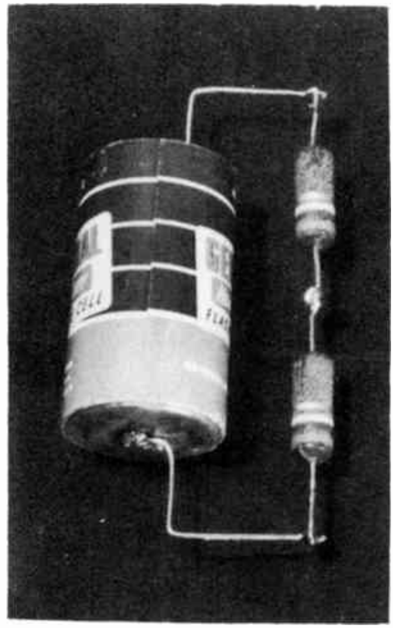


FIGURE 2

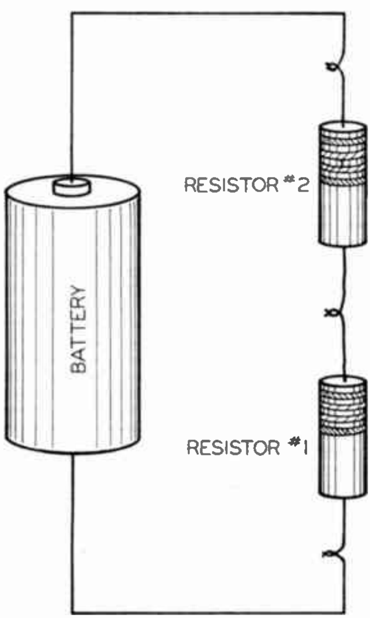


FIGURE 3

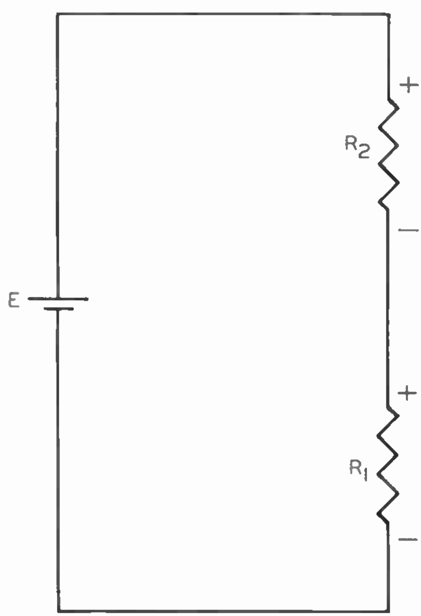


FIGURE 4

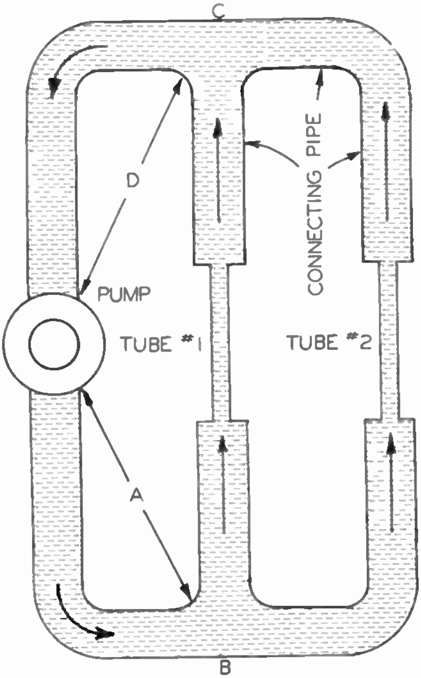


FIGURE 5

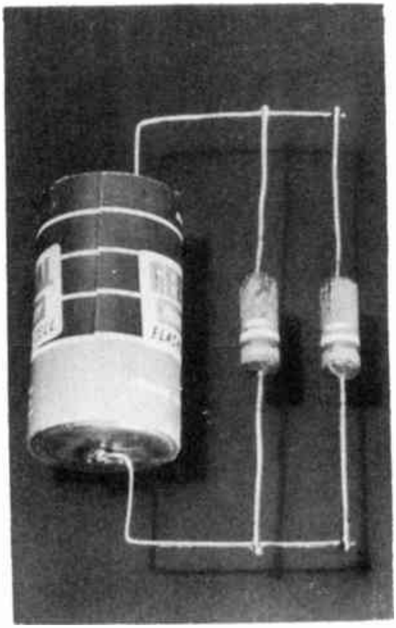
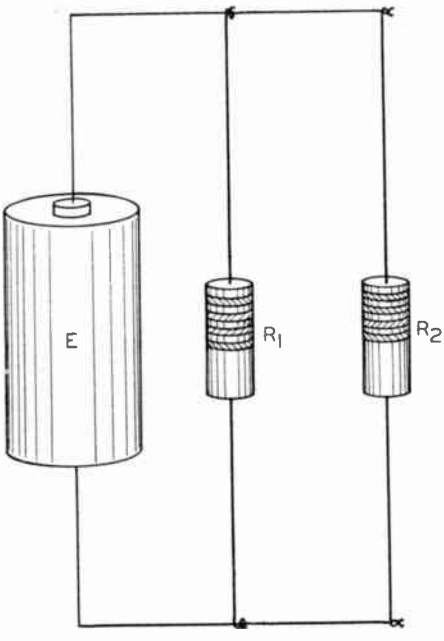


FIGURE 6



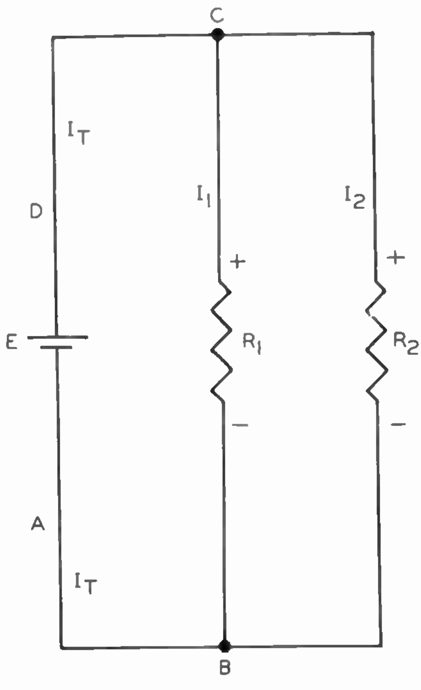


FIGURE 7

FIGURE 8

FROM OUR *Director's* NOTEBOOK

IMPORTANCE OF A GOOD FOUNDATION

While we were making a trip to Milwaukee recently, the train stopped on one side of a bridge on the Sixth Street Viaduct, and we had to get off, walk across the bridge, and board another train waiting on the other side.

Upon inquiring why, we were told that the original foundations for the bridge structure were not strong enough for the bridge to carry the new heavier trains. Consequently, service had to be interrupted now while they were being reinforced.

It is such interruptions in your radio progress that we want to avoid, by stressing all fundamentals and laying a good foundation knowledge that will enable you readily to adapt yourself to new innovations.

After all, there are a number of basic facts and principles that underlie all electrical and radio operations, and any new circuit features, etc., are merely different adaptations of these same fundamentals. Therefore, don't delay your advancement later on by passing lightly over any of these early lessons. Master each one thoroughly today, and you'll be prepared for the new things of tomorrow.

Yours for success,

W. C. DeVry

DIRECTOR

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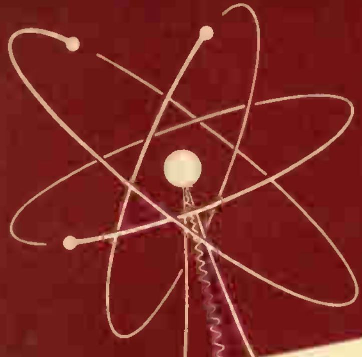


VOLTAGE-CURRENT-RESISTANCE

Lesson AEH-4A

DeVRY Technical Institute

4141 W. Belmont Ave., Chicago 41, Illinois

Formerly DeFOREST'S TRAINING, INC.

AEH-4A

VOLTAGE-CURRENT-RESISTANCE

ELECTRONICS TELEVISION
DTI
DeVRY Technical Institute

ELECTRONS RELAY MESSAGES

With no idea of the vast and expanding field of electronics, the general public regards broadcast radio and television as the principal applications. Actually, these services employ only 1 out of every 20 of the licensed transmitters in use. Most of the electron equipment of this type is used for relay, radiotelephone, facsimile, remote control, telemetering, navigational aids, and experimental work.

Furthermore, all the transmitters in use employ less than one-fifth of the total amount of radio frequency power generated for various purposes, and all the radio frequency power applications form only a part of the gigantic field of electronics. Communication, transportation, medicine, research, industry, commerce, and entertainment all find electronics vital to their success.

VOLTAGE-CURRENT-RESISTANCE

Contents

If yesterday was a dismal failure, then turn those failings into successes today. Josh Billings once said, "It ain't no disgrace to make a mistake. The disgrace comes in making the same mistake twice".

VOLTAGE-CURRENT-RESISTANCE

The 20th century is filled with new inventions and advances in every field. Radio, television, and all of electronics have certainly contributed a huge part of these advances and new inventions. This outstanding success is primarily the result of measurement. Housewives measure with spoons and cups to bake a good cake, a machine operator measures with calipers and micrometer, and even your doctor checks your blood pressure by means of a calibrated mercury column.

In electronics, measurements reveal just how the electric circuit is behaving. With the circuit operating properly one set of readings is obtained; with a trouble or fault in the circuit, different readings appear.

For the same reason that a ruler is marked off in a standard inch, foot, or yard, electric meters must use standard units. E is measured in volts, I is measured in amperes, and R in ohms. An ampere indicates the number of electrons that flow past a particular point in a conductor in a given time.

STANDARD UNITS

The chart in Figure 1 illustrates the letter symbol, the standard unit and its abbreviation, and the meter used to measure this unit. Read each row across for the complete story. That is, the electric pressure E is measured in volts (v) by a voltmeter. The rate of electron flow or current I is measured in amperes (amp.) by an ammeter, and the resistance R given to this flow is read in ohms (Ω) on an ohmmeter. Ω is the greek letter omega used by many people to represent ohms.

With standard units of a VOLT, AMPERE, and OHM, we can make comparisons in an electric circuit. You may suspect that all these standard units are somehow related. They are, and the three combined tell a story which leads to a better understanding of all electric circuits. But, first let's compare two at a time.

VOLTAGE AND CURRENT

The series circuit described in a previous lesson is shown here in Figure 2. IN ANY SERIES CIRCUIT, THE TOTAL RESISTANCE IS EQUAL TO THE SUM OF THE INDIVIDUAL RESISTANCES. Thus, if R_1 and R_2 are each $\frac{1}{2}$ ohm, the total resistance of this circuit is $\frac{1}{2} + \frac{1}{2} = 1$ ohm. A battery voltage of 10 volts will produce a current of 10 amperes in the circuit.

In the water system described in the last lesson, when the pump has a pressure of 10 units, it pumps 10 gallons per minute. When the pressure is increased to 20, it can pump 20 gallons of water per minute through the same pipes. Twice as much water is pumped because the pressure has doubled.

In much the same manner, in the electric circuit of Figure 2 if the 10 volts is increased to 20 volts, the current doubles so long as the resistance remains the same. The voltage is increased by either using two ten volt batteries in series which gives ten plus ten or twenty volts, or replacing the two with a single 20 v battery.

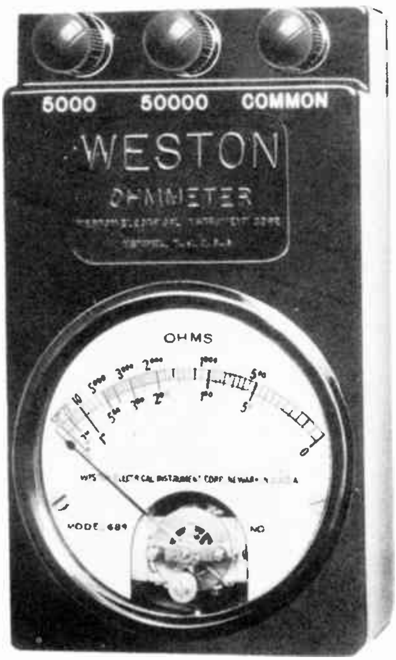
With the 1 ohm resistance, the current I increases to 30 amperes when the voltage is increased to 30 v. In fact, increasing the voltage in the circuit, while the resistance remains constant, always increases the current.

Although the voltage in this electric circuit came from a battery any other source of voltage could have been used. The important thing is: for a constant resistance increasing the voltage increases the current by the same amount.

A multi-service combination which provides a choice of television reception, AM or FM radio reception, or record playing.

Courtesy Zenith Radio Corporation

When one quantity is increased by a specific number of times and another quantity increases by the same amount, the two quantities are **directly proportional** to each other. When the two quantities



Ohmmeters operate by using Ohm's Law. By placing a fixed voltage across the unit and measuring the current, this meter can indicate the resistance of the unit.

Courtesy Weston Electrical Instrument Corp.

decrease together by the same number of times, they also are directly proportional.

The following example shows two quantities NOT directly proportional. Suppose the power supplied by the motor is 20 horsepower when the car speed was 25 miles an hour. If raising the power output to 60 horsepower only increases the speed to 50 miles an hour, then triple power only doubles the speed. In this situation, the quantities do NOT vary in direct proportion.

For two quantities to be directly proportional, they MUST both increase or decrease the SAME number of times from their previous value. When the current increases 1½ times, so must the voltage, when the resistance remains unchanged.

We can state for the above situations: IN AN ELECTRIC CIRCUIT, THE CURRENT I IS DIRECTLY PROPORTIONAL TO THE VOLTAGE E WHEN THE RESISTANCE IS HELD CONSTANT.

Radio, television, and other electronic servicemen frequently take advantage of this relationship to determine whether a circuit has sufficient electron flow. Although a "current meter" can be used for this purpose, as you will find out in the next lesson, it must be connected in series with the other circuit components. Frequently, this requires disconnecting a circuit wire to insert the meter. It is much quicker to use a voltmeter across one of the components. Since the voltage across the component increases with the current through it, the technician can quickly determine whether there is a current, and if it is near normal, without taking the time and effort to disconnect wires.

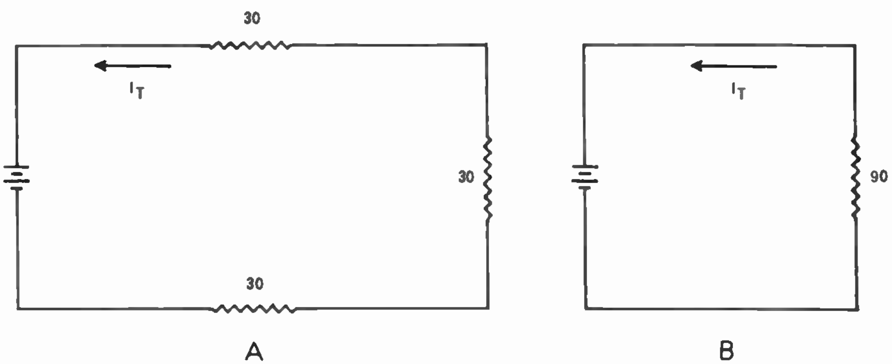
VOLTAGE AND RESISTANCE

We can treat the voltage and resistance relationship the same way we described for current and voltage. Both kinds of changes sometimes occur even in the same circuit. At one time, the voltage and current change and the resistance remains the same, while at a later moment only the voltage and resistance change.

We can learn how the relationship between voltage and resistance works when the current is held constant, by starting with the electric circuit of Figure 2 when E was 10 volts applied across both R_1 and R_2, the total of R_1 and R_2 was 1 ohm, and the current was 10 amperes.

Now suppose the voltage is doubled to 20 volts. To keep the current at 10 amperes, the resistance must double, so the total resistance of R_1 and R_2 is 2 ohms. Again when the battery voltage is increased to a 30 volts, the total resistance must increase to 3 ohms to hold the current constant.

WITH A CONSTANT CURRENT, THE VOLTAGE E IS DIRECTLY PROPORTIONAL TO THE RESISTANCE R. Increasing or decreasing the voltage a certain number of times means that the resistance must be increased or decreased by the same number of times to keep the same current.



So far as circuit current is concerned, the three 30-ohm resistors in series offer the same opposition in circuit A as offered by the single 90-ohm resistor in circuit B.

RESISTANCE AND CURRENT

We have considered two ways in which an electric circuit may change. As you may have guessed there is still a third way: the resistance and current may change at the same time the voltage applied across all the parts remains constant.

Both voltage and resistance, and voltage and current are directly proportional to each other. However, the same relationship does not hold true for current and resistance. In fact, just the opposite is true; as I increases R decreases for any fixed voltage E.

In the electric circuit of Figure 2, if the battery voltage E is 20 volts and the current is 1 ampere, the total resistance of R_1

Several series circuits form parts of the complete circuit of an electron instrument such as this portable radio receiver.
Courtesy Sentinal Radio Corp.

and R_2 is 20 ohms. Now by keeping the voltage E constant but reducing the total resistance to 10 ohms, the current meets less opposition and so it increases to 2 amperes. Halving the resistance doubles the current for the same battery voltage. Suppose the total resistance of R_1 and R_2 is decreased to 1 ohm. With the same battery voltage E, the current becomes 20 amperes. That is, when the total resistance is decreased 20 times, the current is increased 20 times.

When the voltage is held constant in an electric circuit, the current I increases the same number of times that the resistance decreases. This relationship is expressed by saying: The current I and resistance R are **inversely proportional** to each other.

In electronics, there are a large number of circuits in which the voltage remains constant while the other two vary. A very good example is the "ohmmeter" described in your meter lesson and which you build and use in your laboratory work. Frequently it is necessary for the laboratory technician to measure the resistance of a component to see if it is defective or not. Possibly the simplest way is to apply a fixed voltage across the part in question and determine the current it draws by means of a current meter. The more current drawn, the lower the resistance.

In fact this method is so useful that a current meter, voltage source, and other necessary wiring are enclosed in a case and called an ohmmeter. However, instead of showing the current, the meter scale is calibrated to indicate the resistance that permits this current.

OHM'S LAW IN SERIES CIRCUITS

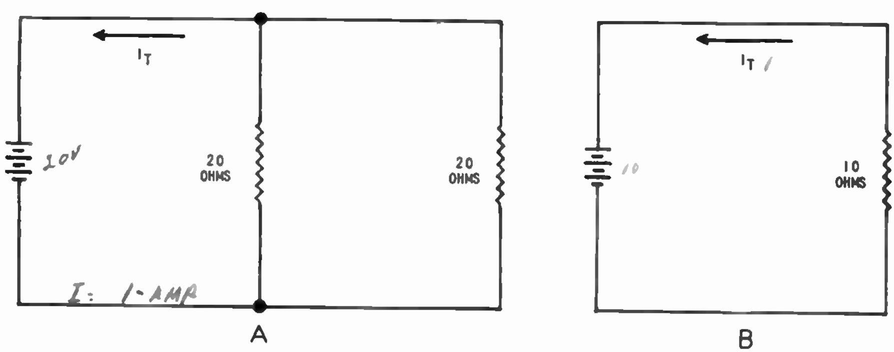
You'll notice that E, I, or R was held constant in each one of the three relationships described. This is done with electric circuits in practical situations. Anyone can discover these three relationships for himself if he so desires by wiring these circuits and measuring the values. These are basic and fundamental relationships which hold true in all electric circuits, whether the voltage is d-c or a-c.

However, all three of these can be expressed in terms of one overall relationship. Therefore, instead of remembering three separate rules you need only to remember one. Everyone who constructs, installs, maintains and services, or modifies equipment uses this one relationship. It is called Ohm's Law and stated in words is:

IN AN ELECTRIC CIRCUIT, THE CURRENT IS DIRECTLY PROPORTIONAL TO THE VOLTAGE AND INVERSELY PROPORTIONAL TO THE RESISTANCE.

All are measured in standard units of amperes, volts, and ohms. Figure 3 is an aid to finding one of the three, the E, I, or R in an electric circuit when the other two are given. It puts all three letter symbols in a short, easy to use form.

How this Figure can be used is illustrated in Figure 4. By placing your finger on the symbol for the value that you wish to determine there are two left exposed. If both symbols are below the horizontal line as shown in Figure 4A, then one must be multiplied by the other, but when one is above as shown in Figures 4B and 4C, the top value is divided by the one left exposed below the line. For Figure 4A, Ohm's Law can be written as:



So far as the total circuit current I_T is concerned, two 20 ohm resistors in parallel offer the same opposition in circuit A as the one 10 ohm resistor in circuit B.

Volts is equal to amperes times ohms.

For Figure 4B, the relationship can be written:

Amperes is equal to volts divided by ohms.

For Figure 4C, the relationship can be written:

Ohms is equal to volts divided by amperes.

An instrument of this type is used when it is desired to measure the voltage, current, or resistance of a circuit.
Courtesy Precision Apparatus Co., Inc.

Note in all three of these statements the value being sought appears as the first word.

How easy and practical this device is can be illustrated by a sample problem or so. For example, when it is known that the current is 5 amperes through a resistor of 5 ohms, then the voltage across the resistor can be determined. After covering up E since it is the value that is unknown as shown in Figure 4A, substitute 5 amperes for the I and 5 ohms for R. Since both symbols are below the line, multiply these two values together, 5 times 5 = 25. Therefore, E is 25 volts.

The three relationships between I and R, E and I, and E and R described for Figure 2 are just special cases of this Ohm's Law.

For our first case we began with 20 ohms and 1 ampere at 20 volts. Then we changed to 10 ohms and 2 amperes, and finally to 20 amperes and 1 ohm. Multiply the 20 by 1, the 10 by 2, or the 1 by 20, and the result in each case is 20 volts. That is, the voltage was held constant at 20.

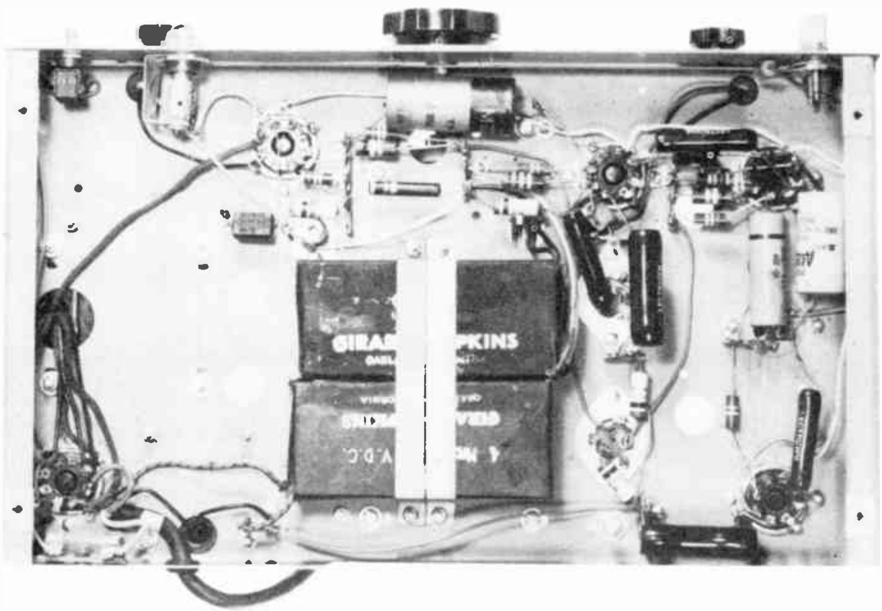
Let's see how Ohm's Law holds in the relationships between E and I. The first case described was 10 volts and 10 amperes; second was 20 volts and 20 amperes; and the third, was 30 volts and 30 amperes. Now recall that the resistance was held constant for all three. Using Figure 4C: 10 divided by 10 = 1, 20 divided by 20 = 1, and 30 divided by 30 = 1. One ohm! So, the resistance used in this circuit for the E and I relationship remained constant at one ohm.

For the E and R relationship described, the current was held constant for all the electric circuits. Let's check it by using Figure 4B. The values for E and R were: 10 volts and 1 ohm, 20 volts and 2 ohms, and 30 volts and 3 ohms. Since 10 divided by 1, 20 divided by 2, and 30 divided by 3, all equal 10, the current remained constant at 10 amperes.

Notice in Figures 4A, 4B, and 4C that two values remain uncovered. This means that two values must be known before the third one can be determined. It is impossible to determine one unless both of the others are known.

To demonstrate this law, let's use the series circuit of Figure 2 again, by letting R_1 be 2Ω, R_2 be 7Ω, and the battery 27v. To find the current, use the total resistance, 2Ω plus 7Ω which is 9Ω, and the 27 v. Substituting both values as in Figure 4B, nine ohms divided into 27 v is 3 amperes.

Since we know the current through each resistor is 3 amperes and its resistance, we can find each resistor voltage using Fig-



Underchassis view of a piece of electron equipment, showing various types of components, some of which form branch parts of parallel circuits.

Courtesy Hewlett-Packard Co.

ure 4A. For the voltage across R_1, 2Ω and 3 amp. gives 6 v. Likewise for R_2, 7Ω and 3 amp results in 21 v. As a check, the total of both voltages should equal 27 v applied across both resistors. Adding 21 v to 6 v gives 27 v, and so our results are correct.

OHM'S LAW IN PARALLEL CIRCUITS

Of the two basic types of circuits, parallel is the more common in ordinary house wiring and every plug-in appliance is connected in parallel into this wiring. Each time you turn on a light, radio, television, etc., you complete one more parallel branch.

At times, there are many appliances on at once. Turning on just one more stops the operation of each, because you "blow" a fuse. One such fuse is ordinarily rated about 20 amperes and the last appliance uses enough additional current to exceed this limit. To protect both the electric circuit and your house, the material inside the protected container of the fuse melts and safely breaks the circuit. For this reason copper pennies or other such substitutes should never be used. Only fuses of the correct rating are proper replacements.

Knowing the current used by each gadget and totaling it, you will find how many appliances can be on at the same time without blowing a fuse.

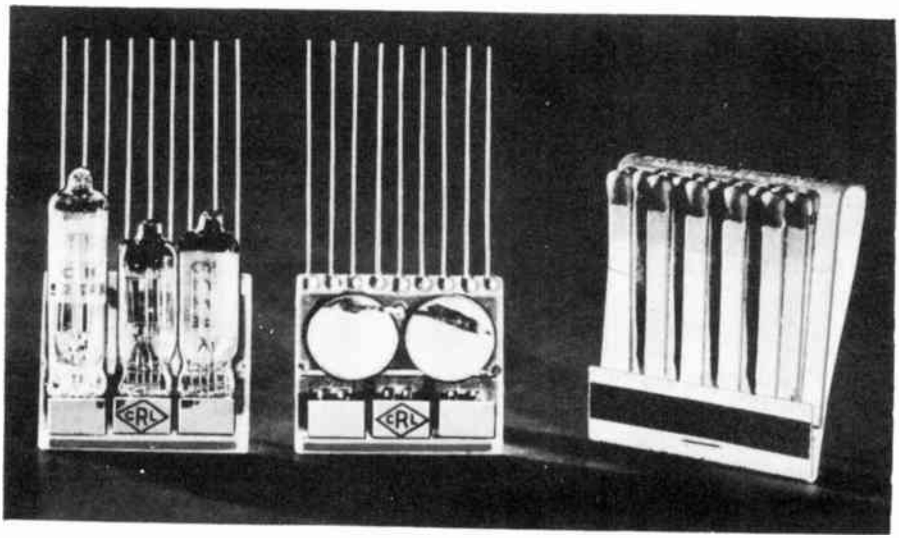
We can go further with parallel circuits by applying Ohm's Law, just as we did for series circuits since, it applies to all circuits equally well. For example, in the parallel circuit of Figure 5, E is an 18v battery connected across two resistors in parallel. R_1 is 3 ohms and R_2 is 6 ohms. In the previous lesson it was stated that voltages across all the branches are the same as the applied voltage. Also, the current paths were described and it was found that the total circuit current I_T is the sum of the branch currents I_1 and I_2. R_1 and R_2 are marked by + and − to remind you of the direction of the current through the resistors. Now the question is: What are I_1, I_2 and I_T?

We know the voltage across R_1, and that the resistance of R_1 is 3 ohms. Only I_1 is the unknown. Substitute 18 v and 3 ohms in Figure 3 by covering up the I as shown in Figure 4B, 18 volts divided by 3 ohms is 6 amperes. This is the current through R_1, and so it is only PART of the total current I_T.

The current I_2 can be found the same way. Substitute 18 volts and 6 ohms into Figure 4B; 18 volts divided by 6 ohms is 3 amperes.

The total current I_T is the sum of 3 amperes and 6 amperes or 9 amperes. Thus, there is 9 amperes from the negative terminal of the battery and 9 amperes back into the positive terminal of the battery.

Since in a parallel circuit the battery voltage across each branch is the same, there is 6 amperes or twice the current through the 3 ohm resistor as through the 6 ohm resistor.



A new technique of circuit design and construction permits the assembly of extremely small electron equipment such as this three tube hearing aid amplifier.
Courtesy Centralab Division of Globe Union, Inc.

Knowing the TOTAL CURRENT and the applied voltage in this parallel circuit, the total resistance of a parallel circuit can be found by using Ohm's Law. Substitute 18 v and 9 amperes into Figure 4C. Divide the 18 volts by 9 amperes, and the answer is 2 ohms. This means that to get the same total circuit current I_T, a three and a six ohm resistor in parallel can be replaced by a single resistor of 2 ohms. Note that the total resistance of a parallel circuit is NOT the sum of 3 and 6; it is LESS than either. THE TOTAL RESISTANCE IS ALWAYS LESS THAN THE RESISTANCE OF THE LOWEST BRANCH IN PARALLEL CIRCUITS.

Let's repeat the procedure to find the currents and total resistance in a parallel circuit before taking another illustration. Both resistances were known along with the applied voltage. Using

Ohm's Law as shown in Figure 4B, the current I_1 was found to be 6 amperes. Using Ohm's Law in Figure 4B, I_2 was found to be 3 amperes.

In a parallel circuit, the total current I_T is the sum of the branch currents. Thus I_T is equal to 3 amperes plus 6 amperes or 9 amperes. Using Ohm's Law, this time in Figure 4C, with the total current and voltage, the total resistance was found to be 2 ohms.

For another example, let E in Figure 5 be 20 volts, resistor R_1 is five ohms, and current I_2 is 2 amperes. Suppose current I_1 and the resistance R_2 must be known. What do we do to find them?

To find I_1 first, we must know the voltage across R_1 and the resistance of R_1 to use Ohm's Law. Both are given, R_1 is 5 ohms and E_1 is 20 volts. Substituting in Figure 3 for E and R, as shown by Figure 4B; I_1 is 20 volts divided by 5 ohms, or 4 amperes.

Using Ohm's Law to find R_2, since the voltage and current I_2 are known, by substituting 20 for E and 2 for I in Figure 4C, 20 divided by 2 is 10 ohms. Thus, by using Ohm's Law twice, R_2 and I_1 are determined. In each case, two things were known before the third could be found.

Since the total current is the sum of the branch currents I_1 and I_2, I_T is 4 amps plus 2 amps or 6 amps. This 6 amperes leaves the negative terminal of the battery and at the junction of R_1 and R_2 divides, 4 amps goes through R_1 and the other 2 amps pass through R_2. I_1 and I_2 rejoin on the "+" side of junction of R_1 and R_2, and the total 6 amps enters the "+" side of the 20 v battery.

Since we know both the total current is 6 amperes and the battery has 20 volts we can find the total resistance by using Ohm's Law. Substitute 20 for E and 6 for I in Figure 4C; 20 divided by 6 is 3.33 ohms.

The total resistance in a parallel circuit is always less than the resistance of each branch. This is true because the total current is larger than any branch current, and using Ohm's Law the same applied voltage divided by the larger current gives a smaller resistance.

Thus in parallel circuits:

(1) The applied voltage is across each branch.

(2) Apply Ohm's Law to each branch or part of the circuit to determine the current or resistance when the voltage is known.

(3) The total current is the sum of all the branch currents.

(4) *The total resistance is found by using in Ohm's Law the total current and the applied voltage.*

(5) *The total resistance is always less than the smallest branch resistance.*

RULES FOR ANY ELECTRIC CIRCUIT

Ohm's Law can be applied in any electric circuit. However, to avoid confusion, don't rush into the problem. Follow a procedure, such as:

(1) *See that the circuit is a complete path, otherwise current will not pass through the parts.*

(2) *Try to trace the current path through all the components at the same time labeling "–" and "+" across each of the components.*

(3) *See which things are known and which are unknown.*

(4) *Decide which of the three forms of Ohm's Law will be used in that portion of the series or parallel circuits.*

(5) *Apply Ohm's Law to each unknown, taking one unknown at a time.*

(6) *Make sure the two values selected when applying Ohm's Law are for the same portion of the circuit.*

(7) *As a check, be sure that the total of the voltages across the parts in a series circuit does not exceed the applied voltage.*

(8) *In a parallel circuit:*

(a) *The voltage across each branch is the same.*

(b) *The total current is the sum of the branch currents.*

Actual voltages, currents, and resistances of the circuit combined with Ohm's Law tell how a circuit operates. In your laboratory projects, you will find that these values are not seen or counted by looking at the circuit and so electric meters must be used to measure them. Therefore, every electronic technician should know how to use meters correctly. These methods are described in the next lesson.

IMPORTANT DEFINITIONS

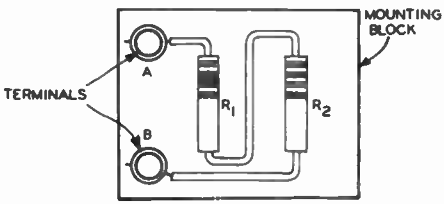
DIRECTLY PROPORTIONAL—Two quantities increase or decrease the same number of times their previous value.

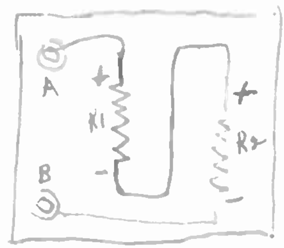
INVERSELY PROPORTIONAL—With two quantities, one increases while the second decreases the same number of times.

WORK DIAGRAMS

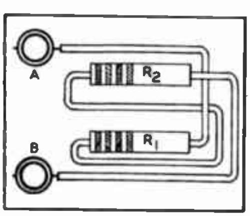
When you have completed these diagrams, check your work with the solutions given on the back of the foldout sheet.

1. The sketch below shows two fixed resistors connected to form a circuit between terminals A and B. Draw the circuit diagram, using the proper schematic symbols for the resistors. Remember, a schematic diagram is arranged to show the electric connections in the simplest manner possible, and does not need to correspond to the physical placement of the parts. Label the resistors as R_1 and R_2, to show that R_1 connects to terminal A, and R_2 to terminal B.





2. Draw the circuit diagram, substituting schematic symbols for the resistors. Arrange your diagram so there are few if any crossed lines, and label the symbols to correspond with the sketch.



LETTER SYMBOL	STANDARD UNIT	METER
E	volt v	voltmeter
I	ampere amp	ammeter
R	ohm Ω	ohmmeter

FIGURE 1

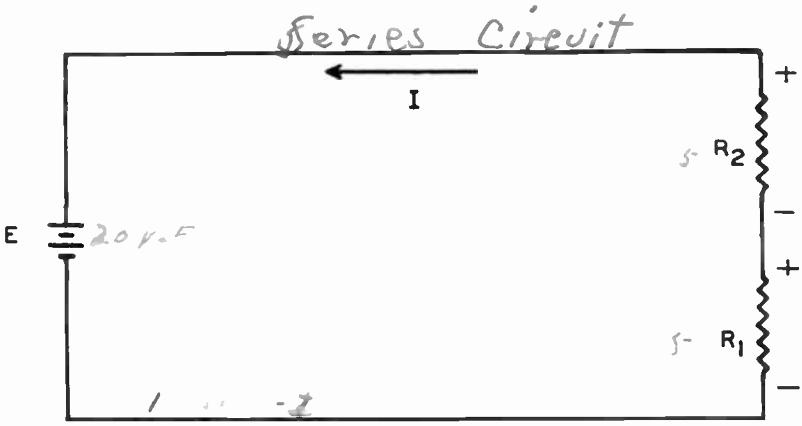


FIGURE 2

R. 10 ohms

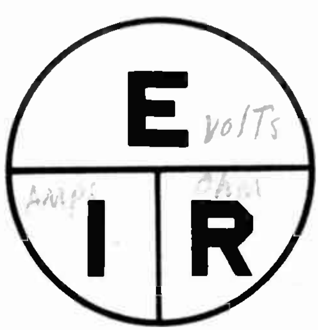


FIGURE 3

WORK DIAGRAM SOLUTIONS

Your drawings may not be arranged exactly like the ones given below, but they should contain the same electric connections.

1. 

2. 

Problems 1 and 2 were made alike, electrically, to show that there are more ways than one, usually, to make the physical connections of any given electric circuit.

6 ÷ 30 = 5

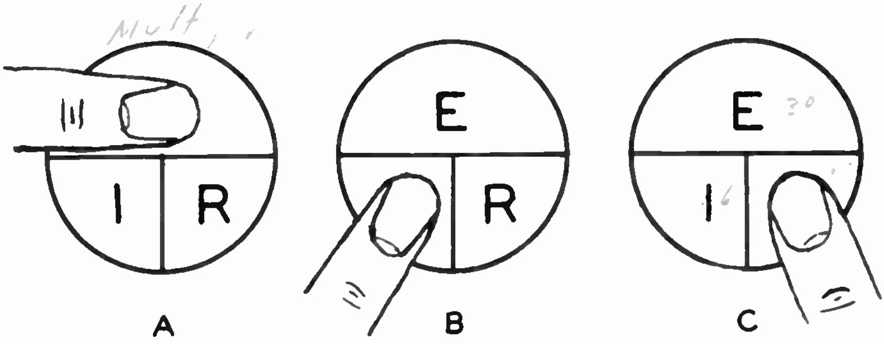


FIGURE 4

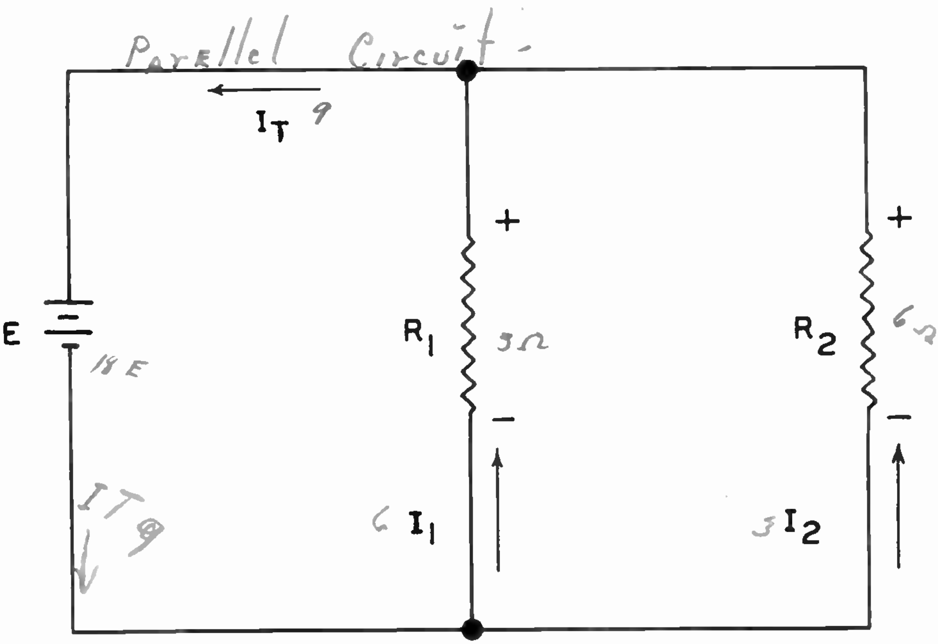


FIGURE 5

FROM OUR *Director's* NOTEBOOK

TODAY IS THE DAY—

Today is the day for action, to move another step nearer toward completing the job that lies before you.

In your race for achievement your strongest competitor is TIME—your keenest adversary is HESITATION—your bitterest enemy is WAIT TILL TOMORROW.

Remember—you can't "put it over" by "putting it off". If you acquire the habit of putting things off, you will soon find your path of progress clogged with a tangling mess of little jobs you have been postponing.

"I'll wait and think it over" has cursed many a man and wrecked many a career.

Charles M. Schwab said: "Keep yourself in training for big achievements by disposing of your duties in hand, swiftly and with determination". The world wants men who have the habit of doing things and getting them done.

Yours for success,

W. C. DeVry

DIRECTOR

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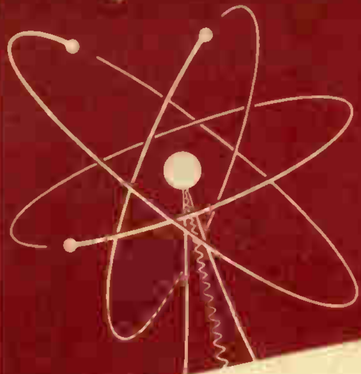


H-6

TWO ELECTRODE TUBES

Lesson AEH-6A

DeVRY Technical Institute
4141 W. Belmont Ave., Chicago 41, Illinois
Formerly DeFOREST'S TRAINING, INC.

AEH-6A

TWO ELECTRODE TUBES

ELECTRONS GAUGE MATERIALS

Formerly a slow, tedious task requiring considerable skill and subject to errors, sorting ball bearings as to size now consists of simply pouring a batch of the bearings into a hopper and letting an electronic gauge do the actual sorting. Quickly, each bearing is tested and then dropped into the proper one of several bins. In each bin, all bearings are within $\frac{1}{100,000}$ of the same size. Using this modern method, one laborer can do the work of 30 skilled operators.

Practically any characteristic of a material such as weight, thickness, color, or hardness, can be measured accurately by electronic devices which form a large proportion of the many types of gauges and other testing equipment used by modern industry.

TWO ELECTRODE TUBES

Contents

Weakness does not prevent success if only the body is weak. The trouble in the average person is not lack of ability, intelligence, or health. It is lack of courage that comes from enthusiasm.

—Arthur Brisbane

TWO ELECTRODE TUBES

Much of the progress in the 20th century is due primarily to electronics, and probably the one single component that has made electronics most possible is the electron tube. Mechanically, it is nothing more than a few parts enclosed in a glass or metal container, yet it possesses some very important features.

Used in a radio, electron tubes bring far away voices and music into your home. Television, again with the aid of the electron tube, brings into your living room the scene with the sounds as they happen. Miles away a valve is closed almost instantaneously because of electron tube action at a central control station.

However, most electron tubes require d-c for their operation, and as you probably know, most utility companies supply a-c. Thus, some means is required within electronic equipment to change the a-c into d-c. The conversion itself usually is performed in a circuit by a two electrode tube.

EARLY ELECTRON TUBE DEVELOPMENTS

In 1883, while developing the electric lamp, Thomas Edison noticed that the inside of the glass bulb became blackened and this caused a reduction in light after the lamp was in use for a short time. In the process of investigating this fault, Edison mounted a metal plate inside the lamp bulb and connected it to a milliammeter as shown in Figure 1. He observed that when the switch made contact with the "+" terminal of the battery, the meter indicated current in the direction shown by the small arrows. On the other hand, when the switch connected with the "−" terminal, there was no meter deflection.

Since he did not attempt to explain or use his discovery, the "Edison Effect" remained nothing more than a scientific curiosity until 1904. Then Dr. J. A. Fleming used a device, like the one shown in Figure 1, in experiments with radio telegraph currents. This first **electron tube** was known as the "Fleming valve" and, although a simple device, it paved the way for the many other types of electron tubes used today.

ELECTRON EMISSION

In order to deflect the ammeter of Figure 1, a current must pass between the filament and plate inside the lamp bulb to complete the circuit. It was not until the advancement of the "electron theory", several years after the discovery of the Edison effect, that scientists were able to explain satisfactorily this conduction between the filament and plate. According to present theory, this conduction is due to a flow of electrons which leave the filament of which they are a part and flow to the plate. This escape of the electrons from the filament is called **electron emission.**

This emission is somewhat like boiling water away into steam. Heated to a high enough temperature some of the water becomes very active. Just look at the way water bubbles when it gets hot! As the very hot water is pushed to the surface, it is moving so rapidly that it overcomes the force holding it to the surface, and escapes in the form of steam.

As explained in an earlier lesson, when a difference of potential exists between two points, electrons flow toward the most positive potential. Figure 1 shows the plate connected to the "+" of the battery and the filament connected to the "—" terminal. Therefore, a force exists between the plate and the filament, and the negative electrons are attracted toward the positive plate.

When certain metals are heated, electrons are emitted readily from their atoms. However, in leaving, these electrons cause a shortage of negative charges which results in positively charged atoms at the filament. Since unlike charges attract, these positive charges attract most of the negative electrons back into the atoms of the filament.

However, when the heated metal is placed in a vacuum, a number of electrons leave the atoms with sufficient force to overcome this attraction and con-

Although the most important single component in electronic equipment, the electron tube is usually a compact unit.
Courtesy General Electric Co.

tinue their movement into free space. This type of electron emission is utilized in most electron tubes and is referred to as THERMIONIC EMISSION.

A practical method of producing a thermionic emission element is to form a metal into a wire, or filament, and place it in a glass bulb like that used for the ordinary light bulb. The air is pumped out of the bulb to form a high vacuum which not only prevents the filament from combining with the oxygen in the air and thus "burning up", but also improves the electron emission. When connected to a voltage source, the resulting current heats the filament and electrons are emitted from its surface. This emission element of an electron tube is called an "emitter".

EMITTERS

In the majority of electron tubes, the emitter is either of the directly heated or the indirectly heated type. The "directly heated" type consists of a **filament** which, when heated, acts as the emitter. Figure 2 shows the mechanical construction of three types of directly heated emitters or filaments which differ in the method of filament support. In each case, the supports connected to the ends of the emitter are conductive and are used to complete an electric circuit from an external voltage source through the base of the tube.

For large electron tubes, directly heated emitters are made of pure tungsten because this metal does not vaporize when heated to a temperature high enough to produce satisfactory emission. However, tungsten requires a comparatively large current to provide the proper operating temperature.

A more common directly heated emitter, known as the thoriated filament, is made by dissolving a small quantity of thorium oxide and carbon in a tungsten wire. When heated, the thorium works its way to the surface of the filament where it is deposited in a thin layer. The emission takes place from this layer at temperatures much lower than required for pure tungsten. As the thorium on the surface is exhausted, a new supply "boils out" from the interior of the wire, thus renewing the outer layer and maintaining proper emission.

Another common emitter is the oxide coated type. It consists of a platinum or nickel wire coated with an oxide of barium, strontium, or calcium. These materials readily emit electrons when heated. This type of emitter is widely used in the small sized tubes because it operates at temperatures only slightly more than half of that required for the thoriated-filament type.

Battery sources of current, called "A" batteries, are used for filament heating in mobile, portable, and other equipment designed to operate independently of local power sources. However, the most common source is ordinary 60 cycle alternating current which is supplied by the utility companies. Not only is it an economical power, but by means of the transformers to be described a couple of lessons from now, the common 110-120 volt 60 cycle supply voltage can be reduced to any desired filament voltage.

Within certain limits, the emission of electrons varies with the temperature which in turn varies with the filament current. Although a desirable source, alternating current drops to zero each time it reverses. With the common 60 cycle supply, the changes take place so rapidly that the filament never cools entirely. However, these periodic changes of temperature are sufficient to cause some variation of emission. For sensitive electron circuits, this variation produces a very undesirable operation.

Because of these conditions, most modern tubes are constructed so that the filament proper is used only to heat a surrounding element that emits the electrons. When heated indirectly in this manner, the emitter temperature doesn't follow these rapid filament heat fluctuations but remains fairly constant. Used in this way, the filament becomes a

The various components of this radio receiver are mounted on two chassis. The one on the left contains the power supply and the output circuits of the receiver, while the other contains the remaining receiver circuits.

Courtesy Espey Mfg. Co., Inc.

heater, and the source of electrons is an "indirectly heated" emitter. Called a **cathode**, this type of emitter is made of metal coated with an oxide just the same as the directly heated types. However, it is in the form of a cylinder which fits snugly around

A high vacuum, half-wave rectifier tube commonly employed in high voltage power supplies. Courtesy RCA

the heater. The heater itself consists of a tungsten or tungsten-alloy wire which is coated with an insulating material.

The constructions of two types of indirectly heated emitters are shown in the cutaway views of Figure 3. In Figure 3A the heater is wound in a double spiral, that is, the wires are twisted about each other. Figure 3B is a folded heater. Different companies hold patents for, or favor one of these two methods.

Usually, individual supports, which are good conductors, are provided for the heaters and the associated cathode. These pass through the base of the tube to the connecting pins below so that the electric circuits of each may be entirely separate.

PLATES

Since the prime purpose of the **plate** or **anode** of a tube is to collect the free electrons, usually it is constructed in the form of a cylinder, like those illustrated in Figure 4, and mounted inside the bulb or envelope so as to completely surround the emitter. As a result, all electrons emitted from the cathode are attracted directly to the plate when it is positive with respect to the cathode. Usually, nickel, iron, molybdenum, tantalum, or various alloys of these metals are used for the plate material. Not only do these metals produce a rigid plate capable of dissipating heat, but they also show very poor electron emission characteristics even when the plate becomes quite hot.

THE DIODE

An electron tube containing an emitter and a plate or anode is called a **diode**. The prefix "di"

Used in industrial electronics, these cylindrical diode tubes are capable of controlling large quantities of electric power.

Courtesy Westinghouse Electric Corp.

comes from the Greek language meaning two, and "ode" is a contraction of the word electrode. Thus diode literally means a two-electrode tube. However, a diode tube may contain a heater, cathode, and plate because the heater and cathode function as one electrode although they are two separate elements.

Construction

As shown in Figure 5A, a modern diode tube is constructed internally so that the heater is surrounded by the cathode which in turn is surrounded by the plate. Connections from the external circuit are made to the tube elements by metal pins which extend through the bottom or base.

When assembled with the bulb in place, some tubes of this type have the general appearance of Figure 5B, with a base pin arrangement as pictured in the bottom view of Figure 5C. Notice that the pins are numbered from 1 to 7 in the clockwise direction starting with the pin after the wide gap. Not only does the gap indicate where the pin numbering starts, but also makes it difficult to insert the tube into a socket in a wrong position.

Figure 5D is the schematic diagram symbol used to designate a diode tube. The circle represents the shell or "envelope", the inverted "T" indicates the plate, an inverted "V" or "W" designates the filament or heater, and the cathode is represented by an inverted "L".

Often adjacent to each element in the symbol, a number is added to indicate which base pin it connects to. Thus, when used in a diagram the symbol indicates the type of tube, the electrodes it contains, their connections to the external circuit, and the numbered base pins.

Operation

The operation of a diode is illustrated in Figure 6. Here, the emitter is of the directly heated type, and is supplied heating current from the battery E_f. E_f is the standard symbol for the heater or filament voltage. In Figure 6A, arrows indicate the path of this current, the complete circuit of which is called the "filament circuit". Heated to a high temperature by the battery current, th emitter "boils" electrons off into the surrounding space. After the circuit has been on for a moment, the emitter is left with a shortage of electrons, or a positive charge, which attracts the electrons back, and at any given emitter temperature, the number pulled back is equal to the number emitted.

Therefore, in the area surrounding the emitter, there is a cloud of electrons, some of which are moving away and others of which are moving toward the emitter. This electron cloud is known as the **space charge.** With no external connection, the plate has no effect on the space charge which builds up to a density determined by the emitter's temperature.

When the plate is connected to a source of voltage, such as battery E_{bb} in Figure 6B, and the emitter connected to the opposite terminal of the same source, a difference of potential is produced between the emitter and the plate. With E_{bb} connected as shown, the plate is made positive with respect to the emitter. Under these conditions, an electric attraction is set up between the two elements. The negative electrons in the space charge are attracted by this positive voltage on the plate.

Collected at the plate, the electrons pass through the external lead to the positive terminal of battery E_{bb}. With the plate taking electrons from the space charge, there are fewer electrons available to return to the emitter than are being given off. Hence, there is a net loss of electrons by the emitter, and a positive charge begins to build up on it. To replace those lost to the plate, and also prevent the emitter from acquiring a positive charge of any appreciable size, electrons flow to it from the negative terminal of E_{bb}.

Thus, a complete path is provided for electron flow from the emitter to the plate inside the tube, and in the external circuit, from the plate, through E_{bb} to the emitter. Indicated by the arrows in Figure 6B, this path is called

A high vacuum, full-wave rectifier tube of the type employed in a-c operated power supplies.
Courtesy RCA

the "plate circuit", and the electron flow is known as the **plate current.**

The difference of potential between the emitter and plate is called the **plate voltage.** *Usually the emitter (filament or cathode) is employed as the reference point for voltages in electron tubes.*

Each element contained in the tube is considered either positive or negative (or zero) with respect to the emitter. In Figure 6B, the plate voltage is said to be positive, because the plate is positive with respect to the emitter.

The number of electrons drawn from the space charge to the plate, and hence the size of the plate current depends upon the plate voltage. As the plate voltage is increased, the plate current increases until a point is reached at which the plate is taking ALL the electrons given off by the emitter.

Raising the plate voltage above this value does not cause any further increase of plate current at the given emitter temperature. This maximum is called SATURATION CURRENT, and the plate voltage necessary to produce it is called the SATURATION VOLTAGE. Since the plate current does not increase after the saturation voltage has been reached, this condition is known as PLATE SATURATION.

On the other hand, if the plate voltage is held constant in the diode circuit of Figure 6B, and the emitter temperature is raised by increasing E_f voltage to produce a larger current in the filament circuit, more electrons are emitted to increase the density of the space charge. With more electrons available, a larger number are attracted to the plate. Thus, the plate current increases even though the plate voltage remains constant.

However, as the emitter temperature is raised, eventually a point is reached at which the repelling force of the negative space charge is so great that it prevents any further increase in emission. For a given plate voltage, the particular emitter temperature above which the plate current does not increase is called the "saturation temperature". This condition is known as CATHODE SATURATION.

If a negative voltage is applied to the plate of a diode, by connecting the battery E_{bb} with the polarity as shown in Figure 6C, then the negative electrons are repelled. Under these conditions, no electron flow occurs in the region between the space charge and plate, and so no current exists in the plate circuit regardless of the plate voltage or emitter temperature.

If the diode plate were capable of emitting electrons, the connections of E_{bb} in Figure 6C would result in plate current in the reverse direction of that indicated by the arrows in Figure 6B. However, since the cathode material was selected for its good electron emission ability and the anode material has poor emission characteristics, emission takes place only from the filament or cathode. Therefore, the diode conducts plate current ONLY when the plate is more positive than the emitter as in Figure 6B.

A very good picture of how a diode is used can be had by first looking at a circuit without a diode and then use the same circuit with a diode inserted. In Figure 7A are two batteries, E_1 and E_2, and each has 3 volts. However, due to the way they are connected, it is possible to produce a current in opposite directions through resistor R. When the switch is in position 1 as shown, the positive end of battery E_1 is connected to the upper end of R_1 and the negative end is connected to the lower end. So long as S is in position 1, E_2 does not make a complete circuit with R since only the lower end is connected to the resistor. Electrons flowing from the negative terminal of E_1 flow to the right and up through R, as indicated by the solid arrow, and back through the switch to the positive terminal of E_1 to produce current I_1. For this condition the voltage across R is the same as E_1. Using Point A as the reference, this would be a +3 volts across R.

By repeating this procedure with switch S moved to position 2, E_2 is connected into the circuit instead of E_1. Due to the reverse polarity of E_2, electrons flow from its negative terminal, through the switch, down through R, and back through point A to the positive terminal. This current is represented by arrow I_2. Now with respect to A, the voltage is −3 volts across R.

A picture of what happens to the voltage across R as the switch is moved back and forth is shown in Figure 7B. If we start at Position 1 we have +3 V on resistor R and this remains until the switch is changed. If the switch was held in position 1 for 5 seconds, a horizontal line at 3 units above the base line indicates that all during these 5 seconds the voltage remained at +3 volts. At the end of 5 seconds if the switch were flipped to position 2, a vertical line from the +3 down to the −3 below the line would indicate that the voltage across R changed from +3 to 0 and down to −3 so quickly that no lapse of time could be indicated. Now if the switch was held in this position for another 5 seconds until 10 seconds have gone by, a horizontal line would show a −3 volts on the resistor for every instant of these 5 seconds. Now switching back to Position 1 would reverse the voltage across R. If the switch was moved back and forth after each 5 seconds we could continue to draw the vertical and horizontal lines as shown. This heavy line is called the WAVEFORM of the voltage across R. Using this plan, the distance across the page indicates the time and the distance of the waveform above or below the zero voltage reference line indicates the voltage for each time instant. For example, at 7 seconds the voltage across R is −3 volts, after 9 seconds it is still −3 volts, but after 14 seconds it is +3 volts.

A high voltage rectifier used in television receivers. The plate connection is through the cap on top.

Courtesy CBS-Hytron

One of the very important applications of the diode is shown by the circuit in Figure 8A. This is the same circuit as Figure 7A except that diode V has been inserted between the switch S and resistor R. The battery E_f does nothing except furnish power for the heater of tube V.

With the switch in Position 1 as shown, battery E_1 applies a positive voltage to the plate of V. Since the negative terminal is connected to the cathode through resistor R, electrons flow from this negative terminal up through R, by emission from the cathode to the plate of tube V, and then back through switch S to the positive terminal of battery E_1. So long as this is true the voltage across R would be nearly +3 volts with respect to point A.

However, when the switch is in Position 2 no electron flow would occur since the negative terminal of E_2 connected to the plate of V would make the plate negative with respect to the cathode. As explained for Figure 6, no electrons are emitted by the plate. Therefore, for Position 2 of the switch the voltage across R would be zero.

The wave-form for the voltage across R in this type of circuit is shown in Figure 8B. For the first 5 seconds, almost the same situation exists as pictured in Figure 7B. However, the voltage across the resistor R and the small voltage that appears across tube V are in series. Therefore, the total of these two voltages must add to equal the applied voltage. As a result, the voltage across the resistor which we can label as E_R is always a little less than the applied voltage E_1. In Figure 8B this is represented by having the solid line wave-form for E_R slightly below the dotted line for E_1.

From 5 to 10 seconds with the switch moved to Position 2 no current is possible and so the voltage across the resistor would be zero. This is indicated by the heavy wave-form line directly on the zero reference line during the time that E_2 is shown at -3 v by the dotted line. After 10 seconds, if the switch is flipped back to Position 1, across R again would be almost $+3$ volts.

From this wave-form it is easy to see that no negative voltage ever appears across the resistor in Figure 8A. It is always about $+3$ volts or zero due to the action of the diode. When a diode is used to take an alternating voltage as pictured in Figure 7B and convert it to a direct voltage as shown in Figure 8B, it is called a rectifier and the process is called rectification.

Although an alternating voltage and current is produced in Figure 7A, by flipping the switch back and forth, it is not a practical means of doing so. In power stations throughout the country, large rotating machinery called alternators develop an alternating current which is conducted by wires to factories, stores, and homes for use.

However, the wave-form for this alternating voltage is not like Figure 7B. Instead it continually changes in value as shown in Figure 9. Starting at zero it builds up to a peak which is shown here as $+3$ volts. Then it decreases through zero and goes negative to a -3 volts. Finally after 10 seconds it returns to zero. In this case each successive instant of time has a slightly different voltage. Although we show a wave-form that goes through a complete "cycle" of events in 10 seconds, the voltage most often encountered goes through this same cycle 60 times per second and, instead of 3 volts, from $+165$ volts to -165 volts.

As shown in Figure 10, frequently a source of alternating voltage is shown as a circle with the wave-form inside and labeled E_A. This symbol serves the same purpose for alternating voltages as a battery symbol does for direct voltages.

BASIC RECTIFIER CIRCUIT

Figure 10 also shows how a diode rectifies this type of alternating current. The a-c source, represented by its circle, the rectifier V, and the load or equipment using the power which is represented here by resistor R_L

all form a series circuit. Although the heater for V is not shown in the tube symbol, it is assumed to be there. It is left out of many diagrams because it is a complete

Note the large metal surface which is the plate in this octal type rectifier popularly used in TV receivers.

Courtesy CBS-Hytron

circuit in itself and does nothing more to the circuit than heat the cathode.

In operation, the alternating voltage E_A makes the plate of tube V alternately positive and negative with respect to the cathode. Whenever E_A makes the plate of the rectifier positive, the tube permits current in the circuit in the direction of the arrows. This current produces a voltage E_L across resistor R_L. The polarity of E_L is indicated by the "+" and "−" signs. When the applied voltage E_A makes the plate of the tube negative, the tube does not conduct. Then, with no current in the circuit, there is no voltage across R_L. Thus, by allowing current in the direction of the arrows only, the rectifier tube converts the alternating applied voltage to a direct voltage across the load resistor R_L. That is, there is a voltage as indicated across R_L when V conducts, but no voltage across this resistor when V is not conducting.

The load voltage E_L varies as shown by the solid line curve in Figure 11. Here, the dashed line curve indicates the variations of E_A with respect to Point 1 in Figure 10, and with respect to this same point, the solid line curve shows that E_L consists of a series of positive "pulses" having the same shape as the positive portion of the wave-form. Since the voltage E_L and a small voltage across tube V are in a series circuit with E_A, E_L will be slightly less than E_A. This is shown in Figure 11 by having the solid line for E_L slightly below E_A.

AN ELECTRONIC POWER SUPPLY

So far we have shown how a diode converts an alternating current into a d-c current. However, Figure 10 is not the complete circuit usually found in practical equipment. Several other components are needed. These include an a-c source, transformers, capacitors, resistors, and frequently two diodes in one tube envelope V_6 as shown in Figure 12. Although all of these components are used in many different circuits, one of their important applications is the power supply shown in Figure 12.

As shown by the solid symbol for V in Figure 12, the basic action of these diodes has been described. The remainder is printed in broken lines to show that they need to be described yet. To understand fully how this circuit works, we must learn more about each of these components.

It so happens that the machinery used to generate a-c at the power station and transformer T_6 both depend on the action of magnetic fields on a wire. Therefore, in order to understand how these work, the next lesson describes magnetism and some of its important characteristics.

IMPORTANT DEFINITIONS

ANODE—[AN ohd]—See Plate.

CATHODE—[KATH ohd]—In an electron tube, that electrode from which the electrons are emitted or liberated.

DIODE—[DIGH ohd]—A two-electrode tube.

ELECTRON EMISSION—[i LEK trahn i MISH 'n]—The escape of electrons from the surface of certain materials.

ELECTRON TUBE—[i LEK trahn too : b]—An arrangement of two or more conductive elements, enclosed in an evacuated envelope, which can control the electron flow in a circuit.

FILAMENT—[FIL un muhnt]—In an electron tube, a heating element that also serves directly as the emitting cathode.

HEATER—In an electron tube, the element that supplies the heat to an indirectly heated cathode.

PLATE—In an electron tube, that electrode toward which the main movement of electrons takes place. Also called the anode.

PLATE CURRENT—In an electron tube, the electron flow from cathode to plate. In the external plate circuit, the electron flow from the plate, through the circuit, to the cathode.

PLATE VOLTAGE—In an electron tube, the difference of potential between plate and cathode.

RECTIFICATION—[rek ti fi KAY sh'n]—The process of converting a-c to d-c.

RECTIFIER—[REK ti figh er]—A device that converts a-c into d-c by permitting a relatively large current in one direction, and zero or negligible current in the other.

SPACE CHARGE—In an electron tube, a cloud of free electrons surrounding the cathode.

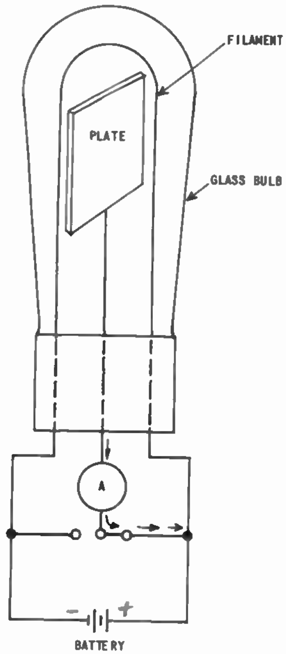


FIGURE 1

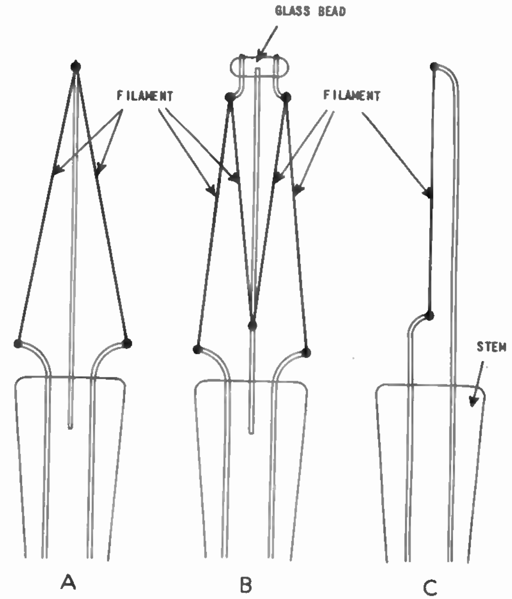


FIGURE 2

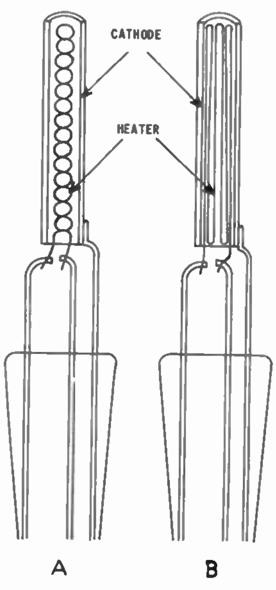


 FIGURE 3

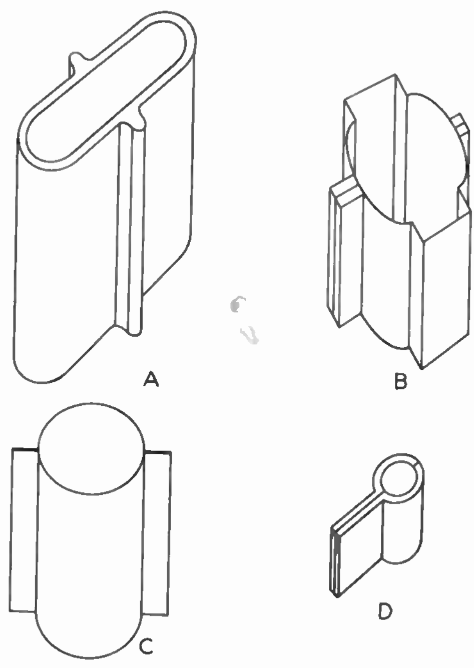


FIGURE 4

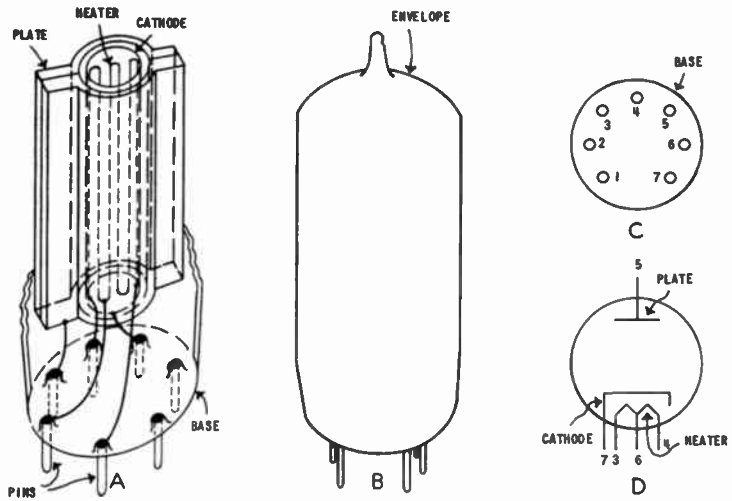


FIGURE 5

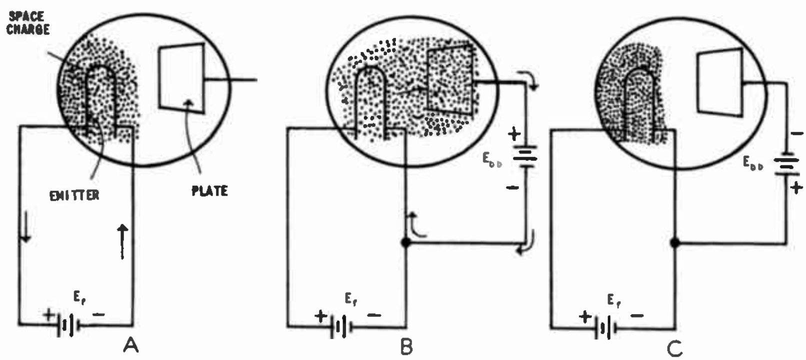
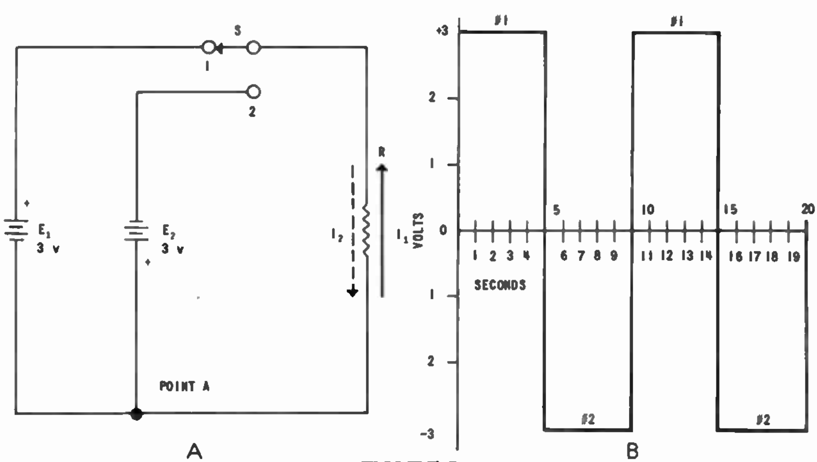
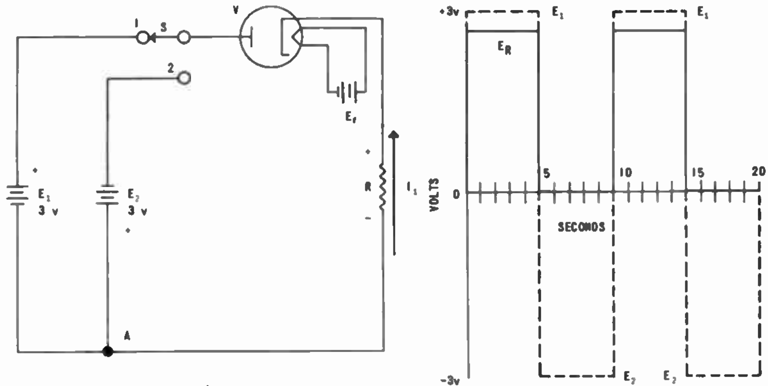


FIGURE 6



AEH-6

FIGURE 7



A

B

FIGURE 8

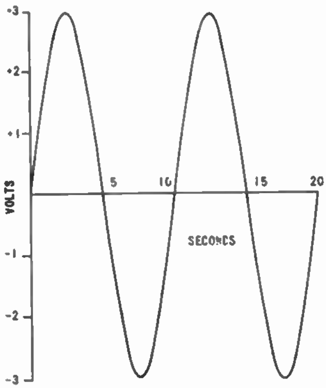


FIGURE 9

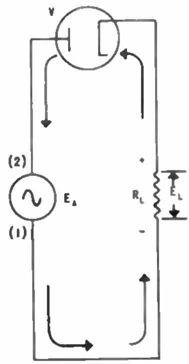


FIGURE 10

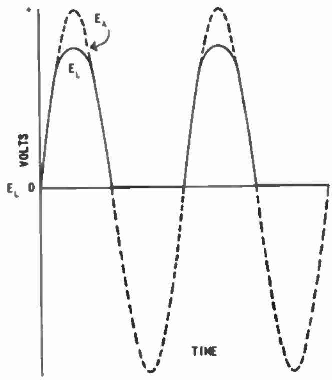


FIGURE 11

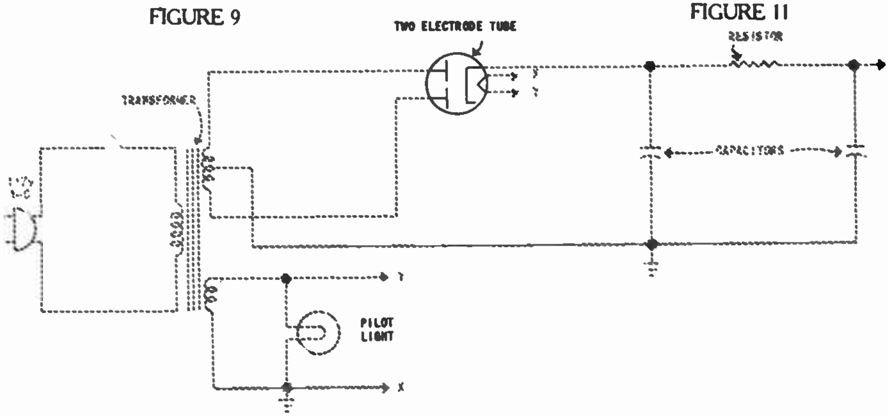


FIGURE 12

FROM OUR *Director's* NOTEBOOK

MONEY IN GADGETS

For the man who can think and scheme, a successful business frequently springs up from some simple idea. Many a fortune has been made on small gadgets that originally were intended merely as a personal convenience.

If we check through our Government patent files, we will find some patents that have been issued on rather complex mechanisms and processes, but we will also find a much larger number that protect only some little device that is simplicity in itself. But by its very simplicity it represents an original idea, and further it is this simplicity that makes the idea useful and valuable.

No one can see into the future, but there certainly are numerous devices and gadets that could be applied to radio and electronic equipment to increase its range of usefulness. With 100 million radio sets in use, such a practical gadget would find a big market. Yes, opportunity still lies ahead.

Yours for success,

W. C. De Vry

DIRECTOR

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MAGNETS AND ELECTROMAGNETS

Lesson AEH-7A

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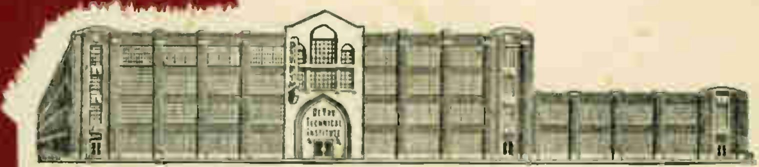


4141 Belmont Ave., Chicago 41, Illinois

DEVRY TECHNICAL INSTITUTE

FORMERLY DE FOREST'S TRAINING, INC.

MAGNETS AND ELECTROMAGNETS

ELECTRONS GUARD FIRE HAZARDS

Should a sudden blast of wind blow out the pilot light on a modern gas burner, a valve snaps shut to prevent gas asphyxiation or an explosion. Thus, no longer are these burners the hazard they used to be, and the improvement is due to the incorporation of an electronic device called a thermocouple. So long as it is heated by the burning pilot light, the thermocouple generates an electric current that energizes a solenoid which locks the valve open. When the pilot light is out, no current is generated, and the valve remains closed.

In addition to this use, thermocouples are employed to measure temperatures, control furnaces and ovens, actuate fire alarms, and operate various other types of thermal-safety devices.

MAGNETS AND ELECTROMAGNETS

Contents

If you wish your merit to be known, acknowledge that of other people.

—Oriental Proverb

MAGNETS AND ELECTROMAGNETS

Magnets and electromagnets have a multitude of uses—every electric motor and generator requires a very strong magnetic field for its operation and with the exception of a few special types, all use electromagnets. Many headphones and loudspeakers have electromagnets, and their operation depends on changes of the electric current in their winding or coil. Corresponding variations in the strength of the magnetic field cause a headphone diaphragm or speaker cone to vibrate and set up sound waves which reproduce the voice or music being broadcast by radio.

Telegraph instruments use electromagnets to attract a movable arm that produces the clicking noises by which messages are received. Such movable arms are called armatures.

Mounted on cranes and hoists, very large electromagnets are used to lift large pieces of iron or steel. These magnets can hold several tons of metal, and are used extensively in foundries, machine shops, and steel mills for loading and unloading cars, or moving metals to various parts of the shop.

Magnets are found in practically every electronic application. For instance, in a small table model radio, there is at least one and in a color television set, there may be as high as a dozen. This does not include the parts which depend upon magnetic effects. If we include these, a typical radio would have about six and a color television receiver at least thirty.

MAGNETIC MATERIALS

The exact nature of magnetism is not known, but a careful and thorough study of magnets and their actions shows that all materials are affected to some extent when brought close to a strong magnet. By testing all the known substances, it has been found that iron and steel are affected very strongly, cobalt and nickel to some extent, while all the others only slightly. In fact, the difference is so marked that iron and steel are called magnetic substances or ferromagnetic, the prefix "ferro" being taken from the Latin word "ferrum" which means iron.

The magnetic effect on iron is so much greater than that on cobalt and nickel, that iron is the only magnetic element which by itself is of commercial importance. However, certain combinations or alloys of iron, cobalt, and nickel are in common use because of their superior magnetic qualities.

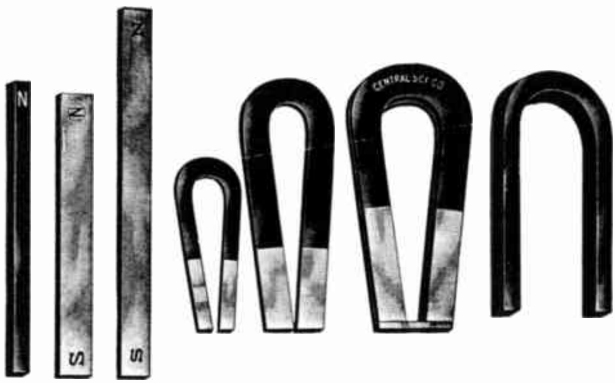
NATURAL MAGNETS

Any magnet found in a natural state is known as a "natural" magnet. Deposits of magnetic ore have been discovered at various places, one of the largest being in Labrador. Pieces of this magnetic ore, known as "magnetite", are natural magnets. The earth itself is considered as a huge natural magnet because it possesses the same properties as smaller magnets. This makes possible navigation by means of a compass.

ARTIFICIAL MAGNETS

Due to their irregularities in size, shape, and strength, natural magnets have little commercial value. When held in contact with a magnet, a piece of steel becomes a magnet, and by the proper treatment called aging, it can be made to keep its magnetism almost indefinitely. For this reason, when properly magnetized and treated, a piece of steel is called a permanent magnet.

While almost any kind of steel can be made into a permanent magnet, some of the alloys mentioned earlier can be magnetized more strongly than ordinary steel. The most popular magnetic alloy that is used today for permanent magnets is "alnico", an alloy of pure iron, aluminum, nickel, and cobalt. By using these metals in different percentages, various magnetic qualities can be imparted to the alloys. Some of the important applications of such alnico permanent magnets are parts for television, radar equipment, and electron measuring instruments.



An assortment of horseshoe and bar magnets. The one on the right is sometimes called a "U" magnet.

Courtesy Central Scientific Co.

When in contact with a permanent magnet, a piece of soft iron becomes magnetized as strongly as a piece of steel, but immediately after the magnet is removed, the iron loses practically all of its magnetism. Therefore a piece of iron, especially soft iron, is called a temporary magnet. Furthermore, since they do not occur in a natural state, all forms of magnetized steel and iron can be considered as artificial magnets.

MAGNET POLES

When a bar magnet is suspended or pivoted, it rotates to a general north and south direction,

A small magnetic compass. The blue end of the magnetized needle is the north seeking pole.
Courtesy Central Scientific Co.

with the same end always pointing toward the north. To illustrate this action, in Figure 1 a bar magnet is suspended by a string so that it swings readily. No matter which way it is pointed, when released the magnet always will come to rest pointing approximately north and south.

The end of the bar magnet that points toward the north is called the north pole, and the end that points toward the south, the south pole. Whenever a permanent magnet has its ends marked "N" and "S", these indicate its north and south poles.

MAGNETIC FIELDS

A magnet is capable of doing some surprising things. When placed close to one end of it, a small piece of iron, such as a nail, actually jumps a quarter of an inch or more to reach the magnet.

The fact that the iron jumps to the magnet shows very clearly that its magnetic effect extends for some distance around it. This area of influence in the space around the magnet is known as the **magnetic field**, which for convenience, is visualized as being made up of **magnetic lines** of force. The magnetic field extends outward around the magnet regardless of the materials in this space. Thus, glass, paper, air, or a vacuum present no opposition to magnetic lines of force.

A simple but effective method of making a magnetic field "visible" is to place a piece of ordinary glass over a bar magnet and then sprinkle iron filings on the glass. Under these conditions, the filings arrange themselves in definite lines to produce the general pattern shown in Figure 2A.

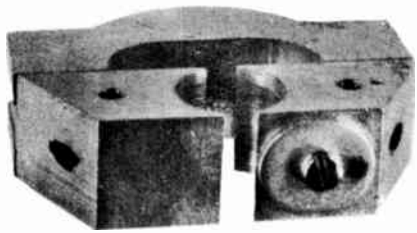
Notice that these lines appear to extend from the north to the south pole of the magnet. These are thought of as lines of force, and it is assumed that they leave the "N" pole and enter at the "S" pole, so that if fully drawn, each one will form a closed loop from "N" to "S" outside the magnet and from "S" to "N" within the magnet.

In thinking of the action of these lines, just imagine that they are small rubber bands, stretched quite tight. Under this condition the rubber bands will try to shorten or contract, and that is exactly what the magnetic lines try to do. Moreover, they crowd each other somewhat and try to push sidewise but never touch. Figure 2B is a perspective drawing illustrating that the magnetic lines are three dimensional, that is, entirely about the magnet. Figure 2C is the same magnet viewed from the end of the north pole. Although these magnetic lines extend indefinitely out into space, only a few are shown in the space near the magnet where the effect is strong enough to be useful.

In addition to providing a convenient means of explaining the action of a magnetic field, the theoretical lines of force also provide a means of measurement.

In practical work, magnetic fields have a comparatively large number of lines and are of all shapes and sizes. Therefore, they usually are described as having a certain number of lines per square inch, which means the number of lines that will pass through each square inch of a surface that is placed squarely across the magnetic field.

Because a given number of lines of force may be spread over a comparatively large field or compressed into a relatively small



This permanent magnet is used in electric meters. A small electromagnet is placed in the cylindrical opening between the poles of the magnet.

Courtesy Burlington Instrument Co.

field, it is necessary to know both the number of lines and the size of the area through which they pass. Thus, the number of lines passing through a given area is known as the density of the field.

To combine the number of lines and the area into a single unit, one line per square centimeter is called a gauss, in honor of the German physicist Karl F. Gauss (1777-1855). A centimeter is .393 inch. Thus, when a magnetic field has a density of 10,000 gausses, it means a magnetic field with 10,000 lines of force per square centimeter.

ATTRACTION AND REPULSION

Figure 3 shows the magnet mentioned earlier in the lesson, suspended on a string and left free to turn. It is marked with an "N" on the end that points north and an "S" on the end that points south, and to find out just how two magnets act toward each other, a second magnet is marked in the same manner.

To begin, the second magnet is held with the "N" end forward, and brought slowly toward the "N" pole of the magnet hanging on the string. As the two "N" poles approach each other, the magnet hanging on the string turns away from the magnet in the hand as indicated by the arrow. The action is the same as though the held magnet was actually touching and pushing the magnet on the string. However, since the magnets do not touch, it is the force of the magnetic field which causes the action.

Next, the held magnet is turned so that the "S" pole is forward, as shown in Figure 4, and again brought slowly toward the magnet on the string. Now the "N" pole of the hanging magnet turns toward the "S" pole as indicated by the arrow, and when close enough, swings over until the magnets touch.

For various applications, permanent magnets are fashioned into a wide variety of shapes and sizes. Pictured are a few representative types.
Courtesy General Electric Co.

If the "S" pole of the held magnet is moved toward the "S" pole of the magnet on the string, it will turn away exactly as it did when the "N" poles were brought close together.

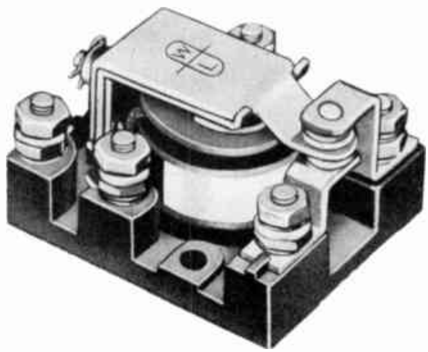
These simple tests prove one of the important laws of magnetism, which is: LIKE MAGNETIC POLES REPEL EACH OTHER AND UNLIKE POLES ATTRACT EACH OTHER.

This same action can be shown by using the plan explained for Figure 2A. This time two magnets are used and placed in line with their "N" poles about one inch apart. A piece of glass is then placed over the magnets and iron filings are sprinkled on the glass.

By gently tapping the glass, the filings will arrange themselves in lines which curve away from the end of each magnet as shown in the simplified sketch of Figure 5. It is customary to sketch magnetic fields on this plan because it is much easier than the drawing of Figure 2A, and yet it supplies the desired information.

By turning one of the magnets around as in Figure 6, and bringing a "N" and "S" pole about an inch apart when the filings are again sprinkled on the glass, they arrange themselves in almost straight lines right across the gap between the "N" and "S" poles. Think of these magnetic lines as always forming a complete circuit, similar to an electric circuit, except that they will pass through every known substance and travel from the "N" pole, out around to the "S" pole, and then back through the magnet to the "N" pole again.

With this in mind, Figure 5 shows that the magnetic lines of each magnet turn around toward



A typical relay. When current passes through the coil, the electromagnetic field attracts the armature directly above it. In moving down, the armature opens one contact and closes the other.
Courtesy Ward Leonard Electric Co.

its own "S" pole and have nothing to do with those of the other magnet. In fact, it looks as if they were trying to crowd each other out of the way. On the other hand, in Figure 6 the lines go straight across from the "N" pole of one magnet to the "S" pole of the other, and one magnetic circuit is completed through both of the magnets.

The action of a compass can be explained in a similar manner.

The earth is like a huge magnet around which there is a magnetic field. The north magnetic pole of the earth is near the South Geographic Pole and the south magnetic pole is located close to the North Geographic Pole. Therefore, when a compass needle is permitted to move freely in the earth's magnetic field, it will point in a general north and south direction by virtue of the attraction of unlike poles.

THE EFFECT OF DISTANCE

Going back to Figure 2A, the magnetic lines form complete loops which appear to meet at a point near each end of the bar. These points are the real poles of the magnet. The pull of the magnet on a piece of iron will change with the number of magnetic lines passing through it. Since the lines are concentrated at the poles, the closer to a pole a piece of iron is moved, the more magnetic lines will be passing through it, and therefore, the stronger the pull will be.

Looking at Figure 2A again, notice that as the lines leave the poles, they spread out in all directions, and if the piece of iron is moved further away from the pole, there will be fewer lines passing through it and the pull on it will be less. This reduction in pull changes quite rapidly, and Figure 7 shows the reason.

A piece of iron that is one inch square is placed one inch from the end of the magnet. Suppose there are 100 lines passing through this piece of iron. If another piece of iron is placed two inches away from the magnet, it cannot be less than two inches on each side in order to have these same 100 lines pass through it. The area of the second piece of iron is now 2 times 2 or 4 square inches.

Yet, for this greater area, the same number of lines are passing through it as through the one inch square. Therefore, only 25 lines pass through each square inch of the material. As a result, by doubling the distance the attraction is reduced to one fourth. To express it as a general statement, the strength of the fields decreases by the square of the distance from the starting point.

MAGNETIC INDUCTION

Experimenting further with magnetism it is found that when a piece of iron, such as a nail, is hung on the end of a magnet, it also becomes magnetized and attracts and holds a second nail. This one in turn becomes magnetized and will attract and hold a third nail. In fact, if the magnet is strong, a string of nails can be formed. However, no matter how carefully the magnet is removed from the first nail, the string falls apart instantly. Being made of iron, the nails are only temporary magnets which do not retain their magnetism.

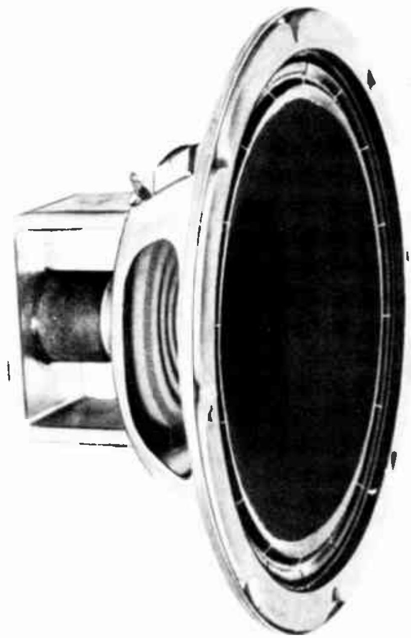
MOLECULAR THEORY OF MAGNETISM

Many actions of magnetism can be explained by the molecular theory. This theory states that all materials are made up of very small particles called molecules and, each molecule can be considered an extremely small permanent magnet with a N and S pole. In iron and steel, these molecules are stronger magnets than any of the other metals.

As shown in Figure 8 where the black end is a N pole and the other end is a S pole the molecules in the ordinary piece of iron or steel are not arranged in any particular order, and so their magnetic fields cancel out within the metal. However, since unlike poles attract each other, when the iron or steel is put in a strong magnetic field, the molecules all turn in one direction, as in Figure 9. Then the individual magnetic fields combine to make the entire piece of metal act as one large magnet, the N pole on the right and the S pole on the left.

RELUCTANCE

Because most of the molecules of soft iron turn quite easily under the influence of a magnetizing force, the overall magnetic effect is quite strong. In some other materials, very few or none of the molecules will turn because of the rigid structure of the material. In other materials the magnetic field for each molecule is quite small. In either of these cases, the total magnetic effect is very weak.



The cylindrical shaped metal inside the U-shaped frame at the rear of the speaker is a permanent magnet. The speaker also employs an electromagnet, not visible in this picture.
Courtesy Permoflux Corp.

Although magnetic lines of force will pass through all substances, some materials do not carry them as readily as others.

This opposition which a substance offers to the passage of magnetic lines is known as its **reluctance.**

Reluctance is a property of every material. Just as there is no perfect conductor, there is no material capable of passing all magnetic lines. However, for practical purposes, soft iron has a very low reluctance.

CHANGING THE MAGNETIC FIELD

Referring to Figure 10, when a bar of soft iron B is placed in the field of a permanent magnet M, the magnetic lines that pass through the iron cause it to become a temporary magnet having a N and S pole as explained for Figure 9.

Since soft iron offers less reluctance to the passage of magnetic lines than the surrounding air, the lines of force leaving the N pole of the permanent magnet are attracted by the S pole of the soft iron, and the lines leaving the N pole of the temporary magnet are attracted by the S pole of the permanent magnet. Thus, the magnetic field is pulled out of its natural shape.

Sometimes the path of a magnetic field is purposely changed as shown in Figure 11. So far as anyone knows, magnetic lines will pass through any material. In making up the magnetic fields with iron filings in the earlier part of this lesson, the magnet was placed under a piece of glass and iron filings were sprinkled on top. The glass, which was used as an electric insulator had no more effect toward insulating magnetism than the air itself.

To prevent magnetic lines from passing through any object, such as a watch, it is necessary to enclose it in an iron case. Being a magnetic substance iron carries the magnetic lines so much easier than air or other materials that, instead of passing through the watch, the field is distorted and passes around it through the iron. This arrangement is called a "magnetic shield", and as indicated in Figure 11, the space inside the iron shield has no magnetic lines passing through it.

TESTING MAGNETS

A very simple way of testing the strength of a permanent magnet is to place a bar of iron across its poles, and then by using a spring type of weighing scale, see how many pounds pull is required to remove the piece of iron.

Also, there are "fluxmeters" which are placed across the poles of the magnet to be tested and their action is very similar to the method explained above, except that the lines of the magnetic field pulls a pointer across a calibrated scale.

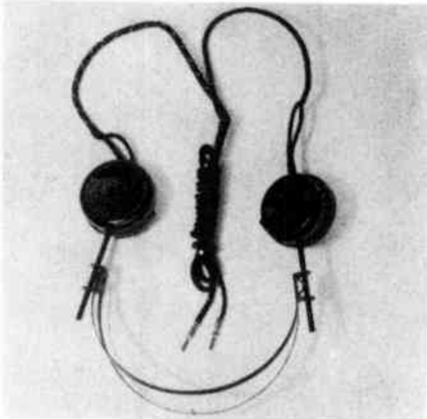
ELECTROMAGNETISM

It has been found that an electric current sets up a magnetic field much like that produced by a permanent magnet. This action, known as electromagnetism, is of extreme importance in a large percentage of electric and electron apparatus for it permits complete control of magnetic fields.

In order to demonstrate the existence and properties of a magnetic field that is produced by an electric current, the experiment shown in Figure 12 is used. A wire is forced through a piece of cardboard and connected to a voltage source so that electrons in the wire will flow from negative to positive, as shown by the vertical arrows.

If a magnetic compass is placed on the cardboard and is moved in a circular path around the wire, the compass needle no longer will point north and south. It changes direction continuously as the compass is moved about the wire. Since the compass needle is a small permanent magnet there must be a magnetic field present, other than the earth's field, which deflects the pointer in this manner.

When there is no current in the wire, the compass will point north and south regardless of its position on the cardboard. Therefore, it is reasonable to decide that it is the current and not the wire that produces the magnetic field.



A typical pair of earphones. Sound is produced when the electromagnets cause the thin steel diaphragms to vibrate.
Courtesy C. F. Cannon Co.

Similar to permanent magnets, the magnetic field intensity is greatest near the wire and decreases with the distance between the wire and the compass.

BEHAVIOR OF A COMPASS IN A MAGNETIC FIELD

Referring back to the laws of magnetism, if the magnetized needle of the compass is placed in a magnetic field, its N pole will turn away while its S pole is attracted towards the other N pole. The same effect will take place at the S pole, but in the opposite direction. The result is a double action, a pull on one end and a push on the other, and this double action causes the compass needle to line up with the magnetic lines of force in which it is placed.

When moved around the wire, as shown in Figure 12, the changing positions of the compass needle will trace a circle, therefore, the magnetic field around the wire is circular in shape. Raising or lowering the cardboard along the wire has no effect on the action of the compass, and it continues to trace a circle as it is moved around the wire.

This magnetic field around a straight wire can be visualized as a solid cylinder as shown in Figure 13. The magnetic field exists uniformly along the wire: that is, at two points the same distance away from the wire, the lines are equally dense.

MAGNETIC FIELD AROUND A WIRE CARRYING CURRENT

To continue this investigation of electromagnetic action, the connections of the circuit of Figure 12 are reversed so the electrons pass down through the wire. Now when the compass is moved around the wire, it still points a circle but in the opposite direction.

Thus, when the direction of electron flow is up through the wire in the cardboard, the compass needle points in a clockwise direction. When the circuit connections are reversed so that the electron flow is down through the wire, the compass needle reverses its direction and points in a counterclockwise direction.

LEFT THUMB RULE

The above actions show that there is a definite relationship between the direction of electron flow and the direction of the magnetic field it produces. It so happens that the thumb and fingers of the left hand can be used as a convenient means of determining this relationship. For example, as shown in Figure 14 BY HOLDING THE WIRE IN THE LEFT HAND, WITH THE THUMB POINTING IN THE DIRECTION OF THE ELECTRON FLOW, THE FINGERS WILL SURROUND THE WIRE IN THE SAME DIRECTION AS THE MAGNETIC FLUX. This is called the "Left Thumb Rule".

This simple rule is very useful, because if the direction of the electron flow is known, the direction of the magnetic field can be found; or should the direction of the magnetic field be known, the direction of the electron flow can be determined.

MAGNETIC FIELD AROUND A COIL

To continue with the investigation, the wire of Figure 12 is taken out of the cardboard and bent into a loop as in Figure 15.

Using the left thumb rule, when the electron flow is in the direction shown by the arrows, the fingers point around toward the inside of the loop no matter on which part of the wire the hand is placed.

magnetic compass is moved around the inside and outside of the coil, it will indicate that the magnetic lines surrounding each turn of the wire separately, appear to combine into one continuous magnetic field of the form and

A wire recorder utilizes an electromagnet which magnetizes a special type of iron wire. Although easily magnetized the wire retains the magnetism. Note the extra spools of wire in the cover.

Courtesy Webster-Chicago Corp.

To investigate still further, the wire is bent into several loops, or a "coil", as in Figure 16, and then connected to an electric circuit that carries electrons in the direction of the large arrows. If a

in the direction shown by the light broken lines.

Note that this flux is similar to that set up by a permanent magnet, with the N pole at the upper end where the compass shows the magnetic lines coming out of the coil. So long as current exists, the coil acts like a permanent magnet. It has an N and S pole; and, if free to turn in a horizontal plane, the coil will come to rest pointing North and South.

LEFT-HAND RULE

As with the straight wire in Figure 12, there is a definite relation between the direction of the current and direction of magnetic flux around a coil. As shown in Figure 17, WITH THE FINGERS POINTING AROUND THE COIL IN THE DIRECTION OF THE ELECTRON FLOW, THE THUMB WILL POINT TOWARD THE N POLE OF THE MAGNETIC FIELD.

This is called the "Left-hand Rule", and can be used whenever the wire is looped or coiled, and the direction of electron flow is the same through its entire length.

In a coil like that of Figure 17, it has all the magnetic qualities of a permanent magnet so long as current exists. Moreover, an increase of current in the coil increases the strength of the magnetic field, and a decrease of current weakens the field.

AMPERE-TURNS

When the number of loops or turns of the coil is increased, but the current remains the same, the strength of the magnetic field will increase. Each loop or turn of the coil sets up its own magnetic field which unites with the fields of other loops. Hence, the more loops, the more magnetic fields unite and reinforce each other, and as the result, the total magnetic field is stronger.

To compare the magnetic strength of different coils, and to obtain a basis for measuring them, it is useful to multiply the number of turns of wire by the number of amperes of current carried by the wire and call the result **ampere-turns.** For example, a coil with 10 turns and a current of 10 amperes will have 100 ampere-turns. Another coil with 50 turns and a current of 2 amperes also will have 100 ampere-turns.

EFFECT OF AN IRON CORE IN A COIL

Earlier in this lesson, it was stated that iron and steel have low reluctance and carry magnetic lines of force much more readily than air and other materials. To increase the magnetic field of a coil, it is common practice to insert a piece of iron through the center of the coil like that shown in Figure 16. The iron is called the **core,** and its low reluctance permits many more magnetic lines of force than the air could possibly carry. The complete assembly of a coil with an iron core is called an **electromagnet.**

The magnetic behavior of a coil carrying an electric current can be summed up in the following three statements:

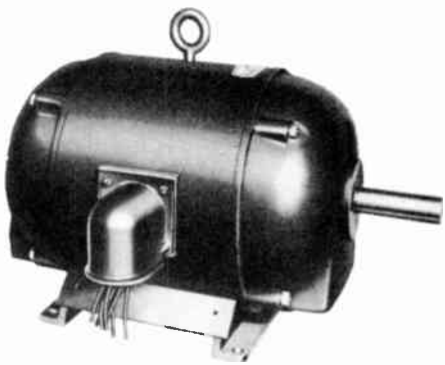
1. *Whenever a current of electricity is present in a coil of wire, a magnetic field is set up in and around the coil, which then exhibits all the properties of a magnet.*
2. *The strength of the magnetic field varies with the number of turns and the current. With no current, there is no magnetism.*
3. *An iron core placed inside the coil, permits a large increase in the strength of the magnetic field.*

MAGNETIC CIRCUITS

Magnetic action is understood better by thinking of the paths taken by magnetic lines of force in much the same way as the current paths in an electric circuit. In an electric circuit, pressure or voltage overcomes the resistance of the conducting path and sets up a current of electricity. In a **magnetic** circuit similar conditions exist, but instead of a voltage, there is a **magnetomotive force** (mmf), which causes magnetic lines through the circuit.

The opposition which the magnetic circuit offers to this flux is known as reluctance. Electrically, nearly all materials have different resistance characteristics some offering little and others high opposition to an electric current. However, with the exception of the magnetic metals, most substances offer nearly equal reluctance. Iron has low reluctance, while air and other nonmagnetic materials have high reluctance.

In comparing the magnetic circuit with an electric circuit; there is an mmf instead of voltage, lines of force, or flux lines instead of current, and reluctance instead of resistance. The relationship between voltage, and current, and resistance in the electric circuit and the relationship between mmf, lines of force, and reluctance in the magnetic circuit are very similar. Just like



This motor depends on electromagnetism for its operation. The attraction and repulsion between the magnetic poles causes the armature to rotate.

Courtesy Robbins and Meyers, Inc.

voltage is equal to current times resistance, magnetomotive force is equal to the flux times the reluctance.

USES OF ELECTROMAGNETS

In general, whenever it is desired to produce mechanical motion by means of electricity, some form of electromagnet is used. In almost every instance, the part to be moved is made of magnetic material and placed quite close to the electromagnet. This is done because the pull of a magnet is inversely proportional to the square of the distance between it and the attracted object.

The common door bell is a good example of the use of an electromagnet to produce mechanical motion. In Figure 18A a bell of this kind is shown with the cover removed to expose the main parts that are named in Figure 18B. Starting at the top, you will see the "gong" or bell proper, while directly below it is the armature which has a small ball or "hammer" attached to its upper end.

The coil of wire for the electromagnet is wound on a cylindrical iron core that is riveted to the center of a "U" shaped iron frame. The armature extends across the open end of the "U" of this frame, and is held in position by the spring which is riveted to both the armature and the frame.

The upper end of the spring is bent away from the armature, and carries a contact which is in line with another contact mounted rigidly on the main base, but electrically insulated from it. The spring tension is in a direction to pull the armature away from the frame and to hold the contacts together as shown in Figure 18A.

There is an electric circuit from the right hand binding post, up through the turns of the coil and over to the stationary contact. As the spring holds the contacts together, the circuit continues through the spring to the left hand binding post. To simplify the drawing, only a few turns of wire are shown in the coil, but actually several hundred turns are employed to fill the entire spool. The larger number of turns provides a great number of ampere-turns at low currents and thus provides a more satisfactory operating condition.

To put the bell into use, it is connected in an electric circuit which contains a source of voltage and a push button type of switch. When this circuit is closed by means of the switch, the resulting current is carried by the coil which sets up a magnetic field across the open end of the U-shaped magnet frame.

Since the iron armature is located in this field, it will be attracted and move toward the frame as soon as the magnetic pull is strong enough to overcome the tension of the spring. When this happens, the armature moves from the position shown in Figure 18A to that shown in Figure 18B.

The movement of the armature does two things. First, the ball on its upper end strikes the gong and causes the bell to ring. Second, the contact on the upper end of the spring no longer touches the stationary contact, and consequently the circuit is opened. As soon as the circuit is opened, the current is interrupted, the magnetic field dies out, and the spring pulls the armature back to the position of Figure 18A. The instant the contacts touch, the circuit is completed, it again carries current, and the entire action is repeated.

The movement of the armature is quite rapid, and therefore, so long as the push button switch is held closed, the armature vibrates with the hammer on its upper end striking the gong each time the magnet pulls it over. While the door bell is a simple example, it illustrates one common method by which the electric current in a coil is converted to a magnetic energy that attracts an armature and causes mechanical motion.

Magnets and electromagnets also are used in reverse. Instead of converting electric power to motion, by using a magnetic field mechanical motion is converted into an alternating voltage or alternating current. Upon this basis the 117 v. a-c is generated both for your house and almost all the equipment used in electronics. A device commonly called a generator performs this action, and how it works is described in the next lesson.

IMPORTANT DEFINITIONS

AMPERE-TURN—(NI)—A unit of magnetomotive force or magnetic excitation, equal to the effect of a current of one ampere through one turn of wire.

CORE—A piece of magnetic material that is inserted through the center of a solenoid to provide a low reluctance path for the magnetic lines of force.

ELECTROMAGNET—[i *lek* troh MAG net]—A coil of wire, wound on an iron core, that exhibits magnetic qualities when it carries an electric current.

GAUSS—[gous]—A unit density equal to one line of force per square centimeter.

MAGNET—[MAG net]—An object that exhibits the property of magnetism.

MAGNETIC CIRCUIT—A closed path of magnetic flux.

MAGNETIC FIELD—The space around a magnet in which the magnetic force can be noticed.

MAGNETIC LINES—(Φ)—Those lines around a magnet along which the magnetic force appears to manifest itself.

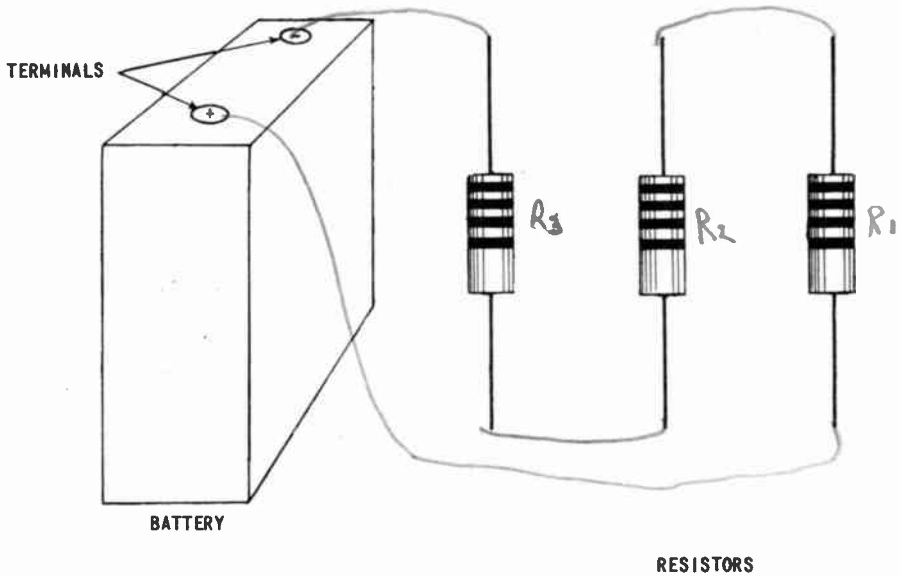
MAGNETISM—[MAG ne tiz'm]—A property possessed by iron and its compounds, when in a certain condition, by which it can exert mechanical forces on neighboring masses of iron.

MAGNETOMOTIVE FORCE (mmf)—[mag *nee* toh MOH tiv fawrs] —The exciting force required to set up magnetic flux within an object.

RELUCTANCE—[re LUK tans]—The opposition experienced by the magnetic flux set up within an object. It corresponds to resistance in an electric circuit.

WORK DIAGRAM

Draw pencil lines to represent wires connecting the battery and resistors in a series circuit.



When you have finished, check with the answer on the back of the fold-out sheet.

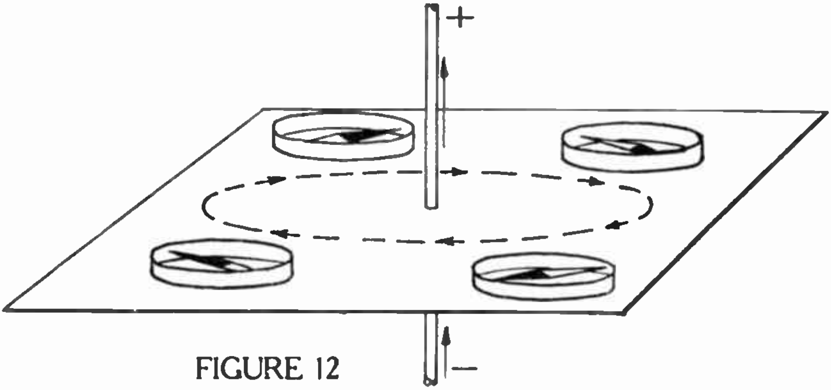


FIGURE 12

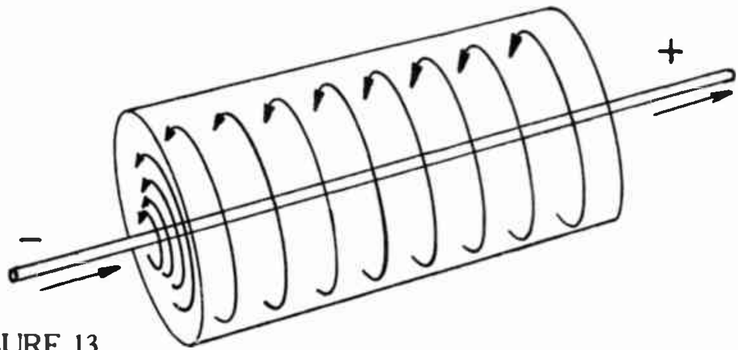
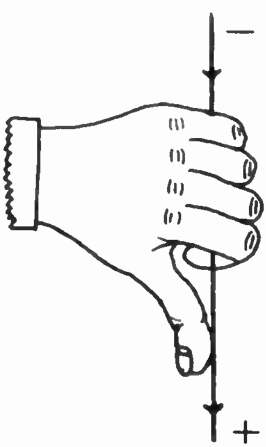


FIGURE 13



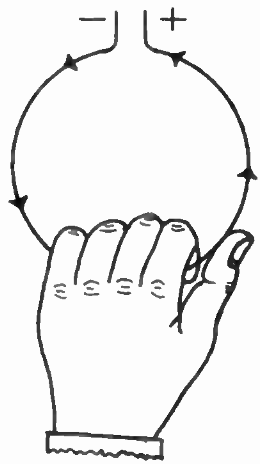


FIGURE 14

FIGURE 15

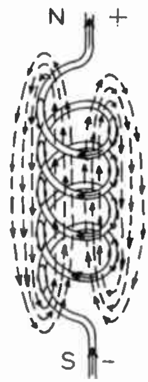


FIGURE 16

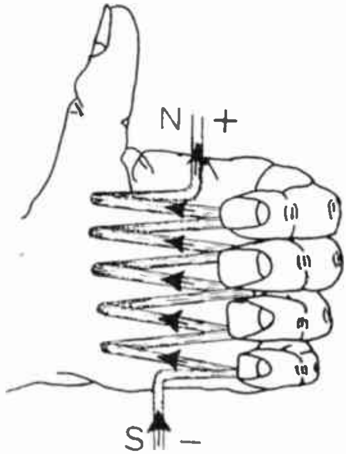


FIGURE 17

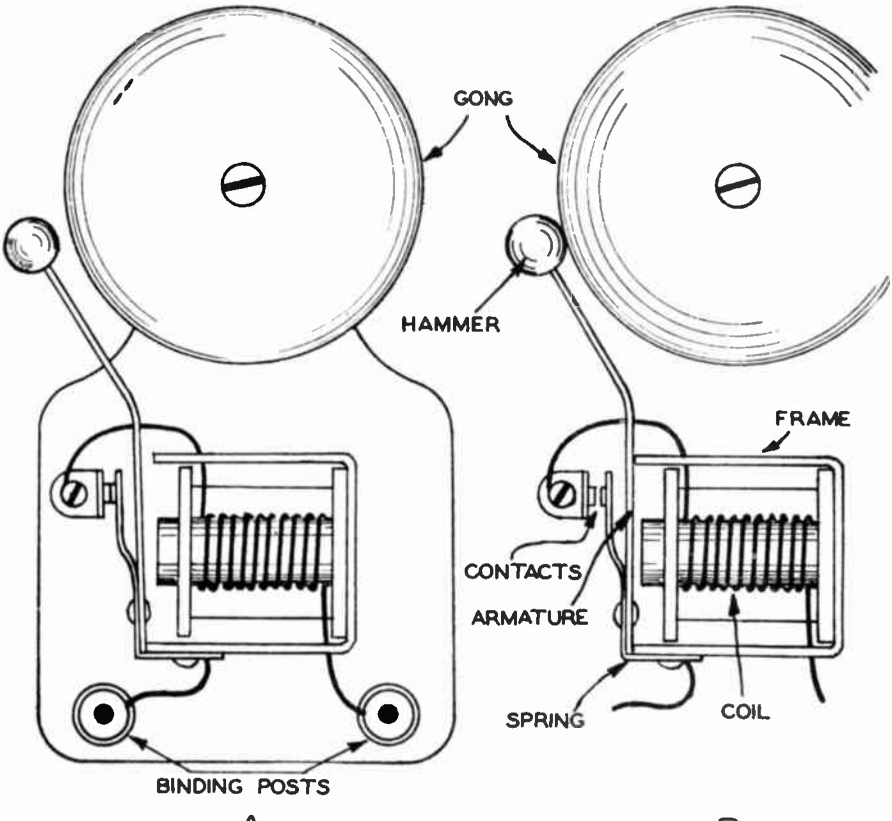


FIGURE 18

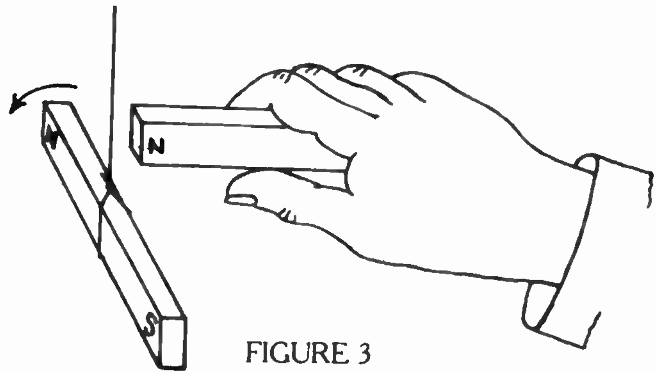


FIGURE 3

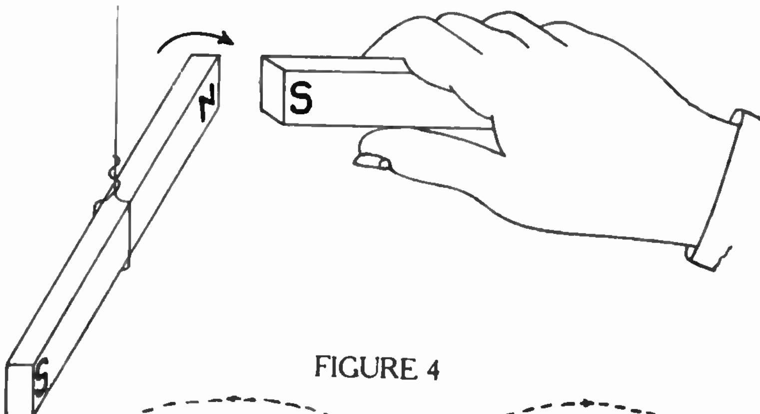


FIGURE 4

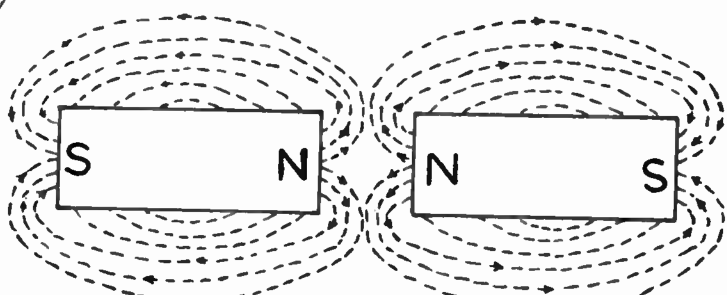


FIGURE 5

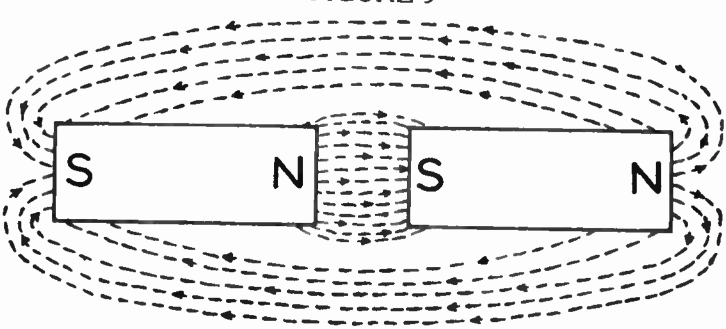


FIGURE 6

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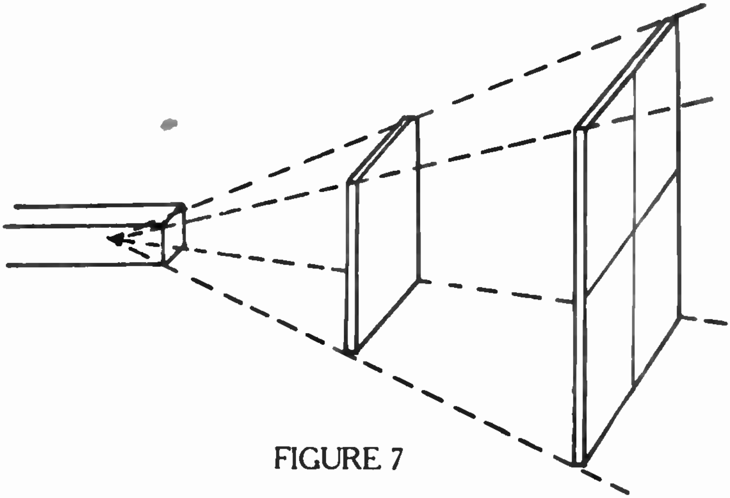


FIGURE 7

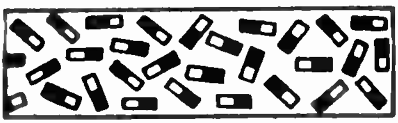


FIGURE 8

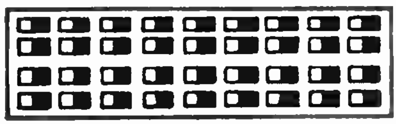


FIGURE 9

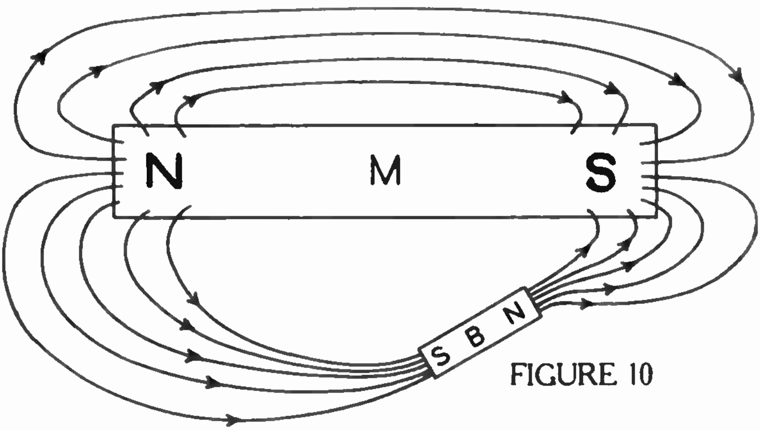


FIGURE 10

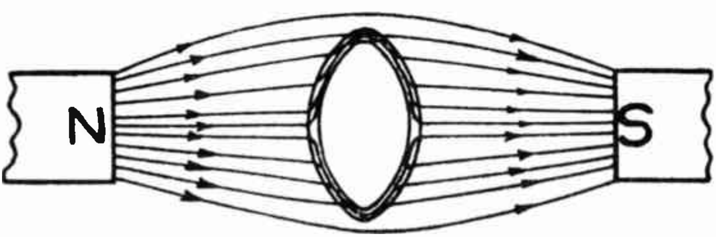


FIGURE 11

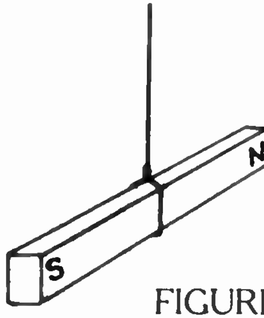
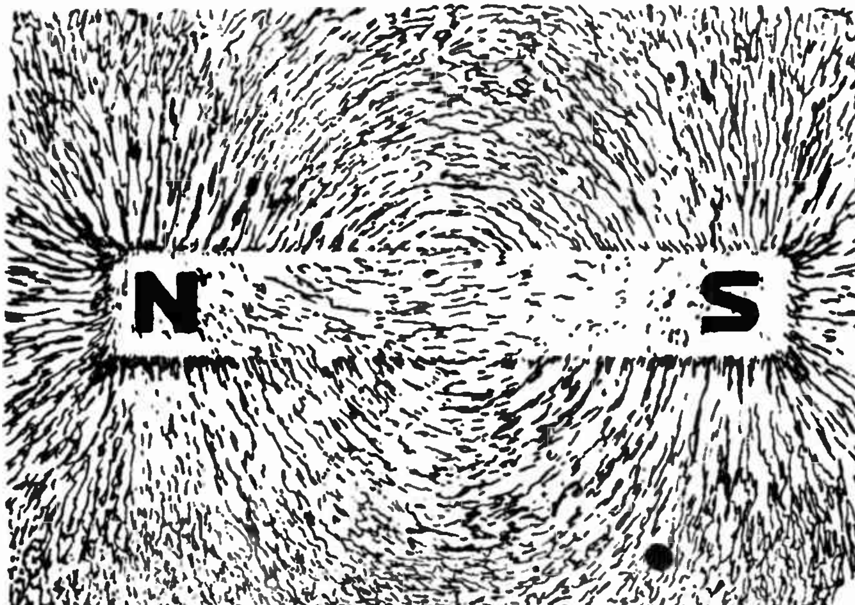


FIGURE 1



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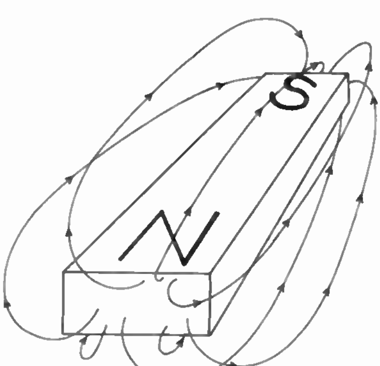

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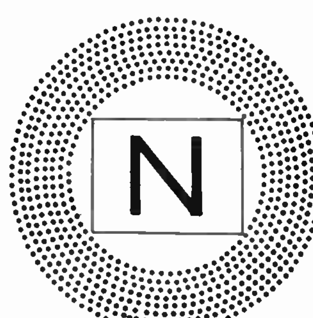


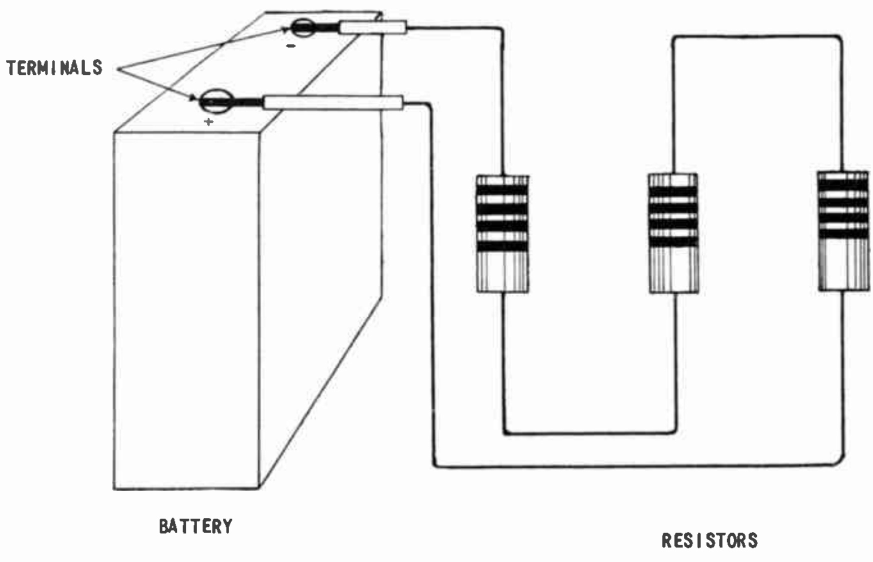
C

AEH-7

FIGURE 2

WORK DIAGRAM SOLUTION

Draw pencil lines to represent wires connecting the battery and resistors in a series circuit.



FROM OUR *Director's* NOTEBOOK

LAYING THAT FOUNDATION

Oftentimes in the process of a young man's training the question arises, "Why must I learn and do all these seemingly useless things, why can't I get into my chosen work right away and do something?"

Before a child can walk, he must first learn to stand, how to move and place his feet, and finally how to take a few steps.

No horse ever won a race until he had been thoroughly trained in all phases of behavior and action on the track.

Similarly as you go through your radio and electronic training you may become a little impatient at times and wonder why you are put through all these preliminaries.

These preliminaries are all essential toward a better understanding of the more advanced subjects and toward acquiring skill and accuracy in your applied work.

Proficiency comes only with practice and training.

These basic lessons have therefore been included with your training as essential steppingstones toward a successful radio career.

Yours for success,

W. C. DeVry

DIRECTOR

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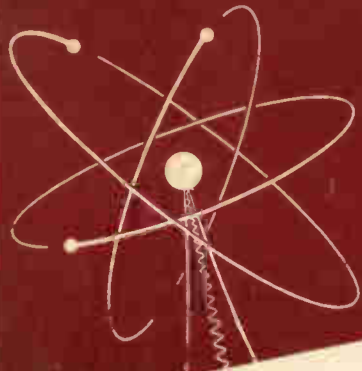


A-C GENERATOR

Lesson AEH-8B

DeVRY Technical Institute
4141 W. Belmont Ave., Chicago 41, Illinois
Formerly DeFOREST'S TRAINING, INC.

EH-8

AEH-8B

A-C GENERATOR

ELECTRONICS
TELEVISION
DTI
DeVRY Technical Institute

ELECTRONS IMPROVE COLOR PRINTING

Colored pictures, such as those found in modern magazines, are made by printing several colors in sequence to obtain the desired final effect. However, to preserve the fine detail in a picture, each color must be located at precisely the same place on the page. Photocells, together with various other electronic devices, control the printing press to provide the precise operation needed.

Popularly known as an "electric eye", the complete list of photocell applications is very extensive. To mention a few, they are used with motion pictures to reproduce the sound, in the light meters employed by photographers and light engineers, to open and close doors, in automatic level controls for elevators, for fire, smoke, and burglar alarms, and for liquid level indicators.

A-C GENERATOR

Contents

Some people fail because they never begin. More people fail because they never finish. Stick-to-it-ive-ness wins oftener than genius or luck. You may make mistakes, others may misjudge you. You may be tired and discouraged. But, if you stick, by and by everything and everybody will give way to you.

If you have principles they will do you no good unless you stick to them. If you do not stick to your friends, you don't deserve friends. If you do not stick to your job, you cannot make a success of it and find a better one. In a troubled and anxious time of the Civil War, General Grant said, "I will fight it out on this line if it takes all summer." Let that be your motto.

—Dr. Frank Crane

A-C GENERATOR

VOLTAGE INDUCED IN A CONDUCTOR

The process of developing a voltage in a wire that cuts across or is cut by magnetic lines of force is known as electromagnetic induction, and this principle is the basis for the operation of all conventional electric generators. Electromagnetic induction is used also in all types of transformers and coils that are employed in many kinds of electronic apparatus.

To illustrate electromagnetic induction as simply as possible, in Figure 1 the "N" end of a permanent bar magnet is shown close to an electric circuit consisting of a length of wire, each end of which is connected to a sensitive meter.

For convenience, this particular meter has the zero in the center of the scale, with the values increasing to the left and right of the zero. With no current in the meter, the pointer rests at zero. With current in one direction the pointer swings to the right, and with current in the opposite direction it swings left.

By taking hold of the wire at points "A" and "B" and keeping it close to the end of the magnet, when the wire is moved up quickly, the pointer swings a little and then drops back to zero. Also, when the wire is moved down past the end of the magnet, the pointer again deflects from zero, but in the opposite direction. However, pulling the wire straight away from the end of the magnet has little or no effect on the meter, nor does pushing the wire straight toward the magnet move the pointer.

We know that the pointer will not move unless there is current in the meter and unless there is a potential difference across a circuit, no current can exist in it. Hence, the movement of the pointer with the motion of the wire definitely indicates that a voltage has been induced.

This simple test demonstrates two important facts. First, since the magnetic lines extend out from the end of the magnet, in order to make the pointer swing, the wire must be moved in such a direction that it cuts through or across these lines. Second, the direction in which the meter deflects depends on which way the wire is moved. When the wire is moved up the needle swings in one direction, and when the wire moves down it deflects to the other side of the scale.

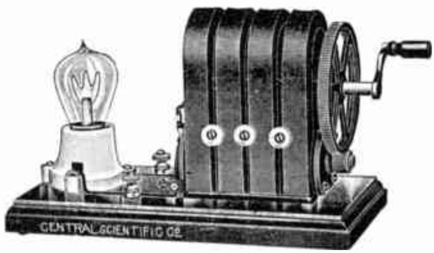
Often it is necessary to know the direction of current caused by the induced voltage for a specific direction of motion of the wire. In order to determine this relationship, the meter can be checked with a dry cell. If the positive and negative terminals of the cell are known, the direction of the current in a circuit connected across the cell terminals is known also.

To make this test, the wire of Figure 1 is removed and terminal C of the meter is connected in series with a resistor to the positive terminal of a dry cell. Then, when meter terminal D is touched on the dry cell negative terminal, the pointer swings to the right. To make certain, the dry cell connections are reversed so that the positive terminal connects through the resistor to meter terminal D while the negative is touched on terminal C. When this is done, the pointer swings to the left. Therefore, an electron flow from "C" to "D" makes the pointer deflect to the left, and from "D" to "C" moves it to the right. This information is all that is needed about the pointer action, so the circuit shown in Figure 1 is restored.

Now, when the wire is pulled up quickly past the end of the magnet, the meter pointer swings to the right. From testing with the dry cell, a needle deflection to the right indicates that "A" is the negative and "B" is the positive of the meter.

Since the circuit is complete, the induced voltage will cause electrons to flow, and their direction will be from "A" to "D", through the meter to "C", along the wire to "B", and back to "A".

If the wire is moved down past the end of the magnet, the pointer swings to left and thus indicates that terminal "D" now is connected to the positive end of the wire



This simple alternator demonstrates how loop rotation speed affects the voltage. The current resulting from the induced voltage lights the lamp. The faster the crank is turned, the brighter the lamp glows.

Courtesy Central Scientific Co.

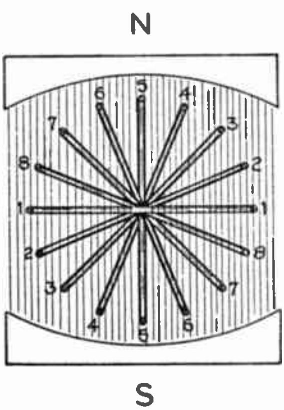
and the current in the circuit is from "B" to terminal "C", through the meter to "D", and back along the wire from "A" to "B".

Up until now the wire was moved at right angles through the magnetic field to generate a voltage causing a current to deflect the pointer of a meter.

We could just as easily have moved the magnetic field at right angles to the stationary wire to generate a voltage in the wire.

The important thing is that either the magnetic field or wire is moving relative to the other.

Applying the Left-Thumb rule described in the previous lesson, we can find the direction of the current through the wire. Figures 2 and 3 show a section of wire of Figure 1. As used in Figure 2 and 3 the fingers of the left-hand corresponds to the direction of the magnetic lines and the thumb points in the direction of the electron flow.



This sketch illustrates how the cutting angle affects the voltage induced in a loop rotating in a magnetic field. When the loop moves from position 1 to 2, each conductor cuts 1 line, from position 2 to 3, 4 lines are cut, and the maximum number of 6 lines are cut between positions 4 and 5.

To begin with in Figure 2, hold the fingers of the left hand straight out and close together while the thumb is spread away from the fingers as far as possible. Then with the palm up, place your hand under the wire so that the wire moves into it while the fingers point to the right. Then the thumb points in an upper left direction.

Now the left hand is in the proper position to indicate the current through the wire of Figure 1 when it was moving downward into the palm of the hand. A voltage induced in the wire causes the section of wire within the magnetic lines to act as a voltage source or battery for the rest of the circuit. Current then inside the source is from A to B, the same as in Figure 1.

For Figure 3, with the fingers of the left hand extended and the thumb full out, place your hand with the palm down over the wire moving up into it with the fingers still pointing to the right and the thumb pointing to the lower right of the page. This time the thumb indicates that the current is from B to A. This is identical to the direction of the current in Figure 1 when the wire is moved upward, again toward the hand.

Looking from the +A end of Figures 2 and 3 the "×" in Figure 2 indicates electrons flow into the paper or away from you while the "." in Figure 3 shows the flow out of the paper or coming at you.

FACTORS CONTROLLING THE INDUCED VOLTAGE

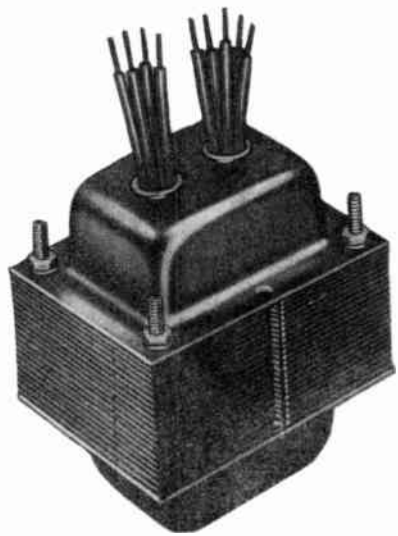
Not only is it important to know the polarity of an induced voltage or direction of the current in a conductor, but often it is valuable to know the factors that determine how much voltage is induced. In Figure 1, it was explained that in order to have a potential difference, the wire or magnet is moved with respect to the other. Further experiments show that the speed with which the wire or magnet is moved also affects the voltage. The faster the lines are cut, the higher is the voltage induced in the conductor.

To determine these factors that influence the induced voltage, a zero center meter can be connected to a large coil of several turns as shown in Figure 4. A bar magnet, much like that in Figure 1, is shown in position to be pushed into the far end of the coil.

In the previous lesson on magnets, the magnetic lines of a bar magnet were shown coming out of the North pole, fanning out, and going around to the South pole. In Figure 1, only these lines coming straight off the end of the magnet are shown, but in Figure 4, the more important lines are those that fan out in such a manner that they will be cut by the coil when the magnet is moved.

When the magnet is pushed into the coil or the coil is pushed over the magnet, the pointer swings one direction, and when they are pulled apart the pointer moves in the other direction. After turning either the magnet or the coil around end for end, the pointer still moves but the deflection is in the opposite direction.

Also, by pushing the magnet into the coil more quickly, by adding more turns to the coil, or by adding a second magnet pointing in the same direction as the first, the voltage induced in the coil will be increased.



Transformers are used in alternating current circuits only. They use an alternating current for their operation.

Courtesy Standard Transformer Corp.

Another factor that determines the induced voltage is the angle at which the conductor cuts through the magnetic field. To illustrate this action, in Figure 5 the magnetic lines of force or

FLUX are represented with light-arrowed lines coming out of the "N" end of a permanent magnet and going directly across a gap to a "S" pole. If the wire is moved at some specific speed up to point "A", it will cut through the entire flux at right angles. Moving the wire the same distance at the same speed to point "B" will make it cut about three-fourths of the flux, but moving it at the same speed and distance to point "C", the wire will not cut through any of the flux lines. Therefore, moving the wire to "A" will produce some definite voltage, moving it to "B" will give about three-fourths of that value, and moving it to "C" will develop very little or no voltage at all.

Considering all of these effects, the following four factors control the amount of induction:

1. *The speed of the motion*, or how fast the magnetic lines and the conductor move with respect to each other. The greater the speed, the greater the induced voltage.
2. *The length of the wire that cuts through the magnetic field*. The longer the wire, the greater the induction. In the case of a coil, the more turns the greater the induced voltage.
3. *The strength of the magnetic lines*, or the number of magnetic lines per unit area. The stronger the flux the greater the induced voltage.
4. *The angle of cutting the magnetic lines* changes the induction. The more nearly the wire cuts squarely across the lines, the larger the induced voltage.

These factors can be summed up into one simple sentence which states:

THE INDUCED VOLTAGE IS DIRECTLY PROPORTIONAL TO THE RATE OF CUTTING THE LINES OF FORCE. By rate is meant the number of magnetic lines cut by the conductor per second, and the rate can be increased by increasing the speed of cutting, the length of the conductor, the strength of the flux, or the angle of cutting.

An important point to remember is that the action induces a voltage in the coil or conductor and, should the conductor that cuts the magnetic flux be a part of a complete electric circuit, then the induced voltage will cause a current in the circuit. You may read or hear a lot about induced current, but to be technically correct it is a current caused by an induced voltage.

ELECTROMAGNETIC INDUCTION IN A LOOP

To generate voltage and a current, the set-up of Figure 1 is highly impractical. To make the generation of voltage and current easy, rotating machines are built with conductors in the form of loops which turn through a magnetic field. Figure 6 shows the simple form of a **generator**, but its operation is the same as those turned by water wheels and turbines at a hydroelectric plant.

A permanent magnet sets up a magnetic field for the wire to cut. Resistor R is external to the generator but completes the electric circuit so that the induced voltage causes a current. With the wire bent into a loop, one side moves closer to the N pole while the other moves nearer the S pole.

Since the loop must move, it is mounted on, but electrically insulated from, a rotating shaft. To connect the loop to the external resistor while the loop turns, each of its ends are connected to a copper ring also mounted on the shaft. External connections are made to a stationary conductor resting on each of these rings. The rings are called **collectors** and the stationary conductors are known as **brushes**. The brushes and rings thus form sliding contacts to connect the rotating loop to the external circuit.

Figure 6 shows the loop in four positions of rotation. For convenience the complete rotation of the loop is divided into 12 positions much like the face of a clock is marked off in hours. Also, as in the clock where 0 o'clock and 12 o'clock is the same position, 0 and 12 Position will be the same point in the rotation of the loop. As on the clock face, 3 will represent the position of the loop after one quarter of the rotation, 6 another quarter of the rotation, 9 the 3rd quarter of rotation, and 12 the complete rotation. Unlike the clock, in this particular illustration the loop starts from a horizontal position and revolves in the reverse or counterclockwise direction.

The typical a-c motor found on washing machines, fans, and refrigerators are alternators operated in reverse. The alternating current causes the armature to rotate in a magnetic field.

Courtesy Robbins & Myers, Inc.

In Figure 6 Positions 0 and 12, the circuit inside the generator is from the upper left brush D through the ring, along side A of the loop, across the back to side B and forward through the other side of the loop and brush C. Even when the loop is rotated, the circuit and the loop connections do not change.

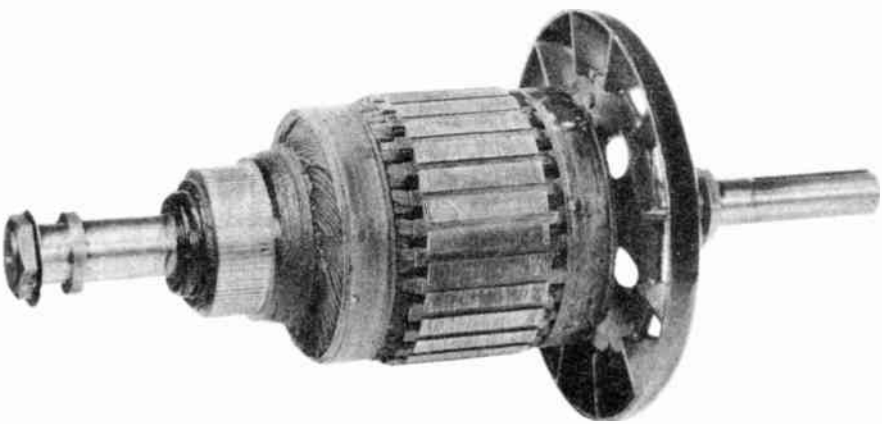
As the shaft is turned in a counterclockwise direction from Position 0 in Figure 6, side A will go up and left past the N pole of the magnet on top, and side B will go down and right past the S pole on the bottom. By using the Left Thumb Rule, the fingers pointing in the direction of the magnetic flux palm faced so wire moves into it, the thumb indicates the direction of the current caused by the induced voltage. On the bottom side of the loop this direction is from the back toward the front, or out from the paper. On the top side, which is moving left, the induced voltage will cause a current from the front toward the back, or into the paper.

The action of the two induced voltages maintains a current around the loop, back on the top side A and forward on the bottom side B. Considered sources of electric energy, the induced voltages are connected in series, and will tend to maintain current in the same direction.

ACTION AS THE LOOP IS REVOLVED

As the loop continues to turn from Position 0 in Figure 6, at the end of a quarter turn it is in Position 3. Here, sides A and B move directly across the magnetic lines and there is a maximum induced voltage.

After the next quarter turn in the same direction, the loop is in Position 6. Notice this condition is exactly the reverse of Position 0. Side A is on the left about to



A typical generator rotor having a large number of windings.
Courtesy The Louis Allis Co.

move down past the S pole, and side B is on the right ready to move up past the N pole.

As the loop moves past Position 6, the induction is exactly the same as at Position 0, that is, the direction of current is back along the top side and forward along the bottom side. However, the loop has turned over, so the induction now causes current back along B and forward along A which is the reverse direction insofar as the sides of the loop are concerned.

By completing another quarter turn to Position 9 in Figure 6, the conditions of Position 3 are reversed. Side A is now on the bottom and side B on the top. Again there is maximum induction because the sides of the loop are moving directly across the magnetic lines. The last quarter turn brings the loop back to Position 12 and since it also is Position 0 the actions will repeat as the loop passes through another complete turn.

To produce a voltage by motion, the principles of electromagnetic induction are used, and by bending the wire into a loop and using both poles of the magnet, the action has doubled. As one side of the loop goes left, the other comes right and the inductive action pushes electrons back on the one side and pulls them forward on the other.

VARIATIONS IN RATE OF CUTTING THE FIELD

Positions 3 and 9 of Figure 6 are conditions of maximum induction, and Positions 0 and 6 are conditions of zero or minimum induction. These conditions are explained by the fact that the induced voltage is directly proportional to the rate of cutting the magnetic field. Earlier in the lesson we stated that the rate of cutting is controlled by four factors:

1. Speed of cutting,
2. Length of the conductor,
3. Strength of the magnetic field,
4. Angle of cutting.

In the simple generator of Figure 6, it is assumed that the Loop is revolving at steady speed in a counterclockwise direction. The length of the loop is fixed, and it cuts through a field of uniform strength. The only remaining factor that can produce a variation in the induction, is a change in the angle of cutting as the loop turns. In Positions 3 and 9 of Figure 6, the angle of cutting is directly across the magnetic lines, and the induced voltage is greatest. As the loop continues to turn counterclockwise away from these positions, the angle of cutting becomes less and less, and the induced voltage becomes correspondingly smaller and smaller. In Position 12 which also is Position 0, and in Position 6; the angle of cutting is zero, and hence, the induced voltage is also zero.

VARIATION IN DIRECTION AND AMOUNT OF INDUCED VOLTAGE

To simplify the explanation and provide more details of this all important action, in Figures 7, 8, 9, and 10, the front half of the generator of Figure 6 has been

A speaker converts alternating current and voltage into sound due to electromagnetic action.

Courtesy Jensen Mfg. Co.

removed. The remaining cross section views indicate only the rear halves of the magnet poles and the rear half of the loop.

In Figure 6, the loop makes a quarter turn in moving from Position 0 to Position 3. From left to right, two intermediate positions of this rotation are shown in Figure 7. At each position, the induced voltage and direction of the resultant current, if any, are shown with a dot and a cross mark. As explained before, the dot in the center of the conductor cross-section represents current out toward you, the cross mark represents current in away from you and the curved arrows show the direction of rotation.

As the loop turns from Position 0 shown at the left in Figure 7 to Position 3 shown at the right, it will cut more and more lines as the angle of cutting increases. The induction increases steadily until the maximum is reached. The current produced by this voltage also increases steadily and is in a direction in on side A and out on side B. Going back to Figure 6, since side A is connected to ring and brush D, and side B is connected to ring and brush C, the external resistor receives increasing "+" voltage from brush D or an increasing "−" voltage from brush C. Thus, in the Position 3 at the right in Figure 7, the loop generates maximum "+" at brush D or maximum "−" at brush C.

In turning from Position 3 to Position 6 of Figure 6, the loop makes the second quarter turn which is shown in greater detail in Figure 8. Here the extreme left position is the same as the extreme right position of Figure 7 in which the preceding quarter turn was completed. Since side A still moves left past the N pole, and side B moves right past the S pole, the directions of induced voltages and current remain the same. However, the angle of cutting is decreasing and so, the induced voltages and resultant current also decrease steadily. In Position 6, no magnetic lines are being cut, therefore the voltage and current drop to zero. Notice that at the beginning of the turn in Figure 7, side A was on the right and B on the left, but now B is on the right and A is on the left.

In turning from Position 6 to 9 of Figure 6, the loop makes the third quarter turn shown in Figure 9. Side A now moves down and right past the S pole, and side B moves up and left past the N pole. As the angle of cutting increases voltage is induced again, but in the opposite direction. Side A is now "−", and B is "+". The angle of cutting increases steadily as the loop turns until there is maximum induction in Position 9 at the extreme right in Figure 9. Notice that the corresponding condition in Position 9 of Figure 6 shows "+" at brush C and "−" at brush D. Again the external circuit has maximum current but in the direction opposite to that for Position 3.

In the final quarter turn, as the loop rotates from Position 9 of Figure 6 around to Position 12, conditions are as shown in Figure 10. Side A still moves right past the S pole and B moves left past the N pole, therefore the direction of induced voltages and current are the same as for Figure 9. However, now the angle of cutting is decreasing and so induced voltages and current decrease steadily. In Position 12, no magnetic lines are cut and the voltage and current drop to zero. The end of the fourth quarter turn brings the loop back to where it started in Figure 7, Position 0, so the events of Figures 7, 8, 9, and 10 will repeat during each succeeding revolution.

ALTERNATING CURRENT

When the loop is turned continuously in the same direction, the induced voltages and resultant current will reverse direction in each side during each complete turn. Since sides A and B connect to the external resistor through the rings and brushes, as the loop is turned, the current in the circuit is first in one direction and then in the other. Starting from the position of zero induction, for the first two quarters of a turn of the loop, brush C is "−" and D "+", and the current is in the other direction. This periodic change of direction of electron flow is called **alternating current** (a-c) and generators that produce alternating current are called **alternators.**

SINE CURVE

During each rotation of the coil there are two positions in which the lines of magnetic force are cut at the greatest rate, and two positions in which the lines are not cut at all, therefore the maximum and minimum induced voltages both occur twice during each revolution of the loop.

With the loop revolving at a uniform speed in a uniform magnetic field, at any intermediate point between the minimum and maximum, the induced voltage is always some fractional part of the maximum. This intermediate or instantaneous value depends on the angle of cutting the magnetic field in that particular position. The minimum, intermediate, and maximum induced voltages for an entire revolution can be shown quite nicely by what is called **a sine curve** like that at the right in Figure 11.

To simplify the explanation and provide additional details regarding the action of the simple generator of Figure 6, only the magnet poles and rear end of the loop are shown in Figures 7, 8, 9, and 10. As the induction is the same in sides A and B of the loop, still further simplification can be made. By omitting side B, all the positions of the loop indicated in Figures 7, 8, 9, and 10 are combined in the diagram at the left in Figure 11 and side A has the same position numbers shown in the previous Figures.

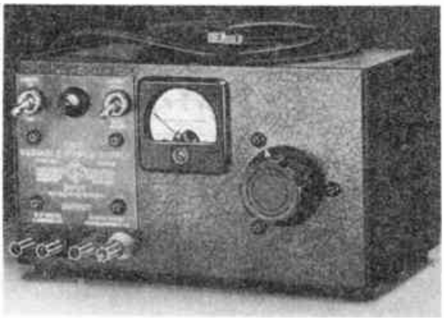
To visualize the induction within a loop, a graph is constructed by first extending to the right a line connecting Positions 6 and 0. Since this line marks the Positions of side A when it is cutting no magnetic lines, it is the zero voltage reference line. With the loop turning at a uniform speed, it requires equal intervals of time for it to move from each position to the next. Therefore, the horizontal line is divided into 12 equal spaces to represent equal time intervals between the different positions of the loop. Vertical lines then are drawn through these division points and labeled "0" to "12" to correspond with the time intervals for a complete turn or revolution of the loop.

The next step is to plot the voltages for each of the 12 positions. When side A is in Position "0" it cuts no lines, no voltage is induced, and the line joining this position and the "0" time line of the graph shows this condition.

When side A is in Position 1 with respect to the magnetic field, it is moving through and cutting magnetic lines, therefore a voltage is induced. The value of this voltage is plotted by drawing a horizontal line from Position 1 to cross or intersect the vertical line for the time interval 1. The same procedure is followed to plot the voltages for the balance of the positions. In each case a horizontal line is drawn from each position of side A to intersect the correspondingly marked time interval line. Connecting these points of intersection with a curved line, provides a graph of the voltages induced in side A for all points of the rotation. The direction of the curve, above or below the horizontal zero voltage line, indicates whether the induced voltage, and the current it will produce, is "+" or "−", and the distance of the curve above or below the zero voltage line indicates the instantaneous value of the voltage induced. Therefore the curve can be used to determine the induced voltage in positions between those plotted.

At positions 3 and 9 of Figure 11, the MAXIMUM values are reached. Sometimes these are called PEAK values. Both are measured from the horizontal line to the highest value, hence, at position 3 a positive maximum occurs, while at position 9 a negative maximum occurs.

Also, the sine curve of Figure 11 summarizes the inductive actions during a complete revolution of the loop. As side A moves past the N pole all the voltages between Positions 0 and 6 are above the horizontal line or "+". These values increase from zero in Position 0 to maximum in Position 3, then back to zero in Position 6. As side A moves from Position 6 past the S pole all the

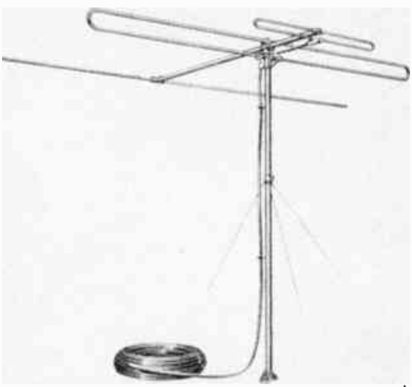


Alternating current of 60 cycles rated at 115 volts is used by this variable power supply.
Courtesy General Radio Company

voltages between Position 6 and 12 are below the horizontal line or "−". These values increase from zero in Position 6 to a maximum in Position 9, back to zero in Position 12, and the same series of voltage variations repeats.

CYCLES AND ALTERNATIONS

The word cycle is used often in the study of alternating current and electronic principles, and should be understood clearly. A cycle is a series of events which takes place over and over again at regular time intervals. Holidays, days of the week, months or seasons of the year, are good examples of events that occur in cycles. For example, the change of seasons depends on the position of the earth in its orbit around the sun. The earth makes a complete revolution around the sun once a year. During the year spring, summer, autumn, and winter appear in turn. Then as



Popular type of TV antenna which picks-up high frequency alternating current from TV stations.

Courtesy American Phenolic Corp.

the earth starts another revolution around the sun, the entire cycle of seasons repeats.

When a revolving object produces different conditions in different parts of each revolution, those conditions are repeated in recurring cycles as the revolutions continue. This general statement also applies to revolving loops and particularly to the variations in induced voltages in different parts of each revolution.

All the changes in the direction and value of induced voltage that occur during one complete turn are considered to be parts of one cycle. As the loop continues to rotate, the same conditions are repeated in recurring cycles. The sine curve of Figure 11 shows one cycle of voltage changes that occur in side A during one revolution of the loop. If the factors affecting the induced voltage do not change, the curves of all succeeding will be exactly the same.

Thus, in Figure 12 with C_1 as the first cycle, the second cycle would be C_2. We could have rotated the generator of Figure 6 in the opposite direction, then the cycle would appear as C_3 where the first alternation is negative while the second is positive. In fact, we could have started the rotation from any position to generate one cycle. For instance, starting from position 9 in Figure 11, we could generate the wave-form C_4 in Figure 12. As long as one complete revolution is performed no matter what the starting position, upon returning to that position one complete cycle is generated.

Since one cycle is completed during each revolution, the time required for each cycle will depend on the speed at which the loop is turned. For example, if the loop is rotated at a speed of 3,600 revolutions per minute, which is equivalent to 60 revolutions per second, it will produce

60 cycles per second (60 cps). The number of cycles that occur in a given time is called the **frequency** (f). Thus, if the loop makes 60 revolutions per second, the frequency will be 60 cycles per second.

However, since the second is used as the standard unit of time in electronics, frequency often is expressed simply as a number of cycles, and per second is understood. For example, ordinary 110 volt a-c used for house lighting normally is expressed as having a frequency of "60 cycles" rather than "60 cycles per second".

Figure 11 shows how each cycle is made up of two like parts, one above and the other below the horizontal zero voltage line. Each part is called an **alternation.** The one above the zero voltage is the positive alternation and the one below the line is the negative alternation. Since a complete cycle is made up of two alternations, the 60 cycle a-c mentioned has 2 times 60 or 120 alternations per second.

A SIMPLE ALTERNATOR

Although it has been common practice to call any machine, that generates electric energy by electromagnetic induction, a **generator,** a machine that develops an a-c voltage is more frequently called an alternator.

Because it supplies an alternating current that changes in magnitude and direction during each complete revolution of the coil, the machine of Figure 6 is a simple alternator. Instead of permanent magnets, in most commercial alternators, the magnetic field is produced by electromagnets. And in place of a single loop, many interconnected loops are mounted uniformly around the shaft to obtain increased induction and output. That part of the alternator which remains stationary is called the **stator** and the moving part is the **rotor.**

As shown in Figure 6 slip rings and brushes are employed to connect the rotor to the external circuit. However, the a-c output from large, commercial service alternators generally is of high voltage and current, and thus would require heavy, well insulated slip rings and brushes. Therefore, the rings and brushes are employed to carry current from a low-voltage d-c generator to the electromagnets that are mounted on the rotor while the high voltage a-c output is taken from the stator windings.

The simple alternator described in this lesson uses a moving wire in a magnetic field to generate an a-c voltage. In contrast, a transformer has stationary wires while the magnetic field alternates or changes. While it generates no voltage, the transformer does convert the a-c from some central source to the desired voltage for use in electron tube equipment. How the transformer is constructed to accomplish this conversion is described in the following lesson.

IMPORTANT DEFINITIONS

ALTERNATION—[awl ter NAY sh'n]—One-half of a cycle consisting of the complete rise and fall of an alternating voltage or current in one direction.

ALTERNATING CURRENT—(a-c)—A current which changes its direction periodically.

ALTERNATOR—[AWL ter *nay* ter]—An alternating current generator.

BRUSHES—Formed pieces of carbon or graphite that provide a sliding contact between the collectors or commutators and the external circuit.

COLLECTORS—The circular contacts used on an alternator which are connected to the rotating loops. Often called slip rings.

CYCLE—[SIGH k'l]—The complete set of values through which an alternating voltage or current passes successively.

FREQUENCY (f)—[FREE kw'n si]—The number of cycles of alternating voltage or current which occur in one second.

GENERATOR—[JEN er *ay* ter]—A machine for converting mechanical energy into electric energy, by causing a series of interconnected coils of wire to cut or be cut by a strong magnetic field.

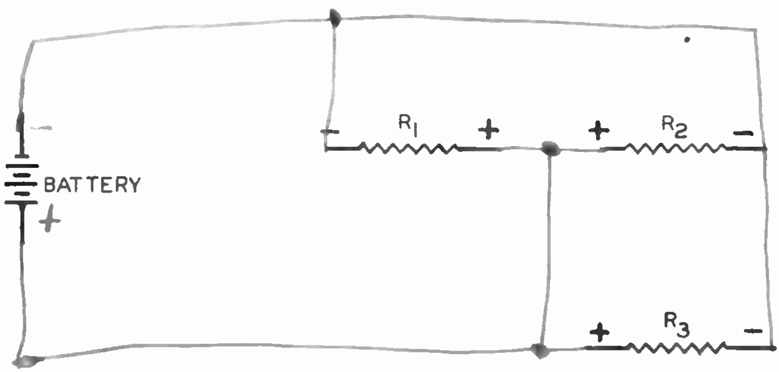
ROTOR—[ROH ter]—The rotating member of a generator.

SINE CURVE—[sighn kerv]—The graph of an alternating voltage or current which shows the instantaneous values for each instant of time.

STATOR—[STAY ter]—The stationary coils of a generator.

WORK DIAGRAM

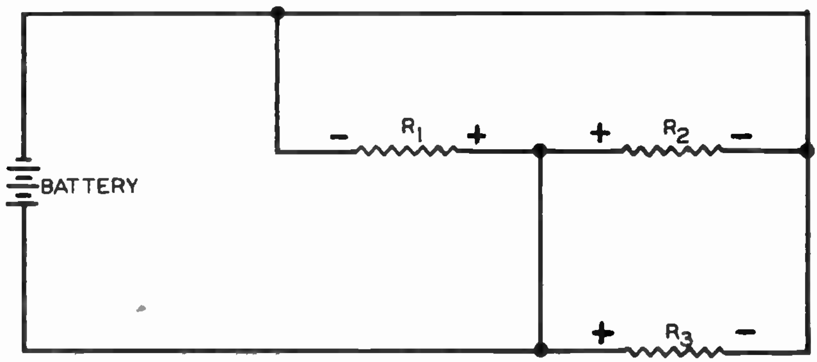
By means of pencil lines, connect these resistors in parallel across the battery so that the correct polarities are indicated.



When you have finished, check with the answer on the back of the fold-out sheet.

STUDENT NOTES

WORK DIAGRAM SOLUTION



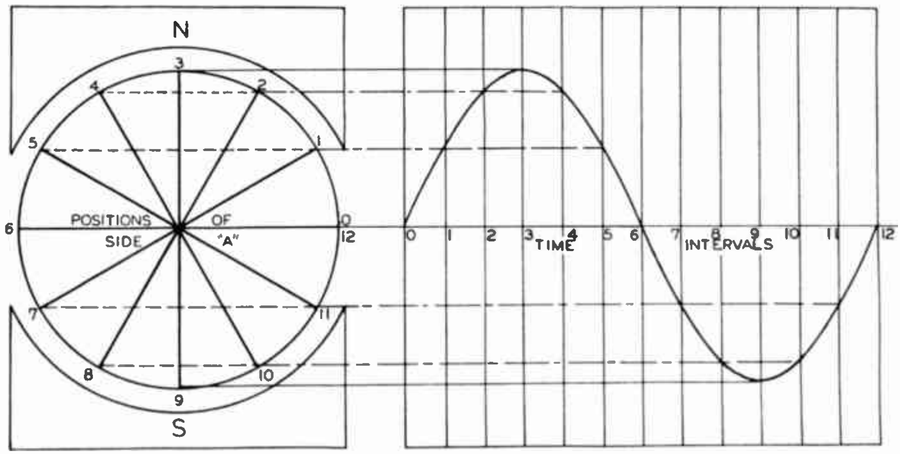


FIGURE 11

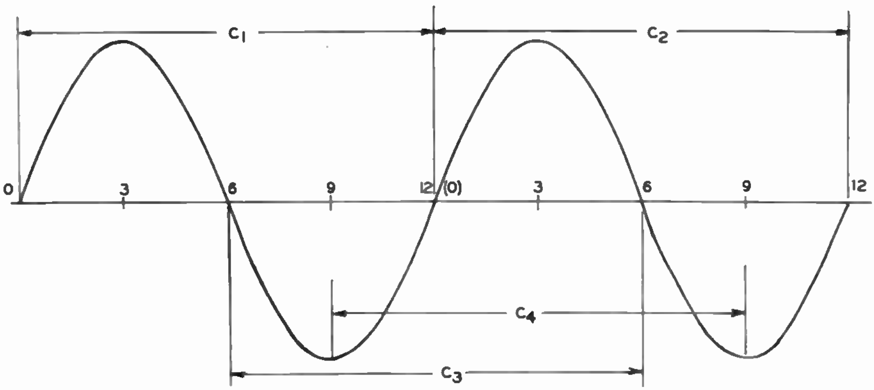


FIGURE 12

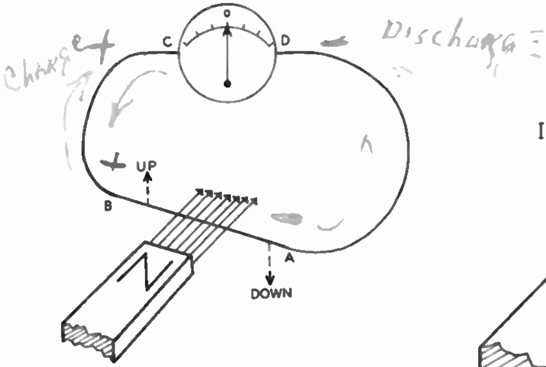


FIGURE 1

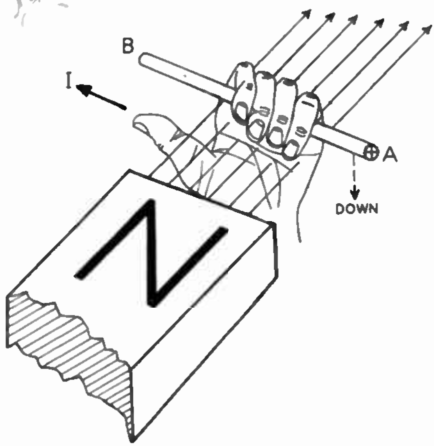


FIGURE 2

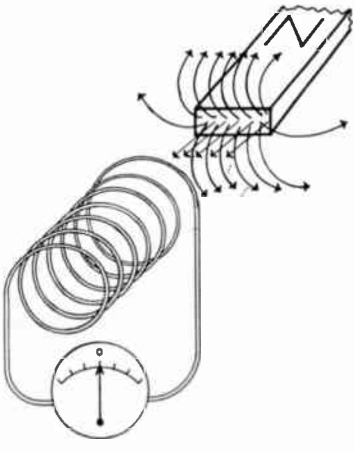


FIGURE 4

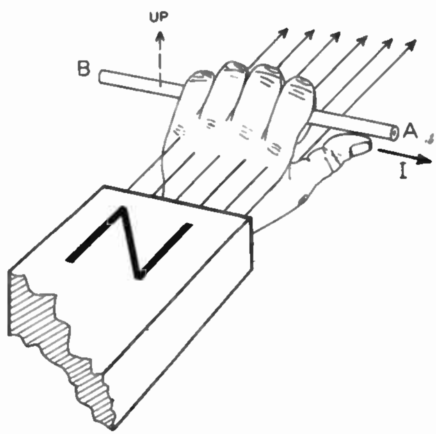


FIGURE 3

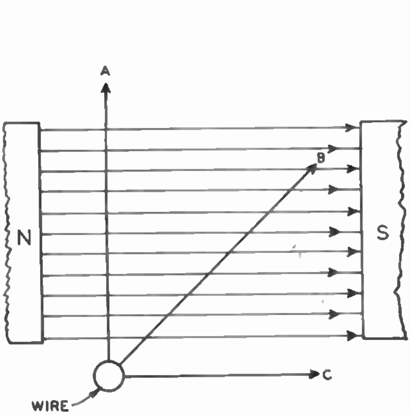


FIGURE 5

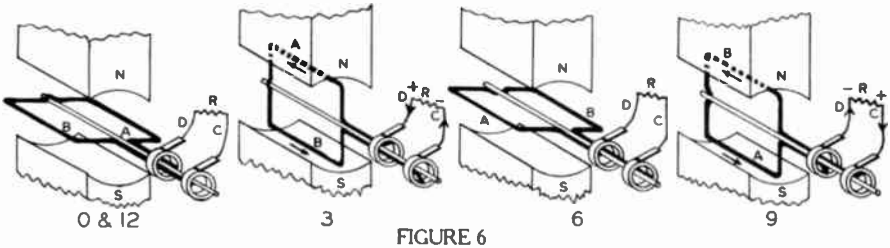


FIGURE 6

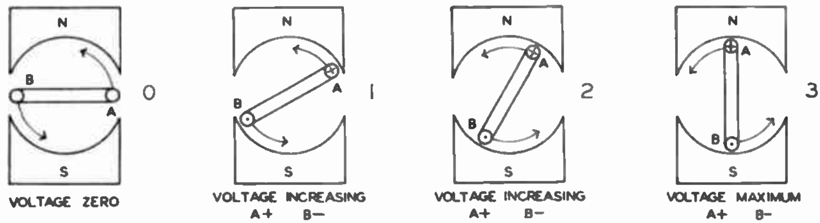


FIGURE 7

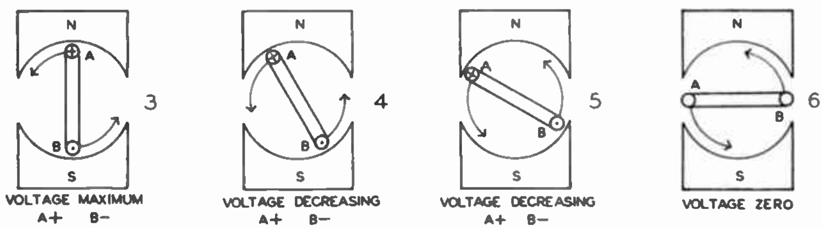


FIGURE 8

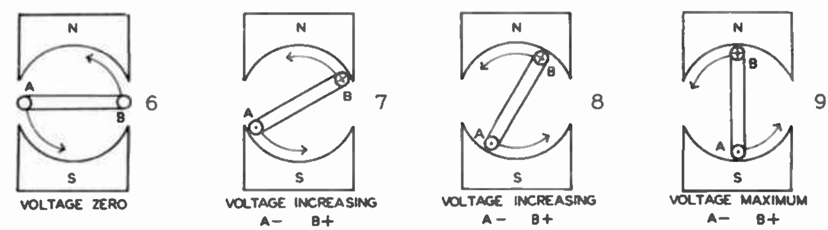


FIGURE 9

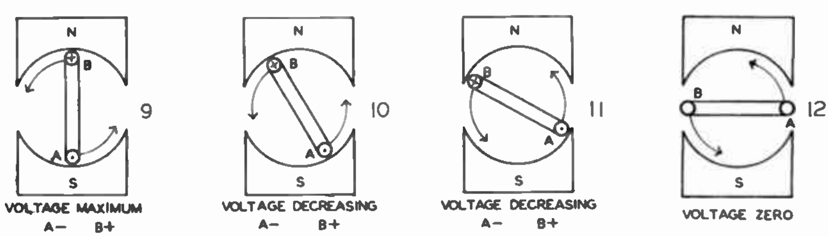


FIGURE 10

FROM OUR *Director's* NOTEBOOK

THE LEADER

The man who is worthy of being a leader of men will never complain of the stupidity of his helpers, of the ingratitude of mankind nor of the inappreciation of the public. These things are all a part of the great game of life, and to meet them and not go down before them in discouragement and defeat is the final proof of power.

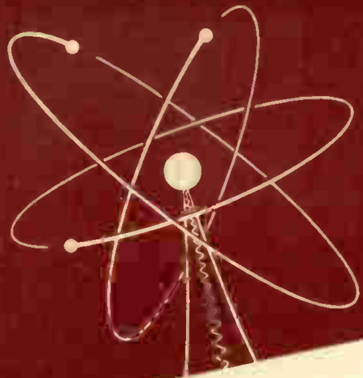
—Elbert Hubbard.

Your for success,

W. C. De Vry

DIRECTOR

PRINTED IN U.S.A.



TRANSFORMERS

Lesson AEH-9A

DeVRY Technical Institute

4141 W. Belmont Ave., Chicago 41, Illinois

Formerly DeFOREST'S TRAINING, INC.

AEH-9A

TRANSFORMERS

ELECTRONS MEASURE STRESS

As the air blast changes within a modern wind tunnel, several hundred meter needles shift on the external control panels. Wired to an electronic gauge about the size of a postage stamp, each meter indicates the strain produced at some particular point on the structure being tested.

Many types of electronic gauges and detecting devices have been developed to prevent accidents and injuries. Phototube equipment stops punch presses and power shears when an operator's hand is in the path of the punch or moving blades. In mines, electronic equipment can be connected to close safety doors, operate traffic lights, turn on blowers, or sound alarms when the gas content in the air reaches dangerous levels.

A stability gauge stops a large crane automatically if the boom is extended too far or is loaded too heavily and there is danger of the crane overturning. Other electronic indicators give advance warning of impending floods, guard industrial plants against night intruders, or detect fire, smoke, and dangerous gas.

TRANSFORMERS

Contents

"A person should never be ashamed of possessing but little knowledge. But a person should be ashamed if he fails to add to his knowledge whenever he can and especially so when he fails to make use of it for himself and his fellow men.

—Arthur Brisbane

TRANSFORMERS

Regardless of its size or use, practically every modern piece of electronic equipment today uses transformers. Most of this apparatus has a transformer in the power supply, but this isn't the only place where transformers are useful.

Whenever one section of the apparatus supplies a voltage and current to another, if this combination isn't correct for best operation, a transformer is inserted between the two. That is, when the voltage is too low the transformer increases the voltage and reduces the current, or where a large current is needed the transformer increases the current but reduces the voltage.

For this operation the transformer makes use of several important factors described in the last two lessons. One of these is that a voltage can be induced into a wire or coil whenever it cuts or is cut by a magnetic field. In the last lesson a coil of wire or loop was moved in a magnetic field. In a transformer, however, the coil is held still and the magnetic field is moved. The second important factor used in transformers is that an alternating current produces a moving field.

To be an efficient technician, you must know how these factors are used in a transformer and how to determine which transformer is needed for a particular application. Therefore, in this lesson we describe the basic features of all transformers by showing how they apply to power transformers such as the one found in Figure 15.

SELF INDUCTION IN A STRAIGHT WIRE

As you know, electron flow through a wire produces a magnetic field. Let's pass a d-c current through a wire shown as a cross-section in Figure 1. As long as the electric circuit is not complete, Figure 1A shows no magnetic field about the wire. However, the instant the circuit is "closed", a current is established and the conditions in Figure 1B exist. The magnetic field has just begun to build up, and starting from its center, the magnetic lines are all inside the wire.

An instant later, as shown in Figure 1C, the field has built up further, and there are more magnetic lines which extend out around the outside of the wire. Each of these lines started at the center and cut through all or part of the wire to reach its present position. In Figure 1D, the current has reached its normal value and the magnetic field has still more lines, most of which have cut through the wire.

If the electron flow in the wire is toward you, or "out" from the paper, by the Left Thumb Rule the magnetic lines will be around it in a clockwise direction.

Figure 2A is the cross section shown in Figure 1A with several additions. The outer circle is the entire solid wire, while the small inner circles are drawn, for purposes of our explanation, to represent the solid wire as being made up of many smaller wires or strands which are labelled A, B, C, etc. Electrons are flowing in each of these strands in the same direction as shown for the wire in Figure 1A. Although part of one solid wire insofar as action is concerned, each of these strands can be considered as separate physical wires, therefore A and B are drawn as separated in Figure 2B. Since A and B have electrons flowing through them, then each has a magnetic field about it.

The magnetic fields about A and B are shown in a clockwise direction as it expands from the center of each strand, just as for Figure 1A. As the magnetic field of A passes outside of strand A, it nears strand B. Since the magnetic field of A resists being broken, it tends to wrap itself about strand B as shown by the dotted lines, but finally, this expanding field cuts strand B and induces a voltage in it. Using the dashed lines as the magnetic field about strand B with the Left Thumb Rule, the voltage induced in the complete circuit is of such a polarity that current is INTO the paper. This is opposite to the source voltage causing current OUT OF the paper in strand B.

A similar opposing current is generated in strand A by the expanding field of B. Thus, since the voltages in each strand oppose each other the effective voltage in each of them is the difference between the original voltage and the induced voltage. Now by recombining all the strands as one wire, the voltage induced in the wire by the expanding field reduces the applied voltage so that the resulting voltage is lower. Hence there is less current in the circuit.

The opposite voltage is called a counter electromotive force (CEMF) or **counter emf** because it opposes the voltage causing the action.

Inducing voltage into the current conductor is called **self induction,** and like all forms of induction it occurs only while the magnetic field is changing. Figure 1D, has the full magnetic field, but since no further change occurs, there is no further induction, and the counter emf dies out. Although this complete action takes place very rapidly, in a small fraction of a second, the self induction does prevent the current from rising instantly to its full value.

In Figure 1E the conditions are the same as at "D", at the instant the circuit is opened. As the current dies out, the magnetic field collapses as shown at "F", "G", and "H", which is just opposite to the way it built up at "A", "B", and "C". Here again there is self induction but, since the magnetic lines are now collapsing, the direction of the induced voltage will be "out" from the paper or opposite to what it was while the field was building up. The self induction which opposed the increase of electron flow before, now has reversed its direction and will attempt to maintain the original current for a brief instant.

SELF INDUCTION IN A COIL

Self induction in a coil of wire is much greater than in a straight wire of the same length, because the magnetic field around each turn cuts not only the turn that sets it up, but also the turns close to it. To show this action, part of a coil of wire is cut away in Figure 3. With the direction of the current as indicated by the arrows, the magnetic field is exactly like the one described in the lesson on electromagnets. The important thing to notice in the cut-away part of the coil is that the magnetic lines set up around the first turn cut the next turn also.

As this overlapping of magnetic lines occurs between all the turns, the induced voltage will be

Various types of small transformers used in radios.
Courtesy General Electric Co.

much greater than in a straight wire, and the amount of self induction in a coil depends on the ampere-turns and the reluctance of the magnetic circuit. That is, the stronger the magnetic field a conductor produces, the greater the self induction.

The effects of self induction are summarized by the following statements:

1. *Whenever a circuit current increases, the induced counter emf opposes the change of current and prevents it from rising instantly to its steady value.*
2. *Whenever a circuit current decreases, the induced emf is in a direction to oppose the change and tends to maintain the current.*

Notice particularly, induction occurs only while the current is changing and the counter emf is always in a direction to oppose the change. With a uniform or steady current, there is no induction and, therefore, no counter emf.

HOW INDUCTANCE CAN BE VARIED

When there is a variation of current in a circuit, the magnetic flux varies also, expanding as the current increases and contracting as the current decreases. In moving, the magnetic lines of force cut any conductor which is within their range and induce a voltage that is always in such a direction as to oppose the current change. Known **as inductance,** the ability to produce a voltage by electro-

The inductance of this transformer can be varied by moving a metallic core in or out by means of the screw adjustment.
Courtesy Meissner Mfg. Div., Maguire Industries Inc.

magnetic induction when the current changes, is a property possessed by a circuit because of its physical arrangement. Thus, a conductor has inductance whether or not a current is in it.

The inductance of a circuit depends on the number of magnetic lines which cut the conductor for each ampere change in current. Anything that increases the number of flux lines cutting the conductor for each ampere change in current increases the inductance. Hence, a conductor wound into a coil as shown in Figure 3 has a greater inductance than a straight wire, because the flux developed by one turn of wire in the coil also cuts practically every other turn as it expands or contracts. For the same reason, an iron core placed within the coil increases the inductance, because the lower reluctance of the magnetic circuit permits a greater flux and therefore, more lines cut the conductor as the current changes. Since a coil of wire possesses the property of inductance it is called an **inductor.**

Induction is the result of electromagnetic action in a circuit containing inductance, and as a general definition: self inductance is the ability of a circuit to produce a voltage within itself by induction when the current in it changes.

INDUCTANCE UNITS

As for all other electric properties, there is a unit of measure for inductance. It is the **henry** (h), named for the American physicist Joseph Henry (1797-1878) who, in 1831, discovered the voltage caused by self induction. By definition, THE HENRY IS THE INDUCTANCE WHICH INDUCES A POTENTIAL DIFFERENCE OF ONE VOLT WHEN THE CURRENT IS CHANGING AT THE RATE OF ONE AMPERE PER SECOND.

The henry is a large unit, consequently for many practical applications, two smaller units are employed. One is the millihenry (mh), equal to one one-thousandth ($\frac{1}{1,000}$) of a henry, and the other is the microhenry (μh), equal to one one-millionth ($\frac{1}{1,000,000}$) of a henry.

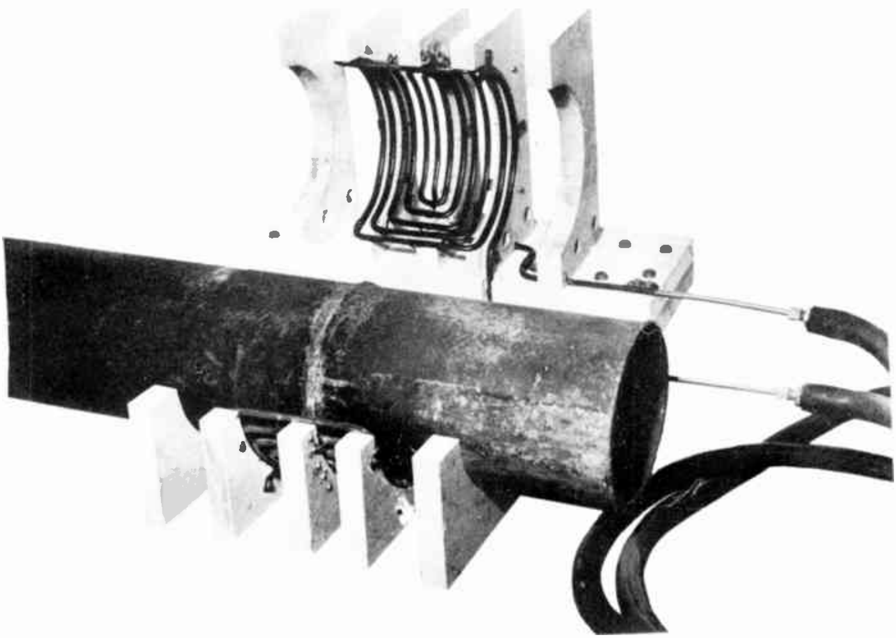
The schematic symbol for an inductor is shown in Figure 4. This symbol remains the same regardless of the type of winding or the number of turns involved. However, when an iron core is used, it is frequently indicated by adding parallel lines, as shown in Figure 5. The letter "L" along with subscripts 1, 2, 3, 4, etc. are added for identification purposes.

ENERGY STORED IN A MAGNETIC FIELD

It is a well established fact that matter cannot set itself in motion, and that energy for its movement must be supplied from some outside source. This truth is illustrated by the fact that a table cannot push itself across the floor. Only when a person supplies the necessary energy does the table move, thus the energy for its movement comes from outside the table. So in an electric circuit, a current cannot set itself in motion, but must be produced as a result of the energy supplied by an electromotive force.

The current produces a magnetic field around the wire, and while the flux is increasing, the counter emf of self induction opposes the current and prevents it from instantly reaching its final value as determined by the applied voltage and circuit resistance. To overcome this counter emf, work must be done. Since it is not destroyed, the energy of the changing current is stored in the magnetic field around the wire or coil.

After the increasing magnetic field reaches its peak strength, no further counter emf is produced and no further energy must be expended to maintain the field. When the electric circuit is opened and the current stops, the collapsing magnetic field returns the stored energy to the circuit in the form of the induced voltage that tends to maintain the current.

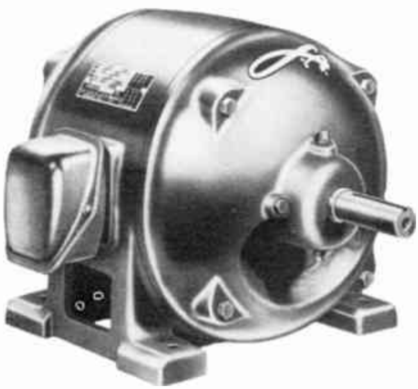


Used in industrial electronics for induction heating, these coils are made of heavy wire for the purpose of carrying a large current.

Courtesy Lepel High Frequency Laboratories, Inc.

INDUCTION USING ELECTROMAGNETS

In the lesson on electromagnets, it was shown that the magnetic lines of force, set up around a current carrying conductor, are exactly the same as those produced by a permanent magnet. Also, with current in a coil of wire, it sets up a surrounding magnetic field like that of a permanent bar magnet. Thus, by arranging the wire or conductor properly, an electric current will produce a magnetic field which can replace the field of a permanent magnet.



The interactions between the magnetic fields of stationary and pivoted coils cause this motor to rotate.

Courtesy Louis Allis Co.

There are several practical reasons why, in many cases, an electromagnet is preferable to a permanent magnet. Thinking of a coil of wire, by using the proper number of ampere turns, a magnetic field of almost any required strength can be produced, and so by regulating the current in the coil, the strength of the magnetic field can be varied as desired. In fact, by opening the circuit, there is no current in the coil and the magnetic field dies out completely. Because it is controllable, the electromagnet has many applications for which the permanent magnet is not suitable.

Induction was explained in the lesson on magnetism by means of a permanent magnet and a coil of wire. The same action is illustrated in Figure 6 but the permanent magnet is replaced by an electromagnet, consisting of a coil of wire wound on an iron core and connected to two dry cells. A second coil is wound on a pasteboard tube large enough to slip over the electromagnet. The ends of this second coil are connected to a sensitive zero center meter.

Pushing the electromagnet into the center of the coil of wire makes the meter pointer swing in one direction. Pulling the electromagnet out swings the pointer the opposite direction. This action, of course, merely shows that a voltage can be induced in a conductor by cutting the magnetic field of an electromagnet and the induction is exactly the same as with a permanent magnet.

Notice, there are two distinct and separate electric circuits, one consists of the battery and a coil of wire for the electromagnet, while the other circuit is made up of a coil of wire and a meter. Both coils are placed so that the magnetic field set up by one will cut through the other.

The coil connected to the battery or source of electricity is called the **primary** because the first action of setting up the magnetic field, occurs around this coil. The other coil is called the **secondary** because the second action or the induction of a voltage, takes place when it is cut by the magnetic field of the primary.

MUTUAL INDUCTION

A voltage can be induced in a wire or coil by a change of current in an adjacent wire or coil. This electromagnetic induction, due to the variable flux caused by one conductor cutting the other conductors, is called **mutual induction.** To illustrate the mutual induction between coils, the primary and secondary circuits of Figure 7 are electrically separate, although the coils are wound on the same core.

The primary circuit consists of the primary winding, the battery, and the switch, while the secondary circuit consists of the secondary winding and the meter. So long as the switch is open, nothing happens. No current is in the circuit, therefore no magnetic lines are set up around the primary, and with no magnetic lines no induction occurs in the secondary.

When the switch is closed, the primary current produces a magnetic field, which starts in the iron and moves out, as pictured with the light arrowed lines. During this interval the magnetic lines cut through the secondary and induce a voltage in it.

Since the primary coil has a fixed resistance, the voltage of the battery can force only a certain current through it. The strength or magnitude of the magnetic field depends on the ampere-turns of the primary. For the short time it takes the magnetic field to build up, the lines will cut through the secondary coil, but when the field reaches its full strength, the lines no longer move out, no longer cut through the secondary, and therefore, induce no further voltage. For this reason, the meter pointer swings when the switch in the primary circuit is first closed, then drops back to zero.

When the primary switch is opened, the current drops to zero and the magnetic lines fall back toward the iron core or collapse, and thus again cut through the secondary, but in the opposite direction to when the switch was closed. Therefore, the pointer deflects momentarily in the opposite direction.

By closing and opening the primary circuit, thus building up and collapsing the magnetic field, the lines cut through the secondary. If the primary switch is opened and closed rapidly enough, to maintain a continuous change of magnetic flux, a potential difference will be induced in the secondary all the time, but it will be of one polarity when the switch is closed and of the opposite polarity when the switch is opened. As the direction of the current caused by this induced voltage reverses direction periodically it is an alternating current.

An important thing to remember is that there must be motion between the magnetic lines and the secondary. A varying primary current causes a changing magnetic field, and a secondary placed in the field will be cut by the magnetic lines as they move away from and return toward the primary carrying this current.

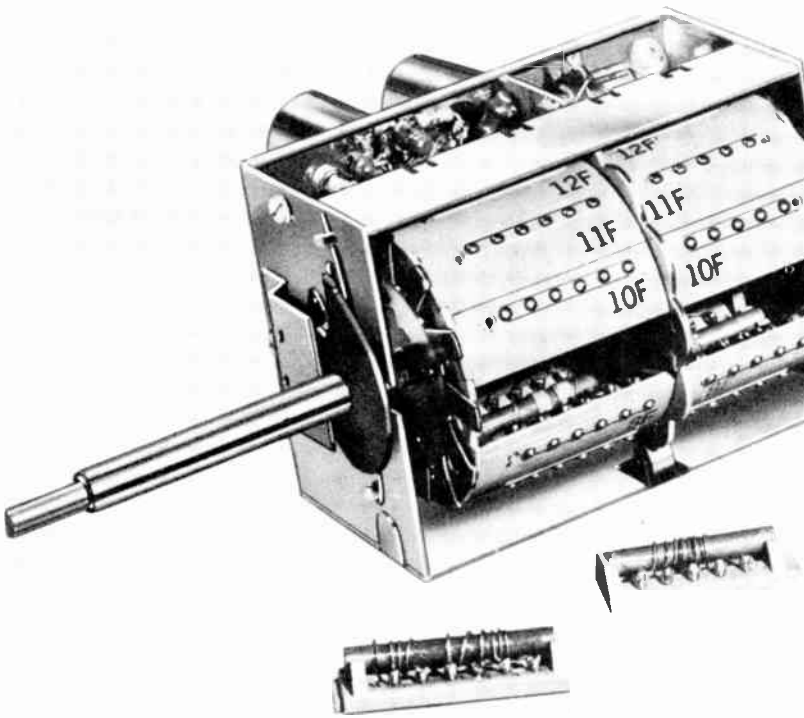
The effect of mutual induction between two wires is the same as that between two coils. To illustrate this action, the two wires shown in Figure 8 are electrically insulated from each other but are placed fairly close together. In Figure 8A, with no current in wire 1 there is no magnetic field around either wire. But in Figure 8B, with a current in wire 1 a magnetic field extends around it and beyond wire 2, and the only way these lines can extend beyond wire 2 is by cutting through it.

With any fixed current in the wire, the field builds up and spreads out to some certain distance and then remains constant. A voltage is induced while the magnetic field is building up and cutting wire 2, because there is a relative motion between the field and the wire during the time interval the field is spreading out. However, when the field becomes constant, there is no further motion, and the inductive action ceases.

When the circuit of wire 1 is opened and the current stops, the magnetic field collapses and falls back in toward wire 1. Thus, the field again cuts through wire 2, but in the opposite direction to when it was spreading out. Again, a voltage is induced, but of opposite polarity.

Just as self inductance is the ability of a wire to induce a voltage within itself, **mutual inductance** (M) is the ability of one conductor or coil to induce a voltage in another. Do not confuse mutual induction with mutual inductance. Mutual induction is the ACT of inducing a voltage in one coil or conductor due to a changing current in another. Mutual inductance is the ABILITY to induce the voltage and this exists regardless of the current in the circuit.

linked by the changing magnetic lines of force, often mutual induction is referred to as inductive coupling. The closer the coils, the



A television receiver tuner with two of the twenty-four coil strips removed.
Courtesy Stondord Coil Products Co.

COUPLING AND FLUX LINKAGE

When two coils are placed so that all or part of the magnetic field of one passes or cuts through the conductors of the other, electric energy is transferred from one coil to the other by the mutual induction between them. Because the two circuits are coupled or

greater the number of lines of force due to the primary current, that link with the turns of the secondary, and the closer or tighter the coupling is said to be.

The product of the magnetic lines of force and the number of turns in the coil through which they pass is called **flux linkage**, In most cases, the position of the coil with respect to the magnetic field determines the actual flux linkage. If the coil is close to a magnetic field so that most of the flux lines thread through the turns, the flux linkage is high, but if the coil is at a distance from the magnetic field, very few lines link with the coil, and the flux linkage is low.

TRANSFORMER ACTION BY INDUCTION

The arrangement of two fixed coils wound on a core, as shown in Figure 7, is known as a **transformer**. A transformer is an electric device, without mechanically moving parts, for transferring electric energy from one or more circuits to one or more other circuits by electromagnetic induction.

A very important point to remember is that although a battery is shown, a transformer will not operate with a steady current in the primary. For electromagnetic induction to occur, there must be a changing magnetic field such as is produced when the switch of Figure 7 is closed or opened. For an instant after the closing or opening of the switch, the magnetic field is building up or dying out and a voltage is induced into the secondary. At all other times, the magnetic field is stationary and no induction can occur.

Thus for the transformer to operate continuously, the primary must be connected either to an intermittent source of current or to some source of alternating current. As explained in an earlier lesson, an alternating current continuously changes in value and periodically reverses its direction, therefore the magnetic field around a primary carrying an alternating current is constantly building up and dying down, first in one direction and then in the other. These changes of the field mean that the magnetic lines continually cut through the secondary and induce a voltage in it.

TRANSFORMER CORES

Frequently transformer cores are formed into a square or rectangular "loop" to provide a complete, closed path or circuit for the lines of magnetic flux. A core with this shape is shown in Figure 9. Here, a solid block of steel with a square hole in the center has the primary coil wound around one "leg" and the secondary on the other. Produced by the current in the primary, the flux is carried almost entirely by the core, and thus passes through the secondary winding to induce the desired emf.

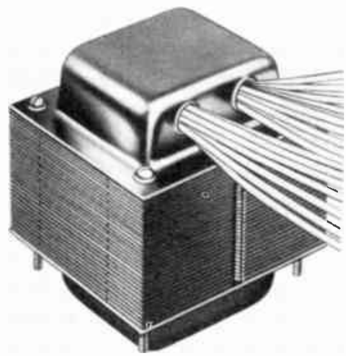
In addition to a magnetic circuit, the solid metal core forms a path for electric currents which are induced in it by the flux. To reduce these currents which cause heat loss, practical metal cores are made of a large number of thin sheets called **laminations** which are bolted together tightly.

The laminations are cut or stamped from thin sheets of steel which generally range from 6 to 25 thousandths of an inch in thickness. The steel sheets used have rust scale on their surfaces, and when the core is formed, the scale insulates the adjacent laminations and thus prevents currents from passing from one to the next, and so loss due to an induced current is reduced to a low value.

To avoid the difficulty of threading the turns of coil wire through the central opening of a solid core like that of Figure 9, the laminations are shaped so that two pieces are required to form a rectangle. By this plan, the coils can be wound without a core and after they are completed, the laminations can be placed in their central opening.

One type of lamination, shown in Figure 10A, has an L shape. With the finished coils in proper position, one L lamination is placed in the center of each coil. Additional laminations are then stacked in the coils, to form the completed core, shown in Figure 10B. Usually one side of the L is longer than the other and they are stacked alternately to provide the indicated staggered joint between adjacent rectangles. Transformers assembled in this way are known as CORE types.

Another common transformer core known as the SHELL type, is made of "E" and "I" shaped laminations as shown in Figure 11A. This arrangement forms two rectangles and all of the coils are made to fit on the center bar of



Notice the laminations of this shell type transformer. The core is laminated to reduce the power loss due to eddy currents.

Courtesy Standard Transformer Corp.

the E. As explained for Figure 10, the laminations are stacked in the center opening of the finished coils to form the assembly of Figure 11B.

Laminations of this shape can be stacked in either of two ways. First, adjacent "E's" are inserted from opposite ends of the coil and each layer completed with an "I". This forms the staggered joints indicated in Figure 11B. Second, all the E's can be inserted from the same end of the coils to provide the core illustrated in Figure 12. Then an equal number of I laminations are placed across the open end of the E's to complete the core.

Figures 10B and 11B are "semi-schematic" insofar as the windings are concerned, in order to show the core construction. The actual arrangement used in a practical transformer with shell type core is illustrated by the cut-away view in Figure 12. Here, the "I" stack is removed to show that both windings consist of a relatively large number of turns.

The primary is wound around the entire center leg of the "E" stack and the secondary is wound around the primary, while a layer of insulation separates the two windings. When the windings and core have been assembled, the entire unit is clamped together with bolts extending through the stacks as shown in Figure 13.

Possibly you have heard a buzzing or humming sound around a radio or television set. This may be caused by the vibration of laminations which have worked loose. Therefore, this noise is a servicing clue to the technician to tighten the bolts.

TRANSFORMER LOSSES

In general, losses of energy in a transformer are the result of core losses, copper losses, and stray losses of various types. Existing only in transformers which employ cores of magnetic material, core losses are of two kinds, hysteresis loss, and eddy current loss.

Copper losses are losses of energy in the form of heat produced due to the currents in the conductors of the transformer windings. They are minimized by employing large diameter conductors to reduce the resistance per unit length of the wires.

In power supply transformers HYSTERESIS forms approximately ¾ths of the core loss. The term "hysteresis" describes a slight lagging of the flux density which occurs when the alternating magnetizing force, due to the primary a-c, sets up the alternating flux in the iron core. This lag is due to the tendency of the iron to oppose a change in magnetism. Thus, whenever the flux density is being increased, the magnetizing force must be a little greater than it would if hysteresis were not present.

Also, after the magnetizing force has reduced to zero at the end of an alternation, a certain magnetization remains in the core, and can be decreased to zero only by the application of magnetizing force in the opposite direction. In the form of these extra magnetizing forces during each cycle, a certain percentage of the total energy supplied is used to overcome the hysteresis effect, and this energy is lost insofar as the transformer action is concerned.

EDDY CURRENTS

Referring to Figure 7 when the switch is closed the direction of electron flow in the primary is from top to bottom on the near or visible side of the coil through the positive of the battery and back to its negative terminal. When the switch is closed, the primary current causes an expanding magnetic field which starts at the center of the core and moves outward in all directions. Cutting the coil wire as they expand, the magnetic lines induce a voltage which opposes the current and prevents it from rising instantly to its full value.

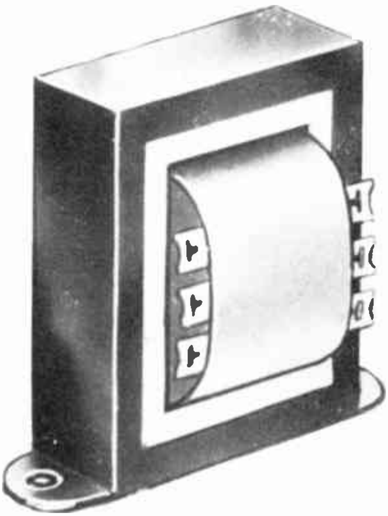
Wound on the same core as the primary, the expanding lines cut the wire of the secondary coil and induce a voltage in it. This induced voltage is in the same direction as the counter emf induced in the primary, but with no other voltage source, if its circuit is closed, the induced secondary voltage will cause a current. This action was mentioned previously to explain the kick of the meter pointer when the primary switch is closed and opened. With the meter removed and the coil ends connected directly, the action will remain the same.

Suppose the coil of wire is replaced by a copper tube with no external circuit, the induced voltage will cause current to circulate around the tube exactly the same as around each turn of a coil. Notice here, the direction of this current is parallel to that in the turns of wire in a coil but at right angles to the axis of the core and the magnetic lines.

Going a little further, the iron core is an electric conductor therefore, any change of the magnetic fields which induces a voltage in the coils will induce a similar voltage in the core also. Like the copper tube, the core can be considered as a closed circuit and thus, the induced voltage will cause circulating current in it. This circulating current in the core will set up a magnetic field of its own which always will be in a direction to oppose the changes of current.

However, more important is the fact that the currents set up in the core will produce considerable heat, which is a waste of energy, impairing the effectiveness of the transformer. Currents produced in a piece of metal in this matter are called **eddy currents.**

By using a laminated core, the eddy currents are reduced without increasing the reluctance of the magnetic circuit. The laminations lie in the same direction as the flux, therefore, the insulating surfaces are directly across the path of the eddy currents. The resulting eddy current reduction greatly improves the operation of the transformer.



A type of transformer having solder lugs for connection.
Courtesy Standard Transformer Corp.

All of these losses make the typical transformer hot when operating under full load. In fact, how much heat the insulation can take without breaking down determines the power limitations of the transformer. Therefore, although most transformers are too hot to hold a hand on with comfort, there should be no odor of burning insulation or varnish or signs of discoloration or smoke. Any one of these would indicate to the technician that the transformer is overloaded, and he would investigate to find out why.

STEP-UP AND STEP-DOWN TRANSFORMERS

Not only is a transformer employed to transfer electric energy from one circuit to another, as we mentioned earlier, it also raises or lowers the voltage to meet certain operating requirements. For example, in practically all alternating current power lines, the voltage is "stepped up" at the power house, carried long distances, and then "stepped down" at the place where it is used. Also, in practically all electronic apparatus, designed to operate from 110-volt a-c lighting circuits, transformers are used to lower the voltage for some circuits and raise it for others.

The induced secondary voltage is affected by four factors: the speed of cutting the lines of force, the length of the conductor, the strength of the flux, and the angle of cutting. The speed cannot be changed in a transformer, because it is controlled by the rate at which the magnetic field of the primary builds up or collapses. When the primary circuit is closed and opened, the change in magnetic flux takes place as rapidly as possible. Also, the strength of the field can be ruled out because it is determined by the core material and the ampere-turns of the primary coil which is made up of a specific number of turns and with a certain resistance, so that it carries a definite current. The angle of cutting cannot be changed, since the coils already are arranged permanently on the core.

Only the length factor is left but it can be put to good use for the purpose. Suppose the secondary is wound with twice as many turns as the primary. Then the same number of magnetic lines, moving at the same speed, and cutting at the same angle, but cutting twice the length of wire, produces twice the voltage in the secondary. The reverse also is true. If the secondary is wound with half as many turns as the primary, then the same number of magnetic lines, moving at the same speed and cutting at the same angle but cutting half the length of wire, produces half the voltage in the secondary.

These two examples illustrate the definite relationship between the number of turns and the voltage of each winding. As a general rule, this relation may be stated as: IN A TRANSFORMER, THE SECONDARY VOLTAGE DIVIDED BY THAT OF THE PRIMARY IS THE SAME AS THE NUMBER OF TURNS IN THE SECONDARY DIVIDED BY THOSE IN THE PRIMARY. That is, in an abbreviated form:

$$\frac{E_s}{E_p} = \frac{T_s}{T_p} \qquad (1)$$

where E_s and E_p are the secondary and primary voltages, and T_s and T_p are the secondary and primary turns.

If the primary turns and voltage are known and it is desired to determine the number of turns required for a given secondary voltage, the expression may be rewritten:

$$T_s = \frac{T_p E_s}{E_p} \qquad (1a)$$

and the known values substituted for the letters. In words, the above says: "Multiply the secondary voltage by the number of turns in the primary and divide this number by the voltage of the primary to get the number of turns in the secondary." To illustrate the use of this equation, assume that the primary of Figure 7 has 30 turns and operates at 3 volts. How many secondary turns are required to produce 300 volts?

T_s = 30 times 300 divided by 3 or 3,000 turns

As mentioned earlier, transformers may be used to raise or lower the voltage. One with more turns of wire in the secondary than in the primary like Figure 10 is known as a **step-up** transformer, since it increases the voltage, while one with fewer turns in the secondary than in the primary like Figure 11 causes a decrease of the voltage and, therefore, it is known as a **step-down** transformer.

TRANSFORMER ENERGY

The mutual induction between the primary and secondary of a transformer makes it possible to transfer electric energy from one circuit to another, and in doing so it is possible to change the voltage of the induced energy. However, a transformer cannot increase the total energy. The energy in the secondary always is slightly less than that in the primary because of certain unavoidable losses that exist in all circuits.

Going back to Figure 10 again, with an a-c voltage applied across the primary, the induced counter emf holds the current to the small amount necessary to replace the energy lost in the resistance of the wire. An equal counter emf is induced in each turn of the primary and secondary, but with no external circuit, there is no secondary current. However, when an external circuit is provided, the induced secondary voltage will cause current.

As the induced voltage opposes the applied voltage, the direction of the current in the secondary is opposite to that in the primary. Therefore, the magnetic field set up by the secondary current will oppose and weaken the field caused by the primary current. This weakened field induces a lower counter emf and so the primary current increases.

The higher the secondary current, the greater the weakening of the overall field and the greater the increase of primary current. These actions are so balanced that any energy delivered by the secondary causes a corresponding increase of energy taken from the source by the primary.

The energy in a transformer winding is measured in volt-amperes and is equal to the voltage times the current. Because of losses due to resistance of the wire in the winding and those of the core in the primary the energy available to the secondary always is slightly less than that in the primary. Although the transformer gets hot, for most circuits these losses are a very small part of the total energy handled. Therefore, for all practical purposes the energy in each winding is so nearly equal that it can be written in abbreviated form as:

$$E_pI_p = E_sI_s, \qquad (2)$$

where:

E_p = primary voltage

I_p = primary current

E_s = secondary voltage

I_s = secondary current.

This means E_p times I_p is the same number of volt-amperes as E_s times I_s. These terms can be rearranged to calculate any one value when the other three are known. For example:

$$I_s = \frac{E_pI_p}{E_s} \qquad (2a)$$

The transformer of a previous example developed 5 volts in its secondary when a 100 volt source was connected across the primary, assuming a primary current of 2 amperes, the secondary current is:

$$I_s = \frac{100 \times 2}{5} = \frac{200}{5} = 40 \text{ amperes.}$$

For the primary, the energy is:

100 volts × 2 amperes = 200 va,

where:

va = volt-amperes

and for the secondary, the energy is:

5 volts × 40 amperes = 200 va.

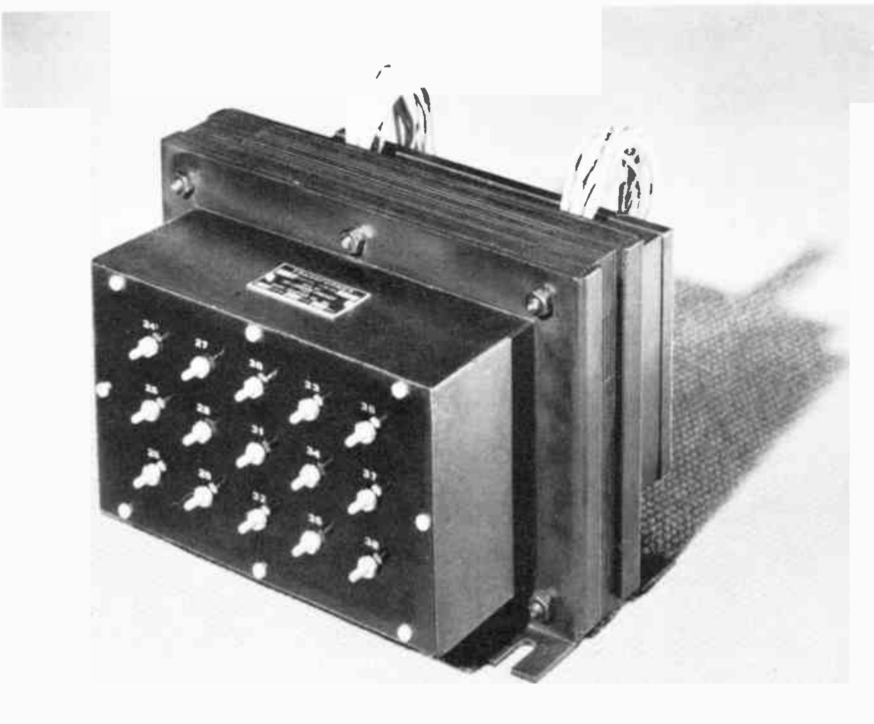
Thus, with no increase in available energy, a transformer secondary can provide higher voltage with lower current or lower voltage with higher current than exists in the primary.

COUPLING

When two coils are placed so that all or part of the magnetic lines of one coil passes or cut through the conductors of the other coil, flux linkage occurs and there is inductive coupling between the inductors. The amount of flux linkage determines the "degree of coupling". For example, if all of the magnetic lines, produced by a current in one coil, cut across its turns and also cut across all the turns of another coil, the flux linkage will be greatest, and a condition of maximum or unity coupling is said to exist.

In actual practice, there is always a certain "flux leakage", that is, some of the magnetic lines will "leak" off into space without cutting the second coil. Therefore, unity coupling is never achieved and the degree of coupling is always less than 1.

This degree of coupling, called the **coefficient of coupling**, is represented by the letter "k". If unity coupling were possible, k would equal 1. If only half of the lines set up by the first or primary coil cut another or secondary coil, or all of the lines cut only half of the secondary, k is .5. That is, the coefficient of coupling is close to zero if the inductors are widely separated and near 1 if they are close together. The coupling is said to be "tight" when the coefficient of coupling is high, and "loose" when the coefficient is low.



This power transformer has a number of taps so that, by making connections to the proper terminals, the desired output voltages can be obtained.

Courtesy Longevin Mfg. Co.

SYMBOLS

Since schematic diagrams will continue to form not only an important part of your studies and laboratory projects, but are needed continually by the practical technician in his work, the symbol for a transformer is given in Figure 14. The loops represent the turns of wire in the coils, the extended lines at each end of the series of loops represent the circuit connections, and the parallel lines in the center represent an iron core. No attempt is made to indicate the number of turns in each winding, although the operating voltages may be indicated as shown.

This symbol is a common type of "power transformer", the primary operates on the ordinary 110 volt house a-c lighting circuit, and is indicated by the coil on the left. Because the house lighting circuit voltages may vary in different locations, the symbol shows that the winding is tapped for operation at 100, 110, or 120 volts.

To explain the operation of these taps, suppose the transformer is designed on the basis of 10 turns per volt. That means a drop of one volt across each 10 turns of the primary and an induction of one volt for each 10 turns of the secondaries. Under these conditions, that portion of the primary indicated by the "100 v" arrow contains 10×100 or 1,000 turns.

As the primary and secondary voltages are proportional to the number of turns the 6.3 volt secondaries have 10×6.3 or 63 turns and 500 volt secondary has 10×500 or 5,000 turns.

Now suppose the supply rises to 110 volts. Connected across the 1,000 turn primary the drop will be 1,000 divided by 110 or 9 turns per volt approximately. Under these conditions the 6.3 volt windings develop 63 divided by 9 or 7 volts and the 500 volt winding will develop 5,000 divided by 9 or 555 volts, approximately.

To prevent this undesirable rise in secondary voltages, the 10 turns per volt factor is re-established by adding 100 turns to the primary winding between the 100 v and 110 v taps. With the 110 volt source connected as shown by the arrow, 110 volts across 1,100 turns provides the normal 10 turns per volt drop and thus produces the normal secondary voltages.

The increased number of primary turns compensates for the increased voltage, the turns ratio of the 500 volt winding is now 5,000 divided by 1,100 or 4.55 approximately and 4.55 times the 110 volt primary is 500.5 volts.

Following the same plan, another 100 turns on the primary will provide normal secondary volts with a 120 volt supply.

Referring again to the symbol of Figure 14, three secondary windings are shown each with a middle connection or "centertap". The upper winding develops 6.3 volts, the center winding 500 volts and the lower winding, 5 volts. Thus, by a comparatively simple symbol, the circuit arrangements and voltages of a typical power transformer with four windings and 13 external connections are shown. As far as the circuit connections are concerned, the symbol provides complete information.

According to this plan, any inductor or transformer can be represented by an accurate symbol. If no iron core is used, the central parallel lines are omitted. In fact, these parallel lines sometimes are omitted from the diagram where there can be no question that an iron core inductor or transformer is used.

In Figure 15, the 117 volt a-c is changed by the transformer into the desired voltage. The diode rectifies the a-c to get d-c. However, this d-c is not smooth enough to be used directly in other tube circuits; capacitors C_{18} and C_{19} and resistor R_{14} are needed. These have not been explained yet, and therefore, the next lesson is about resistors.

IMPORTANT DEFINITIONS

COUNTER EMF—The voltage induced in a wire by self induction which opposes the applied voltage. Also called back emf.

COEFFICIENT OF COUPLING—(k)—A numerical rating between 0 and 1 that specifies the degree of coupling between two circuits. Maximum coupling is 1 and no coupling is 0.

EDDY CURRENTS—[ED i KER ents]—Circulating currents produced in connecting materials by a varying magnetic field. Eddy currents are undesirable in the core of a transformer.

FLUX LINKAGE—The linking of the magnetic lines of force with the conductors of a coil. The value obtained by multiplying the number of turns in the coil by the number of magnetic lines of force passing through the coil.

INDUCTIVE COUPLING—[in DUHK tiv KUHP ling]—The coupling or linkage of two circuits by the changing magnetic lines of force.

LAMINATION—[lam i NAY sh'n]—A thin layer or sheet. As used here, the term refers to the thin iron pieces used to build up the core of a transformer.

MUTUAL INDUCTANCE (M)—[MYOO: chew al in DUHK tans]—The ability of one conductor to induce an emf in a nearby conductor when the current in the first conductor changes.

MUTUAL INDUCTION—[MYOO: chew al in DUHK sh'n]—The electromagnetic induction produced by one conductor in a nearby conductor due to the variable flux of the first circuit cutting the conductors of the second circuit.

PRIMARY—(P)—[PRIGH mer i]—That winding of a transformer which is connected to and receives energy from an external source of electrons. Also frequently referred to as the input winding.

SECONDARY—(S)—[SEC uhn der i]—That winding of a transformer which receives its energy by electromagnetic induction from the primary. Also frequently referred to as the output winding. A transformer may have one or more secondaries.

IMPORTANT DEFINITIONS—(Continued)

STEP-DOWN—Refers to a transformer that has fewer turns of wire in the secondary than in the primary, and hence, causes a decrease or step down of the voltage.

STEP-UP—Refers to a transformer that has more turns of wire in the secondary than in the primary, and hence, causes an increase or step up of the voltage.

TRANSFORMER—[trans FOR mer]—An electric device, without mechanically moving parts, for transferring electric energy from one or more circuits to one or more other circuits by electromagnetic induction.

ESSENTIAL SYMBOLS AND EQUATIONS

E_p	Primary voltage (volts)
E_s	Secondary voltage (volts)
k	Coefficient of coupling
L_1, L_2, L_3	Individual inductances (henrys)
M	Mutual inductance (henrys)
T_p	Turns in primary
T_s	Turns in secondary

$$E_s/E_p = T_s/T_p \quad (1)$$

$$E_pI_p = E_sI_s \quad (2)$$

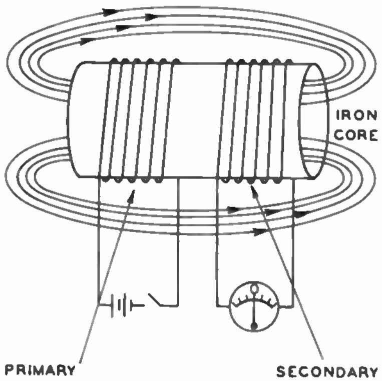


FIGURE 7

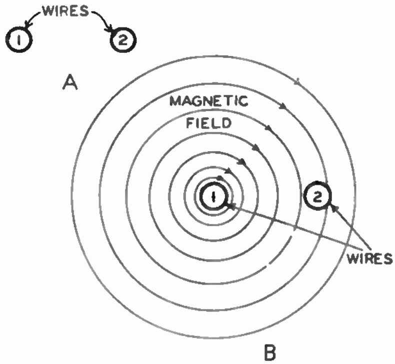


FIGURE 8

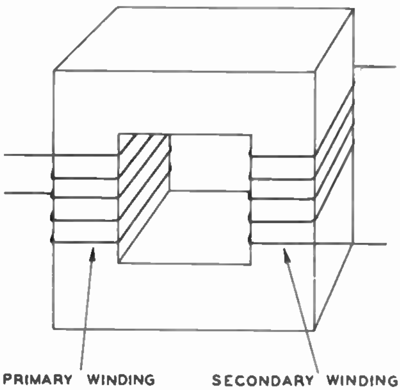


FIGURE 9

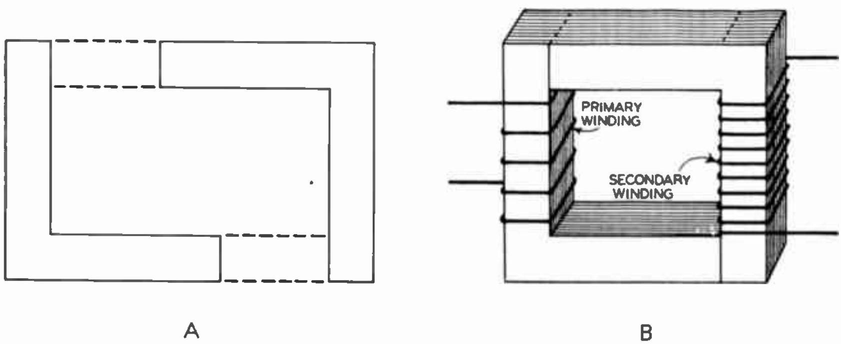


FIGURE 10

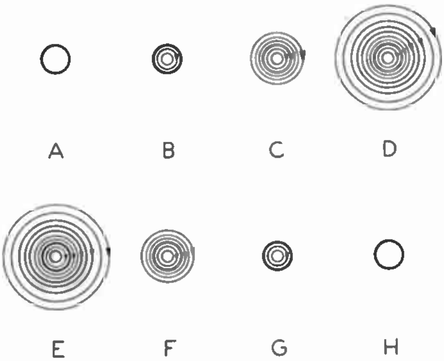


FIGURE 1

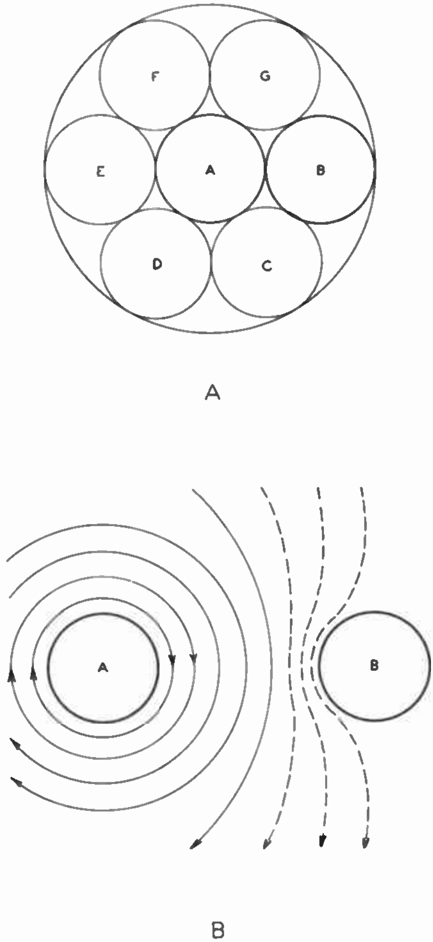


FIGURE 2

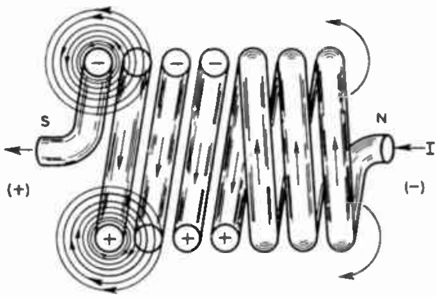
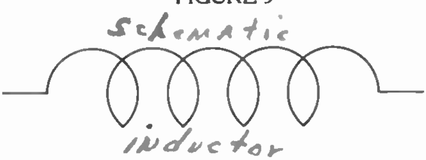


FIGURE 3



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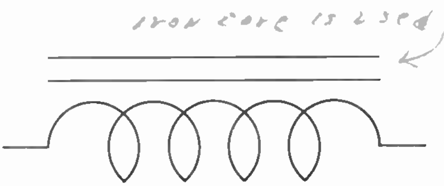


FIGURE 5

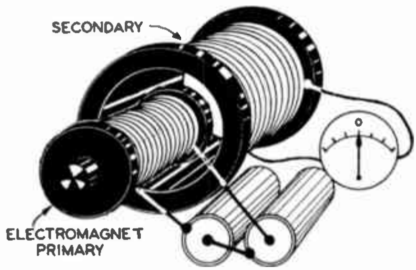


FIGURE 6

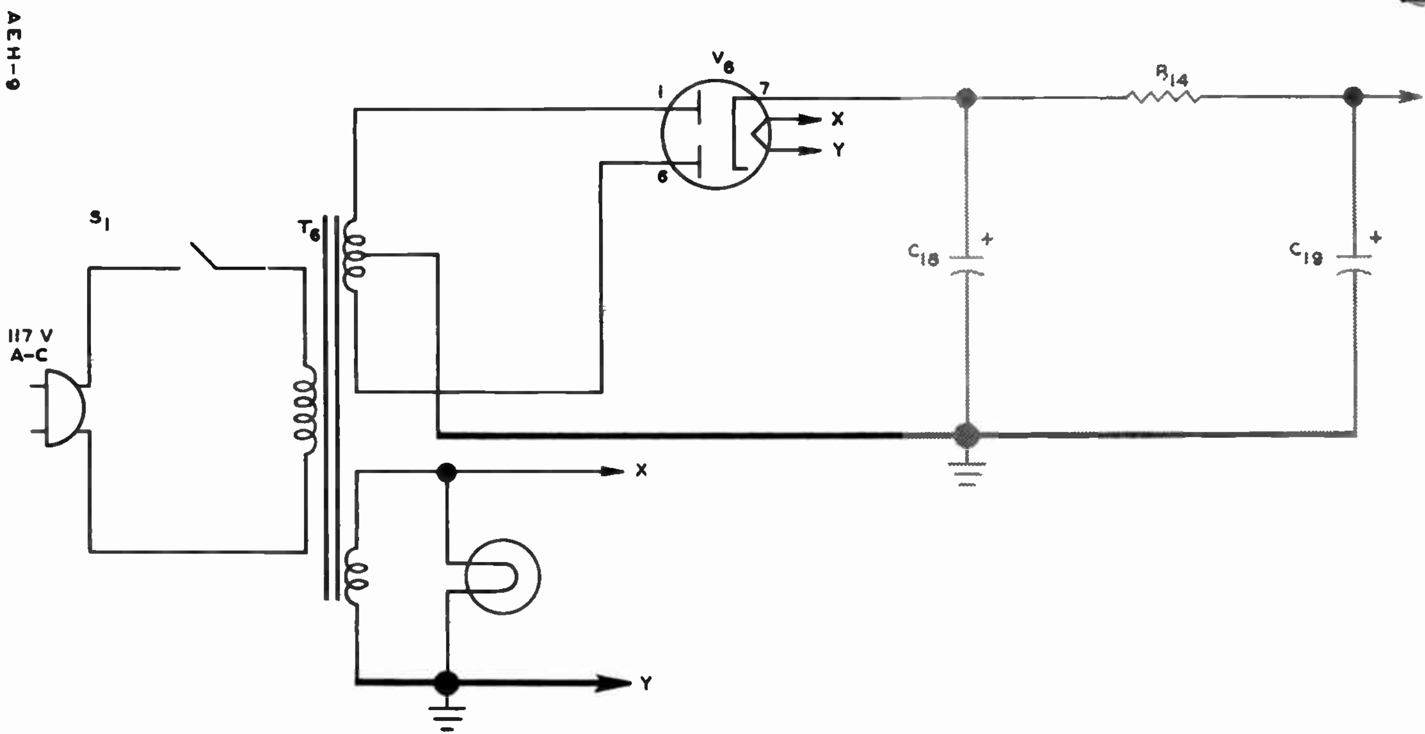
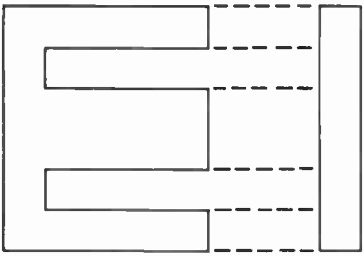


FIGURE 15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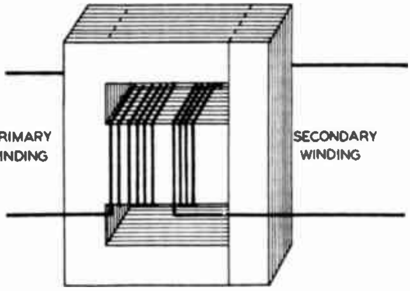

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FIGURE 11

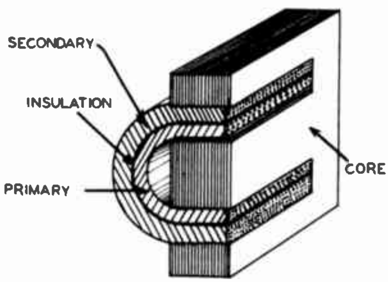
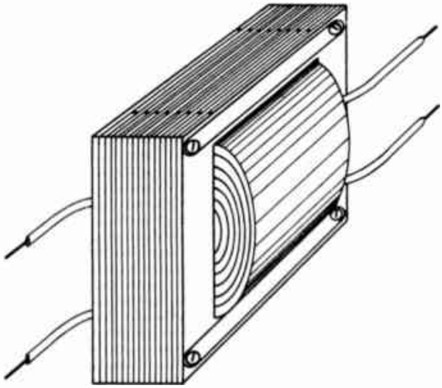


FIGURE 12



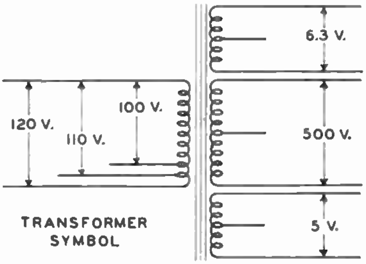
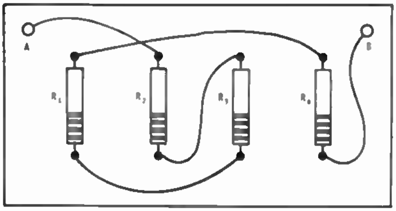


FIGURE 13

FIGURE 14

WORK DIAGRAM

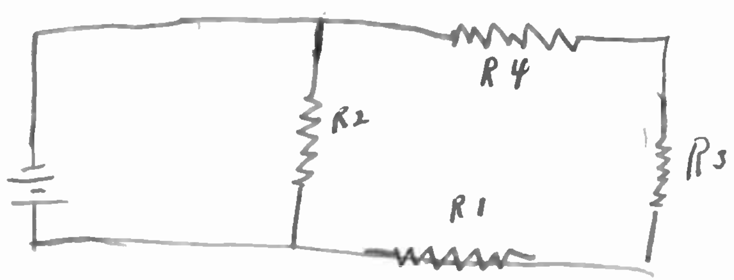
1. Substitute schematic symbols for the resistors in the sketch, and draw the circuit diagram using a minimum of crossed lines.



When you have finished, check with the solutions on the back of the foldout sheet.

WORK DIAGRAM SOLUTION

1. Substitute schematic symbols for the resistors in the sketch, and draw the circuit diagram using a minimum of crossed lines.



FROM OUR *Director's* NOTEBOOK

LOST TIME

Time is the one thing in this world that cannot be recovered or retrieved.

One may lose and regain a friend, a man may lose money and make it up again, an opportunity that you once spurned may reappear — but minutes lost in idleness are gone forever, never to be brought back.

Use your time wisely. There is time for work and time for play, play-time is as necessary as work-time.

The important hours, however, are those early evening hours — they are the 60-minute intervals that add to your day's opportunities. Many a career is made or marred in the hours right after supper, so apply them to your best advantage.

Yours for success,

W. C. DeVry

DIRECTOR

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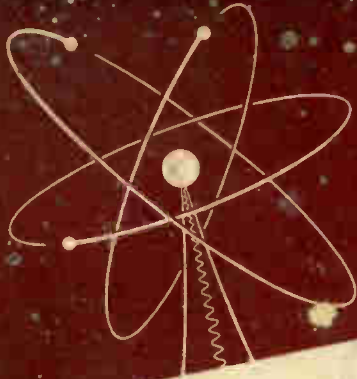


RESISTORS

Lesson AEH-10C

EII-10

DeVRY Technical Institute

4141 W. Belmont Ave., Chicago 41, Illinois

Formerly DeFOREST'S TRAINING, INC.

AEH-10C

RESISTORS

ELECTRONS GUIDE ROCKETS

The rockets that zoom over a hundred miles into the sky have been described in numerous accounts, but what is not generally known is that their main cargo consists of electronic equipment. Not only does this equipment provide remote control of the rocket during the flight, it also collects scientific data on atmospheric conditions, and transmits it by radio to receiving and recording equipment on the ground.

In like manner, electronic equipment is used to receive weather data from balloons and other types of remote, unmanned stations; to control furnaces in steel mills; and to carry on production or assembly of explosives and poisons.

Fundamentals

RESISTORS

Contents

Persons of the highest intelligence never cease to learn and any person, whatever may be his station in life, who devotes a share of his time to self betterment through home study courses, will never regret the time thus spent.
—C. Haile, Pres., M-K-T R.R.

RESISTORS

Television receivers and transmitters, radio communication, motion picture sound amplifiers, industrial electronic controls, geiger counters, nucleonic and medical research instruments and all other kinds of apparatus, employed throughout the broad field of electronics, are but assemblies of numerous parts which are connected together with wire to form the complete unit.

Naturally, devices such as lamps, motors, electron tubes, or electron equipment are considered to be important parts of an electric circuit, but they will not function unless properly connected to a source of electric energy. The connecting wires form a metallic path or CIRCUIT that carries the electricity from the source to the device that uses the energy.

In fact, the whole country is covered with a huge network of wires. From large and small electric power plants, wires carry electricity in all directions, sometimes for hundreds of miles, to the homes, shops, and offices where it is used. Wires from the telephone exchange to your home, and between exchanges, permit rapid and efficient communication to points many miles distant.

Possibly you have seen the underside of a radio or television chassis. No doubt you found many wires. In fact, in some electronic equipment wires of many different colors are used to make it easy to trace from one point to another. Some of these are solid colors while others use two or more colors in an easy to identify combination.

The common types of wires are round or cylindrical metallic threads of uniform diameter. They are made in many sizes, with diameters ranging from those of almost invisible hair-like lamp filaments to bars an inch or more thick. Depending on the application for which it is used, a wire may be large or small in diameter, may be made of one metal or another, but in each case, it is a good conductor of electricity.

WIRE INSULATION

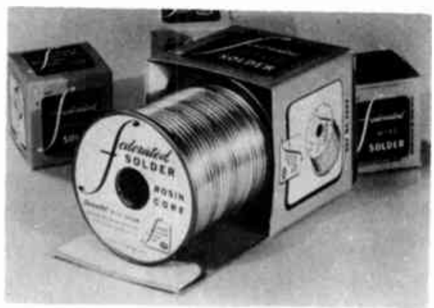
In an electric circuit, the connecting wires must be covered with a protective coating of non-conductive material or insulation in order to keep the electrons in their proper path. Since air is a good insulator, a pair of bare wires separated from each other by open air are very well insulated from each other. A common example of this type of insulation is found in the many telegraph and telephone wires which are strung outdoors on poles. To make the insulation complete, usually the wires are supported at the poles by glass insulators. Thus, the entire wire and circuit is properly insulated although the actual conductor is not encased in a solid insulating material.

Circuits of this kind must be well supported because the air insulation offers no protection if the wire comes in contact with a conducting object. This same general type of construction is employed in certain types of electron apparatus where the use of a solid insulating material around the wire is undesirable.

In other applications, copper wire is wound in coils of various sizes and shapes on forms or spools. In most cases, the turns of the coils are wound quite tightly together and, therefore, the wire itself must be insulated. Should the metal conductors of the individual turns touch or make contact with each other, the electricity would follow this path, from one turn to the next, instead of passing through the entire length of wire. Since a condition of this kind provides a shorter path for the electricity, it is called a short circuit or "short". To prevent this condition, the metal wire is covered with insulation.

WIRE CHARACTERISTICS

Perhaps the greatest advantage of the use of electric energy is that it can be carried almost any distance, over small wires with very little loss from the place where it is produced to where it is used. At first thought, the size of the wire and the material of which it is made, might not appear important. However, the material, diameter and length of the wire, as well as the insulation on it, must be considered when selecting wire to be used in the construction of electron equipment.



To facilitate soldering, solder designed for electronic purposes is sold as a wire with a rosin core.

Courtesy American Smelting and Refining Co.

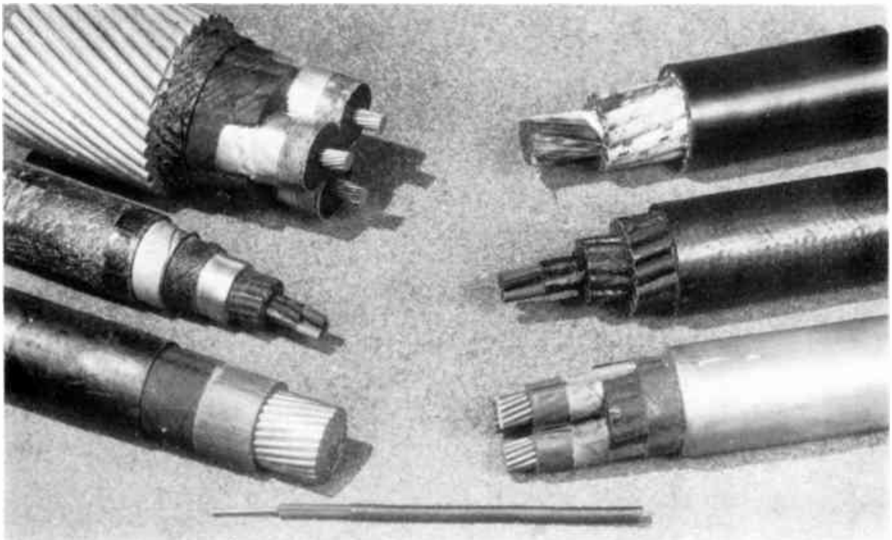
ACTION IN A WATER PIPE

Although the operating conditions are quite different, the action of a pipe on the water it carries affords an illustration of the effect of wire radius, length, and material on an electric current.

Suppose a tank of water has an outlet pipe at the bottom and, to control the flow of water, a valve is placed in the pipe. Also imagine the valve is placed quite close to the tank but that the pipe is ten or twelve feet long.

With a full tank, opening the valve will allow a stream of water to run out of the end of the pipe. The wider the valve is opened the larger the stream of water; but even with the valve completely open, the stream will not exceed a certain size. Summarizing these actions, the factors that control the water current, that is the amount of water flowing through the pipe, are the pressure in the tank and the effect of the pipe. For the purpose of this lesson, only the action of the pipe itself need be considered.

The size of a pipe has a direct bearing on the amount of water that can pass through it. A large pipe will carry a greater amount than a small one. This may be explained in one way by stating that the larger pipe offers less opposition or resistance to the passage of water through it.



To meet various electronic needs, wires are used separately or formed into cables with several conductors enclosed in one overall covering.

Courtesy The Okonite Company

Usually, pipe is measured by its diameter, which is the greatest distance across the inside; but as the water is carried by the entire pipe, the cross-sectional area must be considered. The cross-section is the circle, seen when looking at the end of the pipe, and, from your school days, you may remember the area of a circle is πr^2 with π equal to 3.1416 and "r" as the radius. The "2" at the upper right of the "r" means that it is squared or multiplied by itself. For convenience, this equation often is stated as 0.7854 times the diameter squared. Thus, for a 1 inch diameter pipe:

$$\text{Cross section area} = 0.7854 \times d^2$$
$$= 0.7854 \times 1 \times 1$$
$$= 0.7854 \text{ sq. in.}$$

For a 2 inch diameter pipe;—

$$\text{Cross section area} = 0.7854 \times 2 \times 2$$
$$= 0.7854 \times 4$$
$$= 3.1416 \text{ sq. in.}$$

Since the number 0.7854 remains the same for all sizes, the cross-sectional area of a cylindrical pipe is proportional to the square of its diameter.

The cross-sectional area determines the quantity of water it can carry, and the larger the pipe the less resistance it offers. The cross-sectional area of the pipe varies as the square of its diameter, therefore, its resistance also varies with the square of the diameter. However, this variation is reversed because the larger the area the smaller the resistance.

In technical language WHEN TWO VALUES CHANGE WITH RESPECT TO EACH OTHER SO THAT ONE INCREASES AS THE OTHER DECREASES, THEY ARE INVERSELY PROPORTIONAL. Hence, as a rule, the resistance of a pipe is INVERSELY PROPORTIONAL to the square of its diameter.

For example, comparing two pipes of the same length, one with twice the diameter, will have four times the cross-sectional area and one-fourth the resistance, of the other. Length also has a bearing on resistance, but in this case, the longer the pipe the greater the resistance; for the water has further to go in order to pass through it. WHEN TWO VALUES CHANGE SO THAT AN INCREASE OF ONE IS ACCOMPANIED BY AN INCREASE OF THE OTHER THEY ARE DIRECTLY PROPORTIONAL. Hence, as a rule, the resistance of a pipe is directly proportional to the length. Comparing two pipes of the same diameter, one with twice the length, will have twice the resistance of the other, or with half the length, it will have half the resistance.

The finish which the pipe possesses also has an effect on the resistance it offers to a current of water. The pipe with a smooth inner surface has a lower resistance than a pipe with a rough surface.

To sum up the above statements, the resistance of a water pipe is:

1. Inversely proportional to the square of its diameter,
2. Directly proportional to its length, and
3. It is affected by the inner surface material.

The material of which a wire is made is comparable to the relative smoothness of the inner surface of a water pipe.

FACTORS AFFECTING WIRE RESISTANCE

In a previous lesson it was pointed out that the electrons of some atoms are more readily dislodged than from the atoms of other materials. Also it is the ease or difficulty of dislodging these

Not only are resistors designed for different resistance and power ratings, some are designed with long bodies to withstand high voltages.
Courtesy Resistance Products Co.

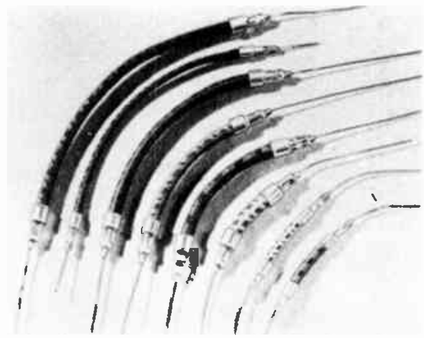
Just as a flow of water is known as a water current, a flow of electrons is known as an electric current. Like water pipes, the wires offer a resistance or opposition to the electric current in them. In fact, the factors that affect the resistance of a wire are the same as those that affect the resistance of a pipe: the diameter, cross-sectional area, length, and material.

electrons, that determines the classification of a material as an electric conductor or insulator. Hence, the material from which a wire is made has a great effect on its resistance. While silver is perhaps the best of all known conductors, copper is very good and so available that it is the most widely used metal for wires of all sizes. However, for special purposes, wires are made of other metals or of mixtures of two or more metals called alloys.

As in the case of a water pipe, THE RESISTANCE OF A WIRE IS INVERSELY PROPORTIONAL TO THE AREA. Since the area is equal to 0.7854 times the square of the diameter, the resistance of a wire may be said to be inversely proportional to the square of the diameter. Thus, if the diameter of a wire is doubled, its resistance is reduced to one-fourth. For example, if a wire, .2 of an inch in diameter, has a resistance of .24 ohm, then the same wire, .4 of an inch in diameter, has a resistance of only one-fourth of .24, or .06 ohm.

THE LONGER THE WIRE THE GREATER THE RESISTANCE, since the electrons will have to travel further. The effect of the length is such that a wire two feet long has a resistance just twice that of a similar piece one foot long.

Temperature is a condition that affects the resistance of a wire, but does not affect the water pipe. Whenever electricity passes through a conductor, it develops a certain amount of heat and the resistance of the conductor changes with temperature. This change varies with different metals, but generally, the resistance increases with an increase of temperature. In some cases the resistance change must be taken into consideration, but for the average application it is not as important as the other factors affecting the resistance.



Wire wound resistors often are made by winding the wire on an asbestos rope and covering it with an insulating cambric. The flexibility provides ease of mounting in close quarters.
Courtesy Clarostat Mfg. Co.

To sum up the above statements, *the resistance of a wire varies:*

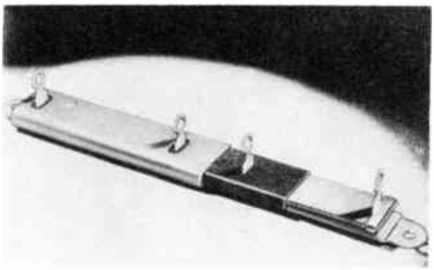
1. *With the material.*
2. *Inversely as its area.*
3. *Directly with its length.*
4. *With temperature changes.*

THE BROWN AND SHARPE COPPER WIRE TABLE

The Brown and Sharpe (BS) copper wire table, shown in Table 1, at the end of the lesson, contains all of the important information about the common sizes of wire without any insulation. Two columns usually given with the table are omitted, since they are not useful to the practical electronic technician. Do not try to memorize these figures, only learn how to use the table, and refer to it whenever needed.

These numbers start at "0000", read as "four oh" and continue down through "three oh", "two oh", "one oh", and 1 to 40.

The second column shows the weight in pounds per 1000 feet of the different sizes, without insulation. The third column is very much like the second column, but is turned around, and gives the number of feet of bare wire in a pound.



Many resistors are made with non-adjustable taps for a specific application. Part of the metal cover and insulating material are removed to show internal construction details.
Courtesy Clarostat Mfg. Co.

The last three columns list the resistances of the various sizes of pure copper wire in three ways: the number of "Ohms per 1000 feet", the number of "Feet per Ohm", and the number of "Ohms per Pound".

To use the table, read down the left hand column to the wire gauge wanted and then read across to the right to the column under the proper heading for the value desired. For example, to find the weight of Gauge No. 20 wire: which usually is called "Number 20" and written "No. 20", go down the left column to 20 and then over to the right to the second column which gives the value of 3.09. Since the top of this column states "Weight in lbs. per 1000 ft.," 1000 ft. of No. 20 bare wire weighs 3.09 pounds.

Reading across for a No. 30 wire, we find it has a weight of 0.30 pound per thousand feet, and 3,287 feet weigh one pound. From the last three columns, No. 30 wire has a resistance of 103.2 ohms per 1000 feet, it requires 9.691 ft. of wire for a resistance of one ohm, and one pound has a resistance of 339.2 ohms.

A table of this kind eliminates many wire calculations, for it can be read directly for any of the common sizes of copper wire. An example will demonstrate how the table simplifies wire calculations in general.

Suppose an 80 foot length of No. 20 wire is employed between two points and we desire to know the resistance of this connecting wire. First, we read down the Gauge No. column to find No. 20. Moving across to the Ohms per 1,000 Ft. column, we find that a 1,000 foot length of No. 20 wire has a resistance of 10.15 ohms. To find the resistance of a length 1 foot long, we divide this value by 1,000. Thus, 10.15/1,000 = .01015 ohms per foot. Finally, to obtain the resistance of the 80 foot length, we multiply the resistance per foot by 80:

$$.01015 \times 80 = .812 \text{ ohm.}$$

Summarizing the procedure: (1) in the Table, find the resistance per thousand feet for the wire gauge used, (2) divide this value by 1,000, (3) multiply by the number of feet used.

RESISTANCE WIRE

Because of its low resistance, copper is used for most connecting wires in electron apparatus and in electric circuits. Copper wires of different diameters and cross-sectional areas offer a different resistance to the passage of electricity, even when the same length. If a relatively small resistance is required, it can be obtained by coiling the required length of a fine copper wire so that it occupies a small space. However, when a large resistance is needed, this method is not practical because the necessary length of wire cannot be coiled into a small enough space.

To permit the construction of compact units of relatively large resistance called resistors, wires made of metals other than copper must be employed. Classed as conductors, all metals, with the exception of silver, have more resistance than copper. By combining two or more in the proper proportions, an alloy having a desired resistance characteristics may be produced. Common alloys of this type are composed of vari-

A typical wire-wound potentiometer with adjusting knob attached. For better heat dissipation, the wire is left exposed.

Courtesy Ohmite Mfg. Co.

ous mixtures of nickel, chromium, and iron, and resistance wires made from these alloys are manufactured in many different sizes.

In practically all electric heating appliances, the active or operating element consists of a coil of resistance wire. The low resistance connecting wires carry the current with no appreciable rise in temperature, but the high resistance of the wire in the element causes the current to heat it and produce the desired results.

With the exception of the filaments and heaters inside electron tubes, the heating effect due to resistance has very little application in electron apparatus. However, resistance is inserted intentionally in a large majority of circuits to control the current. Thus, resistors are one of the most common parts or components of electron circuits, and are made to provide almost any desired resistance in a very small space.

WIRE-WOUND RESISTORS

These resistors are available in a wide variety of sizes and shapes with several distinct methods of construction. In one type of **wire-wound resistor**, shown in Figure 1, the resistance wire is wound on a porcelain or ceramic tube and attached to heavier copper terminal lugs located at each end. The turns of wire are spaced so that they do not touch and short circuit part of the winding. To insulate the entire assembly and to prevent damage to the resistance wire, the unit is covered with an insulating material, usually a cement or a vitreous enamel, which is baked on at a high temperature.

For convenience in making circuit connections, Figure 2 illustrates a method of attaching wire leads to the wire-wound resistor body. A copper strip is bent around and attached to each end and copper wire leads are riveted to lugs formed by these strips. The insulating coating covers the resistance wire and the copper strips, with the exception of these lugs. Thus, in addition to the short copper wire connecting leads, the ends of the copper strips around the ends of the resistor are extended to permit connections to be made directly to them whenever this type of assembly is desired. However, in some makes, the copper strips are not extended but are completely coated with the insulating coating, and therefore, all connections must be made to the wire leads.

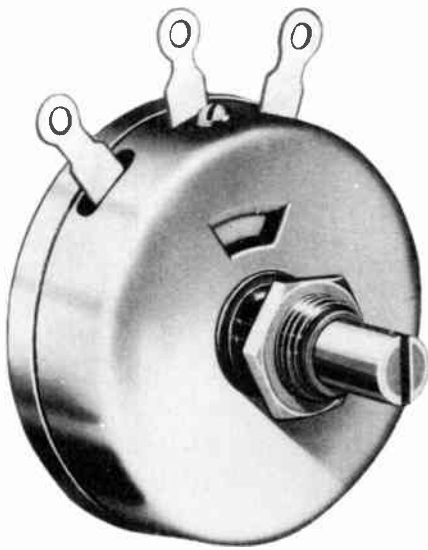
Depending on the length, diameter, and material of their wire, the resistors of Figures 1 and 2 have some specific resistance and are constructed to maintain this value with practically no change. Thus, no matter what the type or size, these units are classed as **fixed resistors.**

For general use, the wire wound fixed resistors are made in standard values from about 100 ohms to 100,000 ohms though there are a number of special values. Also, as will be explained later in this lesson, they are made in sizes to carry different currents.

For some applications, other resistances which may be needed can be obtained with an adjustable resistor like that of Figure 3. The general construction is similar to that of Figures 1 and 2 but a narrow strip of insulation is removed to expose the wire for the entire length of the body. A metal strap, mounted around the body has a "dimple" which extends inward to make contact with the wire. As this strap is moved along the body more or less wire is included between it and the end lugs and thus the available resistance is varied.

This particular resistor is marked "200 Ω" which means 200 ohms, and by sliding the center strap along the body all resistances from 0 to 200 ohms are available between it and either end lug. Once the slider is adjusted to the desired point, it is held in place by tightening the screw located near the slider terminal. The brackets at each end provide a means of mounting the unit.

In addition to ceramic or porcelain tubes, other insulating materials are used as bases on which the resistance wire may be wound. One common construction employs a flat, narrow strip of insulating material as the base. After the resistance wire is wound in place, a contact with soldering lug attached is clamped on each end to complete the unit. In some cases these resistors are used as is, while in others, they are coated with an insulating material. In still other cases, after being coated, the entire unit is enclosed in a metal jacket.



Potentiometers sometimes are provided with a slotted shaft, so that their resistance is varied as a screwdriver adjustment.

Courtesy P. R. Mallory & Co.

Another resistor construction employs a flexible base of asbestos rope around which the resistance wire is wound. Then wire leads are attached and the complete assembly is covered with a glass or fabric sleeve for insulation.

CARBON RESISTORS

A very common type of resistor employs a "mix" made up of a conducting material and a filler or binder. The conductor is usually carbon or graphite while the filler is clay or bakelite. The binders or fillers are insulating material and by combining them in the proper proportions with conducting material, the resulting mix wiil have the desired resistance. After the mix is made, it is usually heated and moulded under pressure in the form of a solid rod. Then the rod is cut into suitable-lengths and connecting wires are attached to the ends.

Because of the conducting material used in the mix, all units made by this general method are known as **carbon resistors.** They are quite small in size and are made in values ranging from several ohms up to several million ohms.

Often large resistances are expressed in "megohms", or fractional parts of a megohm. The megohm is equal to one million ohms. Thus, 10 megohms equal 10,000,000 ohms and .1 megohm equals one-tenth of 1,000,000 or 100,000 ohms.

When several carbon resistors are installed quite close to each other, as is often the case in electron apparatus, there is a possibility they may shift in position and touch each other or the metal chassis on which they are mounted. When a contact of this kind is made, it provides an undesirable electric path or a "short circuit".

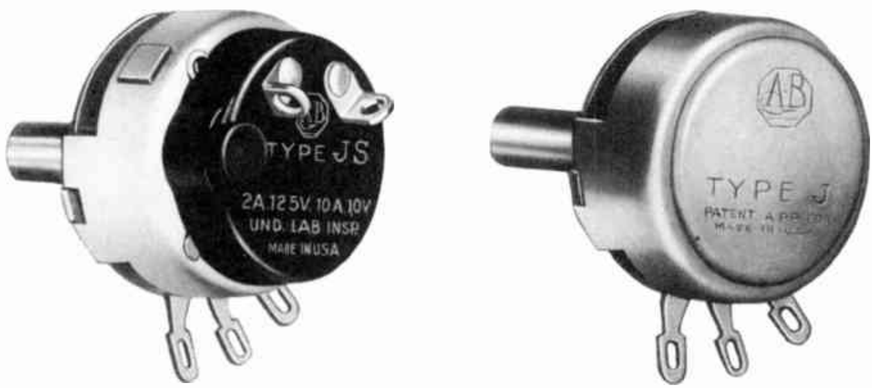
To prevent shorts of this kind, many carbon resistors are made on the plan of Figure 4, which shows the construction used by one prominent manufacturer. The metal beads on the ends of the connecting lead wires are imbedded in the carbon mix and the unit is enclosed in a jacket to provide insulation. Thus, the conducting material of the resistor cannot come in contact with the other parts. These insulated resistors are quite popular because less care is needed for their installation, for should they shift sufficiently to touch another resistor or part, no electric disturbance results.

Similar to a carbon resistor in appearance and size, a metalized resistor consists of a thin coating of a conducting material, usually graphite, sprayed on the surface of a small glass rod. To complete the unit, the rod is enclosed in a ceramic or bakelite tube on the general plan of Figure 4. Also like other carbon resistors these are made available in a large range of resistances.

RADIAL AND AXIAL TYPE RESISTORS

When the connecting wire leads are attached to a carbon resistor, they may be in either of two positions. In Figure 5, the wires are flattened at one end to resemble a nail head, then pressed against the ends of the resistance element, as shown in Figure 4, and sealed in place. These units are known as AXIAL type resistors, because the wires extend straight out from the ends of the body.

In Figure 6, a wire is wrapped around each end of the resistance element and sealed in place. These resistors are known as the RADIAL type because the wires extend straight out from the sides of the body in much the same way that a spoke of a wheel extends out from the axle.



Some potentiometers can be adapted for use with or without a switch merely by removing the rear cover and snapping on the switch.

Courtesy Allen-Bradley Co.

POWER RATING OF RESISTORS

Carried by a resistor, an electric current produces heat, the intensity of which depends on both the resistance and current. The higher the current the greater the heat any resistor must radiate into the surrounding air to prevent excessive temperature. The larger the dimensions of a resistor, the greater its heat radiating surface area, and therefore, the higher the current it can carry safely.

In fact, the heater element in toasters, electric irons, hot pads, and electric stoves are all resistors and their heat rating represents the power that they can dissipate without burning out.

The heat radiating ability of a resistor represents a dissipation of power and, therefore, it is measured in watts. Thus, every resistor has two important ratings:

1. The resistance measured in ohms.
2. The heat dissipating ability measured in watts.

The square of one ampere times one ohm of resistance is one watt. The current through the resistor generates heat. Thus, if the current through a resistor doubles, the power dissipated by the resistor is four times greater. Expressed in words: watts is amperes squared times resistance. Using P for power, I for current, and R for resistance, it can be written in a shorthand notation as:

$$P = I^2R \qquad (1)$$

With the current through a 2 ohm resistor being 3 amperes, the power dissipated is found by using this expression. For example, substitute 3 amp for I and 2 Ω for R, by recalling that the number 2 at the upper right of the 3 means 3×3. The result is:

$$P = 3^2 \times 2 = 3 \times 3 \times 2$$

$$P = 9 \times 2 \text{ or } 18 \text{ watts}$$

When the current is doubled or is now 6 amperes, the power is four times as much or 18×4 or 72 watts. Substituting as before in (1)

$$P = 6^2 \times 2 = 6 \times 6 \times 2$$

$$P = 36 \times 2 \text{ or } 72 \text{ watts}$$

This is the power dissipated by a resistor. At this point, you may recall from an earlier lesson that power also can be determined by multiplying voltage times current. How this is related to the current squared times resistance equation is described in Appendix A at the back of this book.

The wattage rating of a carbon resistor depends mainly on its dimensions or physical size, while its resistance depends mainly on the composition of the mix. That is, the resistors illustrated in Figures 5 and 6 MAY have the same resistance but their heat dissipating ability depends on the physical size of each resistor.

For most electron apparatus, carbon type fixed resistors are available in ¼ watt, ⅓ watt, ½ watt, 1 watt and 2 watt sizes with resistances from about ½ ohm up to 22 megohms. General purpose wire wound resistors, like those illustrated in Figures 1 and 2 are manufactured in 5 watt, 10 watt, 20 watt and up to 200 watt sizes with resistances from about 1 ohm to 100,000 ohms.

In general, WIRE-WOUND RESISTORS ARE USED IN CIRCUITS WHERE A COMPARATIVELY LARGE POWER MUST BE DISSIPATED AS HEAT as in power supplies, and carbon resistors are employed in low power circuits. However, there are exceptions; some carbon resistors are made in sizes larger than 2 watts and a few wire-wound types are made in ½ and 1 watt sizes.

When too much power is handled by these resistors, they may emit smoke or they soon become discolored or charred. Sometimes they get so overheated that they crack, sounding like the pop of a newly opened bottle. In servicing equipment, as a technician you should look for signs of damaged resistors when you have reason to suspect so. Although no outward signs are visible, a carbon resistor may be burned so badly that when lifted slightly with a screwdriver it falls apart. Finally, since some resistors change resistance when overheated, resistors that look good but are suspected of causing trouble, should be checked with an ohmmeter.

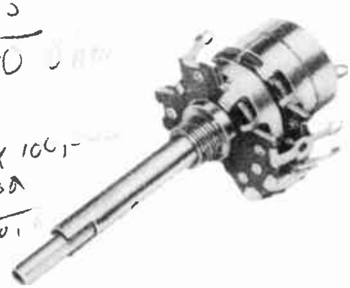
VARIABLE RESISTORS

Although fixed resistors of all types find wide use in most electron apparatus, certain circuit applications require resistances which can be varied to act as a control. Units of this general type are known as variable resistors. In one form of wire-wound variable control, shown in Figure 7, the resistance wire is wound on a flat strip that has been bent into a circular shape and mounted in an insulated housing. A shaft, with a contact arm fastened to the inner end, extends through the housing so that a knob or dial can be attached to its outer end.

One end of the resistance element is attached to the left-hand terminal, the other end is

15 X 10
10
150

15 X 100
100
1500



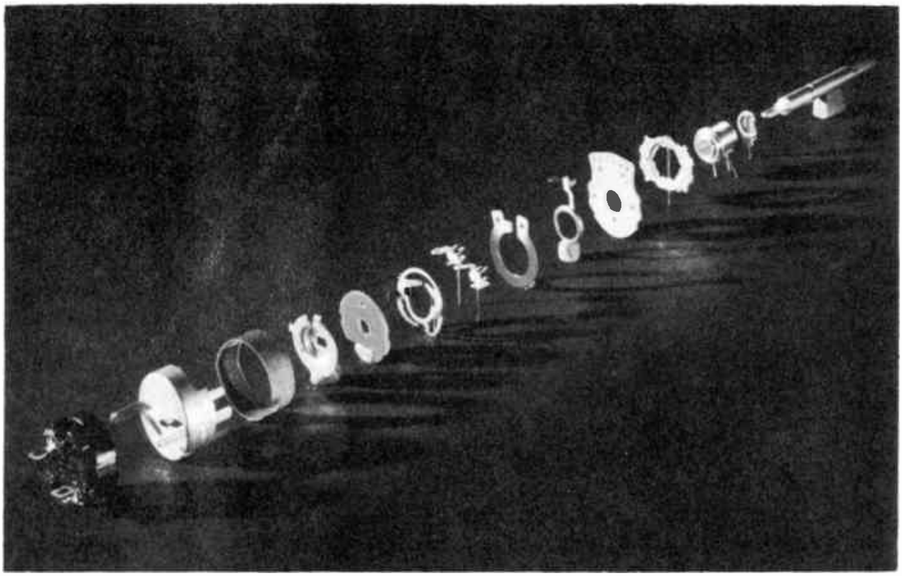
In order to conserve space, two potentiometers sometimes are constructed with one shaft inside the other. The two shafts turn independently of each other.

Courtesy Stockpole Carbon Co.

left disconnected, and the contact arm is connected to the right-hand terminal. As the shaft is rotated, the arm moves and the contact slides along the resistance wire. Thus, the position of the contact determines the resistance between the terminals. A variable resistor of this type, with two external terminals, is known as a rheostat.

In certain circuit applications, it is desirable to have both ends of the resistance element, as well as the contact arm, brought out to terminals. When this is done, the housing has three terminals between the center and one outer terminal increases while the resistance between the center and other outer terminal decreases.

Electrically, the action is similar to that provided by the adjustable resistor of Figure 3. It is a fixed resistor between the



An exploded view of a typical potentiometer. The resistance element is a slotted ring-shaped part with lugs in the center.
Courtesy Centralab Div. Globe-Union, Inc.

as shown in Figure 8. A variable resistor with three external terminals, is known as a **potentiometer** (pot).

As you will learn later, there are many control applications of the three terminal potentiometer. One is a volume control. When the shaft is turned to move the sliding contact, the resistance end terminals with a movable or sliding contact connected to the center terminal. The adjustable resistor is designed for some permanent setting, while the variable resistors or potentiometers of Figures 7 and 8 serve as frequently operated controls.

Figure 8 also shows another construction feature; a metal cap is placed over the resistor end of the housing. This arrangement completely encloses the resistance element and contact arm and protects them from accidental damage and dust.

As with fixed resistors, there are wire-wound and carbon variable resistors. The external appearance of carbon variable resistors is very similar to that of the wire-wound controls, except that normally the carbon types are smaller in size. The resistance element of a carbon unit can be a strip of insulating material like the one shown in Figure 7 but coated with a carbon mix instead of wound with a resistance wire, or the carbon mix may be imbedded in a disc and connected to two terminals as shown in the cutaway view of Figure 9A. The rotating arm makes contact between the carbon mix and collector ring in the center which is connected to the middle lug as shown in Figure 9B. Like fixed resistors, variable carbon units usually have higher resistance and lower current carrying capacity then the wire-wound types.

To save space and to reduce the number of controls, it is common practice to install a switch on the back of some variable resistors. Illustrated in Figure 10, the switch is electrically separate from the potentiometer, but mechanically both are controlled by one shaft. A common example of this arrangement is found in a table model radio in which the set is turned on and off by the same knob that is rotated to vary the sound volume.

In certain electronic circuits, where it is desirable to vary two resistances in some fixed relation to each other, an assembly like Figure 11 is used. Electrically, it consists of two entirely separate potentiometers, similar to that of Figure 8, but mechanically, the same shaft controls the position of both contact arms.

A modification of this assembly is a dual control in which the two poteniometers may be varied independently by means of a two-piece knob. In this type of assembly, the shaft of the front control is a hollow tube through which the shaft of the rear control extends.

Assemblies of this type are found in a wide variety of electron equipment, the most familiar example of which is the television receiver where a dual control, consisting of one knob inside of or in front of another, may be used to vary the picture contrast and the sound volume independently.

POWER RATING OF VARIABLE RESISTORS

Like for a fixed resistor, the power rating for a potentiometer and rheostat is measured in watts. However, the current or voltage from a circuit can be adjusted by using a rheostat or potentiometer respectively. But, in the rating for both, it is the maximum power that the variable resistor can handle using its maximum resistance.

Normally a rheostat is connected in series such that the total resistance of a circuit is changed from a maximum to a minimum. Since the applied voltage usually remains constant in the circuit, the total current also goes from a minimum to maximum. Thus, as both the current and resistance change, the power dissipated changes between a maximum and zero. The maximum power may be stamped upon the rheostat and this value must not be exceeded by any setting of the arm or damage will result.

Suppose a rheostat is rated at 25 watts, and its maximum resistance is 25 ohms. Then with the arm set at 10 ohms the maximum allowable power dissipation is 10 watts and with the arm set at 5 ohms, the maximum power dissipation is 5 watts. Be sure to observe the rule that the maximum power rating applies to its maximum resistance setting only.

A potentiometer also is rated for maximum power dissipation. Therefore the current through the potentiometer between two terminals must not dissipate more power than that portion of the potentiometer can dissipate. That is, if half of the resistance is between one of the end terminals and the slider, only half of the rated power should be dissipated between these two points.

Ordinarily, a potentiometer is connected with its end terminals across a fixed voltage source. Also, one end terminal and the sliding contact are connected to the circuit to which the voltage is to be supplied. THIS ARRANGEMENT PERMITS CHANGING THE VOLTAGE SUPPLIED TO A CIRCUIT BY MOVING THE SLIDER to the proper point on the potentiometer.

Due to the rubbing of the slider over the resistance material in carbon pots, it may finally wear through, and therefore, the resistance no longer varies smoothly with shaft rotation. When the potentiometer is a volume control in a radio or television receiver this defect produces pops and scratching noises when the shaft is rotated back and forth. In fact, this is a quick method for the technician to locate a potentiometer that needs replacing.

Since it usually is enclosed in a dust cover, a defective variable resistor is hard to find by visual inspection. When it is part of a circuit causing trouble, unless it shows up as a noise during shaft rotation, it is necessary to check it by using an ohmmeter. An erratic jump from one resistance to another as the shaft is rotated indicates a defect.

COLOR CODE

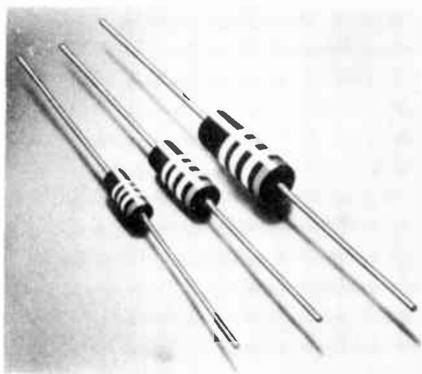
Although the resistance sometimes is printed on the resistor, the Radio, Electronics and Television Manufacturers Association (RETMA) realized that time and effort could be saved if some means of rapid identification was devised. For this purpose, they established a **color code** in which ten colors represent the digits from 0 to 9. By spotting the proper colors in a specified order on the body, the resistance can be marked even on the smallest resistors.

The RETMA color code is given in Figure 12. Notice that each of the first ten colors, starting with black and ending with white, represents a digit between 0 and 9, as shown in the two columns headed BODY and END. In the DOT column, the colors represent a multiplier by means of which the first two numbers must be multiplied to obtain the actual resistance. Note that the multiplier is the digit 1 followed by the number of zeros which each color represents in the BODY and END columns.

For resistances between 0.01 ohm and 9.9 ohms, either of two additional multipliers may be used, as shown in Figure 12. When the dot is gold, the multiplier is 0.1 and a silver dot indicates a 0.01 multiplier. How these multipliers are used can be shown best by examples.

RADIAL TYPE COLOR CODE

A standard radial type resistor is shown at the top of Figure 12, and as indicated by the arrows, it has four colors. The three colors that indicate the resistance



Most carbon resistors have their resistance and tolerance clearly marked on the body by color stripes which follow the RETMA color code.
Courtesy Allen-Bradley Co.

are called the body color, the end color, and the dot color. In some cases, the dot extends all the way around the body in the form of a band.

The colors are read in the order of body color first, end next, and then the dot. The word "bed"; the first letters of body, end, and dot; may help you to remember the order in which the colors are read. Substituting the corresponding number for each color will give the resistance in ohms.

For example, suppose the resistor at the top of Figure 12 has a red body, a green end, and an orange dot. Referring to the table; red means 2, green means 5, while orange in the dot column indicates a multiplier of 1,000. In the form of a table, the colors are read as:

BODY	END	DOT
Red 2	Green 5	Orange ×1,000

The multiplication by 1,000 may be performed quickly by placing three zeros after the 5. Thus, when the numbers are written close together, the resistance is 25,000 ohms.

Following this plan, and checking with the table, any resistance from 0.01 ohm up to 99,000,000,000 ohms can be represented. To illustrate, a few examples are listed in the following table:

BODY	END	DOT	OHMS
Orange 3	White 9	Silver ×0.01	0.39
Blue 6	Green 5	Gold ×0.1	6.5
Brown 1	Green 5	Black ×1	15
Green 5	Black 0	Brown ×10	500
Violet 7	Green 5	Orange ×1,000	75,000
Yellow 4	Violet 7	Yellow ×10,000	470,000

In some cases the colors may be alike, and therefore the resistor actually will show only one or two colors, instead of three. However, the plan of reading remains the same. The following examples illustrate several combinations of this kind.

BODY	END	DOT	OHMS
Orange 3	Orange 3	Gold ×0.1	3.3
Red 2	Red 2	Silver ×0.01	0.22
Red 2	Red 2	Red ×100	2,200
Orange 3	Green 5	Orange ×1,000	35,000
Brown 1	Yellow 4	Yellow ×10,000	140,000
Blue 6	Blue 6	Green ×100,000	6,600,000

For unit values less than 10 ohms, the body and dot colors are both black, so that end color is the only one decoded.

BODY	END	DOT	OHMS
Black 0	Gray 8	Black ×1	8
Black 0	Blue 6	Black ×1	6

AXIAL TYPE COLOR CODE

A slight variation of the method explained is in use on axial type carbon resistors, as illustrated at the bottom of Figure 12. Here all of the colors are in the form of bands and the body color has no significance so far as the code is concerned.

Checking Figure 12, the bands are closer to one end of the resistor than the other, and are read by starting with the band closest to the end. The colors represent the same values and are read in the same way as for the radial type. As an example, if the resistor illustrated at the bottom of Figure 12 has for the first three bands, brown, black, and green, by the chart the resistance indicated is $10 \times 100{,}000$ or 1,000,000 ohms.

TOLERANCE

In the manufacture of fixed resistors, the resistance will vary somewhat due to slight differences in construction which can not be avoided. When completed, the resistors are sorted and then coded, according to their accuracy. Their power or current rating has nothing to do with their tolerance.

Because resistors with a 10% tolerance are satisfactory for most commercial electron equipment, the RETMA have adopted a series of standard resistances. Starting with 1 ohm, each larger standard resistance is 20% greater than the preceding one. Thus there are 13 standard resistances from 1 ohm to 10 ohms inclusive. The same plan is continued between 10 ohms and 100 ohms, 100 ohms and 1000 ohms, and so on up into megohms.

To illustrate the plan, the following table lists the RETMA standard resistances from 10 to 100 ohms.

RETMA STANDARD RESISTORS

10		56
12	27	68
15	33	82
18	39	
22	47	100

In practice, the proper number of zeros are added for higher values and a decimal point is used for lower values, but the number

Many precision resistors are made by winding resistance wire on small spools and covering with a ceramic or bakelite shell.

Courtesy Resistance Products Co.

combinations do not change. For example, standard resistors are available in the following values.

.47	ohm
4.7	ohms
47.	ohms
470.	ohms
4,700.	ohms
47,000.	ohms
470,000.	ohms = .47 megohms
4,700,000.	ohms = 4.7 megohms

Although a 1000 ohm resistor might actually measure 920 ohms or 1060 ohms, it would still operate satisfactorily in many electron circuits. This difference in actual resistance from the indicated value is known as the **tolerance**, and is usually stated in percent of the marked value.

In the example given above 10% of 1000 ohms is 100 ohms, and thus both the 920 ohm and the 1060 resistor would be within 10% of their rated value. On this basis, any resistor from 900 ohms to 1100 ohms is considered as a 1000 ohm resistor with a tolerance of 10%.

To indicate this tolerance a dot or a fourth color code band is placed on the resistor, and as shown by the table in Figure 12, gold indicates 5%, silver indicates 10%, and for no fourth band the tolerance is 20%.

The more accurate the resistance the more expensive the resistor. For commercial electron equipment 10% tolerance is satisfactory, for high quality equipment 5% tolerance is common, while for measuring instruments it is customary to use "precision" resistors with a tolerance of 1% or less.

Referring again to the table, with a 20% increase in successive values and a 10% tolerance, practically all resistances are included. For example, selecting three values from the table,

27 ohms + 10% = 27 + 2.7 = 29.7 ohms

33 ohms − 10% = 33 − 3.3 = 29.7 ohms

33 ohms + 10% = 33 + 3.3 = 36.3 ohms

39 ohms − 10% = 39 − 3.9 = 35.1 ohms

Thus, the RETMA standards, applied mainly to carbon type resistors, include almost any desired resistance.

SCHEMATIC SYMBOLS

As shown in Figure 13, the common symbol for the resistance element is a zig-zag line between the two short straight lines, which in turn represent the external connections.

The symbol in Figure 13A is for a fixed resistor like those shown in Figures 1, 2, 5, and 6. There is no distinction between wire-wound and carbon types so far as the symbol is concerned. However, when it is desired to indicate a wire-wound resistor in a diagram, the letters WW are placed close to the symbol.

In a schematic diagram a fixed resistor with an adjustable tap (Figure 3) is represented by the symbol shown in Figure 13B. In both Figure 3 and Figure 13B, only one tap is shown; however, under some conditions, several may be used. When this is the case, they are represented by additional lines projecting from the side of the resistor element symbol. Resistors of this type also are identified by the letter R and a subscript number.

Figure 13C is the symbol for a rheostat like that pictured in Figure 7. In this symbol, the arrow head represents the sliding contact attached to the shaft. Notice that only two connections to the rheostat are shown, one to the sliding contact and the other to one end of the resistance element. In schematic diagrams, rheostats are identified by means of the letter R and a subscript number the same as for fixed resistors.

The symbol for a potentiometer (Figures 8, 10, and 11) is illustrated in Figure 13D. Shown by the short straight lines attached to both ends of the resistor element and to the arrow head, there are three connections to the potentiometer. For identification purposes, potentiometer symbols in schematic diagrams often are labeled with the letter A, followed by a subscript number the same as for fixed resistors. In some cases, the letter P is used.

R_{14} in Figure 14 is a wire wound resistor. Very likely it is rated at 5 or 10 watts, depending on how much current the power supply must furnish through it. However, in order to explain what purpose it has in this power supply we first have to understand how capacitors C_{18} and C_{19} work. Therefore, in the next lesson these are described.

PRACTICE PROBLEMS

The following problems can be solved according to the explanations of the lesson. To gain maximum benefit, may we suggest that you solve the problems and then check your answers with those on the solution page.

1. A radial resistor is color coded with a brown body, a green end and yellow dot. What is the resistance of the resistor?

2. An axial resistor is color coded with an orange first band, a white second band, a brown third band, and a silver fourth band. What is the resistance and tolerance of the resistor?

3. A resistor of 5 ohms carries a current of 3 amperes. How much power is dissipated as heat?

4. An electric toaster carries 4 amperes when connected to a 115 volt lighting circuit outlet. How much power is dissipated?

5. A 1000 ohm resistor has a silver tolerance band. Between what resistance may the resistor vary and still be satisfactory for use?

APPENDIX

In the previous lesson on transformers it was stated that the power in the primary and secondary is volts times amperes, while in this lesson the power dissipated by a variable resistor is the current squared times the resistance. Actually, d.c. power may be stated in three different ways:

$$(1) \quad P = EI,$$

$$(2) \quad P = I^2R$$

$$(3) \quad P = \frac{E^2}{R}$$

To see how they are equal let's suppose that we applied some voltage E across a resistor R which forced a current I through it. By the first equation above the power is:

$$P = EI \text{ or } P = IE.$$

By Ohm's Law, we know the voltage across the resistor is:

$$E = IR$$

Since the E in the power equation and the Ohm's Law equation for voltage across the resistor are the same, we can substitute the (IR) for the E in the first, thus:

$$P = (I)(IR).$$

In words the equation reads: The current times the current times the resistance is equal to the power. Recall that (I) (I) can be rewritten as I^2, and so the power equation becomes:

$$P = I^2R$$

Thus, by using Ohm's Law, we have illustrated that equation 1 is merely another way of writing equation 2 since they are equal.

A specific example shows that they are equal. In our original supposition, let the voltage we assumed be 10 volts and a current of 2 amperes through the resistor. By equation (1):

$$P = (10)(2)$$
$$= 20 \text{ watts.}$$

By Ohm's Law, the resistance can be found using:

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

Substituting in the above we have:

$$R=\frac{10}{2}$$
$$=5\Omega.$$

Using (2) above, the power is:

$$P=(2)^2 5$$
$$P=(4)(5)$$
$$=20 \text{ watts.}$$

Thus, the power found either way is the same. The reason for having both forms is like having the three forms of Ohm's Law: in practical situations, it is more useful to use one in preference to the other. By using Ohm's Law, we can find the third expression for power.

Using equation (1) above, and Ohm's Law of the form:

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

and substituting for I in equation (1), we have:

$$P=(E)\left(\frac{E}{R}\right)$$

$$P=\frac{E^2}{R} \qquad (3)$$

Thus, in our example, 10 volts and 5 ohms give:

$$P=\frac{(10)^2}{5}$$
$$=\frac{100}{5}$$
$$=20 \text{ watts,}$$

which is the same as the previous two answers.

IMPORTANT DEFINITIONS

CARBON RESISTOR—A resistor in which the resistance element is composed of a carbon or graphite compound.

COLOR CODE—For resistors, a system of colors used to indicate the resistance. The colors represent numerals from 0 to 9.

FIXED RESISTOR—A resistor having a definite resistance and designed to maintain this value with practically no change.

INSULATION—[*in* suh LAY sh'n]—The protective coating of a non-conducting material with which wires are covered. Common forms of insulation are rubber, cotton, silk, enamel, nylon, and various plastics.

POTENTIOMETER (pot)—[poh *ten* shi AHM i ter]—A variable resistor with three external terminals.

RESISTANCE WIRE—Wire made of alloys and designed to present certain desired resistance characteristics.

RHEOSTAT—[REE oh stat]—A variable resistor with two external terminals.

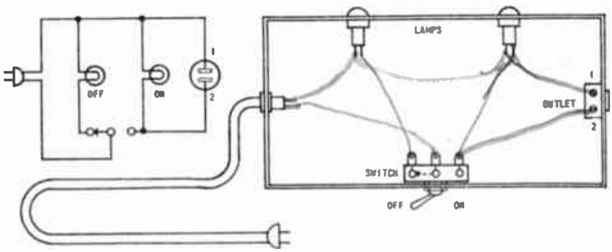
SHORT-CIRCUIT—A condition that provides an undesired path for current.

TOLERANCE—[TAHL er ans]—The amount that the actual resistance of a resistor or other part differs from the marked value. Usually it is expressed as a percentage of the marked value.

WIRE-WOUND RESISTOR—A resistor in which the element consists of a resistance wire wound on a ceramic tube or other insulating material.

WORK DIAGRAM

The schematic diagram shows the circuit of a control box with lamps to indicate whether the power is turned on or off. The pictorial drawing shows the parts mounted in the metal box, but the wiring between parts is omitted. Using the schematic diagram as a guide, draw lines to represent the wires needed to complete the pictorial drawing.



When you have finished, check with the solution on the back of the foldout sheet.

STUDENT NOTES

STUDENT NOTES

Red	violet	yellow
2	7	10,000

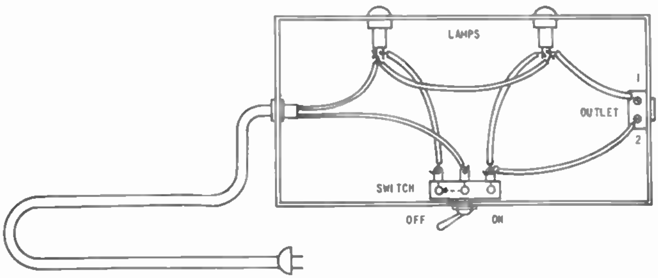
COPPER WIRE TABLE—B. & S.

Gauge No.	Weight in lbs. per 1000 Feet	Feet per Pound	Resistance of Pure Copper in Ohms at 68° F.		
			Ohms per 1000 Ft.	Feet per Ohm	Ohms per Lb.
0000	640.5	1.56	.04901	20400.	.00007652
000	507.9	1.97	.06180	16180.	.0001217
00	402.8	2.48	.07793	12830.	.0001935
0	319.5	3.13	.09827	10180.	.0003076
1	253.3	3.95	.1239	8070.	.0004891
2	200.9	4.98	.1563	6400.	.0007778
3	159.3	6.28	.1970	5075.	.001237
4	126.4	7.91	.2485	4025.	.001966
5	100.2	9.98	.3133	3192.	.003127
6	79.46	12.58	.3951	2531.	.004972
7	63.02	15.87	.4982	2007.	.007905
8	49.98	20.01	.6282	1592.	.01257
9	39.63	25.23	.7921	1262.	.01999
10	31.43	31.82	.9989	1001.	.03178
11	24.92	40.12	1.260	794.	.05063
12	19.77	50.59	1.588	629.	.08035
13	15.68	63.80	2.003	499.3	.1278
14	12.43	80.44	2.525	396.0	.2032
15	9.86	101.4	3.184	314.0	.3230
16	7.82	127.9	4.016	249.0	.5136
17	6.20	161.3	5.064	197.5	.8167
18	4.92	203.4	6.385	156.6	1.299
19	3.90	256.5	8.051	124.2	2.065
20	3.09	323.4	10.15	98.50	3.283
21	2.45	407.8	12.80	78.11	5.221
22	1.95	514.2	16.14	61.95	8.301
23	1.54	648.4	20.36	49.13	13.20
24	1.22	817.7	25.67	38.96	20.99
25	.97	1031.	32.37	30.90	33.37
26	.77	1300.	40.81	24.50	53.06
27	.61	1639.	51.47	19.43	84.37
28	.48	2067.	64.90	15.41	134.2
29	.38	2607.	81.83	12.22	213.3
30	.30	3287.	103.2	9.691	339.2
31	.24	4145.	130.1	7.685	539.3
32	.19	5227.	164.1	6.095	857.6
33	.15	6591.	206.9	4.833	1364.
34	.12	8311.	260.9	3.833	2168.
35	.10	10480.	329.0	3.040	3448.
36	.08	13210.	414.8	2.411	5482.
37	.06	16660.	523.1	1.912	8717.
38	.05	21010.	659.6	1.516	13860.
39	.04	26500.	831.8	1.202	22040.
40	.03	33410.	1049.	.9534	35040.

TABLE 1

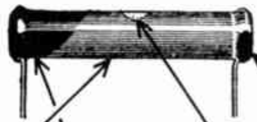
WORK DIAGRAM SOLUTION

The schematic diagram shows the circuit of a control box with lamps to indicate whether the power is turned on or off. The pictorial drawing shows the parts mounted in the metal box, but the wiring between parts is omitted. Using the schematic diagram as a guide, draw lines to represent the wires needed to complete the pictorial drawing.



0,000 Ohm

RADIAL
TYPE



COLOR	BODY	END	DOT	TOLERANCE
	1ST. NUMBER	2ND NUMBER	MULTIPLIER	(PERCENT)
BLACK	0	0	1	
BROWN	1	1	10	
RED	2	2	100	
ORANGE	3	3	1,000	
YELLOW	4	4	10,000	
GREEN	5	5	100,000	
BLUE	6	6	1,000,000	
VIOLET	7	7	10,000,000	
GRAY	8	8	100,000,000	
WHITE	9	9	1,000,000,000	
GOLD			0.1	5
SILVER			0.01	10
NONE				20
	BAND 1	BAND 2	BAND 3	BAND 4

AXIAL TYPE

FIGURE 12

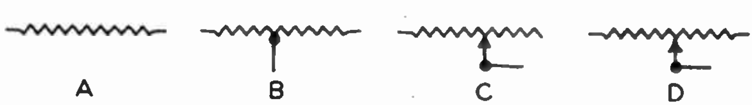


FIGURE 13

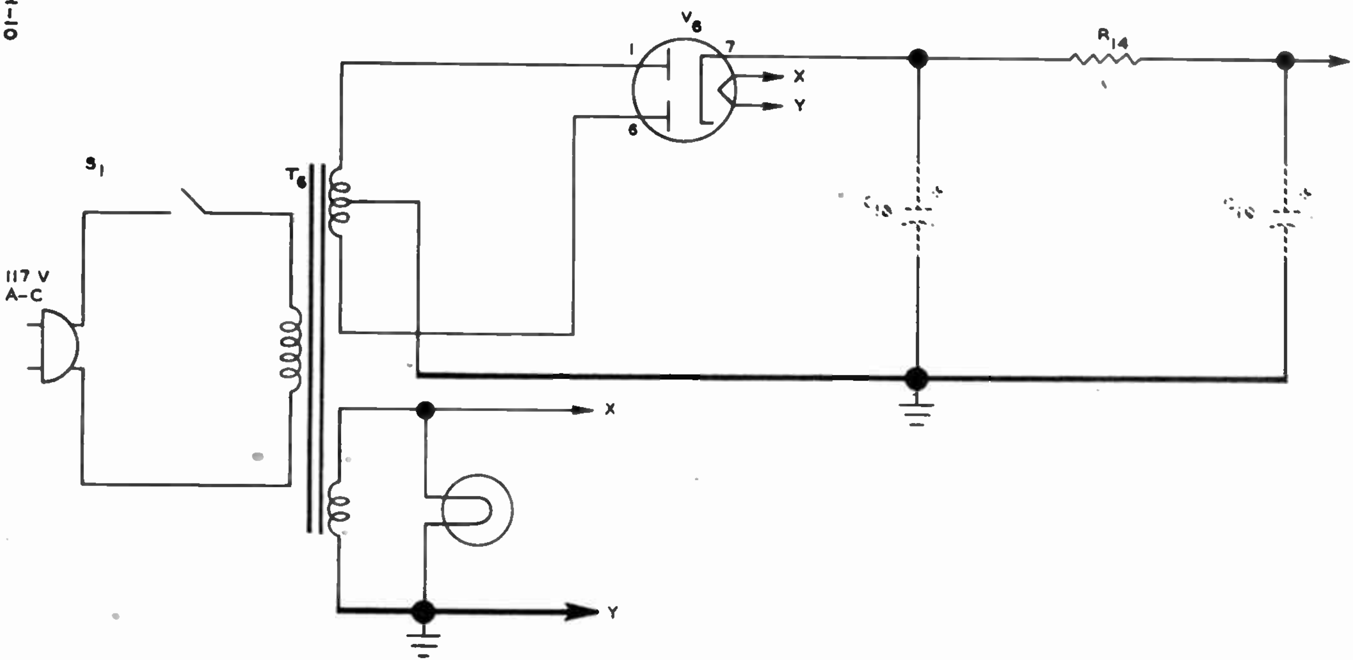


FIGURE 14

Fixed Resistors 100 ohms to 10

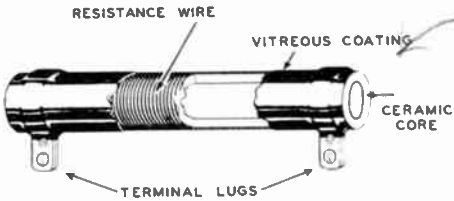


FIGURE 1

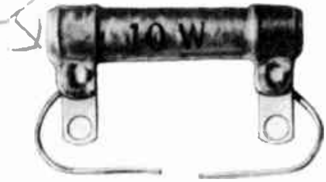


FIGURE 2

FIGURE 3

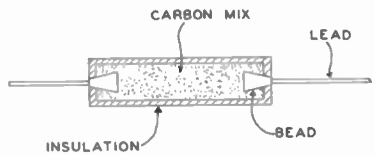


FIGURE 4

FIGURE 5

(Rheostat)

FIGURE 6

FIGURE 7

FIGURE 8

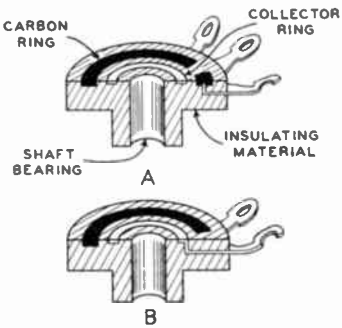


FIGURE 9

Potentiometer

FIGURE 10

FIGURE 11

PRACTICE PROBLEMS SOLUTIONS

1. From the color code chart, for a radial resistor:
   brown body $=1$, green end $=5$, and
   yellow dot $=10{,}000$ as a multiplier.
   resistor resistance $=15\times 10{,}000=150{,}000$ ohms.

2. From the color code chart for an axial resistor:
   band 1, orange $=3$; band 2, white $=9$; band 3, brown $=10$ as a multiplier; band 4, silver $=10\%$.
   Resistor resistance $=39\times 10=390$ ohms with a tolerance of $\pm 10\%$.

3. From $P=I^2R$, and substituting known data
   $P=(3)^2\times 5=(3\times 3)\times 5=9\times 5=45$ watts.

4. From $P=EI$, and substituting known data
   $P=115\times 4=460$ watts.

5. From the color code chart, the silver tolerance band is $\pm 10\%$.
   10% of $1000=100$ ohms.

Since the resistance may vary 10% above 1,000 ohms and 10% below 1,000 ohms, its resistance may increase to $1{,}000+100$ or 1,100 ohms; and it may decrease to $1{,}000-100$ or 900 ohms. Thus, the resistance of the resistor may vary from 900 ohms to 1,100 ohms.

FROM OUR *Director's* NOTEBOOK

THE VALUE OF AN IDEA

Many people still think that it takes a genius to bear a great idea.

But on looking around us, we quickly see that those who have achieved the remarkable, are mostly plain men and women who got an idea, and then had sufficient grit and gumption to see it through and put it into action.

An idea, even though simple, may become big when put into operation. Consider the metal tip on our shoe laces—almost ridiculously simple to us now, yet it is said the originator "cleaned up" big on the idea.

Ideas alone won't push anyone into the foreground—the pushing is a fifty-fifty proposition. The idea pushes the man only as much as the man pushes the idea.

You had an idea when you entered Radio and Electronics—now see that idea through, and let the World know there is a new Electronic Man in the making.

Yours for success,

W. C. DeVry

DIRECTOR

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Power Supply Circuits

Lesson AEH-12B

DeVRY Technical Institute

4141 W. Belmont Ave., Chicago 41, Illinois

Formerly DeFOREST'S TRAINING, INC.

1-12

AEH-12B

POWER SUPPLY CIRCUITS

4141 Belmont Ave.

Chicago 41, Illinois

DeVRY Technical Institute

ELECTRONS INSPECT FOOD

Visit a modern candy factory. An endless conveyor belt carries bulk candy slowly past an inspector who, with a pair of tongs, picks out various pieces of the candy, seemingly at random. The selected pieces are discarded, although to the naked eye, their appearance is exactly the same, as all the other pieces. However, the inspector is using an X-ray device, and particles of foreign material such as small stones, nails, glass, etc. are revealed on a fluoroscopic screen.

X-rays and other invisible radiations are employed in numerous similar applications, and their detection and measurement requires electronic instruments. Besides detecting hidden flaws in materials, X-rays are used in medicine for diagnosis and therapy. Infrared rays are used in navigation and for heating and aging industrial products.

Fundamentals

POWER SUPPLY CIRCUITS

Contents

Many people are "marking time" in their chosen trade or profession because they haven't had the preparation to take them farther. Somebody better qualified is always ahead of them. If they but knew it, they could soon become superior in their work through home study.

—Webster H. Pearce

POWER SUPPLY CIRCUITS

To the average American it is very difficult to understand that the television receiver in his home, a hearing aid, a uranium detector, a large broadcast transmitter, or the new gigantic electronic computers are all part of one field that is called electronics. What he doesn't know is that all of these pieces of equipment use the same basic principles, the same components, in fact many of the same circuits. The big difference is that these circuits are assembled in new combinations to meet the particular need.

Already we have described for you resistance, inductance and capacitance along with several components that use these characteristics. Among these components are resistors, rheostats, potentiometers, inductors, transformers, capacitors, and diodes. Although others will be added later, they all work on these same basic characteristics.

The next step is to combine several components into a circuit and see just how an overall action is accomplished. Possibly the one circuit that is found in more equipment than any other is the power supply. This is easy to understand when one considers that all circuits need electric power, and therefore, a first step for any equipment is to provide power in the forms needed.

Reviewing the action of the electron tube rectifier, it requires a relatively low a-c or d-c voltage to supply the current which heats the filament to a temperature needed for electron emission. The emitted electrons are attracted by and reach the plate only when this plate is positive with respect to the filament. The plate circuit requires a relatively high voltage. Many other types of electron tubes require similar voltages. That is, they also must have a relatively low a-c or d-c voltage for the filament or heater and a relatively high voltage for the plate. In fact, these plates must be supplied a steady d-c voltage.

Batteries of the proper voltages still are used to supply power to portable apparatus, but their bulk, expense, and inconvenience make them quite unsatisfactory for most other types of electronic equipment. In the majority of the cases, the most readily available source of electric energy is the a-c supplied by utility companies for commercial lighting and power.

To supply the needed d-c voltages, each complete unit of electronic equipment normally includes tubes and other parts for the sole purpose of converting the commercial power to the forms useful to the apparatus, and this section is known as the power supply even when it is included as part of the equipment.

Low alternating voltages are obtained either by means of a step-down transformer, or by connecting circuit elements in series with the power line. D.C. voltages are produced either by rectifying the high alternating voltage obtained across the secondary of a step-up transformer, or by rectifying the power line voltage directly.

THE FUNCTIONS OF THE POWER SUPPLY

When a transformer is included in the supply, it is known as the **power transformer.** The general arrangement of this type of supply is illustrated by the block diagram in Figure 1, and it contains a transformer, a rectifier, and a filter composed of capacitors and resistors or inductors.

With these components, the power supply performs three major functions. First, the power line voltage is transformed to the desired higher and lower values needed by the various circuits of the electron device operated by the supply. The low a-c is used for the heaters or filament of the tubes. The rectifier usually has a separate heater or filament winding on the transformer from that used by the other tubes in the circuit. Second, the high alternating voltage is rectified. The output of the rectifier is a series of voltage pulses, all of the same polarity. Third, this pulsating direct voltage is "smoothed" by the filter to form the steady or constant voltage required.

To reduce both cost and weight where the line voltage is sufficiently high for the application, another common type of power supply does not contain a transformer, as shown by Figure 2. Here, the alternating voltage of the power line is applied directly to the rectifier. Again it produces a pulsating direct voltage which must be smoothed by the filter.

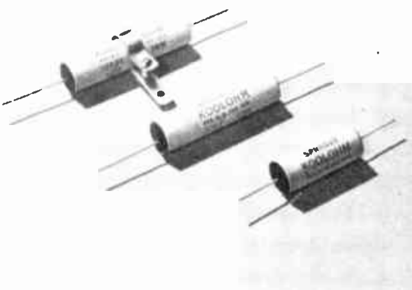
Table model radio receiver. The power supply is built in.

Courtesy Sentinel Radio Corp.

POWER SUPPLY TRANSFORMERS

As we explained in an earlier lesson, the power transformer operates on the principle of electro-magnetic induction. When the primary winding is connected to a source of alternating voltage, the resulting current produces a constantly changing magnetic field which cuts the secondary and induces an alternating voltage in it. With respect to the primary, a secondary voltage is determined by the turns ratio between the primary and secondary windings.

To provide the high and low voltage outputs needed, the power transformer normally contains several secondaries. A common arrangement is illustrated by the transformer symbol in Figure 3. P is the primary winding, and coils S_1, S_2, and S_3 are the secondaries. Having fewer turns than the primary, S_1 and S_3 are low voltage secondaries. Typical voltages produced across these windings are 2.5 v, 5 v, 6.3 v, and 12.6 v. S_2 is called the high voltage secondary. Usually, it has more turns than the primary to produce 300 or more volts, and a lead connected to its center makes it possible to use this winding in a full wave rectifier circuit.



Type of high wattage resistors found in power supplies. Note the strap which is used for rigid mounting.
Courtesy Sprague Electric Co.

HALF WAVE RECTIFIERS

The action of the basic half-wave rectifier circuit shown in Figure 4 was explained in the lesson on diodes. Reviewing briefly, secondary voltage E_S is applied across diode V_1 and resistor R_L in series. When the plate of V_1 is positive with respect to its cathode, it conducts and the electron flow I_S is in the direction of the arrow. The secondary voltage E_S is shown in Figure 5 as the broken line wave-form.

As indicated by the arrow at the bottom labeled t, passage of time goes from left to right on the page. This is used often instead of marking the horizontal line off in seconds where the actual unit of time used is not important to the illustration. For the same reason, letter E_S and the + and − signs indicate that the voltage increases the further away the wave-form is from the horizontal line without stating some particular voltage. Whether the secondary voltage E_S described here is 100 volts, 250 volts, or even 1,000 volts, the basic action remains the same.

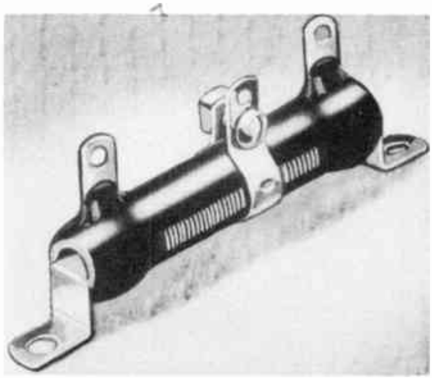
Since some of the secondary voltage appears across V_1 due to the internal resistance of the diode, only about .9 of the positive alternation appears across resistor R_L. Of course, none of the negative alternation appears across R_L, and therefore the voltage for R_L remains at zero during this alternation as indicated by the solid line wave-form.

FULL WAVE RECTIFIERS

The basic full wave rectifier circuit, shown in Figure 6A, includes two rectifiers, V_1 and V_2, and transformer T_1. For direct comparison with Figure 4, transformer T_1 is the same in both circuits, but in Figure 6A, the secondary has a center connection or "tap". Here, the circuit connected across each half of the secondary is like that across the entire secondary of Figure 4. Thus, the voltage E_{S_1} applied across tube V_1 in Figure 6A is only HALF of that for Figure 4 or .5 E_S. In like manner, E_{S_2} across V_2 also is .5E_S.

During the alternations that the upper end of the secondary is positive with respect to the center tap, rectifier V_1 conducts and allows electron flow in the direction indicated by the I_{S_1} arrow. When E_{S_2} or the lower end of the winding is positive, rectifier V_2 conducts electrons in the direction of the I_{S_2} arrow. During the positive alternation of E_{S_1} current I_{S_1} is carried by R_L, V_1 and the upper half of the secondary T_1, while during the next alternation when E_{S_1} is negative and E_{S_2} is positive, I_{S_2} is carried by R_L, V_2 and the lower half of the secondary. For both alternations the direction of current R_L is in the same direction.

Thus, in a full wave rectifier, there is voltage across the load resistor during the full cycle. E_{R_L} has the form shown in Figure 6B. As explained for Figure 4, the magnitude of the rectifier output pulses is 90 per cent of the input voltages E_{S_1} and E_{S_2}. With pulses during both alternations, in the full wave rectifier circuit, the voltage E_{R_L} across the load is equal to 90 per cent of .5E_S. Assuming transformer T_1 has the same primary voltage E_P and the same turns ratio in both circuits, the voltage applied to each rectifier section of Figure 6A is only half that applied to the rectifier of Figure 4.



Rated at 10 watts, this resistor is used as a bleeder in a power supply.
Courtesy Ohmite Mfg. Co.

Figures 5 and 6B show the output of the rectifiers tubes in the circuits of Figure 4 and 6A. The voltages vary all the way from 0 to the peak and back to zero again. Unfortunately, such d-c voltages are not satisfactory for most needs. Most tubes require a d-c voltage with very little change in amplitude. To do this requires an added circuit; a combination of capacitors and inductors or resistors called a filter. When used for this purpose, these components are called FILTER CAPACITORS, FILTER CHOKES AND FILTER RESISTORS.

Electrolytic capacitor with two 8 μf sections. The negative plates are tied to a common lead.

Courtesy Sangamo Electric Co.

FILTER SYSTEMS

Filter Capacitor

In Figure 7A, filter capacitor C_1 is connected across resistor R_L which represents the "load" or circuits drawing current from the half wave rectifier. As the first rectifier pulse rises, electrons flow into the lower plate of C_1 in the direction of the charge arrow and out of the upper plate, through the rectifier V_1 and the secondary. This action charges the capacitor until the pulse reaches its peak when it is charged to peak secondary voltage E_S. At the same time, electrons also flow through R_L, in the direction of the load current arrow, through rectifier V_1 and the secondary, back to the bottom end of R_L.

Then, as the secondary voltage decreases, the capacitor discharges. Because the rectifier permits the flow of electrons only in the direction of charge, the capacitor cannot discharge through the transformer secondary. Therefore, electrons flow in the direction of the discharge arrow from the lower plate of C_1 through R_1 to the upper plate.

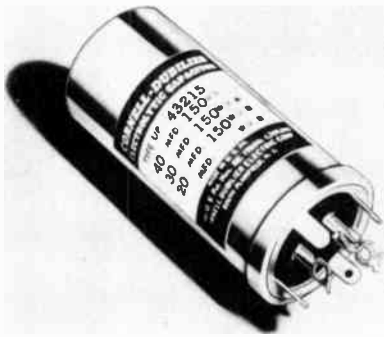
The relatively high resistance of R_L limits the current to such a small value that it takes a long time for C_1 to discharge. Therefore, the load current and capacitor voltage do not decrease as rapidly as the secondary voltage. Capacitor C_1 is discharged only partially by the time the next pulse recharges it to the peak voltage again.

As a result of this action, the load voltage pulses are no longer like those in Figure 5. In Figure 7B the dashed line curve represents the secondary voltage E_S. The solid line curve represents the variations of the charge on capacitor C_1, and the voltage across C_1 and R_L. This alternating voltage across the filter capacitor is called the **ripple** voltage, and is a component of the output voltage. The alternations of secondary voltage E_S which make the diode plate positive charge C_1 until the peak value is reached. This time during which V_1 conducts and C_1 charges is indicated by the shaded area under the curve. Thereafter, C_1 discharges slowly through R_L for a relatively long period indicated by the unshaded areas until the next rising positive pulse exceeds the voltage remaining on capacitor C_1; then C_1 charges again. Since R_L represents the load, the load current has the same wave-form as the solid line voltage curve of Figure 7B.

As explained in a later lesson on combinations of resistors and capacitors, by choosing C_1 and R_1 properly, the discharge is small thus producing a small ripple voltage. The less the capacitor discharges from the peak voltage, the smaller the ripple and the smoother is the d-c output voltage.

A similar action occurs when a filter capacitor is placed across the load terminals of the full wave rectifier circuit in Figure 8A. Again, capacitor C_1 charges during part of the rising portion of each positive pulse, and then discharges through R_L until the next pulse arrives. In this case, the lower plate of the capacitor C_1 connects to the center tap of the secondary. For each cycle of the applied voltage, the upper end of the secondary is positive during one alternation and the lower end positive during the other alternation with respect to the center tap. Hence, two positive pulses charge C_1 during each cycle.

In Figure 8B, the dashed line curve represents the series of charging voltage pulses applied across C_1 and R_L and the shaded areas represent the charging time for capacitor C_1. Like Figure 7B, the solid line curve shows that C_1 charges to the peak voltage of each pulse, and then discharges through R_L until the next pulse arrives to recharge it. This curve also has the same wave-form of



A power supply filter capacitor designed for upright mounting. Either stamped into the metal or printed on the label are the capacitor section ratings and working voltage ratings.

Courtesy Cornell-Dubilier Electric Corp.

the voltage across C_1 and R_L, and the current in R_L.

For the same line voltage frequency, in Figure 8 the applied pulses occur twice as often as those in Figure 7, and therefore, C_1 has a shorter interval for discharge. Consequently the variations or ripple voltage across C_1 is less in the full wave circuit when employing the same filter as the half wave circuit.

Threaded bushing and hex nut are used to mount this electrolytic capacitor. Usually a lock washer is included when this capacitor is mounted in power supplies subject to excessive vibration.

Courtesy Sangamo Electric Co.

Filter Inductor or Resistor

In most electron applications, the filter action of a single capacitor does not produce a sufficient reduction of the ripple voltage. Therefore, additional units must be added, like the filter choke L_1 and capacitor C_2 shown in Figure 9.

The choke is an inductor consisting of a single winding on an iron core, and its filter action is due to the self-induction which opposes any change in current. Connected in series with the rectifier and load, the choke carries the entire load current. As the applied voltage E_s causes the current to rise, the self-induced voltage in the choke opposes the change, and thus prevents the current from rising immediately to its peak.

The filter input capacitor, C_1 charges to the peak of the applied voltage during the first current pulse in the same manner as C_1 in Figure 7. Then, as E_s decreases, C_1 discharges through R_L and L_1, thus reducing the rate at which the load current decreases. At the same time, this decreasing load current induces a voltage in the choke in a direction which tends to maintain the current.

During the first cycle, a pulse of current causes the filter output capacitor C_2 to charge to some extent, but not to the peak of the applied voltage because, at this time, most of this voltage is needed to overcome the induced counter emf of L_1. However, during the next few cycles, the current variations are reduced, as a result the voltage across L_1 is lower, and C_2 charges to its final operating voltage, E_{C_2}.

L_1 and C_2 are connected in series across C_1, therefore the sum of their voltages, $E_{L_1} + E_{C_2}$, is equal to E_{C_1}. The voltage E_{C_2} forms the output voltage of the filter, and is applied across the terminals of the load R_L.

In Figure 9, the voltage E_{C_1} is composed of two components, one direct voltage, and the ripple which varies up and down at the power line frequency. The inductor has a counter emf which opposes only the a-c or ripple, therefore, most of the a-c voltage appears across L_1 and very little across C_2. On the other hand, L_1 offers minimum counter emf to the direct voltage. Hence, very little of this component appears across L_1, leaving almost all of it across C_2. Although E_{C_1} is divided into the two parts, E_{L_1} and E_{C_2}, these voltages do not have the same proportions of the two components. E_{L_1} is mostly alternating voltage, while the filter output voltage E_{C_2} is almost entirely direct voltage.

In applications where the load requires a small current, often the choke of Figure 9 is replaced by the filter resistor shown as R_1 in Figure 10. It is connected in series between the rectifier and load R_L, and forms the series arm of the filter, $C_1R_1C_2$.

In Figure 10, the voltage E_{C_1} is applied to R_1 and C_2 in series. Resistor R_1 does not discriminate between frequency components, but since C_2 passes a-c frequencies and blocks the direct voltage component, a part of the direct voltage and most of the alternating voltage appear across R_1, while the output voltage E_{C_2} is almost entirely direct voltage.

Since the direct voltage drop E_{R_1} across resistor R_1 is lost insofar as the load is concerned, it is desirable that this voltage be kept low compared with the direct voltage E_{C_2} across the filter output. According to Ohm's law, for a given current E_{R_1} is directly proportional to resistance of R_1. The relatively low cost, size, and weight of a filter resistor make it advantageous in those applications which do not require a large current from the power supply such as a table model radio. When a large current is needed, the filter choke is used.

The filters of Figure 9 and 10 are called pi-type, low-pass filters. The word pi comes from the fact that the filter as it is usually drawn in a schematic diagram looks like the greek letter π called pi. The term "low pass" refers to the fact that the filter reduces the amplitude of alternating currents and that the higher the frequency the greater the reduction because the capacitors have less time to discharge between alternations.

After the first pulse, current can exist in this circuit only when E_S has sufficient amplitude and proper polarity to overcome the capacitor voltage E_{C_1}. In Figures

Front view of a complete laboratory power supply having three ranges of variable voltage.

Courtesy Bristol Eng. Corp.

7B and 8B the narrow shaded areas indicate that this period is short and exists between the point on the rising slope when the E_S is equal to E_{C_1} and the peak of the applied voltage. For this reason, the transformer and rectifier provide energy in short pulses to the filter input capacitor.

As shown by the solid line curve of Figure 7B, once the input capacitor C_1 has been charged by the first rectifier current pulse, it never becomes completely discharged while the power supply is in operation. The voltage E_{C_1} in Figures 9 and 10 has polarity opposite that required to produce current in the circuit made up of C_1, V_1, and the transformer secondary winding.

Usually the load requires a constant supply of energy from the power supply. Hence, the filter is a device which receives energy in short pulses of rectified current and stores the electric energy in the capacitors from which current is taken steadily by the load as needed.

Regulation

In the circuits of Figures 9 and 10, any sudden increase of current required by R_L is supplied by electron flow from the lower (negative) plate of C_2, through R_L, and into the upper plate of C_2. This flow decreases the voltage across C_2 and R_L until the capacitor is recharged by electron flow from the negative plate of C_1, out of the upper plate of C_2, through L_1 or R_1 and into the positive plate of C_1.

In most electron applications, it is necessary that the power supply output voltage remain nearly constant regardless of load current variations during the normal operation of the equipment. This important power supply characteristic is referred to as **regulation.**

As mentioned for Figure 9, an increase in load current decreases the charge stored in the output capacitor C_2, and therefore, decreases the available output voltage E_{C_2}. It requires an increase in current in the choke to recharge C_2, and the resistance of the wire in the choke winding increases the direct voltage drop across this unit, thereby reducing the direct voltage available across the output terminals of the filter. Moreover, the increased current reduces the charge on C_1 and therefore, the rectifier current pulses must increase to recharge C_1. The increased current is carried by rectifier V_1 and the secondary winding of the transformer. Since both have some resistance the increased voltage drop reduces the portion of E_S which is available for charging C_1.

To reduce these undesirable effects, the filter capacitors should have high capacitance; the choke should provide high inductance; and the transformer secondary, the rectifier, and the choke should contain low resistance.

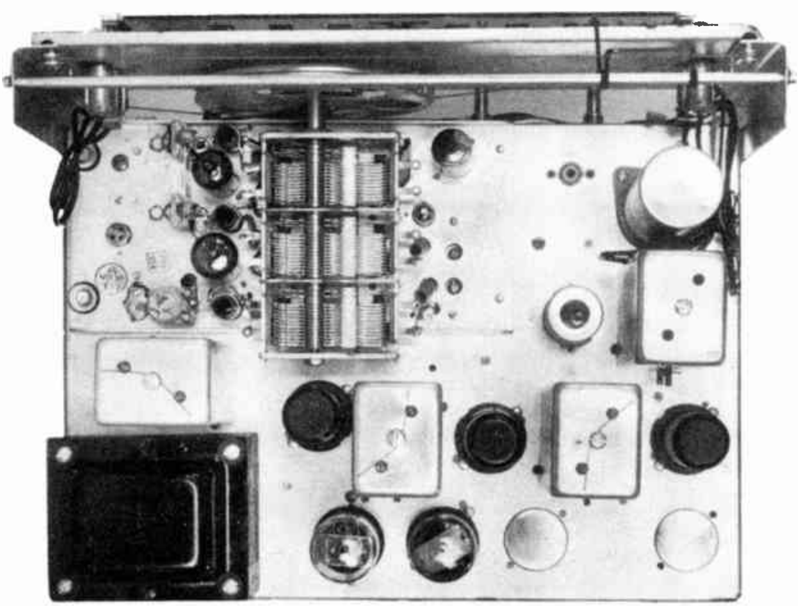
In practice, each power supply is designed to provide a certain maximum current, known as the "full load". On the other hand, when no current is taken from it, the supply is said to be operating at "no load". The voltage at the output terminals is highest under no load conditions, and reduces to some definite value at the rated full load current. The less the output voltage changes with load current variation, the better is the regulation, and since most circuits work best at some particular voltage, GOOD REGULATION is a desirable power supply characteristic.

Types of Filters

Besides their classifications as low-pass, the filters employed in power supplies are designated as to the nature of the component at the input or rectifier end. In the pi-type filter of Figure 11A, capacitor C_1 forms the input component, and therefore, this arrangement is called a CAPACITOR INPUT or "condenser input" filter. This type is employed in the circuits of Figures 9 and 10. The unit of Figure 11B is composed of two "L-sections", L_1C_1 and L_2C_2, and since L_1 forms the input component, this arrangement is called a CHOKE INPUT filter.

The choke input filter provides better regulation, and generally is employed in the applications which require heavy load currents with good regulation. On the other hand, the capacitor input arrangement provides a somewhat higher output voltage with a given power transformer and rectifier. Therefore, it is used for equipment which operates with a relatively light load current and does not have such high regulation requirements.

The most common power supply filter arrangements are shown in Figures 11A, and 11B. Figure 11A is a single section, pi-type



Top view of a radio receiver. Note the transformer in the lower left-hand corner and the electrolytic capacitor in the upper right-hand corner.

Courtesy Capehart-Farnsworth Corp.

filter; Figure 11B consists of two L-section filters.

THE BLEEDER RESISTOR

To show the complete current path, the power consuming equipment or load was represented by resistor R_L in Figures 7, 8, 9, and 10. However, the load is not a part of the power supply proper. In Figure 12A, the transformer, rectifiers, and filter are represented by the block labeled power supply. The output voltage, $E_{d\text{-}c}$, is applied to the load block, which represents the combination of circuits and components which receive their d-c operating voltages and currents from the power supply.

Under usual operating conditions, the total resistance of the load varies from time to time, that is, the power supply must deliver more or less current. As mentioned before, the output voltage $E_{d\text{-}c}$ varies with changes in load current, and the less these variations are, the better the regulation.

To improve the regulation, it is common practice to employ a bleeder resistor across the output terminals of the filter, as shown by resistor R_B in Figure 12B. Thus the supply must furnish a total current which is equal to the sum of the load current plus that carried by the **bleeder**. The resistance R_B does not change, therefore the bleeder current depends only upon $E_{d\text{-}c}$ and R_B, and so it is relatively constant.

With the load connected across the bleeder, its current is only a portion of the total output, and any variations in the load current result in smaller changes in the total supply current. Thus, the changes in $E_{d\text{-}c}$ with load current variations are reduced; that is, the use of the bleeder resistor improves the regulation. Also, when the load is disconnected, the bleeder provides a discharge path for the power supply filter capacitors.

POWER SUPPLY CIRCUITS

One of the most common ways to classify a practical power supply circuit is according to the type of current it is designed to work from. Using this classification; there are A-C SUPPLIES, D-C SUPPLIES, and those which operate from either a-c or d-c called A-C/D-C SUPPLIES.

A-C Operated Supplies

Most a-c operated power supplies employ a power transformer in a typical circuit very similar to that shown in Figure 13. Here, power transformer T_1 has five windings: primary P_1, secondaries S_1, S_2, S_3, and S_4. In series with P_1 and one side of the a-c power line, switch SW_1 makes it possible to turn the power supply and the attached equipment on and off. Both diodes are combined in one tube envelope and use the same heater.

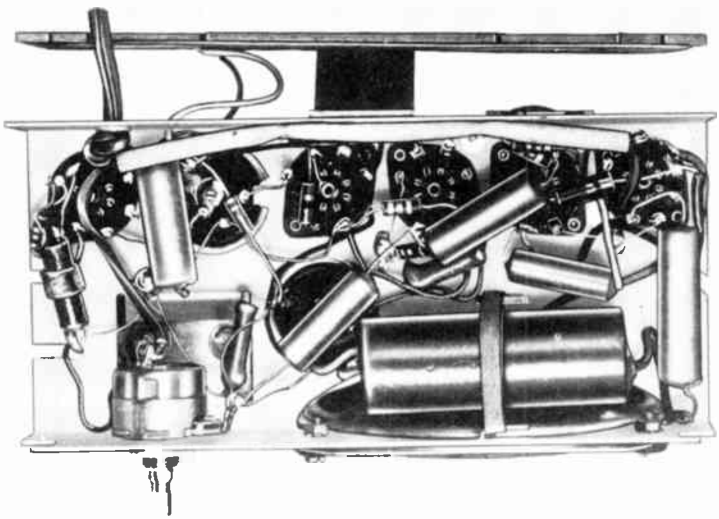
Secondaries, S_1, S_3, and S_4 have fewer turns than P_1, and therefore, provide operating voltages lower than that of the power line. Connected as shown, S_1 provides a-c to heat rectifier tube V_1, while S_3 and S_4 provide heater currents for the electron tubes in the equipment. In this example, S_3 is connected to the heaters by means of two leads in the same manner as S_1 connects to the V_1 filament. However, only one lead from S_4 connects directly to the heaters supplied by this winding. The other end of S_4 is attached to the metal frame or chassis on which the various components are mounted.

Being electrically conductive, the chassis usually is employed as part of one or more of the circuits in the unit, and provides a convenient means of completing these circuits with a resultant saving of wire conductors. Usually referred to as **ground** (gnd.), the chassis connection is designated by the symbol near the lower end of S_4. Depending upon the application of the electron unit, the chassis may or may not be connected by a conductor to the earth to form an "earth ground". In the circuit of Figure 13, one terminal of each heater, supplied current by S_4, is connected to the upper end of the S_4 winding by means of the lead indicated. To complete the circuit, the remaining heater terminals connect to the chassis or "ground".

With more turns than P_1, secondary winding S_2 produces a voltage step-up, and this high alternating voltage is applied to the plates of full wave rectifier tube V_1. As shown, the center tap of S_2, the negative plates of filter capacitors C_1 and C_2, and the lower end of R_1 all connect to ground. Basically, this circuit is just like the full wave rectifier of Figure 8A. Although not included in the Figure, the load is connected in parallel with bleeder resistor R_1; that is, from the upper output terminal marked "B+", to the lower terminal connected to ground.

Tracing the d-c path in Figure 13, when the applied voltage makes the upper plate of V_1 positive, electrons are drawn from the filament to this plate, and flow through the upper half of S_2 to the center tap, to ground, through R_1 and the load to B+, and through L_1 to the filament of V_1. When the applied voltage makes the lower plate of V_1 positive, electrons are attracted from the filament to this plate and flow through R_1, the load, and L_1 to the filament of V_1.

As explained for the filter of Figure 9, during the short intervals rectifier V_1 conducts, capacitors C_1 and C_2 are charged by electron flow from ground into their lower negative plates. Then, supplied by C_1 and C_2, a continuous flow of electrons is carried by R_1, the load, and L_1 during the intervals when V_1 is not conducting.



Bottom view of a table model radio receiver chassis showing its components. Note the placement of the large electrolytic capacitor on the lower right.

Courtesy Motorola Inc.

With C_1 connected from the filament of V_1 to ground, the filter is of the capacitor input type like that of Figure 11A, and includes the iron core choke L_1 and capacitor C_2. Often capacitors C_1 and C_2 are of the electrolytic type and R_1 is the bleeder resistor. As indicated, the ungrounded output terminal of the power supply is referred to as the "B+" or "B plus" terminal.

A-C/D-C Operated Supplies

A power supply which may be operated from either an a-c or d-c source, as shown in Figure 14, does not include a power transformer since transformers cannot operate with d-c. Hence, the power line connects directly to the rectifier circuit. The heater of the half wave rectifier tube V_1 and those of the other tubes used in the equipment are connected in series across the power line.

In the Figure, the upper side of the power line connects through the parallel circuit of pilot light PL_1, resistor R_1, and half of the heater, to the plate of half wave rectifier tube V_1. The other side of the power line connects through the off-on switch SW_1 to ground. The filter, containing C_1, C_2, C_3, R_3, and R_4 is a two-section, pi-type unit. Low resistance R_2 is not a filter resistor; it has just sufficient resistance to prevent a damaging surge of rectifier current while C_1 receives its initial charge when SW_1 is first closed. Therefore, capacitor C_1 is the actual input component of the filter.

When the power line supplies a-c, the rectifier passes a pulse of current during the peak of each alternation in which the upper supply line is positive with respect to the line connected to ground. These pulses of current charge the filter capacitors as explained previously for Figure 10, and the voltage across C_3 is available as the supply output voltage, $E_{d\text{-}c}$.

When the power line supplies d-c, the positive side of the line must be connected to the upper input lead in Figure 14, and the negative side through SW_1 to ground. After an initial surge which charges the filter capacitors, the rectifier conducts continuously, but only carries the relatively small current required by the load.

Actually, the rectifier circuit is not needed when the line supplies d-c, but as used the arrangement provides a convenient means of operating with either type of input without making any circuit changes. The power supply filter removes any variations in the power line d-c to provide a steady voltage at the output terminals of the supply.

Connected in series with the power line and the plate of V_1, lamp PL_1 lights the dials on the front panel of the equipment. The PL_1 filament current is supplied by the V_1 plate current as well as the current drawn by the other tube heaters in series. R_1 and half of the V_1 heater carry part of these currents since both are in parallel with PL_1.

A COMMERCIAL RADIO RECEIVER

As we pointed out earlier in this lesson, power supplies are used in practically every possible type of electronic equipment. A very typical application is in the table model radio receiver shown in black in the schematic diagram of Figure 15. Although the grey portion of the diagram is not described until later lessons, the entire diagram shows how this power supply provides both a-c and d-c for the circuits.

This is the same power supply shown in previous lessons and it is very similar to the circuit shown in Figure 13. As usual a 117 v a-c source supplies current to the primary of transformer T_6. The secondaries of this transformer provide the correct voltages and the high voltage winding has a center tap to permit full wave operation by the two diodes in tube V_6. Note that tube V_5 uses the voltage directly from the input capacitor C_{18} through the primary of transformer T_5. This is a means of securing a high voltage and heavy current for V_5 without using a filter choke instead of resistor R_{14}.

All of the tube heaters connect to the 6.3 volt secondary. The terminals marked "X" are all connected together and so are the "Y" terminals. Therefore, all of the heaters are in parallel across this heater winding. Also, across this winding is a small light bulb called the "pilot light" which is used to light the tuning dial. The symbol for it is the circle with a single loop in it.

Naturally, you must wonder what each of the other tubes in this radio diagram do. Since these very same circuits are used in many other types of equipment we shall describe each in turn and when it is explained it will be shown in black on the diagram. In this manner, before the next six lessons are completed you will understand the overall operation of this receiver.

Possibly as a first step toward this goal, we should explain how "energy converters" work, since at least one is found in every radio or television receiver.

IMPORTANT DEFINITIONS

BLEEDER RESISTOR—A resistor connected across the output terminals of a power supply to improve the regulation by carrying a continuous, fixed current.

CHASSIS—[SHAS i]—The frame or base, usually metal, on which the tubes and other components of an electron unit are mounted.

GROUND—(GND)—A conductive body which serves to complete an electric circuit, and usually provides the reference potential for measurement of voltages in an electron device.

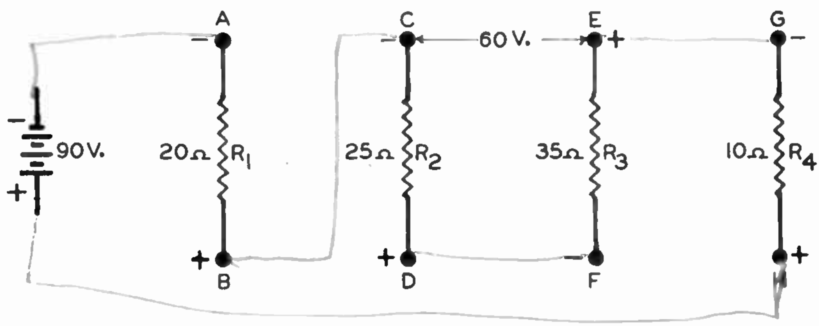
POWER TRANSFORMER—The transformer employed to obtain the required voltage step ups and step downs in an a-c operated power supply.

REGULATION—With regard to power supplies, a measure of the change in output voltage due to a change in load current. The less the voltage change, the better the regulation.

RIPPLE—In the output voltage of a rectifier circuit, the alternating or varying voltage component.

WORK DIAGRAM

Connect these four resistors in series across the 90 v. battery in such manner that the indicated polarities are correct and the potential difference between points C and E is 60 volts.



When you have finished, check with the answer on the back of the fold-out sheet.

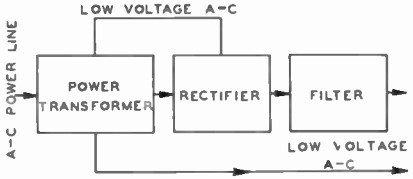


FIGURE 1

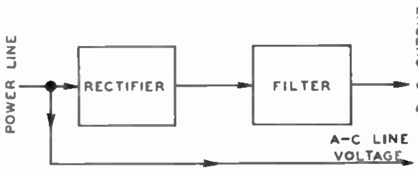


FIGURE 2

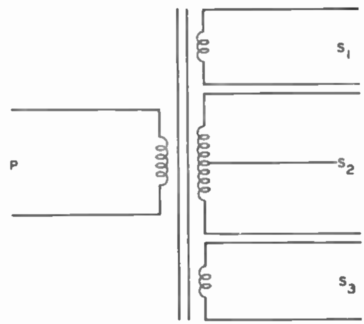


FIGURE 3

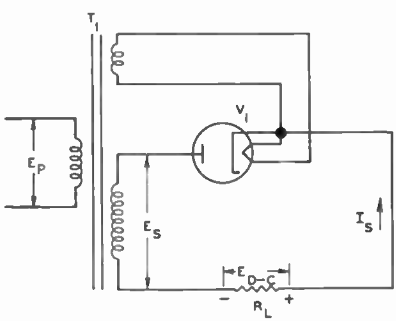


FIGURE 4

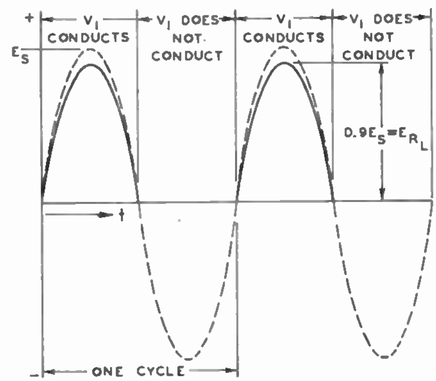


FIGURE 5

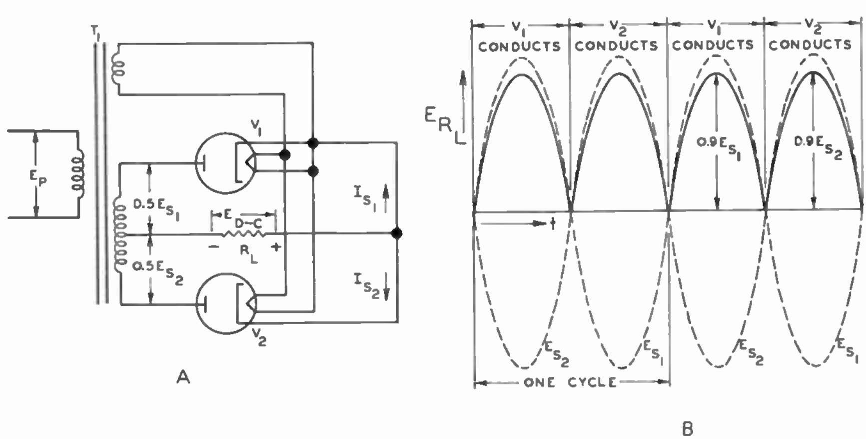
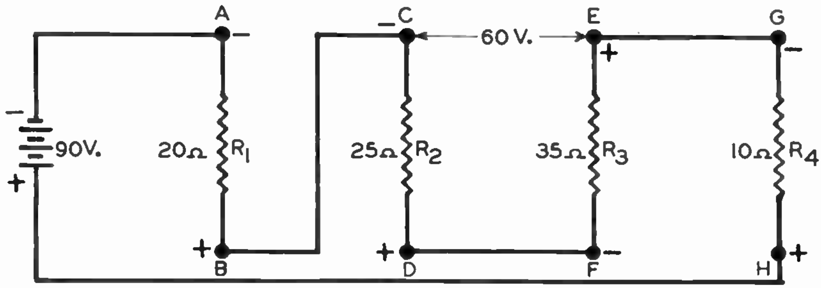


FIGURE 6

WORK DIAGRAM SOLUTION



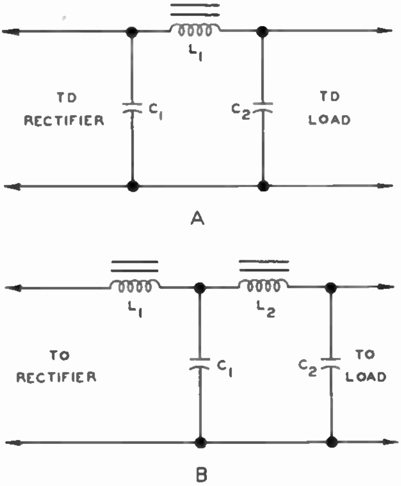


FIGURE 11

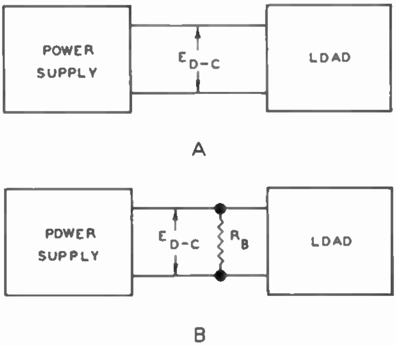


FIGURE 12

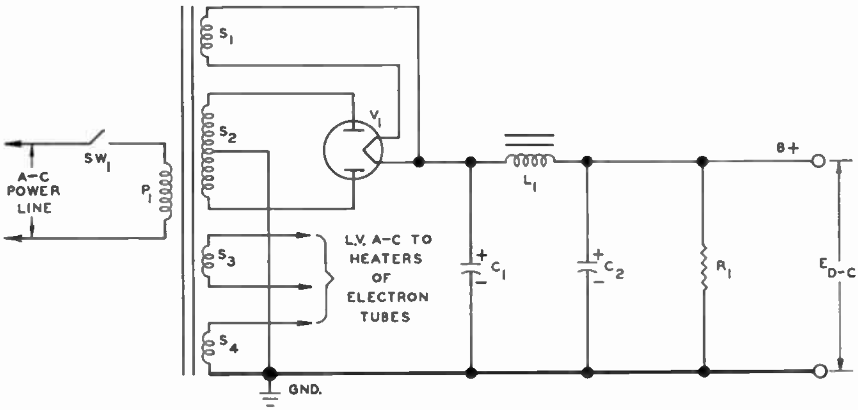
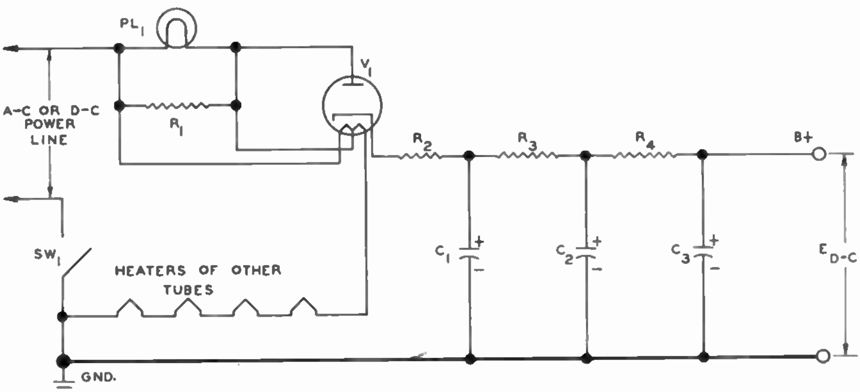


FIGURE 13



AEH-12

FIGURE 14

AEH-12

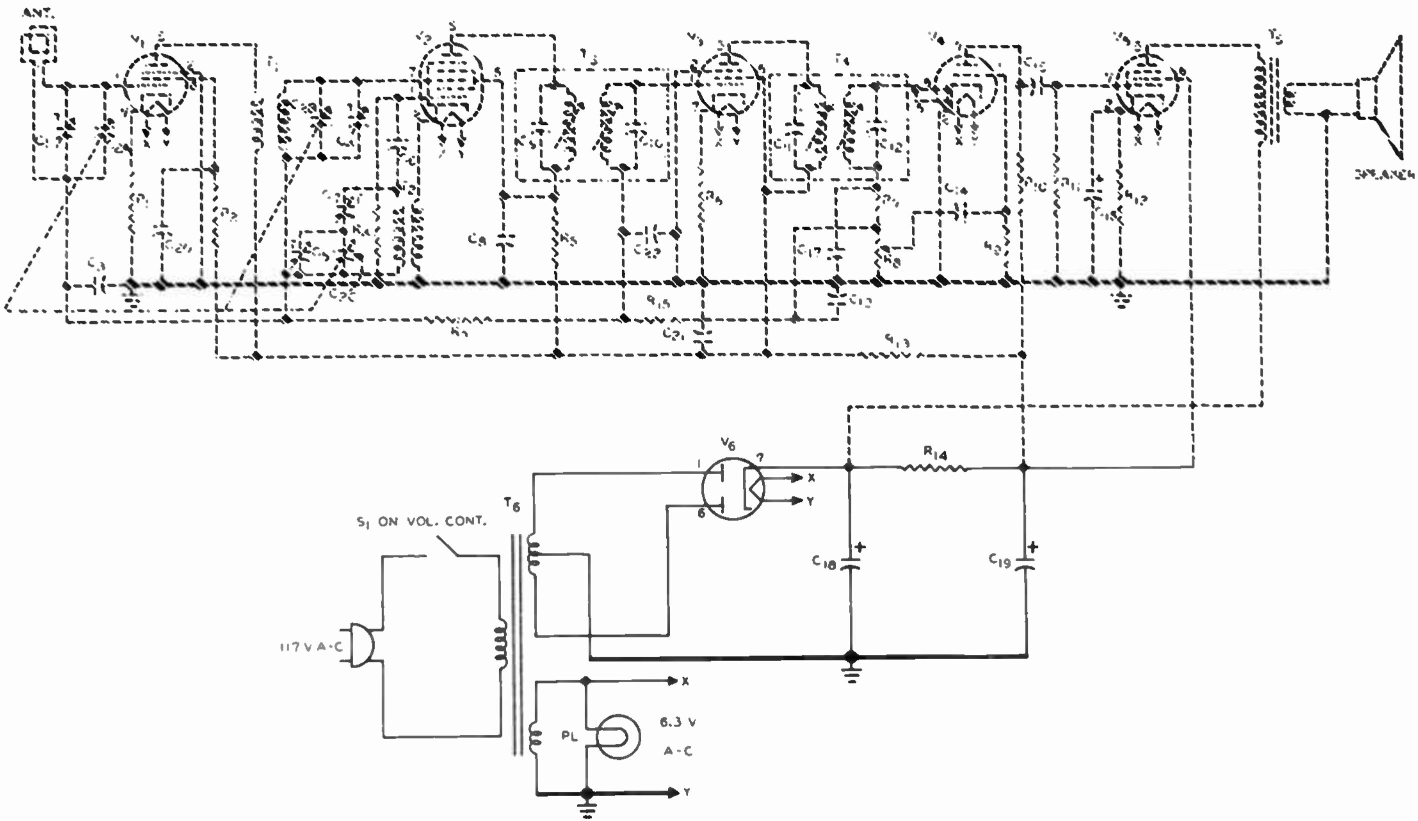


FIGURE 15

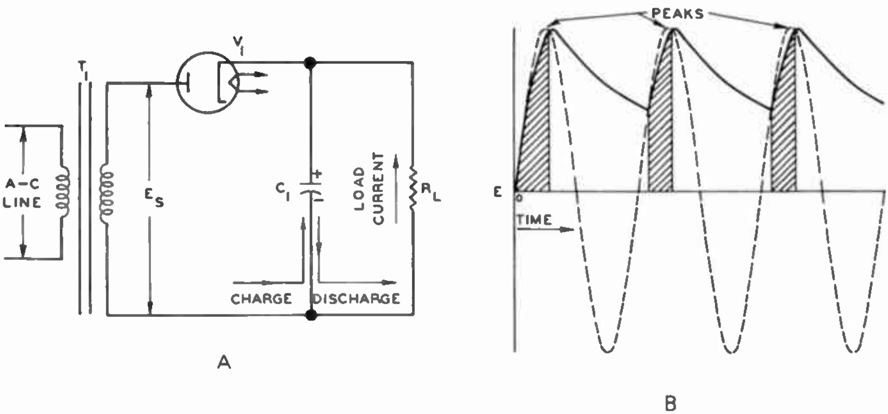


FIGURE 7

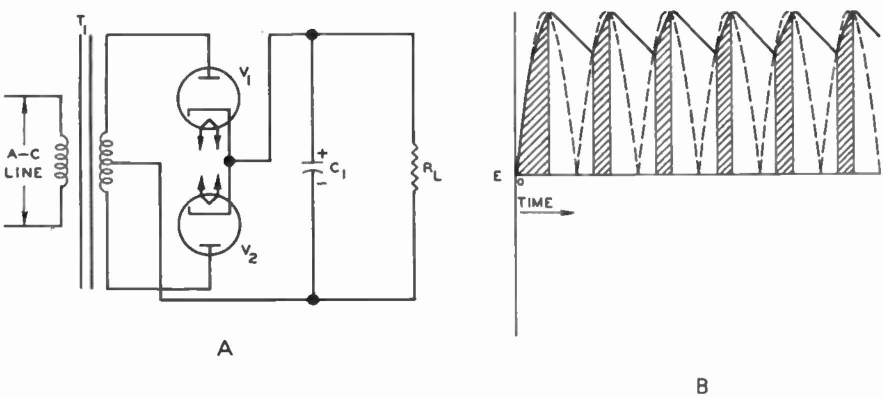


FIGURE 8

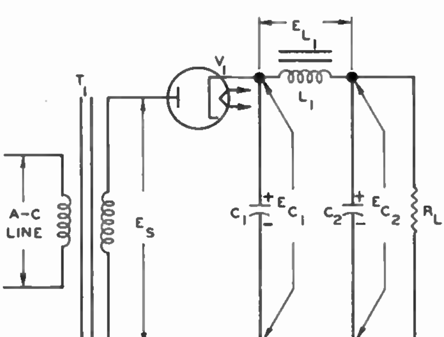


FIGURE 9

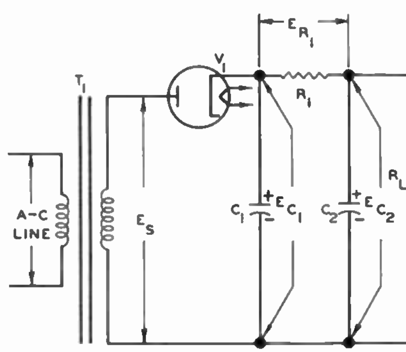


FIGURE 10

FROM OUR *Director's* NOTEBOOK

TAKE TIME to —

Take time to work—it is the price of success

Take time to think—it is the source of power

Take time to play—it is the secret of perpetual youth

Take time to read—it is the fountain of wisdom

Take time to be friendly—it is the road to happiness

Take time to dream—it is hitching your wagon to a star

Take time to love and be loved—it is the privilege of the gods

Take time to look around—it is too short a day to be selfish

Take time to laugh—it is the magic of the soul

—Leinster Leader: Irish Digest

Yours for success,

W. C. DeVry

DIRECTOR

PRINTED IN U.S.A.

AEI

ENERGY CONVERTERS

Lesson AEH-13B

DeVRY Technical Institute

4141 W. Belmont Ave., Chicago 41, Illinois

Formerly DeFOREST'S TRAINING, INC.

I-13

AEH-13B

ENERGY CONVERTERS

4141 Belmont Ave.

Chicago 41, Illinois

DeVRY Technical Institute

ELECTRONS REPRODUCE PHOTOGRAPHS

The press photographer rushes from the newspaper office to a distant scene, quickly snaps a number of photos and develops them on the spot. Then, instead of rushing them back to the office, he opens what appears to be a portable typewriter case, although actually it is a compact facsimile transmitter. With a photo placed on a cylinder, the newspaper office is phoned, and then with the telephone set on a holder provided, the transmitter is turned on. The signal is sent over the telephone wires to the office where a facsimile receiver reproduces the photo.

Known variously as "tele-photo", "wire-photo" or "radio-photo", facsimile also is used to convey pictures of events which occur in remote parts of the world. Business concerns such as banks, law offices, distributing houses, department stores, railroads and many others, use facsimile for rapid transmission of photographs, diagrams, or copies of important papers, containing necessary signatures.

Fundamentals

ENERGY CONVERTERS

Contents

Reading is to the mind what exercise is to the body. As by the one, health is preserved, strengthened and invigorated: by the other, virtue (which is the health of the mind) is kept alive, cherished and confirmed.

—Addison

ENERGY CONVERTERS

Today practically everyone has heard sounds pour out of a radio, the modern phonograph, or the sound system at a movie and many people have seen the picture on the television screen. Yet, few stop to think what actually is happening: that electricity is converted to sound energy or light as a picture on the screen are accepted as a matter of fact.

Actually energy converters are very important to every electronic system. Electricity by itself is almost useless; it is needed to produce or control such things as motion, sound, heat, and light. Converters must be used to change chemical activity, light, heat, or mechanical energy to electricity or eventually convert electricity to one of these forms again.

The microphone that picks up sound, the photocell that detects light rays, and the thermocouple that detects heat are just a few of the very many energy converters used in electronics. Moreover, each of these has many uses. For example, to name but four applications of the photocell, it is used to pick up sound from movie film, open doors, set off burglar alarms, and count objects on a conveyer.

In fact, we had energy converters in our earlier lessons. We showed how electromagnetism was used by an electric current to ring a bell, and, to produce an electric current by a rotating loop. In one, electric energy is converted to the mechanical energy of the moving bell clapper and in the other the mechanical energy of the rotating loop was converted to electricity.

At this time, rather than consider all of possible applications that energy converters are used for, we shall describe only those most likely to be found in a radio receiver. The others can be explained better when we describe their application.

CELLS

Many of the portable radios in use today have some provision for battery operation. In addition, radios usually are almost standard equipment for the car. These too, operate from a battery. In either case, these batteries are made up of smaller units called cells.

In the very first lessons of our training program we used cells as a source of electric current for the circuits. At that time no mention was made of their internal construction. Actually **cells** are energy converters that use chemical action to produce electricity, and these cells belong to one of two basic types: In the **primary cell** once the material is consumed by the chemical action, the cell is done for and must be replaced. In a **secondary cell**, the material can be restored to its original condition by forcing a current through it in the opposite direction. That is, it can be recharged. The flashlight battery is a good example of primary cells and car batteries are made up of secondary cells.

PRIMARY CELLS

A primary cell consists of two different metals, called **electrodes** separated by a solution known as an electrolyte. The electrolyte is always a liquid. However in DRY CELLS, this liquid is absorbed in a porous material just as a blotter soaks up ink, so that the cell cannot spill, whereas the liquid is free to pour from a WET CELL.

Wet Cells

The basic arrangement of a wet cell is illustrated in Figure 1. Here, one electrode is made of copper and the other of zinc, while the electrolyte is an acid solution. Dissolving slowly in the electrolyte, the zinc gives off positive zinc atoms. This action leaves an excess of electrons on the zinc electrode and so it is negative. At the same time, positive atoms created from the electrolyte remove electrons from the copper electrode, thus making it positive.

With the zinc electrode at a negative potential and the copper electrode at a positive potential, there exists a voltage between the two electrodes. Eventually, the chemical action between the electrolyte and zinc reaches a balance, that is, both have an equal number of charges, and the chemical action ceases.

However, if a lamp bulb connected to the battery or the battery is placed in an electric circuit, electrons flow outside of the battery from the negative zinc

A commercial cell used for supplying the current to heat the filaments of radio tubes.
Courtesy National Carbon Co.

electrode, through the lamp and to the positive copper electrode. As current is drawn from the cell. the zinc electrode is consumed until finally it is completely used up, at which time the cell is run down, or "dead".

Voltage developed between the two electrodes, or positive and negative poles as they are sometimes called, depends upon the metals used; some combinations produce higher voltages than others. Two things determine the current: the electrode area and the "strength" of the electrolyte solution.

Dry Cells

Flashlights and most portable electronic equipment employ the familiar type of dry cell. As mentioned, dry cells contain a wet electrolyte absorbed in a porous material thus making the cell nonspillable.

Shown in the cutaway view of Figure 2, the main parts of one commercial cell are the cylindrical bobbin of mix surrounding the carbon rod, the separator, and the zinc can or cup which is closed at the bottom and open at the top. The mix serves as the positive electrode. Frequently called the positive electrode, the carbon rod actually serves as a conductor of electrons from the external positive terminal (the carbon cap) to the interior. The zinc can is the negative electrode, while a layer of paste made from gelatin, called the separator, serves the double purpose of holding the electrolyte and separating the two electrodes.

The top of the cell is sealed with asphalt, which is held a short distance above the mix and separator by means of a paper washer to provide the expansion area. Generated by action within the cell, a gas collects in the expansion area, and the porous carbon rod serves as a vent up to the cap where a tiny pin hole in the brass cap, not visible in Figure 2, permits the gas to escape. A second paper washer insulates the mix from the zinc can at the bottom of the cell, the metal top is formed to make good electric contact with the carbon rod, and the cylindrical surface of the zinc can is covered with a laminated plastic jacket.

Manufactured in a number of standard sizes for different current requirements, these dry cells provide a voltage of from 1.57 to 1.63 volts when new. After a "shelf life" of a year, the voltage of a good cell may drop only about one-tenth of a volt. In service, a dry cell voltage of 1.5 volts is assumed. Most dry cells are intended for intermittent use; only a few types are designed for continuous service.

To determine the performance applications of the intermittent type of cell, it is discharged through a resistance of 4 ohms for a period of 5 minutes once a day until the voltage at the terminals of the cell has reduced to 0.75 volt. On the average, when new, the typical sizes D, C, and

AA flashlight cells last for a total service time of 817, 377, and 95 minutes, respectively.

Every device has a certain resistance within it, and cells are no exception. The electrodes and electrolyte offer resistance to a flow of electrons, and this resistance is called the INTERNAL RESISTANCE of the cell and is measured in ohms. Moreover, the internal resistance increases with age. Therefore, the older the cell the less current it can supply. In fact, for many applications, this current reduction due to increased internal resistance determines a cell's useful life.

Where long life and extra reliable sources of electric power are needed the mercury cell is quite often used. Although more expensive than some of the other primary cells, it is a very light and compact unit for its capabilities.

As shown in Figure 3, the typical mercury cell is entirely enclosed in a steel case. At the bottom is a large pellet made of a mercury compound. It is called a depolarizer pellet since it not only serves as the negative electrode but also absorbs harmful gases formed by the chemical activity of the cell. These gases finally escape through the vent at the bottom. The barrier keeps particles out of this pellet.

An absorbent material soaked with the electrolyte is stacked on top of the negative electrode pellet barrier and the positive electrode or anode pellet rests on top of this. Electric contact to the electrode is made by means of the steel top and steel case which are electrically insulated from each other by a grommet made of a plastic insulating material.

Voltage developed by the mercury cell is 1.345 volts and the type of Figure 3 is about 6/10 of an inch in diameter and height. These can be made in various sizes and shapes depending upon their

A combination A and B battery for portable receivers. Unit contains the flat shaped dry cells.
Courtesy National Carbon Co.

specific application. Moreover, their weight is quite low, the type shown weighing only 0.43 ounce.

SECONDARY CELLS

In the second major cell classification, the chemical action is "reversible". The active materials can be restored to their original condition by connecting an external voltage source to force current through the cell in the opposite direction. These cells are called "storage" or secondary cells, for, by means of this restoring or charging current, a definite amount of energy is stored in the cell.

Lead-Acid Cells

Shown in Figure 4, the simplest form of lead-acid storage cell consists essentially of positive and negative plates, held apart by a

A lead-acid storage battery with three two-volt secondary cells connected in series is the type commonly employed in automobiles, etc.
Courtesy Willard Storage Battery Co.

separator and immersed in a liquid electrolyte. The positive plate is lead peroxide, the negative plate is spongy lead, and the electrolyte is a dilute solution of sulfuric acid.

Figure 4A shows the cell employed to deliver current to a lamp. In use, the cell voltage is maintained by chemical action at both plates. Due to these actions, the negative plate accumulates electrons and the positive plate loses electrons. The resulting difference of potential causes the accumulated electrons to flow from the negative plate, through the lamp, and to the positive plate, as indicated by the arrows.

Inside the cell, the chemical action converts part of the electrolyte from sulfuric acid to water, and the plates to a non-useful substance called lead sulfate. The action can continue until the plates are completely "sulfated", and the liquid is almost all water. However, a cell is never allowed to discharge this far in good practice since some permanent damage to the plates occurs.

To return a cell to its original condition, it is connected to a generator as shown in Figure 4B. The generator "charges" the cell by causing electron flow in the direction opposite that described above. As the arrows indicate, the electrons flow from the negative terminal of the generator to the negative plate of the cell, and from the cell positive plate to the positive terminal of the generator.

This charging current produces chemical actions in the cell which are equivalent to electron flow from the negative plate, through the electrolyte, to the positive plate. These chemical actions reconvert the plates to lead peroxide and spongy lead, respectively, and return the acid to the electrolyte.

To increase the total available current of a storage cell, a number of individual plates are attached to a lead "strap" to form an integral unit called a "group". The strap also contains a lug or post to which the external circuit connection is made. Then, a group of positive and a group of negative plates are interleaved, with one more plate in the negative than in the positive group. This places each positive plate between two negatives to provide good performance. Also, an insulating separator is inserted on each side of the positive plates, as illustrated in the cut-away view of Figure 5. Such an assembly of two groups of plates with their separators is called an "element". The complete element is placed in a suitable container, and the electrolyte added to complete the cell.

Regardless of the size or the number of plates, all lead-acid cells develop the same voltage. While the cell is being charged, the voltage across it rises to about 2½ volts, but three or four minutes after the charging current is stopped, the voltage drops to 2.1. Then, as the cell delivers current, the voltage drops quickly to 2.0 where it remains until the discharge is almost complete, after which it drops very rapidly. For practical purposes, a cell is discharged completely at 1.8 volts.

To keep it from discharging too far, a lead acid cell should be checked frequently. One convenient method is to take a sample of the electrolyte and measure the amount of acid in it. All liquids are not the same weight, and this fact provides one means of comparing them with each other. Because of the large quantities existing on the earth, water is used as a standard of comparison, and the ratio of the weight of a liquid relative to that of water is called its SPECIFIC GRAVITY. Technically, the specific gravity of a liquid is the ratio of the weight of a given volume of the liquid to the weight of an equal volume of water. Sulfuric acid has a specific gravity of 1.853, and therefore, for equal volumes, this acid is 1.853 times as heavy as water which has a specific gravity of 1.

Edison Cell

In the secondary cell known as the Edison cell, the active materials are nickel peroxide in the positive plate, and iron in the negative plate. The electrolyte is a solution of potassium hydroxide to which is added a trace of lithium hydroxide.

In both plates, the active material is in finely divided form, and is held in a container which is porous to allow free circulation of the electrolyte.

Steel tubes containing several hundred holes per square inch are used to hold the potassium hydroxide in the positive plate. In the form of flakes 0.00004 inch thick, metallic nickel is added to

A dry cell of the form used frequently in battery operated radios.
Courtesy Burgess Battery Co.

the potassium hydroxide to make the plate sufficiently conductive. Finely perforated steel "pockets" are employed to hold the iron in the negative plate, and the conductivity is increased by the addition of mercury.

The Edison cell provides only 1.2 volts, but it is more rugged than a lead-acid cell, and hence it can stand considerably more abuse. However, these cells are much more bulky for a given current rating. Since the specific gravity of the electrolyte changes very little during discharge, Edison secondary cells are tested by measuring their voltage which reaches a maximum of 1.8 to 1.9 volts while on charge, and when two readings taken at least 15 minutes apart show no change, the cell is fully charged.

BATTERIES

Most applications require either a larger current, or a higher voltage, than can be furnished by a single cell. When a group of primary or secondary cells constitute the source of electric power in a unit, they are referred to collectively as a **battery.** Although the term battery means more than one cell, it is common practice also to use the word to designate even a single cell power source.

The various cell connections may be compared with certain combinations of water pumps used to provide the water pressure and flow needed for different purposes. It is assumed that each water pump runs at a certain specified speed, develops a given pressure in pounds, and can deliver a water flow up to some maximum amount. The maximum water flow is called the "capacity" of the pump, and is expressed in gallons per minute or cubic feet per second.

amount less than the maximum rated current may be taken from a cell, the electric pressure or emf across its terminals remains essentially constant.

These typical A, B, and C batteries employed in portable radio and other electron applications all use primary cells.

Courtesy Burgess Battery Co.

For this comparison, each cell may be thought of as an electric pump which is capable of supplying a certain maximum current at its rated voltage. Although any

Water Pumps in Parallel

Suppose, for a desired application, a flow of 80 gallons of water per minute is needed at a pressure of 1.5 pounds, and several pumps are available, all the same type, which will develop the required 1.5 lb. pressure but each has a capacity of only 20 gallons per minute.

Although one such pump can meet the specified pressure requirement, it can supply only one-fourth the total water flow needed at that pressure. Therefore, to obtain the necessary capacity of 80 gal. per min., four of these pumps are connected in the manner shown in Figure 6.

Here, with all intakes connected together, and the four outlets feeding the same pipe, the total pressure developed is still the same as with one pump. This arrangement is known as a parallel method of connection, and the group of pumps may be considered a "battery".

The capacity of this battery is equal to four times the capacity of one pump, because each pump takes 20 gallons per minute from the intake and delivers this amount to the outlet. Thus, the total intake and output of the battery is 20 + 20 + 20 + 20, or 80 gallons per minute.

Therefore, when any number of pumps are connected in parallel to form a battery, the pressure developed by the battery is equal to that of one pump, but the total water current output is equal to the sum of the outputs for the individual pumps.

Electric Cells in Parallel

The same action can be obtained electrically by connecting cells in parallel to form a battery, as shown in Figure 7A. Here, the positive terminal is located at the center of each cell, and the negative terminal at the outer edge or rim. All the positive terminals are connected together to form a single "intake" for the electrons from the external circuit, and all the negative terminals are connected together to provide a single output.

There is a separate path for current through each cell, but with the respective positive and negative terminals connected as shown, the separate currents combine to form the total output current taken from the battery. Also with these connections, the total pressure developed by the battery is the same as the emf of one cell.

As an example, suppose it is desired to take a current of not over .05 ampere from each cell of a battery which must supply a total current of .2 ampere at a pressure of 1.5 volts. For this application, the battery may consist of four common type dry cells connected as in Figure 7A. The battery develops 1.5 volts and with the parallel connection, each cell need supply only .05 ampere to provide the required total battery output of .05 + .05 + .05 + .05 = .2 ampere.

WHEN A NUMBER OF ELECTRIC CELLS ARE CONNECTED IN PARALLEL TO FORM A BATTERY, THE VOLTAGE IS EQUAL TO THAT OF ONE CELL, BUT THE TOTAL CURRENT OUTPUT IS EQUAL TO THE SUM OF THE SEPARATE CELL CURRENTS.

Figure 7B is the schematic diagram of the pictorial shown in Figure 7A, but with R_1 added. Using the following form of Ohm's Law we can find the resistance R_1:

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

Thus, knowing the voltage is 1.5 volts and the total current to be supplied is .2 ampere, we can substitute in the above to find R_1 is:

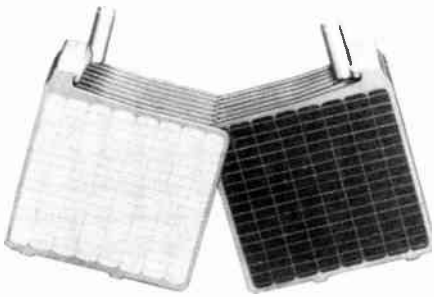
$$R_1 = \frac{1.5}{.2}$$
$$= 7.5\Omega.$$

Each cell is drained only .05 ampere, while, if only one cell were used with the 7.5Ω resistor, it would be drained by .2 ampere. The less current the cell provides, the more closely it approaches its "shelf" life and therefore it lasts much longer.

Water Pumps in Series

Suppose the same four pumps of Figure 6 are to be used in an application which requires a working pressure of 6 pounds, but the needed water flow is not greater than the 20 gal. per min. capacity of one pump. In this case, the four pumps may be connected such that the output of one is fed to the intake of the next as shown in Figure 8. In this arrangement, the pumps are connected in series, and again may be considered a battery.

At the outlet of pump No. 1, the water has a pressure of 1.5 pounds, and at this pressure, it enters pump No. 2 which increases the pressure by 1.5 pounds to provide a total of 3 pounds for the two pumps. In like manner, pumps 3 and 4 step up the pressure by 1.5 pounds each, so that at the outlet of pump No. 4, the total pressure is equal to 1.5 + 1.5 + 1.5 + 1.5, or 6 pounds. Thus, with the series arrangement, the total pressure supplied by the battery is equal to the sum of the pres-



Groups of plates are assembled with a positive plate between two negatives to form an element.

Courtesy Willard Storage Battery Co.

sures developed by the individual pumps.

Since only pump No. 1 connects to the intake for the battery, and only pump No. 4 connects to the battery outlet, no more water can pass through the battery each minute than can pass through one pump, for unlike the parallel pump battery, in the series battery of Figure 8, there is only one path for water.

Beginning at the intake to pump No. 1, this path is through pumps 1, 2, 3, and 4 in order, to the outlet of pump No. 4. Therefore, the capacity of the battery is equal to the capacity of one pump, or 20 gallons per minute.

Electric Cells in Series

Similar conditions exist in an electric battery consisting of a group of cells connected in series. Figure 9A shows such an arrangement which can be compared with that of Figure 8. In the electric battery, the negative terminal of one cell is connected to the positive terminal of the next, and the remaining positive terminal (of cell No. 1) serves as the positive terminal for the entire battery, while the remaining negative terminal (of cell No. 4) forms the battery negative terminal.

This battery negative terminal corresponds to the outlet of the water pump battery of Figure 8. Likewise, the positive terminal of the electric battery corresponds to the intake of the water pump battery. Since only cell No. 1 connects to the battery positive terminal, and only cell No. 4 connects to the battery negative terminal, no more current can pass through the battery than can pass through one cell. That is, with the cells in series, there is only one path for current in the battery.

Beginning at the positive terminal of cell No. 1, this path is through cells 1, 2, 3 and 4 in order, to the negative terminal of cell No. 4. Thus, insofar as the current is concerned, conditions are the same as explained for Figure 8. That is, with only one path for current through the electric battery, the current output of the battery is the same as for one cell.

Assuming ordinary dry cells in Figure 9A, each cell has a difference of potential of 1.5 volts between its terminals. Since the connecting wires represent zero resistance, the positive terminal of cell No. 4 and the negative terminal of cell No. 3 are at the same potential. Now then, the positive terminal of cell 4 is 1.5 volts positive compared with the negative terminal of this cell. And, the positive terminal of cell 3 is 1.5 volts positive compared with its negative terminal, and also compared with the positive terminal of cell 4, due to the connecting wire. Thus, there is a total difference of potential of $1.5+1.5=3$ volts between the negative terminal of cell 4 and the positive terminal of cell 3.

Compare the positive terminal of cell 1 with the negative terminal of cell 4, we begin at the latter point and trace through cells 4, 3, 2, and 1 to the positive terminal of cell 1. As we have passed through all four cells, the total difference of potential between the compared terminals is equal to $4\times1.5=6$ volts. Each time we passed through a cell, we went from a point of one potential to a point 1.5 volts more positive. Therefore, the positive terminal of cell 1 is $1.5+1.5+1.5+1.5=6$ volts positive when compared with the cell 4 negative terminal.

Figure 9B is a schematic diagram of the pictorial diagram in Figure 9A except that R_1 is added. The advantage of four cells in series over the same four in parallel is that a higher voltage is supplied to R_1. A disadvantage is that each cell must supply the total current, while in a parallel circuit, each cell supplies only a part of the total.

Thus, in Figure 9B with all the cells at 1.5 volts and each cell providing .2 ampere, the resistance R_1 is found by using the following form of Ohm's Law:

$$R_1=\frac{E_T}{I},$$

where E_T is 4×1.5 volts or 6 volts, and I is .2 amperes.

Therefore, substituting these values in the above equation, we find:

$$R_1=\frac{6\text{ V}}{.2\text{ A}}=30\Omega.$$

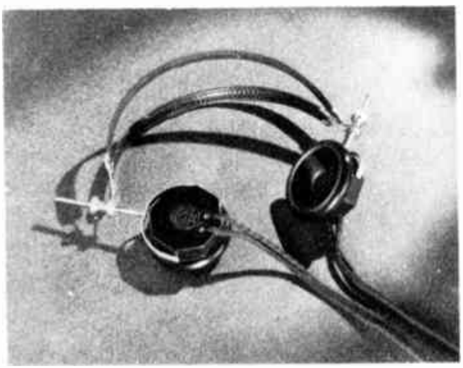
WHEN ELECTRIC CELLS ARE CONNECTED IN SERIES TO FORM A BATTERY THE VOLTAGE IS EQUAL TO THE SUM OF THE VOLTAGES OF THE SEPARATE CELLS, ALTHOUGH THE CURRENT IS THE SAME AS FOR ONE CELL.

To summarize: for a parallel connected battery of Figure 7, the battery voltage is equal to the voltage of one cell, but the battery current is equal to the sum of the several cell currents. For a series connected battery of Figure 9, the battery voltage is equal to the sum of the cell voltages, while the battery current is equal to the current from one cell.

BATTERY CAPACITY

In the explanations concerning parallel and series connections, the word "capacity" was employed to indicate the rate of water flow in a water pump. Although commonly used in this way with respect to water pumps, ordinarily the term capacity has a different meaning when applied to electric cells and batteries. For the latter application, the CAPACITY RATING of a cell or battery refers to the total quantity of electricity which the device can supply.

The unit employed in the capacity rating is the **ampere-hour**, defined as the quantity of electricity equal to a current of one ampere



Two headphones, referred to as a headset, equipped with headband. Use the screws to adjust headset for proper fit. Also note thread tracer indicating positive leads.
Courtesy Brush Development Co.

for a period of one hour. Ampere-hours are calculated by multiplying the current in amperes by the time in hours. Thus, when a battery is rated at 100 ampere-hours, it can supply a current of 10 amperes for 10 hours or a current of 1 ampere for 100 hours.

However, while this 100 ampere-hour battery may be able to supply a current of 10 amperes for a period of 10 hours, this does not mean necessarily that it can furnish 100 amperes for 1 hour. In general, the greater the current the less the capacity, for at a high discharge rate, the electrolyte does not penetrate the active material on the plates rapidly enough, and hence the capacity is reduced.

For example, when discharged at a 6-ampere rate, a 120 ampere-hour car battery like the one shown in Figure 5 can operate for 20 hours, and hence it has a capacity of 6×20 or 120 ampere-hours. But if the discharge current is increased to 150 amperes, the battery will be run down in about 20 minutes (1/3 hour), and so the capacity is reduced to $150 \times 1/3$ or 50 ampere-hours.

APPLICATIONS OF INDUCTION

A few lessons back, a door bell was used to illustrate a basic action of electromagnets. Since this same basic action is used in many energy converters to produce motion let's recall some of the important features.

Each of the parts are labeled in Figure 10A. The electromagnet is a coil of wire wound on a cylindrical iron core which is riveted to the center of a "U" shaped iron frame. The armature extends across the open end of the "U" and is held in position by the spring riveted to both the armature and frame.

The upper end of the spring is bent away from the armature, and a stationary contact is mounted in line with a second movable contact, but electrically insulated from it. The spring tension pulls the armature away from the frame to hold the contacts together as shown in Figure 10A.

Suppose an alternating current were applied to the electromagnet through the two binding posts. The current passing through the coil makes the magnetic field of the cylindrical iron bar so strong that it overcomes the spring holding the armature contact closed.

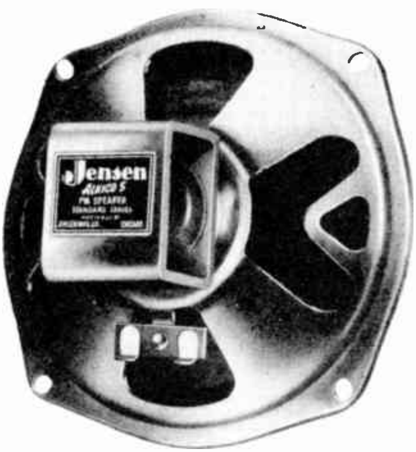
When this happens the contact opens as the armature swings to the right, its hammer striking the gong. As soon as the movable contact is opened, the circuit is broken, the magnetic field collapses, and the spring returns the armature and movable contact to the original position. The instant the contacts touch, the circuit is completed providing you are still pushing the doorbell button. At this instant, electrons flow and the entire action is repeated.

Use of alternating current in most doorbell circuits makes it possible to use a step down transformer from the 117 v.a.c. power line to provide the low voltage needed. However, this is not the only advantage of alternating current. Figure 10B shows a much simpler device called a "buzzer" which works only on alternating currents. Its structure is like Figure 10A except that there is no gong, hammer, or contacts, and the armature is short. Since the armature is short, it moves much more quickly than the long heavy armature and hammer for the bell in Figure 10A. Also, in this particular example the iron core is replaced by a permanent magnet. Although the buzzer operates just as well without the magnet, the magnet model produces the operation we desire.

Now the coil is connected directly to the binding posts and so the current passes through the coil regardless of the armature position. When the switch is closed, one alternation of the current produces a magnetic field in the same direction as the permanent magnet field. This combined attraction overcomes the spring and draws the armature over until it strikes the "U" frame. However, on the next alternation the coil field opposes the magnet. Therefore, they cancel out until the spring overcomes the magnetic attraction and snaps the armature back to the position shown. This action is repeated for successive cycles of the alternating current and the armature striking the "U" frame at such a rapid rate makes the buzzing sound which gives the device its name.

HEADPHONES

Of course, bells and buzzers are not used in very many radio receivers. However, both of them are found in the home and demonstrate the basic action of many



One of the numerous types of PM speakers.
Courtesy Jensen Mfg. Co.

energy converters. For example, the **headphone** used in telephones, hearing aids, and many radios used in communications operates on the same basic principle as the buzzer of Figure 10B.

To explain the action, Figure 11 shows a cross-section of one type of headphone mounted inside a protective case ordinarily made of a hard plastic material. A "U" shaped pole piece is fitted into the case. Held in the center of this pole piece, a small magnet is surrounded by a bobbin of wire or coil forming an electromagnet. A screw on cap holds the circular, thin, metal disc called the **diaphragm** in position just above the magnet and the ends of the pole piece. Since this diaphragm rests on the outer case, there is a small air gap between it and the permanent magnet.

The magnetism of the permanent magnet attracts the diaphragm and holds it under tension. By electromagnetic action, current in the coil sets up a field in addition to that produced by the permanent magnet (PM). Since the polarity of the electromagnetic field depends upon the direction of current through the coil, in one current direction it aids the PM field and in the other direction it opposes this field. When both fields are aiding, the attraction is increased, the diaphragm is pulled closer. In the other direction, the current produces an opposing field, therefore the magnetic attraction is weakened and the diaphragm moves away.

As a result WHEN ALTERNATING CURRENT PASSES THROUGH THE ELECTROMAGNET, THE DIAPHRAGM VIBRATES AND THE VIBRATION CORRESPONDS WITH THE CURRENT. For high frequency alternating currents the diaphragm moves to and fro rapidly and for low frequency currents the motion is slow.

Sound is a vibration of the air. As it strikes our eardrums it causes them to vibrate in a like manner and this vibration is carried back to the nervous system by means of small bones. In fact, everything that produces a sound vibrates. It is the vibration of the vocal chords that produce the voice sounds, a vibrating string is used for violin music, and the hammer striking the gong on a bell produces the ringing sound. These vibrations cause the surrounding air to vibrate and the ear detects these vibrations as the sound.

In the same manner the vibrating diaphragm produces sounds in Figure 11. The higher the frequency of the alternating current the faster the diaphragm vibrates, and the higher the pitch of the sound produced. Also the larger the current, the further the diaphragm vibrates, and the louder is the sound produced. Thus, the sounds heard from the headphone are completely controlled by the amplitude and frequency of the current going through the coil of wire.

Without the aid of the permanent field the diaphragm would normally be released and each alternation of the current would produce a field that would pull the diaphragm in. As a consequence, the diaphragm would be pulled and relaxed twice for each cycle. Hence, the diaphragm would convert the current frequency into twice the mechanical vibration and this in turn would double the frequency of the sound. Therefore, the sounds would sound high and unnatural.

Connected as an output element in a circuit, the headphone coil carries all the current. If there is a direct current component, the field set up by the direct current must aid that of the permanent magnet. Otherwise this field will reduce or cancel the PM field causing the double frequency sound mentioned above. To assure the proper current direction, one wire of most headphone cords has a colored thread tracer in the insulation to indicate that it should connect to the positive terminal. The other wire connects to the negative terminal, which usually is ground.

In order to generate the required magnetic field to move the diaphragm, the headphone coil consists of many turns of wire of small diameter. All coils do not have the same d-c resistance; one common type is about 1,000 ohms. Depending upon the current output for a circuit, different resistances of headphones are required. For instance, if the d-c resistance of the headphone is too high, the current passing through the coil is too small and hence the sound is weak. On the other hand, if the resistance is too small, then the coil may heat sufficiently to be damaged. In your laboratory projects, the circuits and headphones used are adapted to each other to prevent either of these occurrences.

Not all headphones have the same mechanical structure as Figure 11, some use two coils as shown in Figure 12.

In this case the permanent magnet is a flat "C" shaped ring which is mounted on the bottom of the case. The core and pole pieces are formed as one part and are "L" shaped as seen from this side view. This pole concentrates the magnetic field and passes it through the core of each electromagnet. The electromagnet action is the same as before for each coil. Both are connected in series and only two leads, one with a color tracer, comes out of the case.

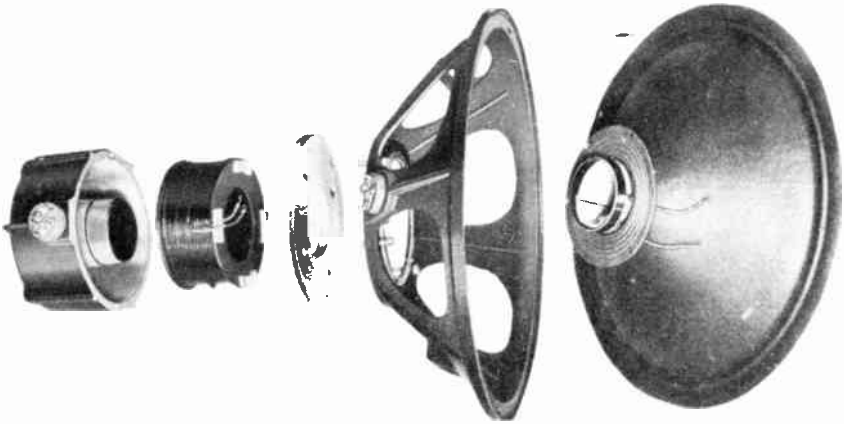
However, in spite of these mechanical variations, the headphone in Figure 12 has the same basic action as Figure 11. Normally the permanent magnet holds the diaphragm under a steady tension. When the current is in one direction through the coils their fields add to the permanent magnet field and the overall attraction is increased. When the current is reversed the field from the electromagnets oppose the permanent magnet. As a result, the attraction is weakened and the diaphragm is relaxed.

Headphones are well suited for giving privacy to the wearer. However, the amount of sound produced by the headphone is quite limited. This limitation is due to the fact that too much diaphragm vibration causes it to chatter against the pole pieces. Moreover, if the gap between the diaphragm and pole pieces was increased, the attraction would be weakened and a very large current would be needed then to vibrate the diaphragm. Finally, for such large gaps the sound would be distorted since the attraction would vary appreciably with the diaphragm position as it vibrates to and fro.

LOUDSPEAKERS

To avoid these difficulties where sufficient sound must be produced for a whole room or auditorium, a somewhat different structure is needed called a **loudspeaker.** Loudspeakers are used to produce sounds in radios, phonographs, television receivers, at movie theatres and wherever public address or intercom systems are needed.

Like the headphones, loudspeakers convert electric energy into mechanical vibration to produce sound. There are a number of types which do this, the differences being determined by the particular application. Figures 13A and 13B are the back and side views of a loudspeaker using a permanent magnet while Figure 13C shows one using a large electromagnet to perform the same function. To identify each, the one in Figure 13A is popularly the pot and the frame or basket. Around this pole piece but not touching either the pole piece, or the pot is a hollow cardboard tube with a coil of wire on it. This is called the **voice coil** and plays the same role that the bobbin of wire does for the headphone.



Exploded view of an EM speaker showing its main parts.
Courtesy Jensen Mfg. Co.

called a PM speaker while Figure 13C is referred to as an EM speaker.

In general, every PM speaker is constructed about the same. In Figure 13B, the side view shows up almost all of the parts. The magnet is cylindrical in shape with a soft iron wafer in front of it. Both units are friction fitted inside of a large rectangular piece of soft iron labeled the pot. Thus, the magnetic path from the slug magnet is completely enclosed.

Part of the pole piece extends through a hole in the junction of

Centered by very flexible fibre or thin metal washers called a **spider**, the voice coil is cemented to the speaker **cone.** The cone is cemented by its rim to the frame and held tight all around by a cardboard ring. The voice coil terminals are brought out to insulated terminals mounted on the frame. Connecting wires are soldered to these voice coil terminals easily, but it is never done beyond these terminals since this may impair proper speaker operation.

EM speakers in general have the same features. In Figure 13C, this cross-section view illustrates some of the same parts. Ring clamp, cone, basket, spider suspension, voice coil, frame and, pole piece are in about the same location. Instead of a permanent magnet, large numbers of turns are wound about the pole piece and a direct current is passed through the coil to set up a strong magnetic field. For this reason it is called the **field coil.** Frequently the leads are color coded to indicate the proper connections. In this manner, the high voltage is applied to the outside end of the coil instead of the inside where it might break down the insulation between the coil and loudspeaker frame.

When the current is passing through the voice coil in one direction it produces a magnetic field of opposite polarity to the permanent magnet, and since unlike poles attract the coil is attracted by the magnet. When the current is reversed, the polarity of its field is reversed and so the coil is repelled away from the magnet. The large cone is attached to the coil, and so these coil vibrations produce cone vibrations. Since the cone pushes a large amount of the air back and forth loud sounds are produced. Moreover, since the coil is free to move quite a distance each way, considerable amounts of sound can be produced without causing a chatter.

Loudspeaker Cone

Practically all speakers radiating sound directly into the air use a cone shaped diaphragm made of paper. These usually are produced by means of a system called felting; in which a mixture of pulp and paper is drawn through a master screen having the desired diaphragm shape. After drying, the cone is removed from this screen. Although in certain applications, it is possible to obtain a greater diaphragm area by making them oval, for most purposes this circular cone is preferred.

Many cones are made of special types of paper. Where maximum efficiency in getting the most sound out is desired, a very rigid paper is best while softer, flexible papers result in high quality reproduction. Sometimes to compromise these two points, corrugations are introduced at the proper intervals on a soft cone.

Three types illustrating some of these features are in Figure 14. That of Figure 14A has a simple cone shape, while that of Figure 14B is more flared and consequently more rigid. Figure 14C is a flexible, corrugated cone so popular in radio and television PM speakers. Contrary to popular belief just because the cone has a larger diameter it is not better than that having a smaller diameter. The material used, the shape, and the suspension of the cone all play an important role.

Since these cones are very soft, considerable care must be taken in handling them. The fingers or any similar object very easily punctures the cone and these holes may cause inferior sound reproductions or undesired noises.

Cone Suspensions

One method of suspending the outer rim speaker cone has been described in Figure 13. Used in these same types of speakers to suspend the cone at its inner edge is the spider or corrugated disc of Figure 15 either of which centers the voice coil properly. Note the cut-outs which look like the legs of a real spider in Figure 15A. The center of the spider has a hole through which a screw is passed to fasten it to the pole piece.

This system, though simple and inexpensive, does not allow the cone to move as freely at all frequencies. Therefore, there is a slightly distorted sound emitted. Figure 16A shows another type of suspension using a corrugated felted paper on the outside of the cone near the voice coil. This system allows better movement and results in a better sound quality.

Speaker Field Magnets

Speakers employing an EM are sometimes called ELECTRODYNAMIC or DYNAMIC speakers. The strength of its field depends upon the same factors as that of any electromagnet such as the number of turns, the current, the permeability of the core, and so on.

For any electrodynamic speaker, the needed strength of the magnetic field is approximately equal to the power required to be handled by the voice coil. If this power is known, and the d-c resistance of field coil is measured, then the field-coil current and voltage to be applied is calculated from the following equation:

$$P = \frac{E^2}{R}$$

For convenience, the above can be rearranged as:

$$PR = E^2$$

Suppose the power required is 4 watts and the measured field coil resistance is 2,500Ω. Substituting in the above equation:

$$4(2{,}500) = E^2$$

$$10{,}000 = E^2$$

$$100\text{ v} = E$$

Thus, the voltage applied across the field coil must be 100 v. The current through it must be the voltage divided by the resistance:

$$\frac{100\text{ v}}{2{,}500\Omega} = .04\text{ amps.}$$

This power may be obtained from a separate power source or since the coil has inductance as well as resistance, it is often used as part of a power supply pi-filter acting as a filter choke at the same

This microphone is mechanically a miniature speaker.
Courtesy Altec-Lansing

time. When used to smooth out the a-c present from a rectifier, often enough ripple voltage is induced in the voice coil causing it to vibrate at the power frequency and produce a hum. To eliminate this hum, another coil is mounted at the end of the field coil next to the voice coil and connected in series with it. It is arranged so that the hum in it opposes the hum in the voice coil and so it is called a "hum bucking" coil.

In early radios, EM speakers were used almost exclusively since PM were not available to give the same field strength. However, with the new magnets made of aluminum, nickel, and cobalt, called alnico magnets this disadvantage has been largely overcome.

Detailed drawings in Figures 16A and 16B show two popular field structures. In the top view of a speaker in Figure 16A, a large ring shaped magnet provides a strong magnetic field. Its path is closed by the flat disc and center pole piece. Lower strength magnets as used in ordinary table model radio receivers have slug magnets as in Figure 16B. This is similar to the type shown in the side view of Figure 13B and there are numerous variations depending upon the manufacturer. The pot may be closed as shown, or it may be open. The less expensive have open pots.

In servicing either type of speaker keep in mind the function of each part. Especially, take care not to stretch or deform in any way the speaker cone. When the cone is damaged, the sound is weak and distorted. Small tears may be repaired with speaker cement as it remains pliable when dry; other cements or glues harden and ruin the cone.

Another trouble common to both types is a badly centered voice coil. Any loud sounds are badly distorted in comparison to low volume sound. Usually it's not advisable to repair these unless you have the same set-up the manufacturer has.

Open voice coils are a rare trouble and just as difficult to repair. In either case, cheap loudspeakers must be replaced and the expensive models returned to the manufacturer for repairs. He has the necessary equipment to do the job right.

BAFFLES

Speaker performance and hence the sound quality is greatly dependent upon the air that is directly about it. The cone not only pushes away the air mass in front, but pulls the air mass in behind. If the pushed or compressed air in front combines with this thinner or rarefield air in back, they mix and cancel. This effect is quite noticeable at the low audio frequencies.

Sound travels about 1,129 ft. per second in air. Therefore, it takes a very small fraction of a second for sound to go from front to rear of the speaker. The only frequencies at which cancellation is not serious are those high enough that the cone has reversed direction before the sound travels from one side to the other. Then the compressed air from the front aids the air now being pushed by the cone at the back and no cancellation occurs.

Generally, cancellation is reduced by the use of some type of a partition or panel called a **baffle** in which the speaker is mounted to increase the length of the path between the front and back of the cone. Thus with a baffle it takes longer for the sound to reach from front to rear. As a result, much lower frequencies can be produced by the speaker before the cancellation becomes noticeable.

Figure 17 shows how a speaker is mounted in the center of a square baffle. Without a baffle, as when the speaker is removed from its cabinet for servicing or when using the speaker in your lab projects you may note that its full tone has disappeared. Taking a baffle board about 1 foot square, with a hole in the center that the speaker fits over, and mounting the speaker on it restores almost all of the full tone. Actually, the low frequencies cannot cancel out and so more of that sound is heard. Going to a 2 foot square baffle improves the sound more and still lower frequencies are heard. Going to a 3 foot square baffle improves it still further, however, the most noticeable difference probably ocurs for the first situation. Radio cabinets perform the same function as a flat baffle. They increase the sound path from front to rear.

MICROPHONES

So far, in this lesson all the applications of the induction principle have dealt with the conversion of electric energy into mechanical motion. Using the principle of induction, a **microphone** performs the reverse process: converting mechanical motion of sound into electric energy. This meets our earlier definition of an alternating current generator; actuated by a mechanical motion or movement due to sound, a microphone can be said to convert mechanical motion into electric energy, and therefore, it is an a-c generator. Thus, the microphone plays the opposite role to that of a loudspeaker. Since the action that takes place in a microphone is just reverse to a speaker, this makes it possible to use a speaker as a microphone. All of the speakers described in the lesson may be used as microphones though in actual practice only the smaller PM speakers like Figure 13B are so used. These are especially suitable for inter-communications systems in the office, home, or factory.

When sitting in a quiet room you can feel the vibrations produced by your voice if you speak loudly into a book or magazine held close to your face. The same thing happens in a microphone. The voice produces sound waves which vibrate the microphone cone or diaphragm.

For example in Figure 13B, as the sound moves the cone back and forth the attached coil moves with it. Since it is in the magnetic field of the permanent magnet, the moving coil has a voltage induced in it whose voltage and polarity are determined by the speed and direction of the coil motion.

Figure 18A shows an inset of the voice coil of Figure 13B. This is a side view after a cross-section has been sliced away. Figure 18B shows part of one turn of the voice coil and magnetic field passing out from the pole piece assuming the N pole is at that end.

When the wire moves in the direction of the arrow toward the pole piece, it cuts the magnetic lines. Extending the fingers in the direction of the field and the palm turned so that the wire moves into it, the thumb points in the direction of the current which is into the paper or away from the reader. When the voice coil moves away from the pole piece, the current reverses. Thus, as the cone vibrates, an alternating voltage is generated at the voice coil.

The headphones of Figures 11 and 12 also can be used as microphones. For example in Figure 11, when the diaphragm is close to the magnet and pole pieces, the reluctance of the magnetic path is low and a large number of flux lines pass through the coil. However, when the diaphragm moves away, a large air gap in the magnetic path increases the reluctance and reduces the flux lines. As a result, when the diaphragm vibrates, the moving flux lines induce a voltage in the coil.

In any case, the voltage developed by a microphone is very small and there isn't enough power to do much of anything directly with it. For example, the power produced by the microphone might have to be increased 1,000 times in order to drive a loudspeaker to its full capacity.

Were it not for the ability of electron tubes to produce this power increase, input devices such as these microphones and loudspeakers would have a very limited value. In fact, the ability of electron tubes to "amplify" or increase signals has been the key to the great expansion and growth of electronics. Paving the way for radio, television, giant brain computers, electronic control, instrumentation, and so many devices too numerous to list, the electron tube still remains the key component to their success. Therefore, just how the electron tube amplifies a signal is important for you to know. This action is described in the next lesson.

IMPORTANT DEFINITIONS

AMPERE HOUR—[AM pier our]—The unit of measure of the capacity of a cell or battery; equal to a current of one ampere for a period of one hour.

BAFFLE—A flat partition used with loudspeakers to improve the quality of the sound by changing its path.

BATTERY—[BAT er i]—A combination of two or more cells connected to have desired voltage and current characteristics. Common usage also applies this term to a single cell used independently in an electric or electron circuit.

CONE—In a loudspeaker the vibrating part causing sound; normally made of soft paper in the shape of a circular cone.

CELL—[sel]—A single chemical unit which converts other energy into electric energy.

DIAPHRAGM—In a headphone, the flat disc caused to move or vibrate due to electromagnetic action.

ELECTRODE—[i LEK trohd]—In electric cells: one of the strips, rods, or plates of metal or other material at which chemical action produces either a surplus or a deficiency of electrons.

FIELD COIL—In an EM speaker, the coil providing the magnetic field produced by a permanent magnet in a PM speaker.

HEADPHONE—[HED fohn]—An electric to sound converter used primarily for individual listening.

LOUDSPEAKER—A device which converts electric energy into sound energy.

MICROPHONE—[MY kro fohn]—A device which converts sound energy into electric energy.

PRIMARY CELL—[PRIGH muh ri sel]—An electric cell in which the chemical action is not reversible, to generate electric energy one or both electrodes are consumed.

IMPORTANT DEFINITIONS—(Continued)

SECONDARY CELL—[SEK un dar i sel]—An electric cell in which the chemical action is reversible. After being discharged, it may be recharged by an electric current passed through it in the direction opposite that of the discharging current.

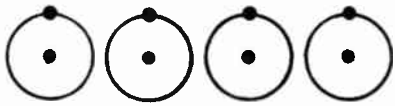
SPIDER—In a loudspeaker, a circular disc centering the voice coil about its magnet.

VOICE COIL—In a microphone or loudspeaker, wound near the magnet the coil of wire which converts either sound or voice vibration into a voltage or a voltage into sound.

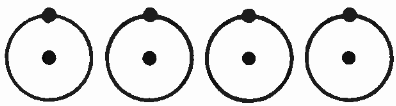
WORK DIAGRAMS

When you have completed these work diagrams, check your work with the solutions on the back of the foldout page.

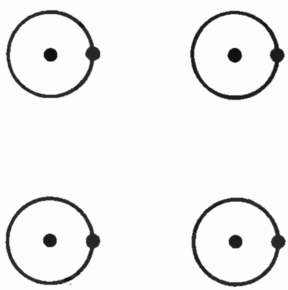
1. Draw the lines necessary to connect the terminals of the four cells so that the cells are in parallel. Indicate the polarity of each cell terminal, and of the battery terminals.



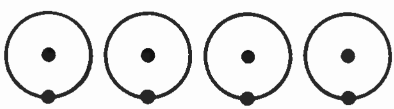
2. Draw lines connecting the four cells in series. As before, indicate cell and battery terminal polarities.



3. Connect the four cells so that the battery thus formed has terminal voltage and current capacity equal to twice that of a single cell. Indicate terminal polarities.



4. Connect the terminals of the four cells to form a battery such that one terminal is $+4.5$ volts and another is -1.5 volts with respect to a third terminal employed as a reference point. Indicate the potentials of the three battery terminals.



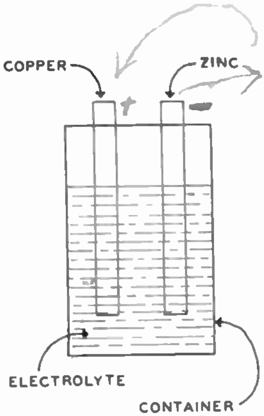


FIGURE 1

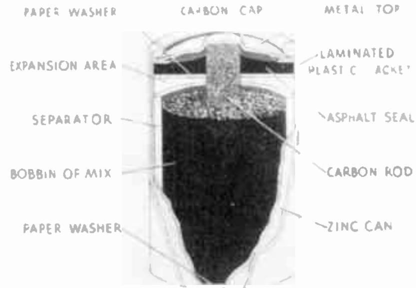


FIGURE 2

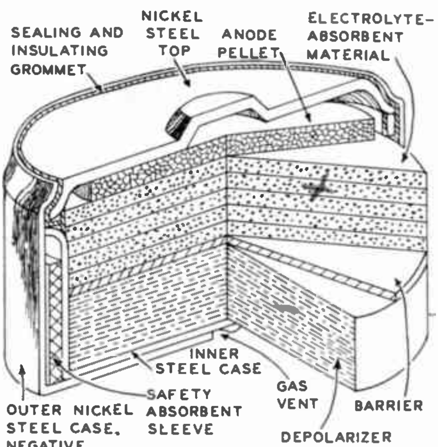


FIGURE 3

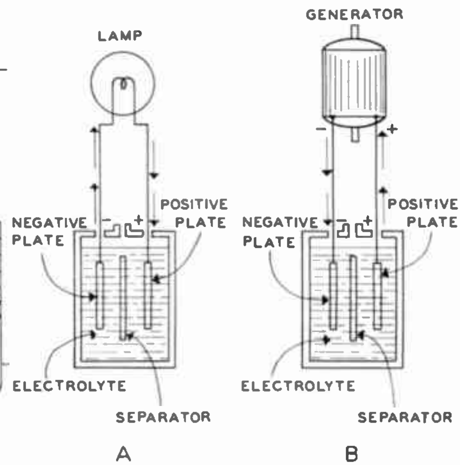


FIGURE 4

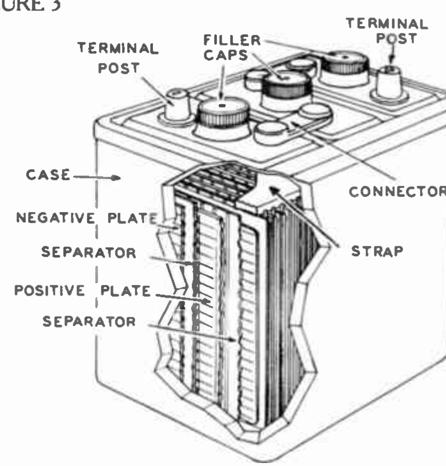


FIGURE 5

PARALLEL

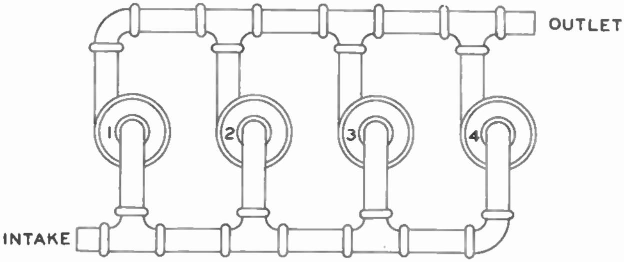
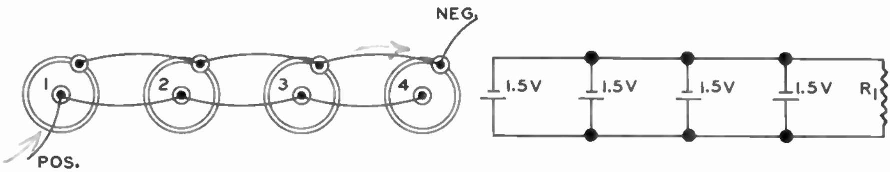


FIGURE 6



A

B

FIGURE 7

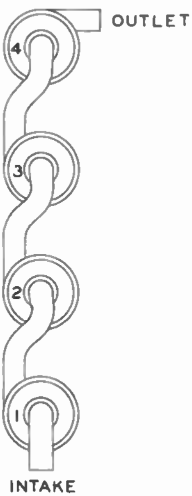
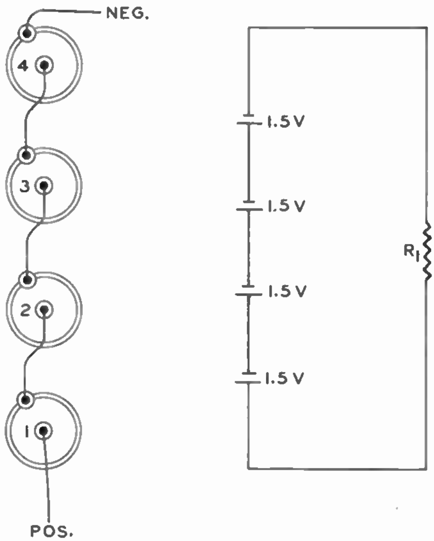


FIGURE 8



A

B

FIGURE 9

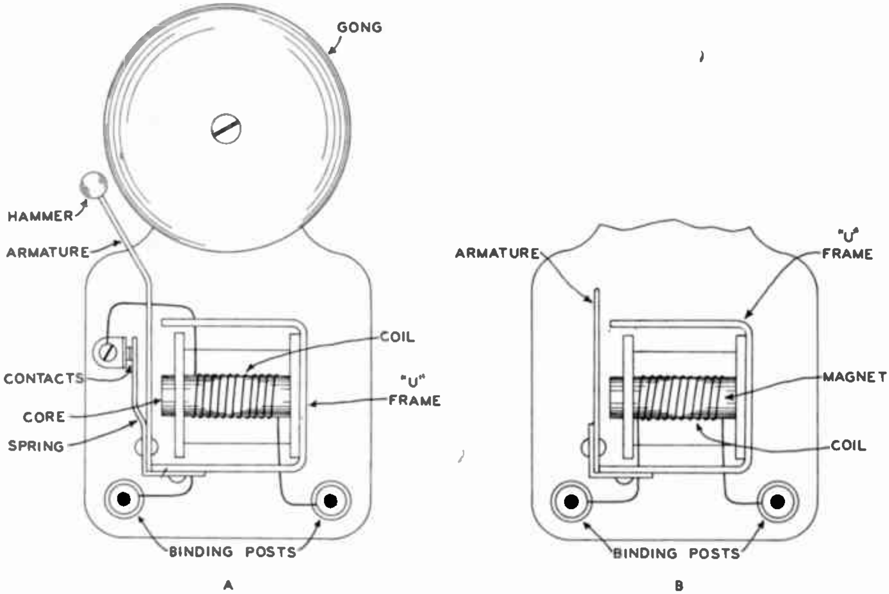


FIGURE 10

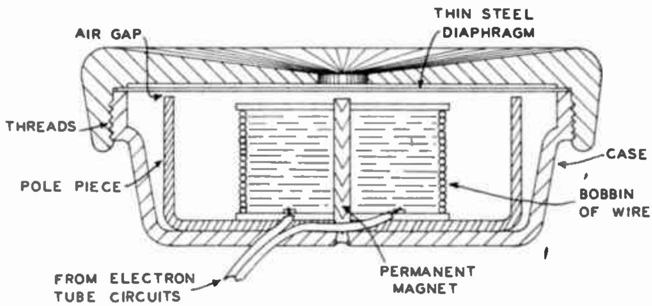


FIGURE 11

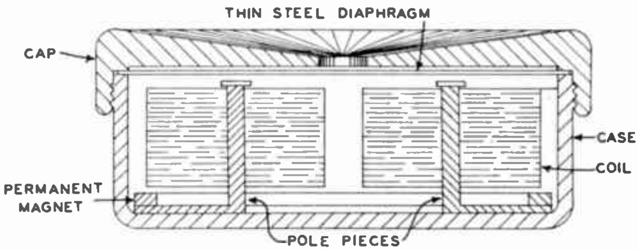


FIGURE 12

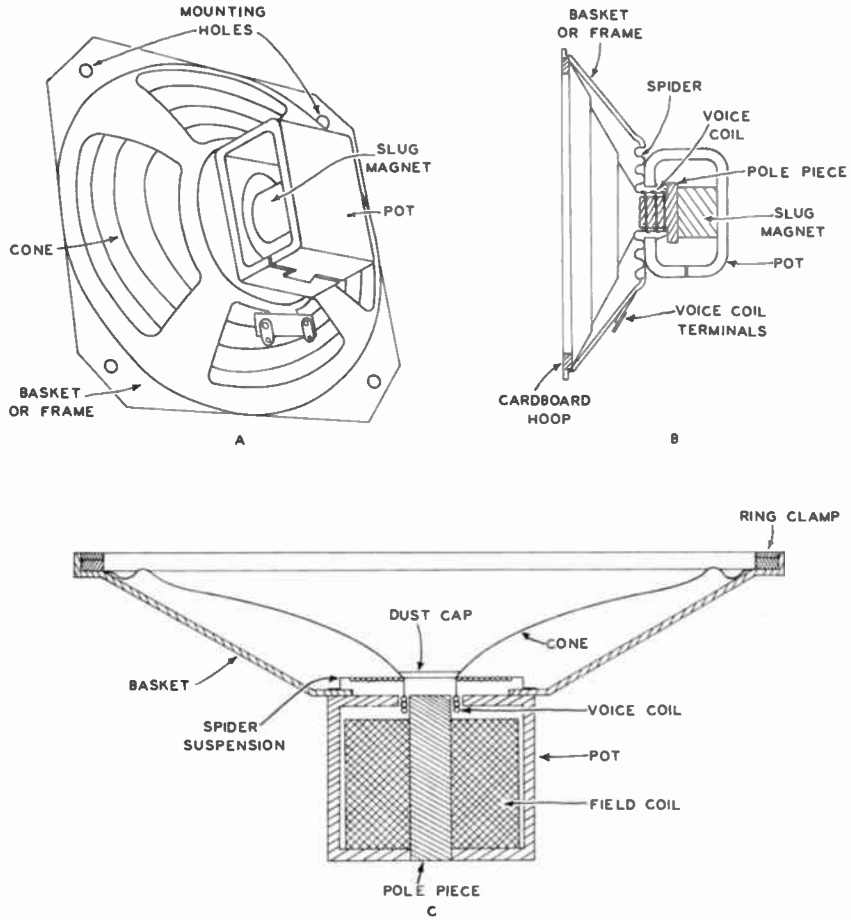
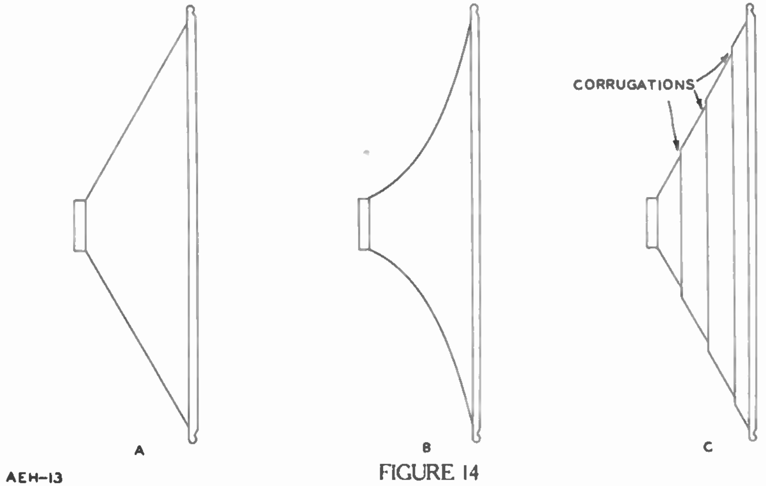


FIGURE 13



AEH-13

FIGURE 14

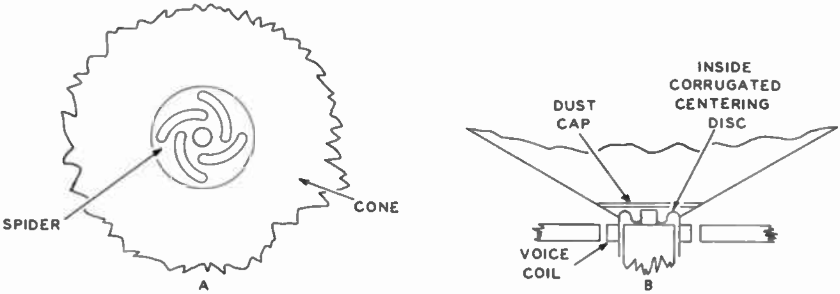


FIGURE 15

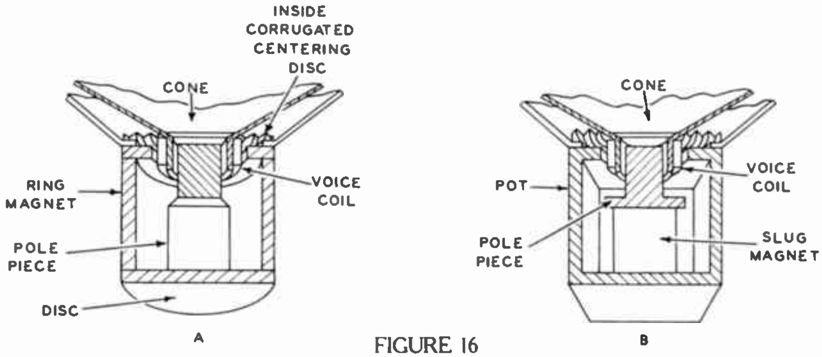


FIGURE 16

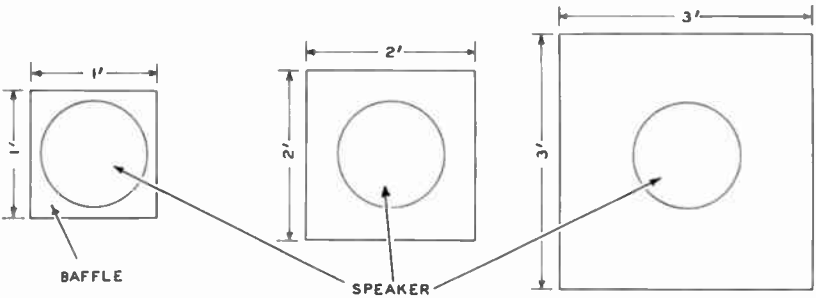


FIGURE 17

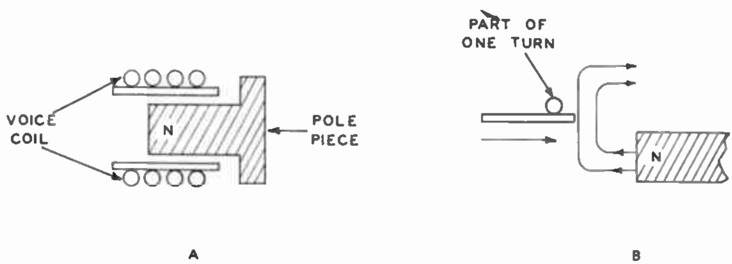


FIGURE 18

FROM OUR *Director's* NOTEBOOK

OBSERVING THESE RULES WILL HELP A WORKING DAY

Never show your temper.
Indulge in no sarcasms.
Permit other people to have views.
Never contradict an irritated person.

Keep unpleasant opinions to yourself.
Be considerate of the rights and feelings of others.
Always use pleasant words.
Take time to be polite.
Never order people about.

Be gracious and accommodating.
Always grant a reasonable favor.
Don't try to fool your caller, he may be a smart man.

and make sure your way is best before insisting upon it

Yours for success,

W. C. DeVry

DIRECTOR

PRINTED IN U.S.A.

AE

THREE ELECTRODE TUBES

Lesson AEH-14A

DeVRY Technical Institute
4141 W. Belmont Ave., Chicago 41, Illinois
Formerly DeFOREST'S TRAINING, INC.

THREE ELECTRODE TUBES

4141 Belmont Ave.

Chicago 41, Illinois

DeVRY Technical Institute

ELECTRONS CONTROL MOTORS

Often it is desirable in industry to operate heavy equipment in tandem. For instance the paper may need to pass through two presses or the sheet metal must go through two rolling mills. To accomplish this feat, the machines must have identical feed speeds or the material will break, stretch, or tangle while passing from one to the other. To obtain these identical speeds, electronic motor controls are employed.

In fact, to start large motors manually, requires skill. To avoid risk of serious damage to the motor and expensive delays in production, it is now customary to employ electronic controls to start, stop, reverse, or maintain the speed or torque of the motors automatically as predetermined by the operator.

Fundamentals

THREE ELECTRODE TUBES

Contents

Things don't turn up in this world until somebody turns them up.

—Garfield

THREE ELECTRODE TUBES

In addition to the basic circuit properties of resistance, inductance, and capacitance; several explanations of the earlier lessons have mentioned the importance of electron tubes. In fact, the present development of radio, television, and communications; and the rapidly increasing applications of electronics are due mainly to the many duties these tubes can perform.

With no mechanically moving parts, they act as switches of almost unlimited speed, as rectifiers to allow current in one direction only, as generators of alternating current from low to ultra high frequencies, as amplifiers to increase the magnitude of a-c voltages or current, and as detectors to indicate and measure minute quantities of electric energy.

By itself, the electron tube has only a few applications but when combined with the other components, such as resistors, capacitors, and inductors, its internal actions permit many more applications than the few just mentioned. Furthermore, with the proper external connections, electron tubes can be made to act as resistors, inductors, or capacitors that vary as desired with the changing electric conditions in their circuits. This action alone forms the basis for countless automatic electron controls.

To serve these many purposes, electron tubes are made in a wide variety of sizes and types. However, all tubes consist of two or more conductive elements or electrodes enclosed in an evacuated glass or metal envelope. The simplest form of tube, the diode, was explained in an earlier lesson as a rectifier. As its action is basic, a drawing from this earlier lesson is reproduced here as Figure 1.

The plate current of the diode tube is controlled by the number of electrons emitted from the emitter and the magnitude of the plate voltage. Starting with the conditions of Figure 1A, the emitter is heated to its normal operating temperature by voltage source E_f. Without an external connection, the plate voltage is zero, and with no attraction by the plate, the emitted electrons form the space charge around the emitter. Under these conditions, the plate current is zero.

In Figure 1B, the plate is connected to the sliding contact of the variable resistor R_1, one end of which is connected to the positive terminal of the plate supply battery E_{bb}. The E_{bb} negative terminal connects to the emitter. Each position of the R_1 sliding

These are but a few of the large number of tubes having various sizes and shapes that are used in electron equipment. In fact, all of the tubes shown here are used in one television receiver.

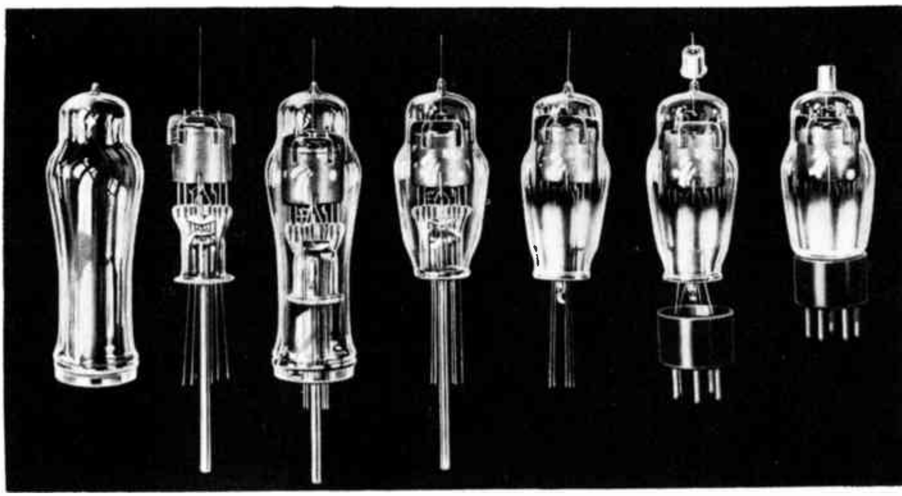
Courtesy Hytron Radio and Electronics Corp.

contact varies the resistance in series between the plate and the positive terminal of E_{bb}. Carried by resistor R_1, the plate current causes voltage across it. Therefore, the plate voltage can be varied by moving the sliding contact of R_1.

With the sliding contact at the open end of resistor R_1, maximum resistance is in the circuit, and the plate is just slightly positive with respect to the emitter and only a few electrons are drawn from the space charge.

As the slider is moved closer to the connected end of resistor R_1, less resistance is in the circuit and the voltage across the resistor is reduced. With less voltage across R_1, the plate becomes more positive, a corresponding larger number of electrons are drawn from the space charge, and so the plate circuit current increases.

For any given emitter temperature, the positive plate voltage can be increased, until the plate attracts all of the emitted electrons. Raising the plate voltage above this value does not increase the plate current. This maximum is called the SATURATION CURRENT, and the plate voltage necessary to produce it is called the SATURATION VOLTAGE.



Several steps are necessary in the assembly of an electron tube. Many tubes have the grid connection at the top. One reason for this is the large separation between plate and grid connections.

Courtesy Sylvania Electric Products Co.

In the circuit of Figure 1C, battery E_{bb} maintains the plate at a constant potential with respect to the emitter, but a variable resistor R_2 is placed in series with the emitter. As explained for R_1

Constituted appointed or made up, elect, enact, Establish

of Figure 1B, changing the position of the sliding contact varies the total resistance of R_2. With a constant voltage source E_f, these changes of circuit resistance change the emitter current. Since the heat varies directly with the current, the variable resistor controls the emitter temperature.

As the temperature is increased, more electrons are emitted and the density of the space charge increases so that more electrons are available for attraction to the plate. As a result, the plate current increases although the plate voltage remains constant. However, by continuing this action, a point is reached eventually, at which the repelling action of the space charge is so great that a further increase in temperature causes no increase in emitted electrons. Hence, for a given plate voltage, the emitter temperature above which the plate current does not increase is called the SATURATION TEMPERATURE.

Thus, by varying either the emitter temperature or the plate voltage it is possible to control the plate current. However, neither method provides any real advantages. The same control can be accomplished by a simple poteniometer without the use of the tube.

TRIODE CONSTRUCTION

In 1907, Dr. Lee De Forest placed a third electrode between the emitter or cathode and plate of the diode type tube. The additional electrode, now known as a grid, constituted one of the important steps in the development of the field of electronics, for by placing voltages on the grid, it

This loctal type tube is held securely in its socket by a locking arrangement of the center guide pin at the bottom of the tube.
Courtesy Sylvania Electric Products Co.

controls the flow of the electrons in the plate circuit. In fact, the flexibility of this arrangement is so great that its applications are proving limitless.

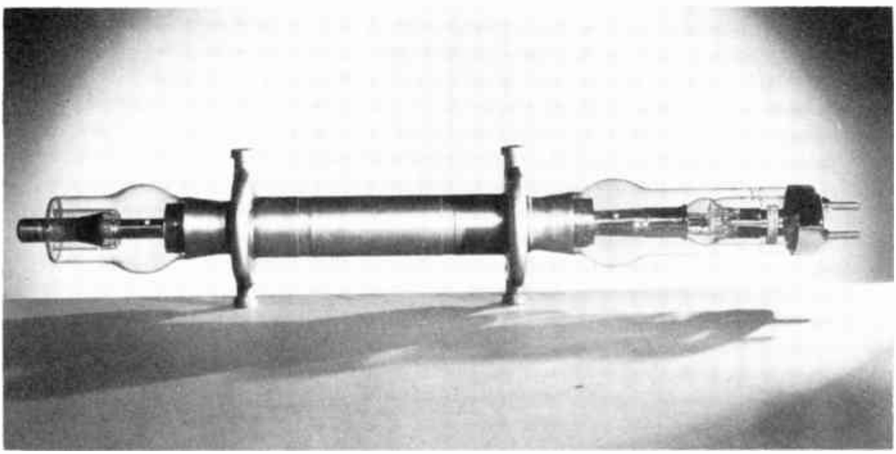
As pictured in Figure 2, usually the grid consists of a coil of wire held in position by two vertical supports. In most types, the wire is made of molybdenum, since this metal is a very poor emitter of electrons, and the space between turns is so large, compared to the diameter of the wire, that there is practically no physical obstruction to electrons passing through the grid coil.

A three-electrode tube of this general type is called a **triode**, using the prefix "tri" which means three. The emitter or cathode may be directly or indirectly heated and the plate usually is a cylinder, which is very similar in material and construction to that used for a diode.

In Figure 3A, the plate is cut away to show the arrangement of the elements in a directly heated emitter or filament type of triode which at one time was popular. Since the grid surrounds the filament and the plate surrounds the grid, all electrons flowing from the filament to the plate pass between the turns of the grid coil.

Figure 3B illustrates a more modern triode tube with an indirectly heated emitter known as a cathode. To start the assembly, a number of support wires are embedded in a piece of glass called the press. All of these wires extend upward to serve as supports and some of them extend downward to provide connections for external circuits. The press is hollow to provide an exhaust tube with openings at both top and bottom.

The heater is mounted on the two central support wires, both



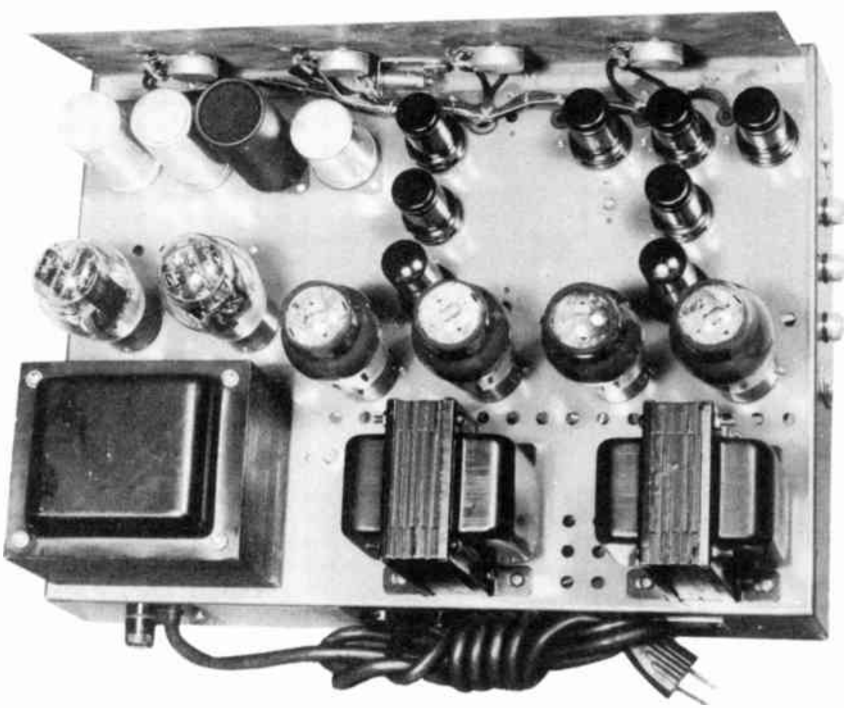
This triode is used in large broadcasting stations. Since it conducts heavy current, it is water cooled.

Courtesy Western Electric Co.

of which extend through the opposite end of the press. In the same way, the cathode and grid are mounted separately on supports which also extend through the opposite end of the press. The plate is mounted on the two outer supports only one of which extends through the press.

This assembly of mounted electrodes is placed inside the envelope, the lower end of which is fused with the lower end of the press. Thus, the electrodes are enclosed in an airtight space, and, by a vacuum pump attached to the lower or outer end of the exhaust tube, the air is removed from inside the envelope. When this process is complete, the outer end of the exhaust tube is sealed to maintain the vacuum.

For convenience of installation and replacement, a plastic base fitted with hollow metal pins is cemented to the lower end of the envelope. The wires, extending from the lower end of the press are threaded through the pins and soldered.



Top chassis view of an amplifier unit. Note the accessibility of the tubes for removal and replacement.

Courtesy Stromberg-Carlson Co.

The tube of Figure 3A has a four pin base, a bottom view of which is shown in Figure 3C. Two of the pins are of large diameter and, starting at the left larger pin, for identification they are numbered 1, 2, 3, and 4, in a clockwise rotation. The internal circuits for this tube and base are indicated by the symbol of Figure 3E where the numbers at the ends of the electrode are those of the base pins to which they connect.

A typical octal socket. Note the large hole in the center with a keyway. This permits a tube to be placed in the socket in one position only.

Courtesy Meissner Mfg. Div. Maguire Industries, Inc.

The circuit in which the tube is used includes a receptacle, called a socket, which has openings of the same size and spacing as the pins on the tube base. Insulated from each other, these openings are metallic and connected permanently to the circuit wires. Thus, when the tube base is inserted in the socket, the circuits are connected to the electrodes inside the envelope.

Although its construction is similar, the tube of Figure 3B is shown fitted with an eight pin or octal base, a bottom view of which is shown in Figure 3D. Here the pins are of equal size and spacing around a central post with a raised key. Starting to the left of the key, the pins are numbered from 1 to 8 in a clockwise direction. The schematic symbol of Figure 3F shows the pins to which the various electrodes are connected.

For this particular tube, pins 1, 4 and 6 are not used and may be omitted from the base. However, the positions of the remaining pins are not changed.

FUNCTION OF THE GRID

As explained for the diode of Figure 1, the flow of electrons from emitter to plate can be controlled to a certain extent by varying the plate voltage or the emitter-temperature. With the exception of the rectifying action, these control methods have very limited applications.

A grid like that of Figure 2, placed between the emitter and plate, provides a much more effective method of controlling plate current. All electrons attracted to the positive plate pass between the turns of the grid coil. However, since like electric charges repel, a negative voltage on the grid repels the negative electrons and tends to force them back toward the emitter. This repelling action varies with the negative grid voltage which therefore controls the number of electrons which reach the plate. Since these electrons constitute the plate current, it is controlled by the grid voltage.

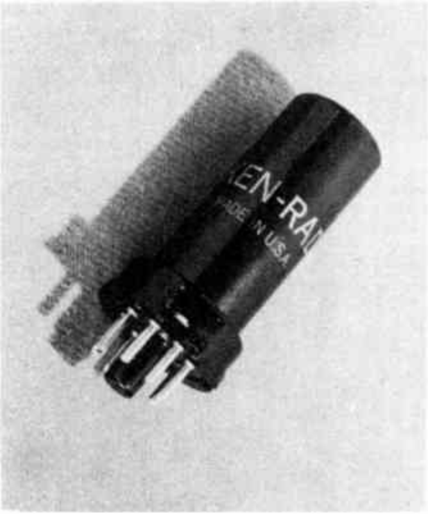
To illustrate this control action, in Figure 4 the grid is represented as a venetian blind while the emitter and plate are similar to those in Figure 1. For simplicity, the external circuit connections are omitted, but we will assume that the tube electrodes are connected to proper voltage sources to provide a heated emitter, a negative voltage on the grid, and a positive voltage on the plate.

Figure 4A illustrates the condition that exists for some intermediate negative grid voltage. In this case, the venetian blind grid is partly open so that some of the electrons are able to pass through the relatively narrow slits and continue to the plate, while others are blocked and "bounce" back.

In Figure 4B, the wide open venetian blind indicates the negative grid voltage has been reduced, and practically all of the electrons are able to pass through to the plate, until with zero grid voltage, the action is essentially the same as explained for the diode of Figure 1.

Although the action of the grid does not increase the number of emitted electrons, its negative voltage can be increased sufficiently to completely block them from the plate as pictured in Figure 4C. This condition is known as PLATE CURRENT CUTOFF.

Actually, the grid structure does not physically open and close like the venetian blind, but electrically its effect is the same. The varying force of repulsion which

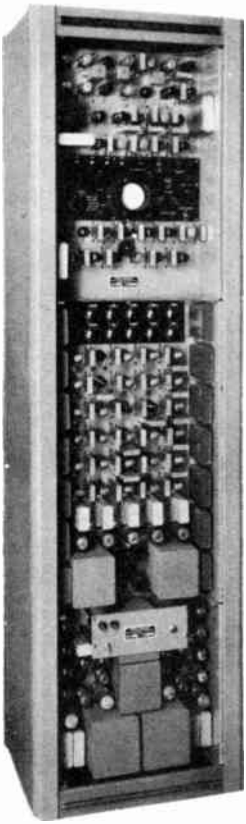


An octal tube has a center aligning pin so that the prongs will enter the proper socket openings.

Courtesy General Electric Co.

the changing negative grid voltage exerts on the negative electrons, controls the number that reach the plate. The more negative the grid voltage, the more the electrons are repelled, and fewer are the number that can pass.

To produce the actions illustrated in Figure 4 a complete circuit is shown in Figure 5, where the tube V_1 is indicated by the



Over 90 tubes are used in this synchronizing generator to generate the pulses required for television camera operation.

From DeVry Tech. Labs.

symbol of Figure 3F. The external plate circuit extends from the plate, through the plate supply battery E_{bb} from positive to negative, and over to the cathode. In this circuit, the direction of electron flow, which constitutes the plate current, is in the direction indicated by the arrow heads.

The grid connects to the sliding contact of potentiometer R_1 which in turn is connected across the grid supply battery E_{cc}. Since the midpoint of this battery connects to the tube cathode, the grid can be made more negative than the cathode by moving the slider toward the "−" end of the battery, or more positive by moving it toward the "+" end.

When the slider is in the extreme right position the grid is at the maximum positive voltage and the plate current is maximum. In contrast, when the slider is moved to the extreme left, the grid reaches a maximum negative and the plate current drops to minimum.

ANY VARIATION OF VOLTAGE APPLIED TO THE GRID CIRCUIT CAUSES A CORRESPONDING VARIATION OF PLATE CURRENT. It is this control of the grid voltage on the plate circuit current that is used in so many electron circuits. However, to fully understand just what occurs, certain operation characteristics of an electron tube have to be considered.

TRIODE CHARACTERISTICS

To understand the detailed performance of triode, and for that matter all electron tubes, it is very helpful to make voltage and current readings. For instance, when plate current readings are recorded for each control grid voltage reading as shown in Figure 6B, if the other electrode voltages remain constant, it is possible by examining this chart to learn more about the triode.

The readings for grid voltage and plate current for any particular tube type are obtained by means of a circuit like the one shown in Figure 6A. As its sole purpose is to maintain the cathode at the proper operating temperature, the heater circuit and supply are not included in the diagram. However, assume that all the circuits are complete and that the tube is in normal operating condition.

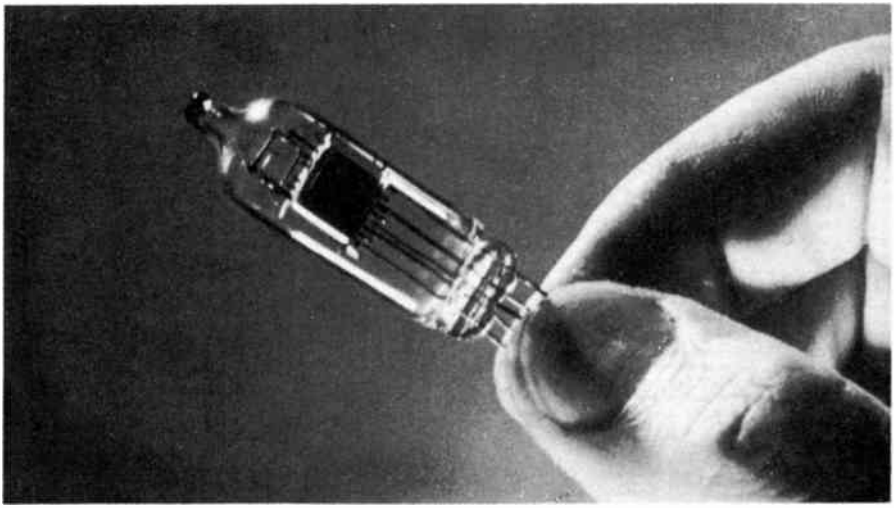
The rest of the circuit is like that of Figure 5, but arrangements are included to connect an alternating voltage E_g between the slider of R_1 and the grid of the tube. Also, a voltmeter V is connected between the grid and cathode to indicate the grid voltage and an ammeter MA is connected in series with the plate to indicate the plate current.

By moving the slider of potentiometer R_1 one way or the other, several values of positive and negative voltage are applied to the grid as indicated by the voltmeter. For each position of the slider, the resultant plate currents are indicated by the milliammeter and the readings of both meters are tabulated in the chart of Figure 6B.

According to this chart, for the particular tube under test, the plate milliammeter reads zero when the R_1 slider is adjusted so that the voltmeter reads 4 volts negative. SINCE THE PLATE CURRENT IS ZERO, THE GRID VOLTAGE AT THIS POINT IS CALLED THE **cut-off bias**. When R_1 is adjusted so that the grid is 3 volts negative, the milliammeter reads .1 ma. With the grid 2 volts negative the plate current is 4 ma, for 1 volt the plate current is 8 ma and for zero grid voltage the plate current rises to 12 ma.

Normally, the grid is maintained negative with respect to the cathode, but in certain applications, it is permitted to become positive for at least a portion of the time. Therefore, to complete the picture of a tube's performance, several readings are included for positive grid voltages.

With the grid at +1 volt the milliammeter reads 18 ma; with +2 volts on the grid, the plate current reading is 21 ma; and for this particular tube, +3 volts on the grid still indicates 21 ma. In fact, any further increase in positive grid voltage does not increase the plate current. Since this indicates that all of the electrons emitted by the cathode, except for the few attracted to the positive grid, are reaching the plate, it is called saturation.



Sub-miniature tubes are very small. This hearing-aid tube is only ¾ in. long and ⅜ in. in diameter.

Courtesy Sonotone Corp.

Thus, for all practical purposes, the operating range of the tube is from cut off bias to plate saturation. These are the extreme limits of the tube. Sometimes the tube may be operated exactly at cut-off bias and other times it may be operated at saturation. However, for most purposes it is operated between these two extremes.

By examining Figure 6B, we can see why it is desirable to operate about half way between these values. Note that for 0 volts on the grid the plate current is 12 ma, and changing the grid voltage to a negative 1 volt, the plate current decreases to 8 ma. Thus, a change in grid voltage of 1 v produces a change in plate current from 12 to 8 or 4 ma. Going from a negative 1 volt to a negative 2 grid volts, produces a change in plate current of $8 - 4 = 4$ ma; changing the grid voltage another volt to a negative 3 volts, produces a current change of $4 - .1 = 3.9$ ma. Going to a negative 4 grid volts, cuts off the plate current. That is a 3 grid volt change only gives $.1 - 0 = .1$ ma instead of 4 ma change. Each of these first three steps of 1 grid volt produce approximately 4 ma change in plate current, but for the last situation, this no longer was true, nor is it true going from one positive grid voltage to another.

The range producing an equal plate current changes for equal grid voltages is where the triode usually is operated. As either a positive grid voltage is reached or cut-off bias is neared, the grid voltage does not vary the plate current by the same amount. Therefore, a d-c voltage somewhere near the center of this range is applied to the triode grid for best results.

TRIODE AMPLIFICATION

To demonstrate the typical operation of a triode, let's pick a grid voltage of -1 volt. According to Figure 6B, this permits a d-c plate current of 8 ma through the tube. Figure 7A represents the grid voltage in the vertical direction for different intervals of time along the horizontal line. Figure 7B is the d-c plate current I_b with the grid at -1 volt for the same time intervals. The vertical distance from the line represents the values of grid voltage in Figure 7A and the plate current in Figure 7B.

Going back to the circuit of Figure 6A, if the wire between points X and Y is removed and the a-c source E_g connected as shown there will be two voltages connected in series in the grid-cathode circuit of the tube V_1. Thus, the total grid voltage consists of a d-c component, supplied by the E_{cc} battery and an a-c component supplied by source E_g.

This is shown by Figure 8A. Here 1 volt a-c or E_g is added to the -1 volt for E_{cc} d-c. At point 1, their total is -1 volt since the a-c is zero and the d-c is -1 volt. At point 2, their total is zero since $+1$ and -1 d-c exactly cancel. At points 3 and 5, the grid voltage again is -1 volt, while at point 4, their total is -1 and -1 or -2 volts.

During one alternation, the a-c aids the d-c and the total voltage is equal to their sum. During the next alternation, the a-c opposes the d-c and the total voltage is equal to their difference. Thus, the grid voltage varies continuously above and below the d-c voltage.

This is a very common condition in tube grid circuits and the d-c or fixed voltage is called grid bias or C-bias. By definition, bias means a voltage or difference of potential between two electrodes of a tube. However, the term is used almost exclusively to refer to the fixed or d-c grid voltage. Since THE CATHODE IS THE USUAL VOLTAGE REFERENCE POINT of an electron tube, and in most application the grid is negative with respect to the cathode, usually it is assumed that the grid bias is negative, and the a-c, applied in series with the grid bias is called the signal voltage.

The d-c grid bias, −1 volt for this example, determines the operating point of the tube. That is, depending upon its direction at any instant, the signal voltage either decreases or increases the negative grid voltage, and hence, swings about this operating point.

A picture tube is a special type of electron tube. It has a heater, cathode, and control grid in addition to other electrodes.
Courtesy Radio Corporation of America

At the same time the grid voltage is changing in Figure 8A the plate current changes as shown in Figure 8B by I_p. All the points are identical in both Figures. At point 1, in Figure 8B, since the grid voltage is 1 volt, according to Figure 6B the plate current is 8 ma. At point 2 in Figure 8B, the grid is now at 0 volts, or has become less negative. Not as many electrons are repelled and the plate current increases to 12 ma. At points 3 and 5, the current I_p is at 8 ma. At point 4, the bias is −2 volts and the greatest repulsion occurs, so the plate current drops to 4 ma. A small change in grid voltage of 2 volts produces a plate current change of almost 8 ma. Thus, as indicated by Figures 8A and 8B, the plate current variations have the same form as the grid voltage and so long as the circuit conditions are maintained, this action repeats itself during each successive cycle.

The action for the circuit in Figure 9 is similar to Figure 6A. Variable resistor R_1 represents the resistance of tube V_1 and E_{bb} is the same in both Figures. As the arm of R_1 is moved toward the end marked "cathode" more resistance is placed in the circuit. By Ohm's Law, a higher resistance divided into a constant voltage E_{bb} gives a smaller current. In terms of the tube V_1 in Figure 6A, this is the same as increasing the bias and hence reducing the plate current.

By moving the arm of R_1 toward end marked "plate" there is less resistance in the circuit, hence the current increases. Since this is the same action as provided by tube V_1 in Figure 6A when the bias is decreased and the plate current increases, a tube acts just like an automatic variable resistor. In fact, for many purposes, it is helpful to think of an electron tube as a variable resistor.

Figure 6A and the explanation in Figure 9 show how an electron tube can be used to control a current by a small voltage. Frequently it is necessary to control a large voltage with a small voltage. For this purpose we need to add a fixed resistance called the **plate load resistor** in the plate circuit as shown by R_L in Figure 11. How this circuit works can be seen by using Figure 10 where R_1 represents the triode and R_L is the added fixed resistor. Moving the arm of R_1 toward the plate is the same as decreasing the bias and it decreases the total resistance in the circuit. Again, the current increases and so the voltage across R_L increases. A larger current I_p times R_L gives a higher voltage E_L across R_L.

Moving the arm of R_1 toward the cathode increases the total resistance of the circuit. The current therefore decreases and the small current through resistor R_L results in a lower voltage E_L across R_L.

Thus, as the grid voltage in Figure 11 changes, the plate current likewise changes. As the a-c signal on the grid goes positive the plate current increases and the voltage E_L increases. As the a-c signal on the grid goes more negative, the plate current decreases, and the voltage across E_L decreases. A "+" a-c signal on the grid decreases the bias and the voltage E_L increases.

Actually the variations in the voltage E_L across load resistor R_L are larger than the voltage variations applied to the triode grid. For example if the circuit in Figure 11 has the grid voltages and plate currents shown in Figure 6B when plate load R_L has a resistance of 10,000 ohms, this variation can be determined by Ohm's Law. For 0 v on the grid the 12 ma of plate current produces $.012 \times 10{,}000$ or 120 volts across R_L. For -2 v on the grid 4 ma of plate current produces $.004 \times 10{,}000$ or 40 volts across R_L. Therefore a change of 2 volts on the grid produces a $120 - 40$ or 80 volt change across R_L and 1 volt on grid produces a 40 volt change.

At the same time that the voltage varies across R_L it also varies on the triode plate.

In Figure 10 as the resistance of R_1 is decreased, the current increases and E_L increases. Thus, since E_{bb} is constant and E_L is increased, there is less voltage across R_1. R_1 represents the tube, and so there is less voltage across the tube V_1 in Figure 11.

On the other hand as the resistance of R_1 is increased, the current decreases and E_L decreases.

Since E_{bb} is constant and E_L is decreased, there is more voltage across R_l. That is the plate voltage is increased.

The small a-c signal on the grid controls a large a-c voltage on the plate. Figure 12 shows the relationship between the voltages for a complete cycle. The horizontal line E_c in Figure 12A indicates the d-c bias and a-c or E_g goes above and below this reference. In Figure 12B the horizontal line indicates the plate voltage E_b during the time d-c bias is applied and so the a-c plate voltage E_p due to the a-c signal on the grid riding goes above and below this line.

During the positive alternation of the grid signal, the plate voltage makes a negative alternation, while during the negative alternation of the grid signal, the plate voltage makes a positive alternation. Moreover a small a-c grid signal controls a large a-c signal on the plate and this is referred to as the **amplification** of the tube. So long as the plate load R_L is a resistor, the a-c voltage on the plate is exactly inverted with respect to the a-c grid voltage.

It is this ability to amplify that makes the electron tube so useful. For example, light rays, too weak to do much, can generate a voltage in a photocell. This weak voltage is amplified by tubes until large enough to operate a bell, relay, or motor. Or, a pressure too weak to turn a valve can be converted to a voltage and the voltage amplified until strong enough to actuate the solenoid that closes the valve.

The antenna for the radio in Figure 13 is a conductor that intercepts very weak magnetic fields radiated by the broadcast station. Naturally these magnetic fields induce very small voltages in the antenna. Therefore, one of the important functions of the tubes in a radio is to build up this weak signal to a useful voltage.

But amplification isn't the only function for these tubes, and diodes and triodes are not the only tube types. Although Tube V_4 is a triode tube with two added electrodes for other independent purposes and V_6 has two diodes, all of the other tubes in Figure 13 have added electrodes which affect the main operation of these tubes. In order to understand fully how this radio works we must know why these electrodes are needed and how they function. And so, we describe these multi-electrode tubes in the next lesson.

IMPORTANT DEFINITIONS

AMPLIFICATION—Referring to the ability of an electron tube to make a large a-c plate signal from a small a-c grid signal.

CUTOFF BIAS—That d-c voltage which applied to the tube grid, reduces the plate current to zero.

GRID—A control electrode, usually in the form of a spiral wire or mesh, placed between the cathode and plate of an electron tube.

GRID BIAS—(E_c)—[GRID BIH uhs]—A d-c voltage used to maintain the grid of an electron tube negative with respect to the cathode and thus establish the operating point. Known also as C bias.

OCTAL BASE—[AHK tuhl BAYS]—An electron tube base having a central part plug and aligning key, and eight equally spaced positions for the connecting pins.

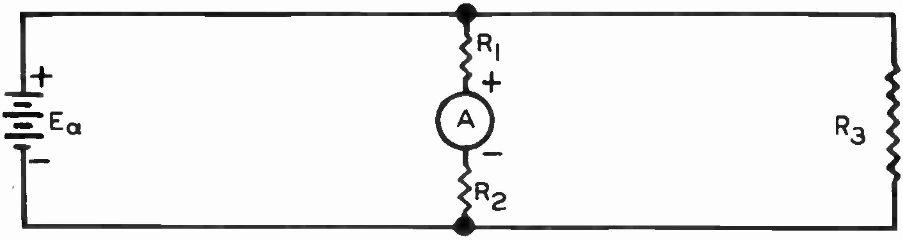
PLATE LOAD RESISTOR—As used in this lesson, a resistor in the plate circuit through which current passes thus developing the output signal voltage.

SIGNAL—(E_g)—The a-c voltage applied to the grid of an electron tube.

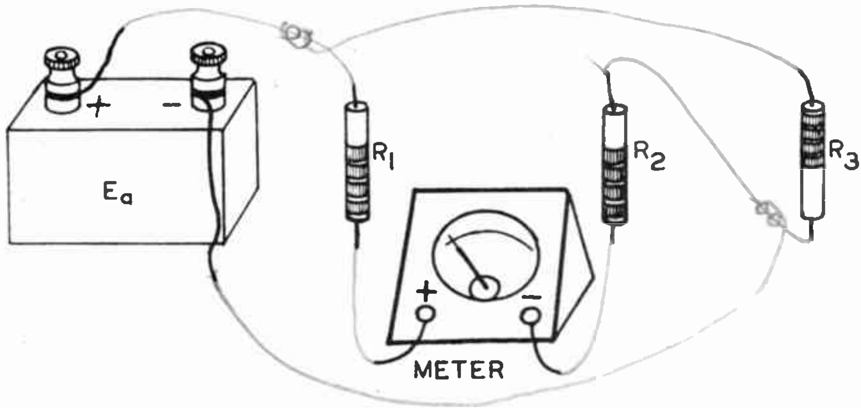
TRIODE—[TRIGH ohd]—A 3-electrode tube containing a cathode, grid, and plate.

WORK DIAGRAM

By pencil lines, connect the pictorial units as indicated by the schematic diagram.



SCHEMATIC DIAGRAM



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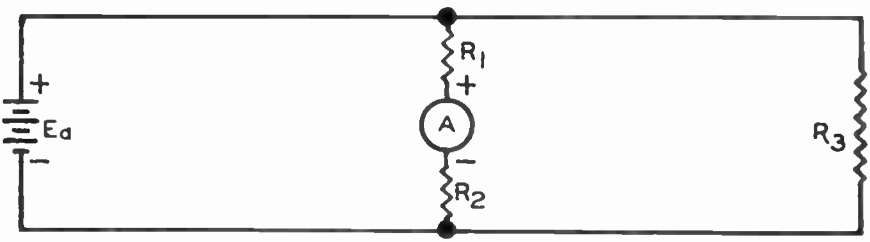
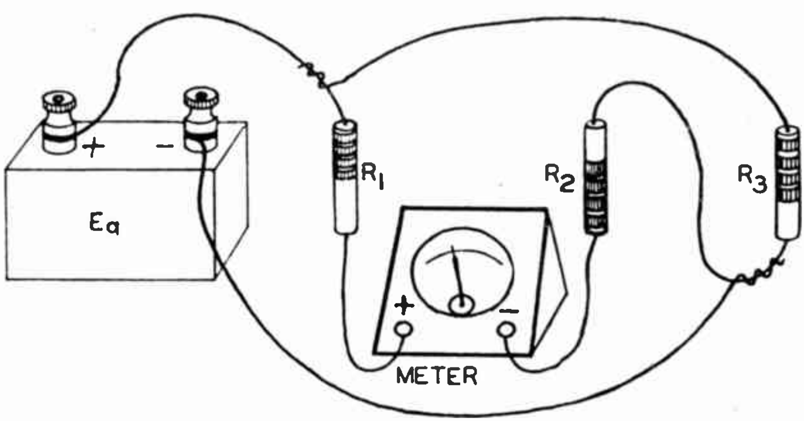
WORK DIAGRAM SOLUTION



SCHEMATIC DIAGRAM



Diode

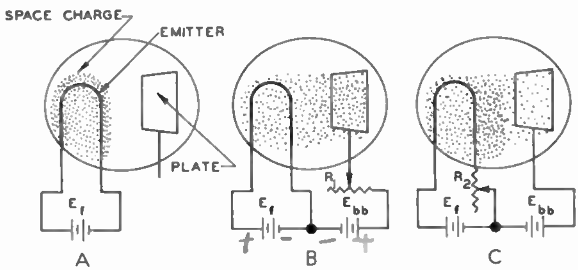


FIGURE 1

Grid:

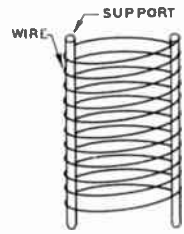


FIGURE 2

Triode Tubes

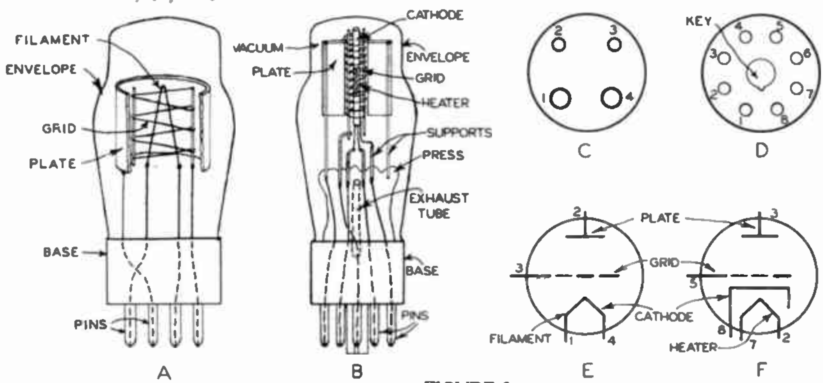


FIGURE 3

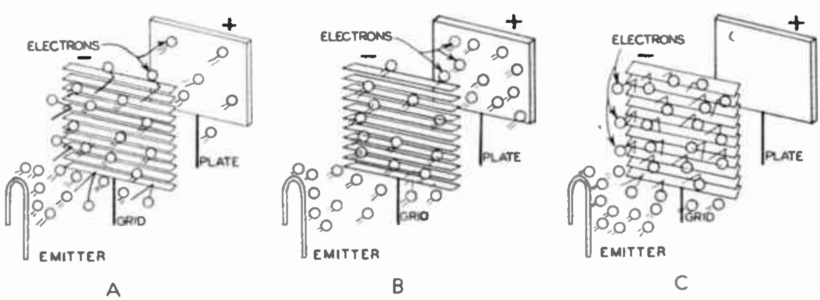


FIGURE 4

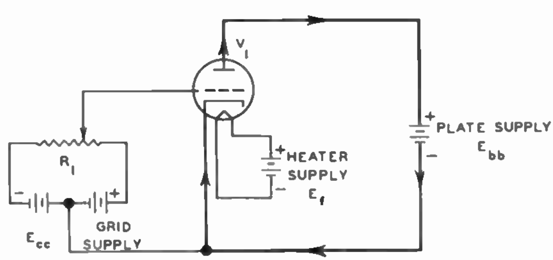
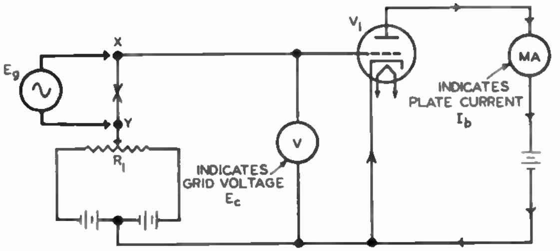


FIGURE 5

AEH-14



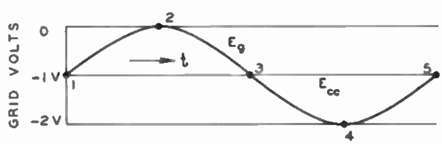
A

GRID VOLTAGE	PLATE CURRENT
−4V	0.0 MA
−3V	0.1 MA
−2V	4.0 MA
−1V	8.0 MA
0V	12.0 MA
+1V	18.0 MA
+2V	21.0 MA
+3V	21.0 MA

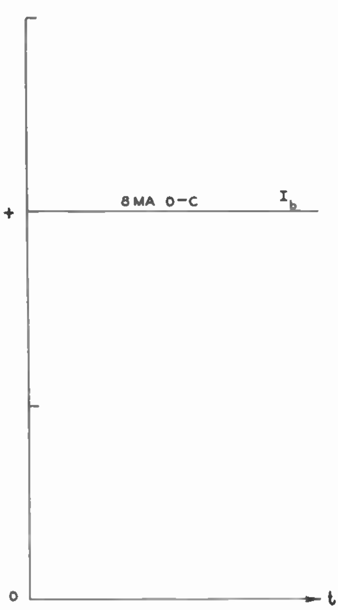
B

FIGURE 6

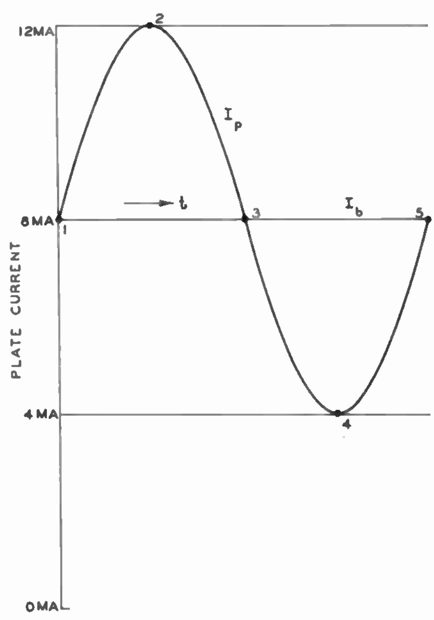
A



A



B



B

FIGURE 7

FIGURE 8

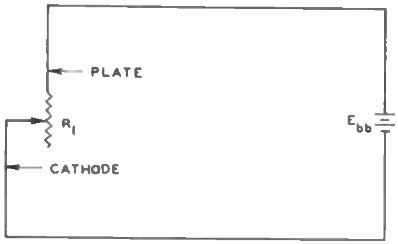


FIGURE 9

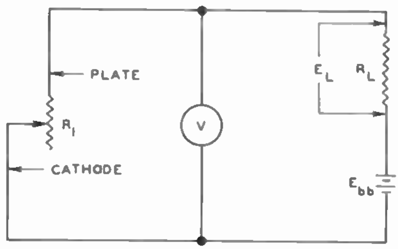


FIGURE 10

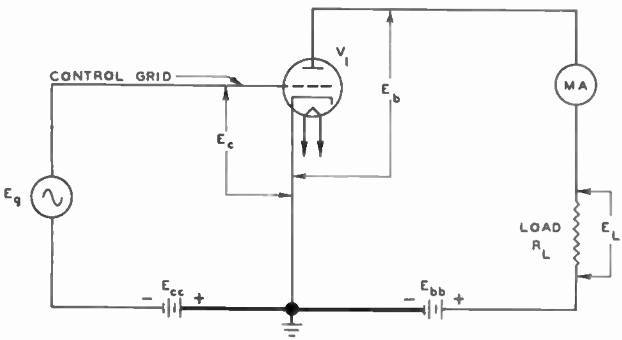


FIGURE 11

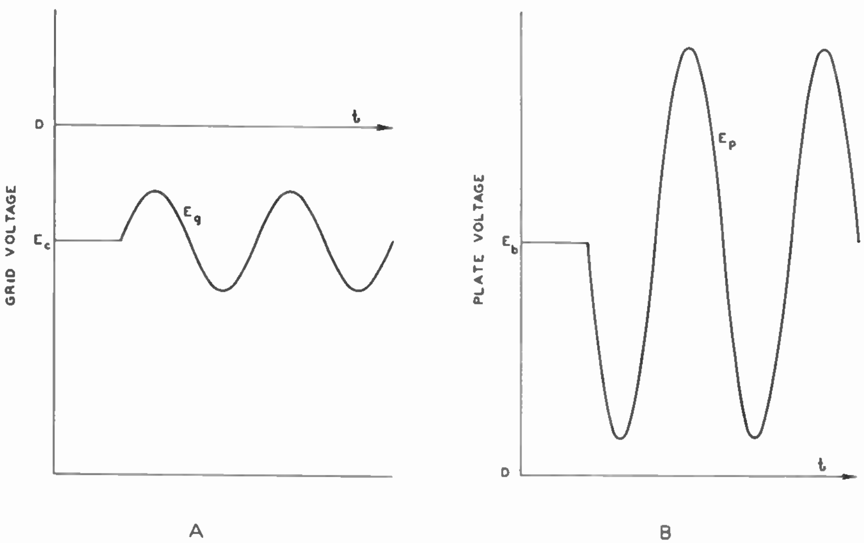


FIGURE 12

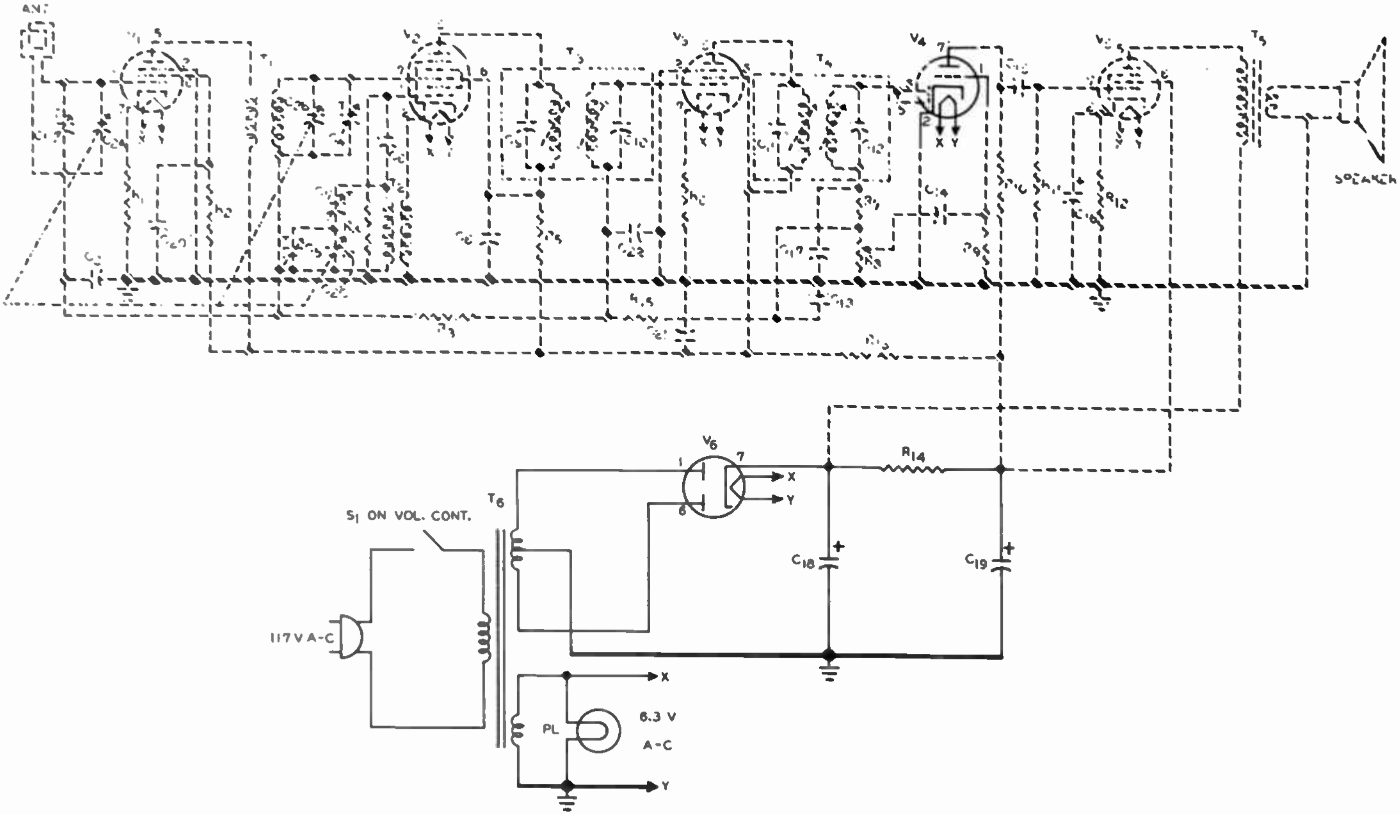

ANT
V1
V2
V3
V4
V5
V6
T5
T6
SPEAKER
R14
C18
C19
S1 ON VOL. CONT.
117V A-C
PL
6.3 V
A-C
X
Y

FIGURE 13

FROM OUR *Director's* NOTEBOOK

THE EIGHTH MISTAKE OF MAN

A well-known writer advises that there are seven mistakes Man is prone to make:

1. That individual advancement can be made by crushing others.
2. Worrying about things which cannot be changed or corrected.
3. Insisting that a thing is impossible because we ourselves are unable to accomplish it.
4. Refusing to set aside trivial personal preferences in order that important cooperative benefits may be achieved.
5. Neglecting to develop mental refinement by the habit of cultural reading.
6. Attempting to compel other persons to believe and live as we do.
7. Failing to establish the habit of saving money.

AN EIGHTH MISTAKE

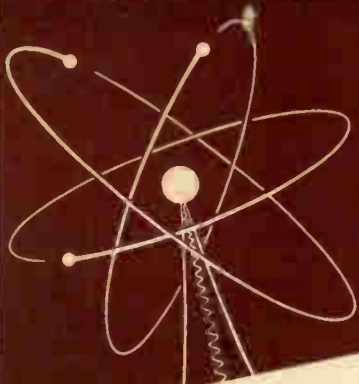
Allowing others to persuade us that we can get something for nothing.

Yours for success,

W. C. DeVry

DIRECTOR

PRINTED IN U.S.A.



MULTI-ELECTRODE TUBES

Lesson AEH-15A

DeVRY Technical Institute

4141 W. Belmont Ave., Chicago 41, Illinois

Formerly DeFOREST'S TRAINING, INC.

-15

AEH-15A

MULTI-ELECTRODE TUBES

4141 Belmont Ave.

Chicago 41, Illinois

DeVRY Technical Institute

ELECTRONS EXTEND VISION

A large ocean liner is being maneuvered through close quarters to its dock. On the ship's bridge, the officer in charge cannot see whether sufficient clearance exists at all points because of the great size of the boat. To check at some remote section, he flips a switch and a view of the section appears on a screen before him. This view is provided by television equipment of the same type employed for entertainment purposes in the home.

Little does the average person realize that there are many applications of television other than entertainment. Uses by industry include observation of hazardous operations carried on by remote control from a safe distance, three dimensional television facilitates remote control of intricate manipulations, and medical schools employ color television to demonstrate the details of important surgical techniques to large classes.

Fundamentals

MULTI-ELECTRODE TUBES

Contents

It is well for a man to respect his own vocation whatever it is, and to think himself bound to uphold it, and to claim for it the respect it deserves.
—Charles Dickens

MULTI-ELECTRODE TUBES

Patented in 1907, the triode type of electron tube was designed for use as a sensitive detector of Wireless Telegraph signals, the only form of radio in use at that time. The triode operated successfully in its intended application, but it was some time before the amplifying and a-c generating capabilities of the tube were even suspected.

However, since then, intensive studies of its action have disclosed many new applications as well as characteristics both desirable and undesirable. By adding electrodes and modifying the internal structure, designers have developed several hundred types of electron tubes, each of which is adapted especially for some particular application. Therefore, to fully understand the operation of many electron circuits, it is necessary to know the reason for these modifications.

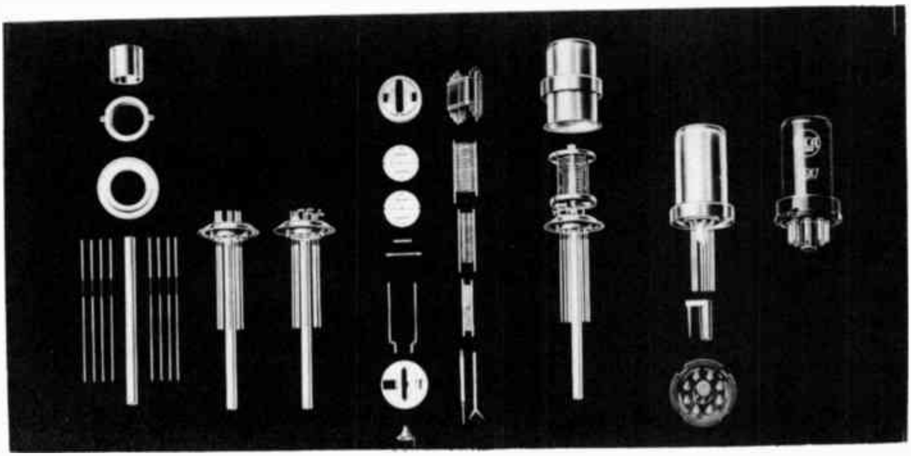
INTERELECTRODE CAPACITANCE

In the lesson on capacitors it was pointed out that when two conducting surfaces are separated by an insulating material, they form a capacitor. Two parallel wires form a capacitor, and the capacitance depends on the length of the wires, the distance, and the type of material between them. Thus the electric power, telephone, and telegraph wires which are mounted on poles possess capacitances, however, because of the relatively large spacing between the wires, it is too small for normal considerations.

In any triode tube, the cathode, grid, and plate form a system of capacitors, with each electrode acting as a plate. Thus, a small but definite INTERELECTRODE CAPACITANCE exists between the cathode and grid, the grid and plate, and the plate and cathode. In the triode tube symbol of Figure 1, dotted lines represent these capacitances between electrodes. The capacitance between grid G_1 and plate P is labeled C_{g1p}; between grid G_1 and cathode K is C_{g1k}; and C_{pk} is between plate and cathode.

Generally, the capacitance between the grid and plate has the greatest effect on the operation of a triode. In the previous lesson it was explained that a signal applied to the grid causes changes of plate current which produce variations of voltage drop across a load resistor.

Voltage variations on the plate produce charge and discharge of the interelectrode capacitance between plate and grid. The resulting displacement currents produce voltage drops across any resistances in the grid to cathode circuit. Consequently some of the voltage in the plate circuit appears in the grid circuit by the "coupling" action of the interelectrode capacitor C_{gp}. Due to the small capacitance, at low frequencies this coupling action is not noticeable, but for high frequency alternating currents it becomes too serious to ignore.



Structural parts of a typical metal tube. Looking from left to right you will see the tube stem parts, the tube stem, the tube mount parts, the tube mount, the evacuated tube, and the finished tube.

Courtesy RCA

TETRODES

In order to reduce the grid to plate capacitance for tubes used in certain high frequency circuits, another grid is inserted between the control grid and the plate. Since it screens the grid from the capacitive effects of the plate, it is referred to as the **screen grid.** An electron tube with four active electrodes is known as a **tetrode.** The emitter is counted as one electrode whether heated directly or indirectly.

As shown in the tetrode tube symbol of Figure 2, the addition of the screen grid changes the grid to plate capacitance C_{gp} into two series capacitances, the screen grid to plate capacitance C_{pg_2} and the control grid to screen grid capacitance $C_{g_1g_2}$. The total capacitance between the control grid and plate is essentially the same as before, however its effect is greatly reduced, by connecting a large capacitor C_1 from the screen grid to ground.

To understand this reduction, two facts must be kept in mind: (1) capacitors C_1 and $C_{g_1g_2}$ are in parallel in most tube circuits, and (2) the current in parallel capacitors depends upon their individual capacitance.

C_1 and $C_{g_1g_2}$ are in parallel since each one connects to the screen on one side and to the ground on the other. Although $C_{g_1g_2}$ does not

Surrounding the tube elements in this pentode, the perforated metal cylinder is connected to the screen grid and helps to shield the plate from the control grid.

Courtesy General Electric Co.

connect directly to ground, it connects from the grid, through the grid circuit to ground in most circuits much like the grid circuit of Figure 4.

Parallel capacitors charge to the same voltage and the quantity of the charge in each capacitor is directly proportional to its capacitance. Also, on charge or discharge, the shift of electrons as they enter one plate and leave the other is called the displacement current. Hence, if capacitor C_1 has a capacitance 1000 times as large as $C_{g_1g_2}$ it accepts 1000 electrons of the displaced current for every electron received by $C_{g_1g_2}$. Therefore only one thousandth of the C_{pg_2} displacement current is displaced into the grid circuit by $C_{g_1g_2}$. Hence, the effect is too small to be harmful even at high frequencies.

As shown in the cutaway view of Figure 3, the mechanical construction of a tetrode is quite similar to that of the triode described in a previous lesson. All of the electrodes are mounted on wire supports embedded in the stem press and the wires for external circuit connections are carried down through the base pins.

The cathode surrounds the heater, and a grid surrounds the cathode. For identification, this grid is indicated as g_1 in the symbol of Figure 2 and labeled control grid in Figure 3. In this particular type tube, the control grid connection is brought out through the top of the envelope and terminates in an external grid cap. However, for most tetrodes, the control grid connection is made through a base pin to form what is known as a "single ended" tube. These will plug into the same octal or miniature sockets as the triodes.

Similar in construction, the screen grid is mounted around the outside of the control grid and the plate surrounds the screen grid. To provide additional isolation of the plate, the shield which surrounds it is connected electrically to the screen grid.

As indicated in the schematic diagram of Figure 4, normally the screen grid is operated at a positive voltage slightly less than the plate. In this case, a battery is used as the power supply, therefore, capacitor C_1 of Figure 2 is unnecessary. The internal battery resistance is so low that it conducts the C_{pg2} displacement current directly to the cathode and ground of the circuit.

Since the screen is positive with respect to the cathode, it attracts the electrons much like the plate in a triode. However, due to its open structure, most of the electrons do not strike the screen but continue on to the plate. In fact, this attraction is so effective that the plate voltage variations produce only a small change in the plate current since a large number of the electrons attracted by the screen continue on to the plate for all positive plate voltages.

SECONDARY EMISSION

When electrons are emitted from the cathode they are attracted by the positive voltage on the plate. Thus the speed of the electrons increases progressively as they move from the cathode to the plate. Usually the electrons attain sufficient speed to dislodge one or more other electrons from the

Two complete triode units are mounted in this evacuated tube to conserve space and material.

Courtesy Hytron Radio and Electronics Co.

surface of the plate upon impact. This effect is called **secondary emission** and the released electrons are known as SECONDARY ELECTRONS.

Secondary emission produces no difficulty in diodes or triodes because the positive plate attracts and eventually recaptures these electrons. However, in tetrodes the nearby positive screen grid attracts the electrons produced by secondary emission. As a result

This tube has three diodes and a triode enclosed in the same envelope.
Courtesy General Electric Co.

of this robbing effect, the plate current is reduced, and the signal output of the tube goes down.

PENTODES

To overcome the disadvantages of secondary emission in tetrodes, another grid is added between the screen grid and plate as shown in the cutaway drawing of Figure 5. This third grid connects to the cathode or to some other point in the circuit which is negative with respect to the positive plate and screen grid.

The electrons which travel from the cathode to the plate are slowed down by the negative grid, nevertheless, they still have sufficient speed to travel through the openings in this third grid and onto the plate. Very few electrons are stopped and repelled back to the screen grid.

Due to the decreased speed of the electrons as they reach the plate, the secondary emission is reduced considerably. Even the secondary electrons which are emitted are repelled back to the plate by this negative grid. Thus, the added grid isolates the plate and the screen grid, and thereby greatly reduces the effects of secondary emission.

A tube containing five electrodes is called a **pentode.** The symbol and connections of a pentode are shown in Figure 6, and the various grids, indicated by the letters G_1, G_2, and G_3, are numbered in the order of their positions outward from the cathode.

G_3 is called the **suppressor grid** —or "suppressor". Thus, in the pentode tube of Figure 6, the five electrodes are: the cathode "K", the control grid "G_1" the screen grid "G_2", the suppressor grid "G_3", and the plate "P".

Figure 6 also shows the connections of a simplified pentode tube circuit. The suppressor grid G_3 is brought out to a separate connection or base pin, which permits circuit variations where necessary. However, many pentodes are built with the suppressor grid connected to the cathode inside the envelope.

BEAM POWER TUBES

Although the action of the pentode suppressor grid has an advantage in that it reduces the effect of secondary emission from the plate, it also has some disadvantages. Since it is located between the screen grid and the plate, it is an obstruction in the path of the electrons that travel from the cathode to the plate. To minimize this obstruction, it is made of an open wire network or spiral, but then its repelling action on the secondary emission electrons is not uniform over the entire plate area. This uneven action results in distortion of the signal and limits the power that the tube can deliver.

To overcome these difficulties and thus provide considerably higher current-carrying capabilities than either the tetrode or pentode, the beam power tube has been developed. The basic construction of a beam power tube, shown in Figure 7, includes a cathode, control grid, screen grid, "beam-confining electrodes", and a plate. In some models a suppressor grid also is included.

The mirror-like finish on the inside of the envelope is due to the deposit of the getter on the glass after it has been flashed.

Courtesy Sylvania Electric Products, Inc.

By connecting these beam forming plates to the cathode, a negative voltage is placed on the two beam-confining electrodes. Since like charges repel, these electrodes repel the negative electrons and compress them into beams as they travel from the cathode to plate. The flattened cathode not only gives a larger emitting area in the direction of the beams but aids in forming them to produce a higher plate current change for a small grid voltage change.

Suppressor action is obtained by making the distance between the screen grid and plate much larger than the distances between the other electrodes. With this increased distance and the beam forming action, a large number of electrons appear in this space and create a dense space charge. To further crowd the electrons, often the plate is operated at a voltage lower than the screen grid, thereby slowing down the electrons and bunching them closer together. Due to its negative charge, this dense beam of electrons repels the secondary emission electrons back into the plate. Hence, suppressor action is obtained without having a metal obstruction in the electron path.

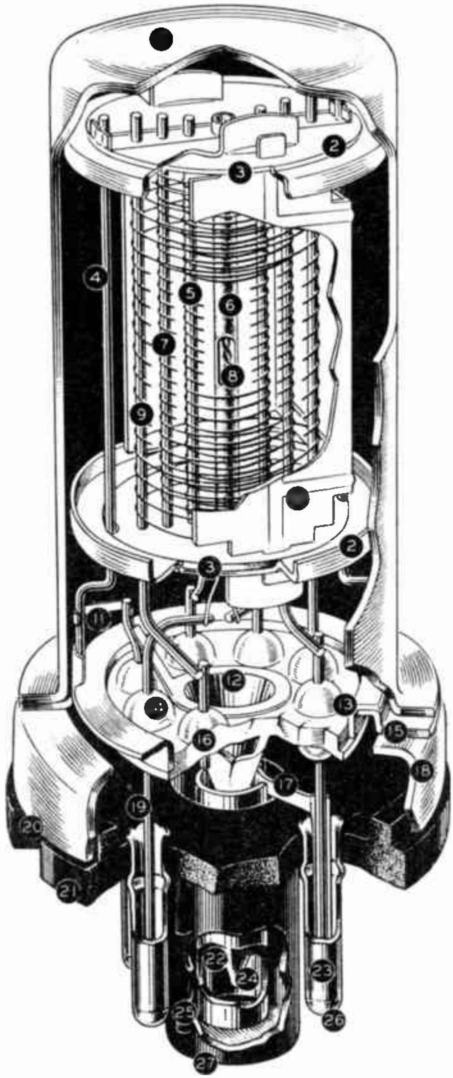
Another feature of the beam power tube is the location of the screen grid in the "shadow" of the control grid. That is, the screen grid wires are placed directly in line with the control grid wires so that, as the electrons pass through the grid openings, they travel in sheets and very few are able to strike the screen grid. Because of this arrangement, the screen grid current is low, and considerably higher currents can be produced in the plate circuit without overheating the tube.

Beam power tubes are represented in circuit diagrams by the symbol of either Figure 8A or 8B. In every type, the beam-confining plates are connected internally to the cathode. Therefore, external circuit connections are made to the cathode, control grid, and plate as in a tetrode. In fact, these tubes often are referred to as "beam power tetrodes"

COMBINATION AND SPECIAL PURPOSE TUBES

To conserve space and to reduce cost without sacrificing performance, it is common practice to combine the elements of two or more complete tubes in one envelope, and to mount the combination on a single, standard base. Some of these combinations use a common cathode, while in others separate cathodes are provided.

One such combination is the DOUBLE TRIODE, shown by the symbol of Figure 8C. The two triodes are electrically independent of each other, and the physical construction and location of the various elements are such that both can operate without interfering with each other. Other examples of combination tubes are the DUO-DIODE-TRIODE of Figure 8D and



A cutaway view of an octal type pentode with a metal envelope.
Courtesy Radio Corporation of America

the TRIODE-PENTODE of Figure 8E. In both of these types a single cathode is used.

In addition to these combinations, there are also a number of special purpose tubes which were developed for specific functions. For example, the PENTAGRID CONVERTER shown in Figure 8F is a special purpose tube which contains five grids, hence the name **pentagrid**. Some of the grids are connected internally, while others are brought out for external connections. The descriptions of special purpose tubes are not included here, but are postponed until later lessons, since the actions of these tubes can be ex-

This pentagrid converter contains five grids in addition to a plate, cathode, and heater.
Courtesy Radio Corporation of America

plained more readily when their specific applications are understood.

TUBE CLASSIFICATION

Electron tubes are classified in many ways according to their structure, the number of elements, type of base, type or shape of the envelope, operating characteristics, or their use in a circuit.

One method of classification is based on the number of electrodes which the tube contains. Examples are found in the naming of the diodes, triodes, tetrodes, and pentodes already described. The same method is used in classifying other tubes such as those containing six elements, called "hexodes", those with seven elements are "heptodes", and those with eight elements are called "octodes". These prefixes come from Greek words signifying the numerals 2 to 8 as follows:

2—Di	5—Penta
3—Tri	6—Hexa
4—Tetra	7—Hepta
8—Octa	

A second method of classification of tubes is in accordance with their use such as "rectifier", "amplifier", "detector", and "cathode ray".

Diodes, triodes, tetrodes, pentodes, and beam power tubes all can be found in a variety of tube envelopes and bases. Hence, they are designated also as "miniatures", "octals", "lock-ins" or "loctals", or "metal tubes".

Sometimes, tubes are referred to as "vacuum" or "soft" to designate their internal condition.

Vacuum tubes are those which have been highly evacuated of air before they are sealed. To increase the degree of vacuum, a material that vaporizes easily is added before the tube is sealed and then "flashed" by heating after the sealing operation is completed. When the material vaporizes, it absorbs the residual gases to form a more perfect vacuum. The vaporizing materials, called "getters", are compounds of magnesium or barium. In fact, the mirror-like surface inside some glass tubes is due to a film of the getter deposited on the inside of the envelope when the tube is flashed.

Soft tubes are not fully evacuated, but have gas left in them, either accidentally or purposely added to obtain certain desired operating characteristics. Gas-filled diodes are used in rectifier circuits, while gas-filled triodes and pentodes are employed in control circuits of electronic equipment.

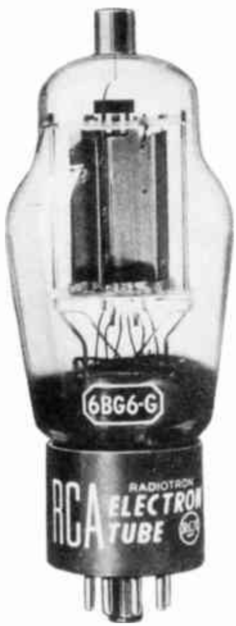
Another type of tube classification comes from the amplification characteristic of the tube which was described in the previous lesson. The greek letter mu (μ) is used to indicate how many times the change of plate voltage is larger than the change in grid voltage causing it. When the control grid wires are placed close together with very small spacing between them, changes in grid voltage have a large effect on the plate current. This type is called a HIGH-MU tube.

On the other hand, if the grid wires have a large separation, it will have less control over the plate current. Hence, this type is a LOW-MU tube. For the same reasons, a MEDIUM-MU tube has a medium spacing of the control grid wires.

When a large signal is applied to the grid of a high-mu tube, the negative peaks cause the plate current to be cut off. This action produces a distorted output, an undesirable feature that has been overcome by the unequal spacing of the grid wires. As shown in Figure 9, the grid wires have open spacing at the center and close spacing at the ends.

When a weak signal is applied to the tube, the effect of the unequal spacing of the grid is essentially the same as with equal spacing. However, as the grid becomes more negative, the plate current near the ends is cut off. Then the current is dependent on the electron flow through the open spacing, and an extremely large negative bias is necessary to cut off the plate current entirely.

Some tubes have high-mu properties at low negative grid voltages and low-mu properties at high negative voltages. For this reason, this type of design provides what is called a VARIABLE-MU tube. It is known also as a REMOTE CUTOFF tube since a large negative voltage is necessary to cause the plate current to cut off.



This beam power tube is capable of conducting large currents.
Courtesy RCA

In contrast, the high-mu tube is referred to as a SHARP CUTOFF tube.

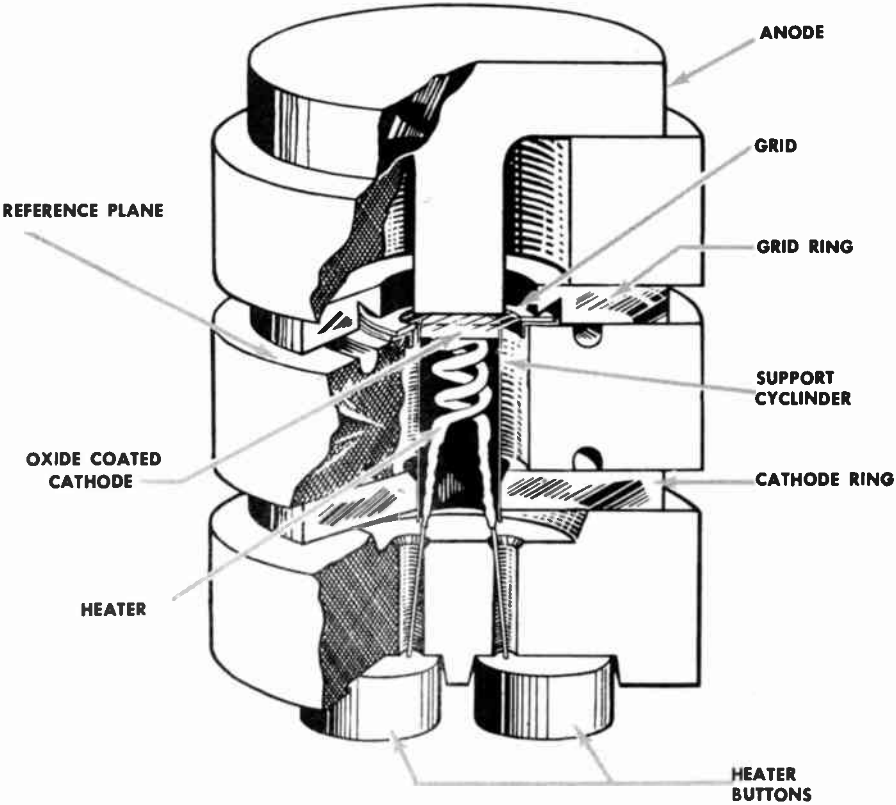
MAXIMUM TUBE RATINGS

Proper operation of electron tubes requires that certain maximum ratings be observed. When these ratings are exceeded, the life of the tube is shortened. For example, one important rating is the MAXIMUM PLATE DISSIPATION. This rating in watts indicates the maximum electric energy that can be converted into heat and dissipated safely and continuously by the plate. This energy conversion takes place when the electrons bombard the plate at high velocity.

Another maximum rating is the PEAK HEATER-CATHODE VOLTAGE in tubes having a separate cathode terminal, and is used where high voltages are applied between the heater and the cathode. This rating indicates the highest voltage that can be applied safely between the heater and the cathode without breaking down the insulation.

No matter how carefully these maximum ratings are observed, electron tubes do become defective. Typical faults are: the heater breaks, two electrodes touch, the cathode loses its electron emission capability, or gas develops in the tube vacuum. All of these can cause defective or no operation. In fact, since the electron tube is the most fragile of the electronic components, tubes are suspected first when the equipment fails to function properly.

Frequently the faulty tube can be located by touch or sight. A glass tube may have an extra heavy blue glow indicating that it is gassy, or sparks or a red glow



This triode has a very unusual construction to make it shock resistant and suitable for ultra high frequency amplifiers. Notice how close the plate or anode is to the cathode.

Courtesy of General Electric Co.

about the plate or screen indicate a short. A light tapping of the tube may produce noises or intermittent operation due to loose electrodes. Glass and metal tubes that remain cold after the rest of the tubes are hot may have an open heater. Likewise, a tube that gets too hot might have an internal short. However, be careful; many rectifiers and beam power tubes normally operate too hot to handle. More than a light, quick touch will give a bad burn.

Of course, all of these symptoms can bc produced by other causes; it just happens that the tube is most often at fault, therefore, it pays to check these first. Replace the tube with one of the same type known to be good. Then if the fault remains, trouble is somewhere else. How these other troubles can be located with a minimum use of time and effort are described later in your training program.

The electronics of today would not be possible without electron tubes, for they are the very heart of the electron circuits. So the information given in this lesson is extremely important. In the advance assignments of this training program, these tubes will be applied to various circuits the action of which depends on how the tube functions.

In Figure 10 is our radio circuit again. Since their structure has been described, the tube symbols now are black. Tubes V_1 and V_3 are the same as that tube in Figure 6 which is a pentode. Tube V_2 is the same as the pentagrid converter shown in Figure 8F. Tube V_4 is identical to that shown in Figure 8D which is a duo-diode-triode. Tube V_5 is a beam power amplifier using the same symbol as found in Figure 8A. Tube V_6 is a full-wave rectifier described in an earlier lesson on power supplies.

In the next lesson, some of the basic actions in amplifier circuits are described such as methods for developing bias and how the signal is passed from one stage to another. In fact, the entire action of the circuit for the triode section of V_4 and the beam power tetrode V_5 are described in the next lesson.

IMPORTANT DEFINITIONS

BEAM POWER TUBE—An electron tube constructed with special beam-confining electrodes which concentrate the electrons into beams, and provide high current-carrying applications.

PENTAGRID—[PEN tuh *grid*]—An electron tube containing five grids.

PENTODE—[PEN tohd]—An electron tube with five active electrodes.

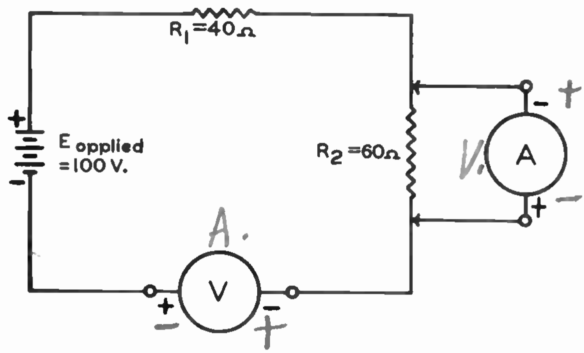
SCREEN GRID—A grid placed between the control grid and plate of an electron tube to screen the control grid electrically from the plate.

SECONDARY EMISSION—Electrons liberated from the plate due to the impact of the electrons arriving from the cathode.

SUPPRESSOR GRID—A grid placed between the screen grid and plate in a tube. Often it is connected to the cathode, and its function is to suppress the secondary emission by repelling the dislodged electrons, thus forcing them back into the plate.

TETRODE—[TET rohd]—An electron tube with four active electrodes.

WORK DIAGRAM



Ammeter scale

0-2 ampere

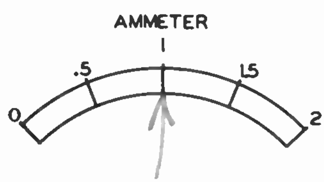
Voltmeter scale

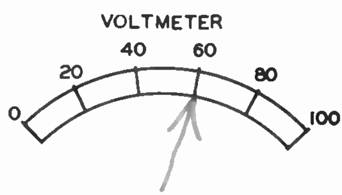
0-100 volts

(a) What is wrong with the above diagram?

(b) Using the same symbols, draw the circuit correctly so that V measures the voltage across R_2 and A measures the current in R_2.

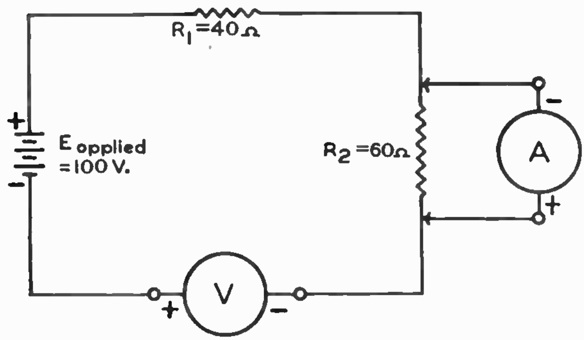
(c) On the scale faces of the ammeter and voltmeter, show the approximate position of the meter pointer for correct measurements.





When you have finished, check with the answers on the back of the fold-out sheet.

WORK DIAGRAM SOLUTIONS

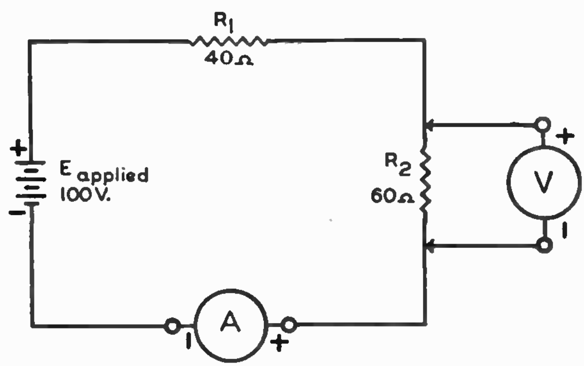


Ammeter scale
0-2 ampere
Voltmeter scale
0-100 volts

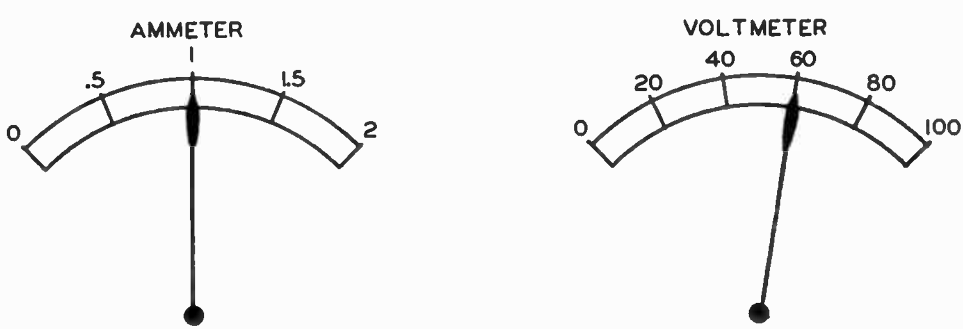
(a) What is wrong with the above diagram?

The voltmeter and ammeter are in exchanged positions. The polarity of the meters terminals are reversed.

(b) Using the same symbols, redraw the circuit.



(c) On the scale faces of the ammeter and voltmeter, show the approximate position of the meter pointer for correct measurements.



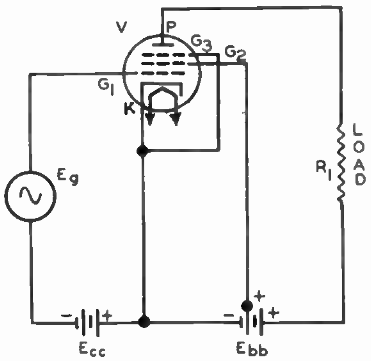


FIGURE 6

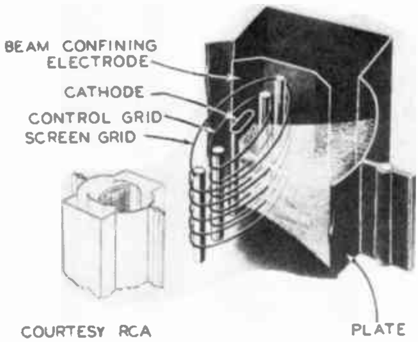
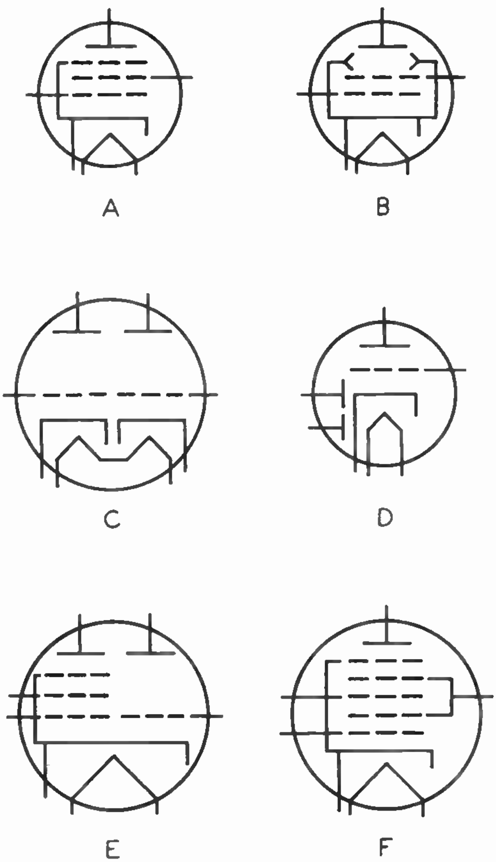


FIGURE 7



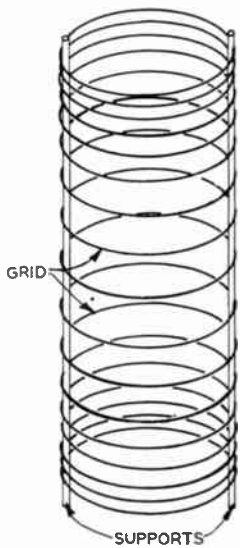


FIGURE 9

FIGURE 8

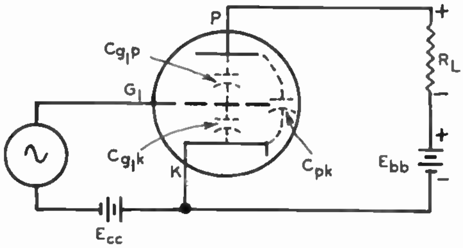


FIGURE 1

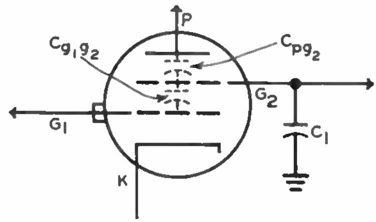


FIGURE 2

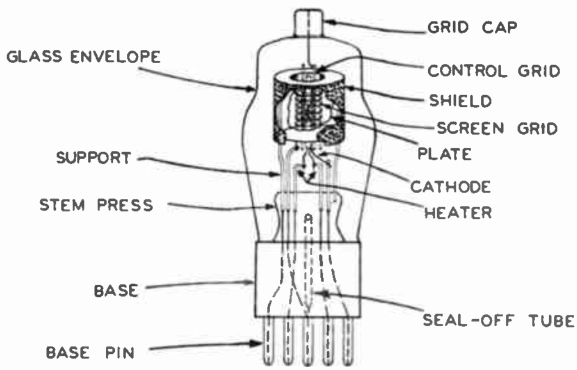
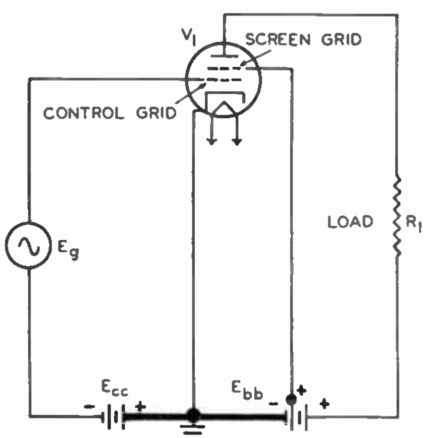


FIGURE 3



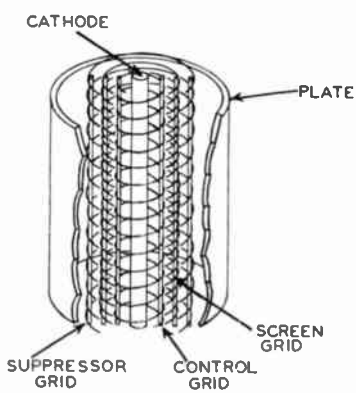


FIGURE 4

FIGURE 5

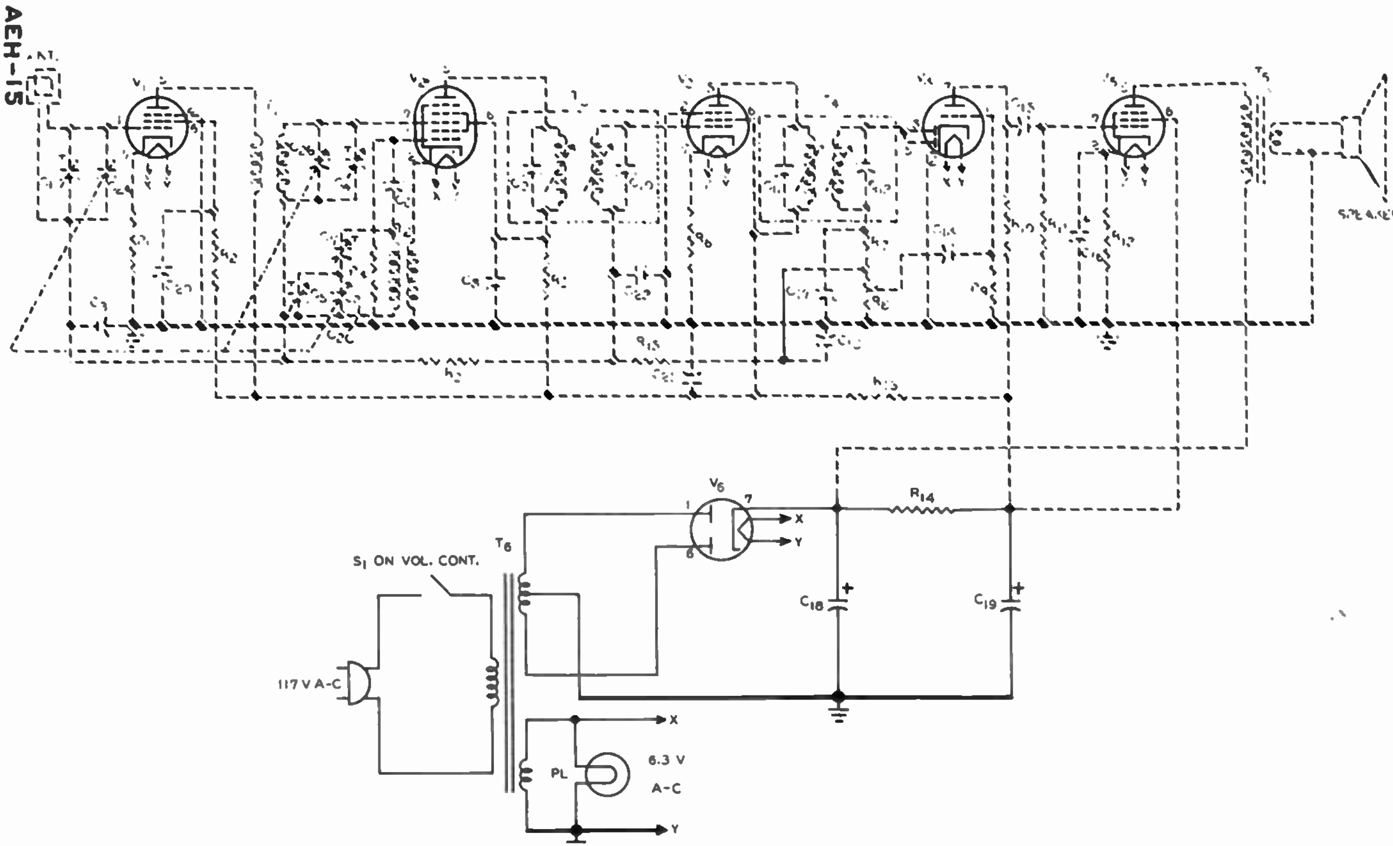

AEH-15
SPEAKER
V6
R14
S1 ON VOL. CONT.
T6
C18
C19
117 V A-C
PL
6.3 V
A-C
X
Y

FIGURE 10

FROM OUR *Director's* NOTEBOOK

INITIATIVE

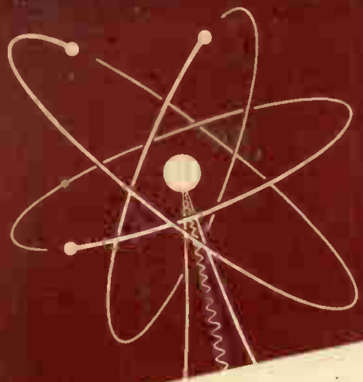
Elbert Hubbard once said: The world bestows its big prizes, both in money and honors for but one thing. And that is Initiative. What is Initiative? I'll tell you: It is doing the right thing without being told. But next to doing the thing without being told is to do it when you are told once. Those who can do this get high honors, but their pay is not always in proportion. Next, there are those who never do a thing until they are told twice: such get no honors and small pay. Next, there are those who do the right thing only when necessity kicks them from behind, and these get indifference instead of honors, and a pittance for pay. This kind spends most of its time polishing a bench with a hard-luck story. Then, still lower down in the scale than this, we have the fellow who will not do the right thing even when some one goes along to show him how and stays to see that he does it; he is always out of a job, and receives the contempt he deserves, unless he happens to have a rich Pa, in which case Destiny patiently awaits around the corner with a stuffed club. To which class do you belong?

Yours for success,

W. C. DeVry

DIRECTOR

PRINTED IN U.S.A.



AMPLIFIERS

Lesson AEH-16B

DeVRY Technical Institute
4141 W. Belmont Ave., Chicago 41, Illinois
Formerly DeFOREST'S TRAINING, INC.

-16

AEH-16B

AMPLIFIERS

4141 Belmont Ave.

Chicago 41, Illinois

ELECTRONICS TELEVISION DTI DeVRY Technical Institute

ELECTRONS PILOT AIRCRAFT

Once the desired altitude is obtained and the course established, the air line pilot flips a switch and then relaxes while an electronic pilot flies the plane. Flying conditions change from time to time, but the predetermined altitude, speed, and direction are maintained by the equipment which automatically compensates for the changing conditions.

So dependable is this operation, engineers seriously predict that, in the near future, once an airplane is "checked out" on the runway, pressing a button in the control tower will cause the plane to automatically take off, assume course, and land at the chosen destination.

This is only one example of the many robot controls possible with electronics. Familiar examples in the home are the automatic pop-up toaster and the washing machine which, unattended, washes, rinses, and drys clothing.

Fundamentals

AMPLIFIERS

Contents

On some street cars there is the sign, "Pay as you enter". It would be a good thing if that sign were pasted over every career in life. For you get only what you pay for, and pay for in advance.

In any calling of life, the money, or study, or pains, or whatever it is, must first be paid before the rewards come.

—Dr. Frank Crane

AMPLIFIERS

One important reason for the enormous growth of electronics is the almost unlimited speed at which the tubes and circuits can operate. For example, the small spot of light which illuminates the screen of a 21 inch television receiver travels at an average speed of nearly 13,000 miles per hour. But that is not all. During its movements across the screen, to reproduce the light and dark areas of the picture, the light intensity of the spot may vary as often as four million times per second.

In the form of electric energy, these variations are expressed as a-c frequencies in terms of cycles per second. When converted to sound energy, frequencies from about 15 cycles to 20,000 cycles affect human ears, and therefore, can be heard. These are called audio frequencies. There are no exact or definite limits to the range of audio frequencies, because the response of human hearing varies considerably for different individuals.

Designed only for speech, the telephone systems operate on frequencies from 300 to 3,000 cycles per second. To reproduce both speech and music, many sound recordings and radio broadcast programs include frequencies from about 50 to 5,000 cycles per second. Although 14,000 cycles per second often is regarded as the upper audio frequency limit for the average listener, much higher frequencies are necessary for high fidelity reproduction.

Just as important, but not so well known, in industry there are many changes of temperature, pressure, weight, movement, and speed which occur at these low audio frequencies. By means of energy converters similar to the headphone and loudspeakers described in a previous lesson, these changes are converted to corresponding electric voltages or currents.

All of these changes provide desirable applications for automatic electronic control but, in practically every case, the original electric frequencies produced are so small that they must be amplified sufficiently to operate even a meter much less relays, motors, or other mechanisms.

Modern radio and electron applications are based on the important fact that very weak signals can be built into strong ones. A majority of the tubes used in electronics do just this. Although some amplifiers amplify substantially a single frequency or a narrow range of frequencies, for many applications the amplifier is designed to operate efficiently over a range of frequencies. For example, all of the audio signals generated in a microphone must be amplified until they can operate loud speakers, recording devices, radio or television transmitters.

In the previous lessons on triodes, tetrodes, and pentodes, we described how an electron tube amplifies voltage changes or signals applied to the grid. At the same time we pointed out the need for a d-c voltage or bias on the grid so that the tube operated properly about midway between cutoff and saturation. We also showed a radio receiver where the signal is amplified by one tube and then passed on to the next. However, we did not stop and explain to you how the d-c voltage needed to bias each tube was produced nor what was necessary to pass the signal from the plate circuit of one tube to the grid of the next. Since both of these are important in practical amplifier circuits, we will stop and consider these needs now.

GRID BIAS METHODS

Since the GRID BIAS determines the operating point of a tube, it is very important that whatever method is used maintains this negative voltage at the desired voltage in order to have proper operation. At the same time, the method must be simple to be practical. Four methods are shown in Figure 1. Although each method differs from the others in certain details, basically they all develop and apply a fixed negative voltage on the grid with respect to the cathode.

Separate Supply

Where a highly stable grid voltage is essential, a separate battery can be used as shown in Figure 1A. When used for this purpose it is called the **C battery.** Normally, it is made up of a number of 1.5 volt dry cells connected in series to deliver the required voltage. Some batteries have a number of terminals making available several different voltages from 4½ to 22½ volts, or more. By connecting the positive terminal to ground as shown in Figure 1A, and connecting the bottom of

An amplifier is used in practically every electronic application. This particular unit is capable of supplying sound from a microphone, radio, or phonograph to a large audience.

Courtesy Altec Lansing Corp.

the grid resistor R_{in} to a selected negative terminal the required bias is applied to the grid.

In most operations, the grid of the tube draws little or no current. Therefore in these applications a "C" battery in a bias circuit like that of Figure 1A, lasts as long as its "shelf life". Also, since little or no current is drawn from the battery, the cells are very small. This makes for a compact battery.

Tubes designed for power amplifier applications are usually larger than other amplifier tubes to make them more capable of dissipating the heat generated.

Courtesy General Electric Co.

For some large electronic equipment such as a broadcast transmitter, the grid is driven positive by the alternating voltage, and the grid draws an appreciable current. This grid current would soon run the battery down. Therefore, a separate power supply or small d-c generator is used sometimes in place of the battery to supply this fixed bias voltage. The positive terminal of the "C" supply connects to the cathode and the negative terminal to the grid resistor.

When a battery or other independent source of d-c is connected in the position of E_{cc} Figure 1A, it is called a **fixed bias.** It is used in amplifiers where the required operating bias is near or beyond plate current cutoff.

Cathode Bias

To eliminate the independent voltage source in the grid circuit, many amplifiers employ the self-bias method shown in Figure 1B. With no signal at the input to the amplifier stage, the tube is said to be in its "static" condition. That is, the plate current remains at a steady or d-c value. The path of the plate current is from the negative terminal of the "B" supply (B−), up through the cathode resistor R_1, from the cathode to the plate within the tube, and then through the plate load R_L back to the positive terminal of the plate supply (B+).

Since the electrons flow from the ground to the cathode end of the resistor, the voltage across R_1 is positive at the cathode with respect to the ground end. Then with the grid of the tube connected to ground through the grid resistor R_{in}, the grid is at a point negative with respect to cathode.

That is, the cathode is positive with respect to ground and the grid. Thus, the voltage developed across resistor R_1 in the cathode circuit serves to bias the tube grid.

When an alternating voltage is applied to the tube grid, the plate current fluctuates. Since the plate current determines the voltage across cathode resistor R_1, the grid bias varies with this current. Generally, this unsteady grid voltage is undesirable, and so it is necessary to connect capacitor C_1 across R_1 to eliminate the variation.

With a steady current, C_1 charges to the fixed voltage across R_1. When the current decreases, C_1 has to discharge through R_1 before the voltage can decrease, but not enough electrons discharge through R_1 to permit an appreciable change in voltage before the current increases again.

Thus, the charge and discharge action of the capacitor tends to maintain a constant voltage across R_1 in spite of plate current changes. It has the effect of passing the alternating portion of the plate current around the resistor and for this reason it often is called a **cathode bypass capacitor.**

The **cathode bias** method avoids the bulk and expense of a separate "C" supply. However, it is

This tape recorder incorporates an amplifier to build up the signals from a microphone or radio until large enough to operate the "recording head".

Courtesy Brush Development Co.

not good for circuits that must be operated at cut-off. A large grid voltage is required to cut the tube off but when the tube is cutoff no plate current exists to produce the bias.

Grid Leak Bias

Another method of self bias employs a resistor and capacitor combination in the grid circuit of the stage as shown in Figure 1C,

Amplifiers are used in radios to build up the signal until enough power is available to operate a loudspeaker like the one pictured here.
Courtesy Jensen Mfg. Co.

using R_1 and C_1. When the a-c input signal is in the positive half of its cycle, the grid, acting as a diode plate, draws a small current which charges capacitor C_1 to a negative polarity at the grid end. During the negative half of the a-c input signal cycle, since electrons cannot flow from the grid to cathode the capacitor discharges from its negative terminal through resistors R_1 and R_{in} back to its positive terminal. The direction of this discharge current is such that the grid end of resistor R_1 remains negative with respect to the other end which connects to the ground and cathode.

In order to maintain a fairly constant voltage drop for biasing, the capacitance of C_1 is so chosen that it will charge quickly with the grid current, and a high resistance is selected for R_1 so that the C_1 charge thus leaks off slowly. This method is called **grid leak bias.**

Grid leak bias is seldom found in amplifiers operated midway between cut-off bias and saturation. These are circuits where the signal in the plate circuit should be just like the one on the grid except amplified. Since grid leak bias depends on the grid swinging positive on the a-c peaks to charge C_1, it operates only in circuits where the signal is changed or distorted.

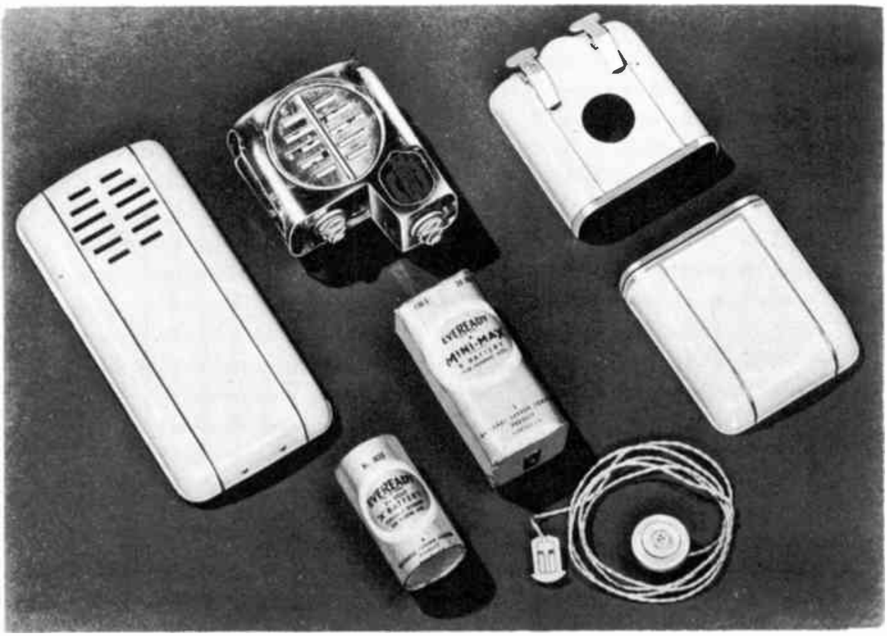
Negative Leg Bias

A form of self and fixed bias, called **negative leg bias,** is shown in Figure 1D. In this circuit, the path of the total plate current of several or all other tubes is from the negative terminal of the plate supply (B−) through R_1 to ground. This develops a voltage across R_1 with a polarity which is positive at the ground end and negative at the other end where the grid resistor R_{in} is connected. This places a negative potential on the grid with respect to the cathode, thereby biasing the tube. As in the other self-bias methods, capacitor C_1 prevents a-c voltage changes from appearing across the bias resistor R_1.

Practically all of the electronic equipment uses one of these four types of bias. Although the method used in Figure 1A can be used in practically every circuit, it is expensive. The method that costs the least and still does the job is preferred and in describing various circuits in this program, we shall point out the bias method and why it is used.

TYPES OF COUPLING

In an earlier lesson, electron tubes were described as being able to produce a large variation of voltage in the plate circuit for a small variation in grid voltage. This process is called amplification and the circuits used for this purpose are referred to as ampli-



Enclosed in the metal case just above the "B" battery is the small amplifier required to build up the signal picked up by the microphone behind the grill work until it is sufficient to operate the earphone in the lower right corner.

Courtesy Paravox, Inc.

fier circuits or amplifiers. Their output voltage may be further amplified by impressing it upon the grid circuit of another tube. Each tube and its associated circuits are known as a **stage,** and when a SIGNAL passes from one stage to the next in sequence, such an arrangement is called **cascaded stages.** For instance, V_1 and V_2 of Figure 2, 3 or 4 are cascaded stages.

The passing of the signal from one amplifier stage to another is called coupling. For cascade operation coupling is quite important. Three basic methods used in amplifiers are:

1. Resistance coupling
2. Impedance coupling
3. Transformer coupling

Resistance Coupling

Figure 2 shows a coupling arrangement consisting of resistors R_2 and R_3 and capacitor C_2. Usually this arrangement is called a **resistance coupled amplifier,** although some call it RESISTIVE-CAPACITIVE COUPLING. The circuits of tube V_1 are the same as explained for Figure 1B except that the plate load resistor is labeled R_2 instead of R_L. The grid and cathode circuits of V_2 are the same as those at V_1.

Capacitor C_2 connects between the plate of V_1 and the grid of V_2 and has two distinct functions. One is to block the positive d-c plate voltage of tube V_1 from the grid of tube V_2. The other function is to transfer or pass the amplified a-c signal from the plate of V_1 to the grid of V_2.

Amplifiers are important in these nuclear laboratory instruments used to measure the radioactivity of a sample in front of the counter tube in lower left corner.

From DTI Labs.

When the circuit is in operation but with no input signal voltage, electrons flow from B− through R_1, through V_1 from cathode to plate, and back to B+ through R_2. Also, there is a path from B− through R_3, to C_2. There is no continuous current in this path but electrons will flow from B− through R_3 only until C_2 is charged. While C_2 is charging, electrons will leave it and flow along with the V_1 plate current through R_2 to B+.

Under these conditions, C_2 is charged to the plate supply voltage minus the voltage across the plate load resistor R_2. When capacitor C_2 is fully charged, there is no current through or voltage across R_3, the grid resistor of tube V_2. At this same time, capacitor C_1 charges to the voltage across R_1.

Suppose now, a positive alternation of signal voltage across R_{in} drives the grid of V_1 less negative and thereby causes an increase of plate current. According to Ohm's Law, the increase of current causes an increase of voltage across R_1 and R_2. However, as explained for Figure 1, the action of capacitor C_1 tends to prevent a change of voltage across R_1, but the increased voltage across R_2 reduces the plate voltage and also the voltage across C_2 and R_3 in series.

With reduced voltage across it, C_2 starts to discharge and the path of the discharge current is down through R_3 to B−, and through R_1, and V_1 back to C_2. This discharge current causes a voltage across R_3 which makes the grid of V_2 more negative with respect to its cathode.

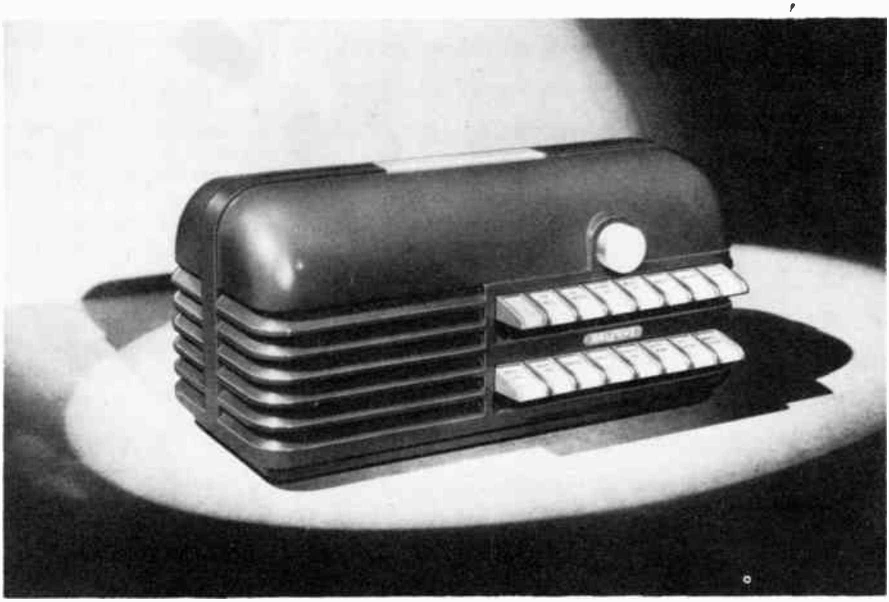
When the input signal voltage reduces or reverses polarity on the negative alternation so that the grid of V_1 becomes more negative with respect to the cathode, the plate current is reduced. With less plate current the voltages across R_1 and R_2 are reduced. Again, the action of C_1 tends to maintain a constant voltage across R_1 but the reduction of voltage across R_2 allows an increase of voltage across C_2.

With an increase of applied voltage, capacitor C_2 charges and, as explained previously, the path of the charging current is from B− through R_3 to one plate of C_2 and from the other plate through R_2 to B+. The voltage across R_3, caused by the charging current, makes the grid of V_2 more positive with respect to its cathode. Thus, by causing capacitor C_2 to charge and discharge, the a-c component of the plate current in V_1 produces an a-c voltage across R_3 and the grid-cathode circuit of V_2. For good results, the resistance of the plate resistor R_2 should be fairly high and capacitor C_2 must have sufficient dielectric strength to prevent a breakdown which would allow d-c plate voltage from V_1 to leak through to the grid of V_2.

Changes in frequency have practically no effect on the voltage across a resistor, therefore, the FREQUENCY RESPONSE of resistance coupled amplifiers is fairly uniform over a frequency range which makes for good quality sound reproduction. With the efficient performance of modern amplifying tubes, it is possible to achieve economical operation at relatively low plate voltage, and therefore, the voltage drop in the plate load resistor is not a serious disadvantage. The coupling units consisting of resistors and capacitors are compact, light in weight, and relatively inexpensive. Hence resistance coupling makes for a good, economical amplifier.

Impedance Coupling

In the circuit of Figure 3, inductor L_1 replaces resistor R_2 of Figure 2 and, with coupling capacitor C_2 and grid resistor R_3, it forms what is known as an **impedance coupled amplifier.** The inductor is made of a number of turns of wire wound on a form. Some have an iron core as indicated in Figure 3. Due to its self-inductance, the coil presents a high opposition to the frequency



Amplifiers are used in office inter-communication systems.
Courtesy Bell Sound Systems, Inc.

variations of the plate current but has a low resistance to direct current.

In general, the action of impedance coupling is much like that of resistance coupling but the lower d-c resistance of the inductor causes a smaller loss of power supply energy. However, since the self-inductance of inductor L_1 varies with frequency, for equal input signal voltages, the voltage developed across it varies with changing frequency. Therefore, the response of the impedance coupling circuit is not uniform over the same range as for resistance coupled amplifiers. Another disadvantage of this coupling method is that an inductor with a large number of turns and a laminated core, is heavy and relatively expensive.

Transformer Coupling

Figure 4 shows a **transformer coupled amplifier** arrangement using an iron core transformer T_1. The transformer primary is in series with the plate circuit of tube V_1, while the secondary is in the grid circuit of tube V_2. Changes in primary current induce a corresponding voltage in the secondary. In addition to the amplifying action of the tubes, the transformer can be made to step up the signal voltage nearly directly proportional to the turns ratio of the windings.

However, there is a limit to the number of times a transformer can step up the signal voltage. Practical considerations normally keep the step-up ratio relatively low. For proper operation, the primary must present sufficient inductance at low audio frequencies, and therefore must be wound with a comparatively large number of turns.

To obtain a step-up ratio, the secondary winding must have more turns than the primary, but as turns are added, the "distributed capacitance" between the adjacent turns and the various layers increases. That is, due to the closeness of adjacent turns, they act as plates of small capacitors and the more turns, the greater the number of small capacitors. These capacitors tend to short the signal across the secondary as the frequency increases. Such shorting action is undesirable because it prevents the signal from reaching the grid of tube V_2 at the maximum voltage. Thus, the number of primary turns must be sufficient to provide proper opposition due to self-inductance at low frequencies, while the number of secondary turns must be limited to keep the shunting effect of the capacitors low at the higher frequencies. To satisfy both requirements, the transformer turns ratio seldom exceeds 3 to 1.

Since transformers are more expensive than resistance coupling, they are not used unless some special circuit requirement can be better met by the transformer. For example, an electron tube produces a large voltage change and a moderate current but a loudspeaker requires a large

Tubes designed to deliver very powerful signals must use fins like these or a water cooling system to keep from overheating.
Courtesy Amperex Electronic Corp.

current and small voltage. Here is where the transformer coupling is very useful. As explained in a previous lesson by using fewer turns in the secondary it has a larger current and smaller voltage than the primary. PRACTICALLY ALL LOUDSPEAKERS ARE COUPLED TO THE LAST TUBE IN THE AMPLIFIER BY MEANS OF THE TRANSFORMER.

AMPLIFIERS IN A RADIO

Figure 6 is the schematic diagram of the radio receiver introduced in an earlier lesson.

Signals from the broadcast station are intercepted by the antenna and passed from stage to stage until it reaches the loudspeaker. Among other things each tube that it passes through amplifies the signal.

The path that the signal takes is illustrated by the block diagram in Figure 5. Since the power supply does not handle this signal, it has been omitted. The three cornered symbol represents the antenna. The signals broadcast by the radio stations are intercepted by it and fed to the "RF-AMP".

Every broadcast station is assigned a particular frequency to radiate its program on. Since high frequencies are required to radiate for an appreciable distance, all frequencies above the audio range are often referred to as radio frequencies (r-f) and any amplifier designed to amplify these frequencies is called an r-f amplifier.

Since it would not be desirable to receive signals from all stations at the same time, the one desired is selected in the "RF AMP." When you adjust the tuning knob on a receiver it rotates a variable capacitor that determines which station's frequency is tuned in. Since we are now considering amplification, how this selection is accomplished is described in another lesson.

This selected frequency is fed into the converter stage. Here, the broadcast station frequency is changed or converted into a lower frequency within the radio. This is done because the radio amplifies this second frequency better than the one from the broadcast station. The converted frequency is referred to as an intermediate frequency and is amplified by the intermediate frequency amplifier, abbreviated IF AMP.

In the fourth stage, this amplified intermediate frequency signal is "detected" by a rectifier and amplified. Due to the formation of the signal broadcast, the rectified signal is the same as that produced by the sound at the broadcast studio. These are called audio frequencies, and they are amplified by the audio amplifier, AUDIO AMP. Finally, these amplified audio frequencies are again amplified by a power amplifier, POWER AMP, which drives the loudspeaker.

Certainly, the electron tube is a magic device, taking sounds in a room miles away and putting them into your living room. And this is not all, in television both the sound and the scene are transferred into your living room by a very similar process.

Referring again to Figure 6, among other things each of the tubes, except rectifier V_6, amplifies the signal before passing it on to the next stage.

Car radios have a circuit similar to Figure 6. Courtesy Motorola, Inc.

V_1 uses cathode bias produced by resistor R_1 in the cathode circuit. However, there is no cathode bypass capacitor. Since the signal is very small at this point, R_1

doesn't have to be large to produce sufficient bias to keep the grid from going positive during the positive peaks of the signal. As a result very little undesirable effect is produced by leaving the capacitor off. In fact, as you will find out in a later lesson and your laboratory projects it often improves the operation of high frequency stages. T_1 is the transformer coupling between V_1 and V_2. Few turns and no core are needed in the transformer at radio frequencies, therefore, it is a compact, economical coupling method.

V_2 uses grid leak bias developed by C_6 and R_4. Again the signal is coupled by a transformer, T_3, to the grid of V_3. Like V_1, V_3 uses cathode bias developed across R_6 and without a cathode bypass capacitor. Transformer T_4 couples the output of V_3 to a rectifier circuit called the detector which uses plates numbered 5 and 6 and the cathode of V_4. The fluctuating voltage across potentiometer R_8 is developed by this rectifier.

Depending on the position of the sliding contact on R_8, more or less of this voltage is coupled by C_{14} to the grid of the triode in V_4. Therefore R_8 is the volume control, and the lower part of R_8, C_{14}, and R_9 provide resistance coupling for the signal.

Although V_1, V_2 and V_3 have other functions besides amplifying the signals, the triode section of V_4 and the beam power tetrode V_5 are just amplifiers.

Triode V_4 in Figure 6 uses a unique bias method, called CONTACT BIAS. Due to its closely spaced grid wires, a number of electrons going from cathode to the plate strike the grid and thus make it negative. If R_9 is a very high resistance these electrons leak off slowly, and therefore the grid remains sufficiently negative to keep the signal from making the grid positive.

Since the bias voltage is developed by the electrons coming in contact with grid wires this method is called CONTACT BIAS. Although all tubes develop this effect, usually it is far too small to use. Only with high mu tubes and small signal voltages is it useful.

Plate load resistor R_{10}, capacitor C_{15}, and grid load resistor R_{11} resistance couple the amplified output of V_4 to the grid of V_5. V_5 is cathode biased by R_{12} which is bypassed by C_{16} to prevent undesirable fluctuations in the bias.

Notice that the plate of V_5 is connected through the primary winding of T_5 directly to the rectifier output while the screen grid is connected to the output of the pi filter consisting of C_{18}, R_{14}, and C_{19}. T_5 couples the amplified signal for V_5 plate to the loudspeaker.

In this lesson only amplifier circuits were described. There is a multitude of electronic applications where these amplifier circuits are used, but these are not the only uses for electron tubes. From what we have said about the operation of the radio receiver in Figure 6, you know that these tubes can perform several other major operations. What some of these circuits are and how they are applied to this radio receiver are described in the next lesson.

IMPORTANT DEFINITIONS

AMPLIFIER—[AM pli *figh* er]—A circuit designed and used to increase the current, voltage, or power of the signal.

"C" BATTERY—A low voltage-low current battery used as a source of fixed voltage for grid bias.

CASCADE STAGES—[kas KAYD STAY j's]—A number of stages so connected that the output of one impresses the signal on the input of the next.

CATHODE BIAS—A bias voltage obtained by tube current through a resistor in the cathode circuit, making the cathode positive in respect to grid.

CATHODE BYPASS CAPACITOR—A capacitor connected across the cathode resistor to maintain a steady voltage drop across this resistor.

CONTACT BIAS—The bias developed across a high resistance grid load resistor due to a current caused by electrons bombarding the grid.

COUPLING—[KUHP ling]—The association between two related circuits that permits the transference of energy from one to the other.

FIXED BIAS—A bias voltage obtained from a battery, power supply or generator, which is fixed in value and not determined by tube current.

GRID LEAK BIAS—A bias voltage developed across a resistor-capacitor combination in the grid circuit of an electron tube by grid current flow.

IMPORTANT DEFINITIONS—(Continued)

IMPEDANCE COUPLED AMPLIFIER—A type of low frequency amplifier in which an inductor forms the plate load of one stage, and the signal is transferred from the plate of one tube to the grid of the next by means of a capacitor.

NEGATIVE LEG BIAS—A bias voltage developed across a resistor in the negative leg of the "B" supply by total tube or circuit current.

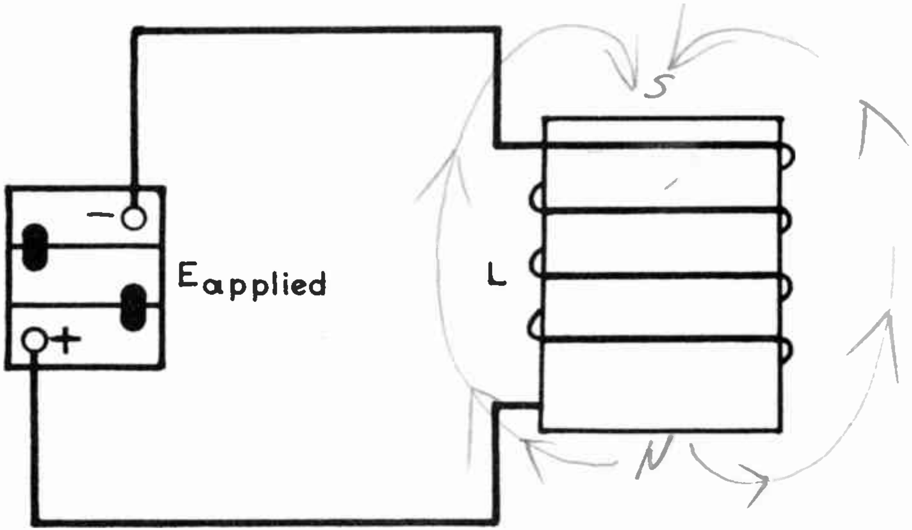
RESISTANCE COUPLED AMPLIFIER—A type of low frequency amplifier in which a resistor forms the plate load of one stage, and the signal is transferred from the plate of one to the grid of the next stage by means of a capacitor. Sometimes it is referred to as a resistance-capacitance coupled amplifier.

STAGE—All of the components of a circuit containing one or more tubes with one input and a single output.

TRANSFORMER COUPLED AMPLIFIER—An amplifier in which the signal in the plate circuit of one stage is coupled to the grid of the next by means of a transformer.

WORK DIAGRAM

(a) With arrowed lines, indicate the direction of magnetic flux lines around the coil, and mark the magnetic poles.



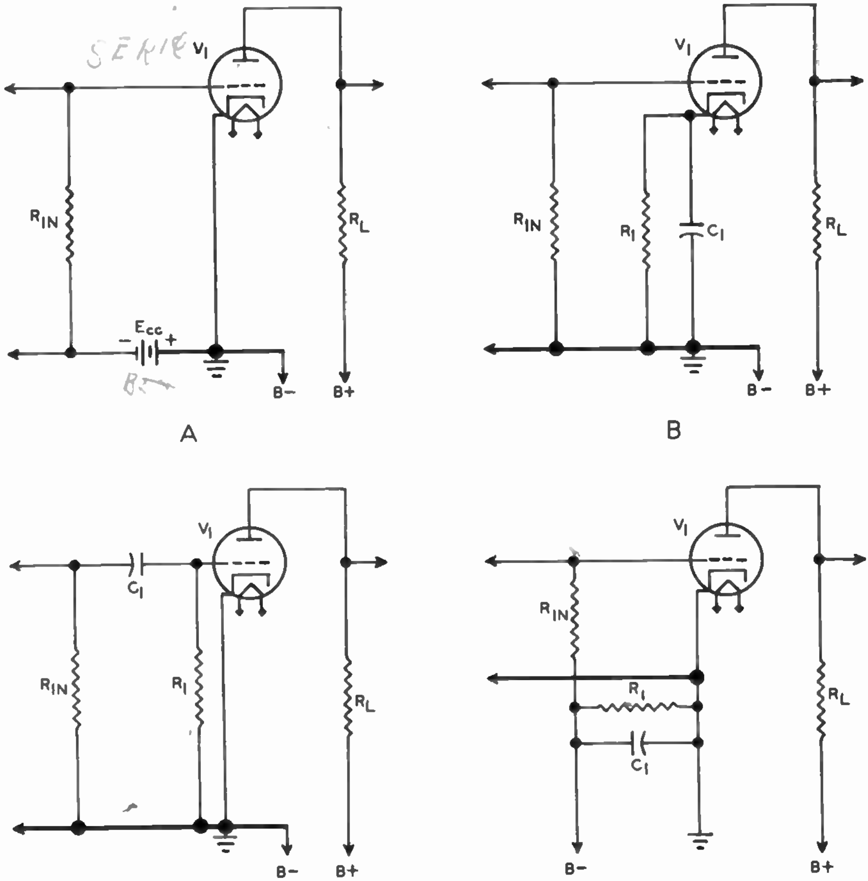


FIGURE 1

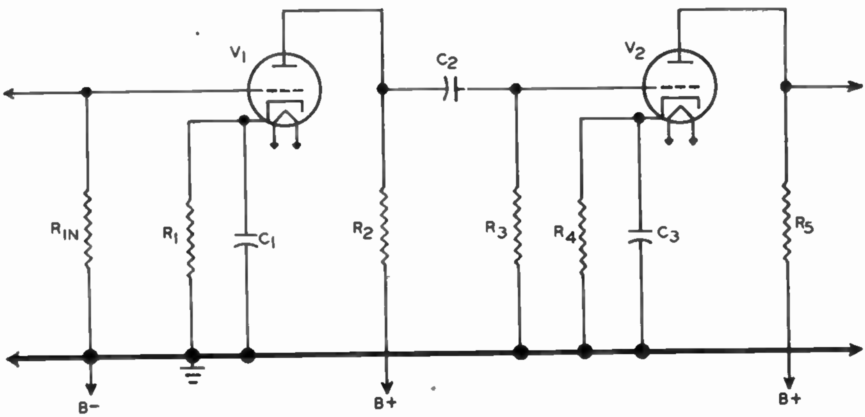


FIGURE 2

IMPEDANCE Coupling

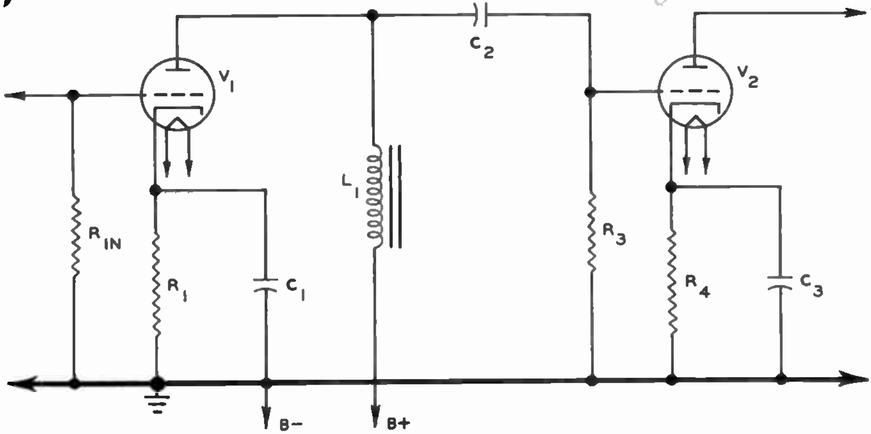


FIGURE 3

Transformer Coupling

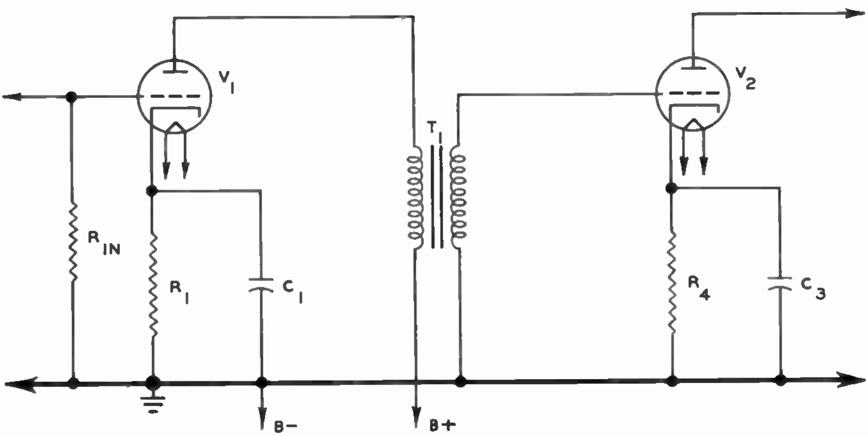
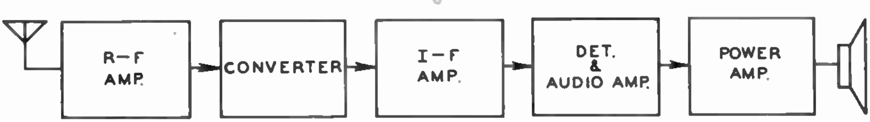


FIGURE 4

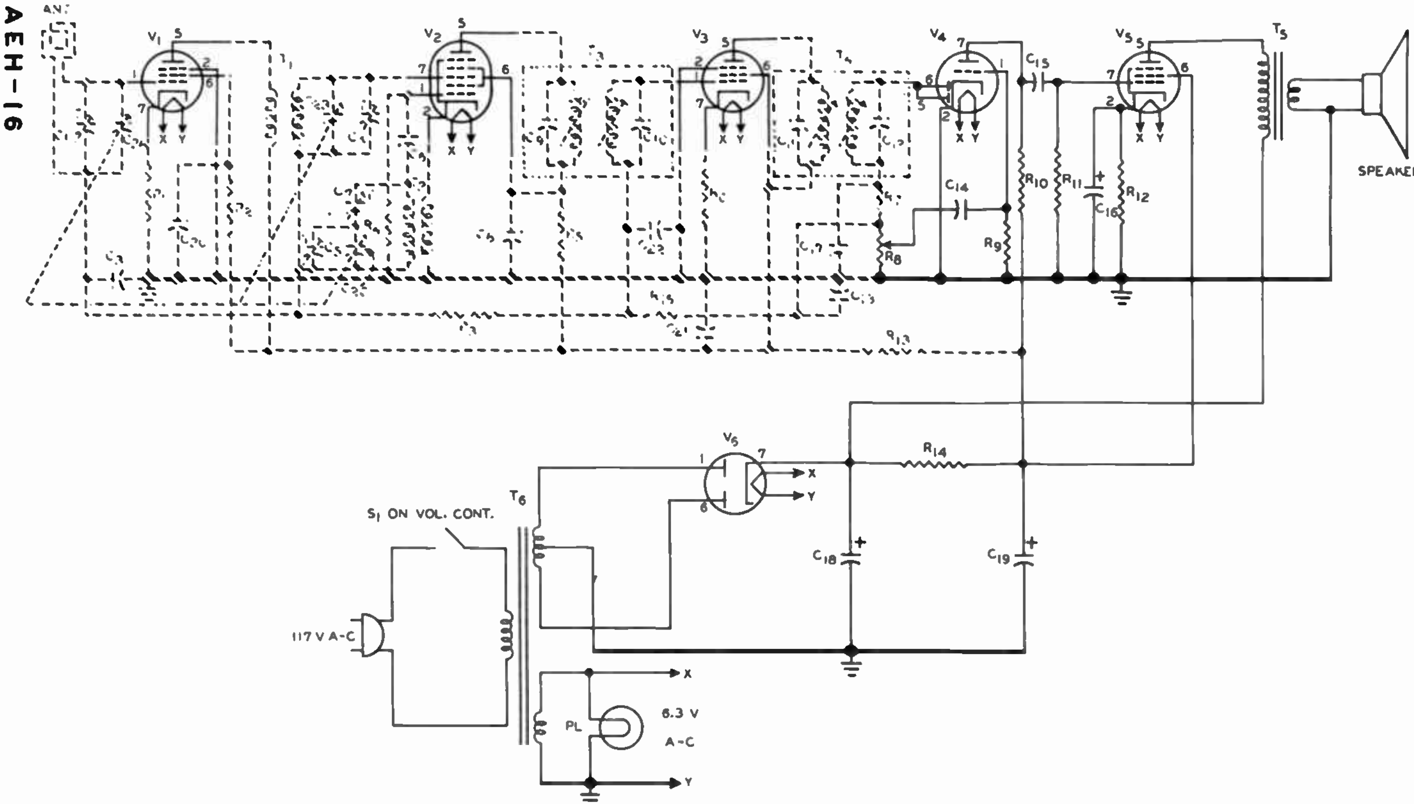
Radio frequencies

intermediate



Amplifier

FIGURE 5



AEH-16
ANT
V1
V2
V3
V4
V5
V6
T5
T6
C14
C15
C16
C18
C19
R8
R9
R10
R11
R12
R13
R14
SPEAKER
S1 ON VOL. CONT.
117 V A-C
PL
6.3 V
A-C

FIGURE 6

FROM OUR *Director's* NOTEBOOK

A FRIEND

"What is a friend? I will tell you. It is a person with whom you dare to be yourself. Your soul can go naked with him. He seems to ask you to put on nothing, only to be what you are. He does not want you to be better or worse. When you are with him you feel as a prisoner feels who has been declared innocent. You do not have to be on your guard. You can say what you think, so long as it is genuinely you. He understands those contradictions in your nature that lead others to misjudge you. With him you breathe free. You can avow your little vanities and envies and hates and vicious sparks, your meanness and absurdities, and in opening them up to him they are lost, dissolved on the white ocean of his loyalty. He understands. You do not have to be careful. You can abuse him, neglect him, tolerate him. Best of all you can keep still with him. It makes no matter. He likes you. He is like fire that purges all you do. He is like water that cleanses all that you say. He is like wine that warms you to the bone. He understands. You can weep with him, laugh with him, sin with him, pray with him. Through and underneath it all he sees, knows and loves you. A friend, I repeat, is one with whom you dare to be yourself."

Yours for success,

W. C. DeVry

DIRECTOR

PRINTED IN U.S.A.

METER CIRCUITS

Lesson AEH-18B

DeVRY Technical Institute

4141 W. Belmont Ave., Chicago 41, Illinois

Formerly DeFOREST'S TRAINING, INC.

METER CIRCUITS

4141 Belmont Ave.

Chicago 41, Illinois

ELECTRONICS TELEVISION
DTI
DeVRY Technical Institute

ELECTRONS SOLVE PROBLEMS

In the course of a military action, an artillery battery is to lay down a barrage immediately at a point many miles from its position. Reference to a set of charts permits the proper trajectory to be determined quickly, and in a few minutes the shells are landing on the target. Calculation of a trajectory consists of an involved and time consuming series of mathematical computations, to simplify which, the set of charts has been worked out with the aid of an electronic calculating machine.

Much of the success in modern research and development depends on results obtained from elaborate mathematical computations. An expert mathematician could not complete some of these problems in a lifetime yet an electronic calculator or "brain" can solve them in two or three weeks. Applications in business include calculation of insurance premiums, and machines which keep books, bill the customer, record payments, or maintain perpetual inventory.

Fundamentals

METER CIRCUITS

Contents

If the control of one's self is the greatest of goals, the control of one's thoughts is still greater, for what a man thinketh, so he is.

—Dr. Frank Crane

METER CIRCUITS

Electric meters are the eyes through which the radio, television, or other electronic technicians see their circuits. How true this is becomes apparent when you compare the mechanic's job to an electronic technician's. The mechanic can watch the machine in action. He can see what is stuck, broken, or slips. On the other hand, look into the chassis of a radio receiver which shows most of its parts. Other than a warm tube there is no activity to see. Only with a meter can the technician "see" what voltage, current, or resistance is wrong.

To be a good pilot, you must know how an airplane flies. It isn't enough to know which controls do which, you must know how each one does its duty. The same holds true with meters. Although you can use one by knowing which knobs to adjust and how to read the scale, the real competent use of the meter comes in knowing what is inside. With this knowledge you can know the advantages and disadvantages of the meter, or its use in a particular circuit. Therefore, this lesson describes how a meter operates.

MEASURING THE MAGNETIC EFFECT

By a simple experiment, the presence of a magnetic field around a current carrying wire can be indicated by moving a magnetic compass around the wire. There are two important points to remember here. First, the compass needle points in the direction of the magnetic lines of force. Second, the strength of the magnetic field varies with the current in the wire.

These actions can be used to measure current by means of the simple arrangement shown in Figure 1. A magnetic compass is placed under a wire and as long as there is no current in the wire, the compass needle will line up with the magnetic field of the Earth and point toward the North as shown in the Figure. The wire is then turned until it is parallel to the compass needle and directly above it.

The left thumb rule shows that, regardless of its direction, current in the wire will produce a magnetic field with lines of force that cut square across or at right angles to the compass needle. Thus, with current in the wire, the resulting magnetic field will tend to turn the compass needle away from its north position. The turning movement of the needle varies with the strength of the electromagnetic field which in turn, varies with the current in the wire.

To make a measuring instrument, or meter, out of this arrangement, the movement or deflection of the needle from its normal resting position must be calibrated by some sort of a numbered scale. To make a scale of this type, a blank sheet of paper is placed under the compass. Then with the circuit arranged so that there is exactly one ampere of current in it, a number 1 is written in line with the compass needle end. Next, the circuit is rearranged so that there is exactly 2 amperes in it and a number 2 is written in line with the new needle position.

This process can be kept up, increasing the current in the circuit and marking the points where the needle stops each time, until it is pointing squarely across the wire. Due to the direction of its lines of force the electromagnetic field is not able to move the needle further.

Reversing the current through the wire will deflect the compass needle on the other side of zero. Repeating the same procedure that part of the line is calibrated in the same way.

When the marking or calibration is complete, this arrangement can be connected in any circuit and, by watching at which number the compass needle stops, the number of amperes in the wire will be known. This arrangement is the simplest kind of meter and it indicates the presence of electric currents by means of mechanical motion resulting from the magnetic effect produced by the current. Such a device is known as a galvanometer, and since it is calibrated to show the number of amperes in the wire, it also is called an ammeter. However, for everyday use, it would not prove very practical because if the compass was moved closer to or farther from the wire, the reading would vary.

There are a number of other disadvantages to an "open" meter of this kind. For measuring small currents, the magnetic field produced may not be sufficient to overcome the earth's magnetic field. In that case, the reading is highly inaccurate. Furthermore, other magnetic fields like those produced in ordinary house wiring may affect the deflection. It wouldn't be convenient to place such an arrangement for instance in a radio where there may be magnetic fields.

Meters can be built to overcome magnetic and other disturbing effects by doing two things: fixing the position of the meter with respect to the current being measured, and making it almost impossible for any outside magnetic field to change the deflection.

D'ARSONVAL METER

One of the most common, and perhaps the most reliable type of meter for direct current measurement is the D'Arsonval, in which a light weight coil of wire, supported on jeweled bearings between the poles of a permanent magnet, is rotated by the effects of an electric current in the coil. The main parts of a D'Arsonval meter are shown in the sketch of

A handy "pocketsize" multimeter ideal for service work in the home.
Courtesy Precision Apparatus Co., Inc.

Figure 2A. Here the largest part is a U-shaped permanent magnet, on the lower ends of which are shaped pole pieces of soft iron. The inner ends of the pole pieces are curved to fit the round or cylindrical piece of iron that is mounted between and quite close to them. This arrangement provides a magnetic path of all iron or steel, except for the small air gap between the pole pieces and the cylindrical center piece of soft iron, and creates a more uniform magnetic field unaffected by outside fields.

The moving coil, which carries the current, is wound on a rectangular aluminum frame that is large enough to fit over the cylindrical iron center piece but small enough to pass between the pole pieces. In order that it can turn freely, the frame is mounted on jewel bearings between the permanent magnetic poles on the general plan of Figure 2B. Thus, the position of the meter always is fixed with respect to the current it measures.

A coiled hairspring is mounted at each end of the frame and a pointer that can swing across a calibrated scale is attached to one end. The hairsprings provide flexible electric connections to the moving coil and at the same time hold the pointer on the "0" scale position when there is no current in the coil.

The entire assembly of moving coil, magnet, hairsprings, pointer, and calibrated dial, when mounted in a case with external terminals, is called a METER MOVEMENT. On the outside of the case, many meters have a small screw head sometimes marked zero set which, when rotated, compensates for slight changes of hairspring tension and resets the pointer to zero on the scale.

With current in the coil, it produces a magnetic field of its own, the N pole of which is repelled by the N pole and attracted by the S pole of the permanent magnet. The result is a force that rotates the coil against the tension of the springs. Since the strength of the permanent magnet field is always the same and the strength of the coil magnetic field varies with the current, the magnetic pull and resulting rotation varies directly with the current.

The shape of the pole pieces and the cylindrical center piece maintain a uniform magnetic field for every position of the coil. Regardless of the initial position, the same current change will move the pointer an equal distance, and therefore, the divisions on the scale are equally spaced or linear, as shown in Figure 2B.

Since the movement of the coil in a D'Arsonval meter depends on the attraction and repulsion of the coil magnetic poles by those of the permanent magnet, reversing the coil poles will cause the coil to move in the opposite direction. Thus, by reversing the current in the coil, the pointer may be moved in one direction or the other. Making use of this condition, meters may have the "0" of the scale at either end, in the center, or part way between, depending on the desired requirements.

As shown in Figure 2B, most meters have their "0" position at the extreme left and the pointer moves to the right. D'Arsonval movements usually have the correct polarity for a "left to right" swing of the pointer marked on the external terminals and this polarity must be observed when connecting the meter into the circuit.

THE OPERATION OF THE METERS of Figures 1 and 2 IS DUE TO THE INTERACTION OF TWO MAGNETIC FIELDS, one produced by a permanent magnet and the other by current in a wire or coil. The difference is that in Figure 1 the interaction of the fields causes the permanent magnet to move, that is the compass needle, whereas in Figure 2, it is the coil that moves. A reversal of current in the coil reverses the polarity of the magnetic field it produces, and therefore, its interaction with the field of a permanent magnet is reversed. As a result, the deflection of the compass needle or meter pointer reverses with a reversal of coil current.

ELECTRODYNAMOMETER TYPE METER

An ELECTRODYNAMOMETER is a moving coil indicating instrument in which the stationary magnetic field is produced by a system of fixed coils instead of a permanent magnet. As shown in Figure 3, the stationary or fixed element consists of a pair of coils, L_1 and L_2, which are connected in series and placed end to end, with a small space between them for the shaft of the moving coil or element. Depending on the application, the fixed coils may be wound with heavy wire for an ammeter or fine wire for a voltmeter.

Pivoted between jeweled bearings, the shaft of the moving element carries coil L_3 which is wound with fine wire and arranged to rotate within the fixed coils. Also attached to the shaft is a light weight pointer which moves over a calibrated scale.

Following the plan of Figure 2B, a coiled hairspring is mounted on each end of the shaft. These springs are adjusted to balance the moving coil mechanically so that, with no current, it will always come to rest in a position at which the pointer indicates zero on the scale. Secondly, they provide electric connections between the moving coil and the external circuit. Thus, the springs carry the moving coil current.

The primary application for the dynamometer is to measure the voltage and current at the same time, that is; watts. The single instrument is called a **wattmeter** and its scale is calibrated directly in watts. The stationary coils L_1 and L_2 of Figure 3 are connected through terminals 1 and 2 into the circuit in series to measure the current through a part R_L while the moving coil L_3 is connected in parallel with R_L to measure the voltage across it as shown in Figure 4. The resulting magnetic field is a product of current I due to the stationary coils and the voltage E due to the moving coil. Since power is:

$$P = IE$$

the meter measures power in watts.

In Figure 4, the moving coil L_3 is wound with fine wire and a series resistor R_2 limits the current to a low value. This resistor is chosen so that the current through L_3 is a measure of the voltage supplied to R_L connected in parallel at terminals 3 and 4.

Resistor R_1 is in parallel with the stationary coils to provide a separate current path since the fine wire of these coils would burn out if they handled all of the circuit current. Thus, this resistor serves as a SHUNT since it is in parallel with L_1 and L_2. The smaller this resistor is, the more current passes through it.

Referring to the circuit of Figure 4, the path of the current is from E−, through component R_L, terminals 3 and 2, coils L_2 and L_1 or shunt R_1, and terminal 1 to E+. From the E− end of R_L, there is a circuit through terminal 4, resistor R_2, and moving coil L_3 to terminal 3. Thus, the magnetic fields set up by stationary coils L_2 and L_1 are proportional to the current in R_L while the magnetic field set up by moving coil L_3 is proportional to the voltage drop across R_L.

Since this wattmeter has four terminals, the proper polarity must be observed when connecting it to a circuit, that is, the positive terminals of both sets of coils must be connected to either the positive side of the circuit or the negative side, but not two different potentials.

When used as a voltmeter or ammeter, L_1, L_2 and L_3 in Figure 3 are connected internally in series as suggested by the broken line and the test leads connect to terminals 1 and 4. Therefore, when the direction of current is reversed, all magnetic polarities are reversed also. Thus, the turning force on the moving coil remains in the same direction and no reverse readings are possible. No polarity need be observed when connecting this meter to a circuit and the instrument is suitable for use on both direct and alternating current circuits. In fact, the same scale is used for both d-c and a-c. However, for most applications the D'Arsonval movement is preferred because of its linear scales and accuracy.

AMMETERS

As the name implies, an ammeter is designed to measure current in amperes and therefore, it must be connected in series with the circuit so that all of the current passes through it. This also means that, in order to prevent an appreciable decrease in the circuit current, the resistance of the ammeter must be low.

This multimeter has two sensitivity ratings: 20,000 Ω/v on d-c and 1,000 Ω/v on a-c.

Figure 5 shows a D'Arsonval meter connected as an ammeter. Each end of the moving coil is brought out to a terminal by means of which the meter may be connected into a circuit.

The range of values that may be measured by a given ammeter depends upon its construction: the number of turns and size of the wire in the coil, the strength of the magnet, the physical size of the coil, and the strength of the springs. To simplify the explanation, assume for the moment that the meter of Figure 5 requires a current of 1 ampere in the coil to set up a magnetic field strong enough to move the pointer completely across the scale. With the pointer in this position, it has FULL-SCALE DEFLECTION, and as shown, a number 1 is placed on the scale at this point. Additional values between 0 and 1 may be located on the scale by adjusting the meter current to the useful values and marking the scale properly at each point. After the scale has been calibrated, all that is necessary to measure any current between 0 and 1 ampere is to connect the meter in series with the circuit and read the current from the scale under the end of the pointer.

Ammeter Sensitivity

The sensitivity of an ammeter is defined as the current required for full scale deflection of the pointer. Hence, an ammeter that requires 1 ampere for full scale deflection is said to have a sensitivity of 1 ampere. A sensitivity of one milliampere means that one milliampere is required for full scale deflection. The most sensitive meter is one that requires the least current for full deflection. On this basis, a one milliampere meter is more sensitive than a one ampere movement.

Ammeter Shunts

In actual practice, often it is necessary to measure currents greater than the full scale range of a given meter. To permit these measurements of higher currents, it is customary to connect a low resistance conductor in parallel with the moving coil of the meter. When used for this purpose, the relatively low resistance conductor is called a SHUNT.

When the meter is connected in the circuit, the current will divide so that the moving coil and shunt each carry a part. Like any parallel circuit, the current divides inversely as the resistance of the branches. Therefore, by proper selection, the shunt will carry any desired portion of the total current. As this part remains always the same, the meter scale can be calibrated to indicate the total current, although the moving coil carries only a definite portion of it.

Shunt Calculations

In Figure 6 is a ammeter, two shunt resistors, and a 3 position switch to select the shunt desired. In order to illustrate a method of calculating the proper shunt resistance we will assume that the moving coil has a resistance R_m of 50 ohms and requires a current I_m of 1 milliampere (.001 ampere) for full scale deflection.

With the switch in Figure 6 in the 1 ma position as shown, the shunts are disconnected and the moving coil carries the entire current between the − and + meter terminals. Thus, a circuit current of 1 ma causes full scale deflection of the meter pointer.

Turning switch S_1 to the 10 ma position connects shunt R_3 across the moving coil. This provides two parallel current paths between the meter terminals. With a 1 ma or .001 ampere, 50 ohm moving coil, for a 10 ma range, the resistance of shunt R_3 can be found. According to Ohm's Law, E_m is .001 times 50 or .05 volts. R_3 for the 10 ma range has 9 ma or .009 amp through it. Since the coil and R_3 are in parallel the voltage across them are the same. Therefore, we know the voltage across and the current through R_3. According to Ohm's Law, the resistance of R_3 is:

$$R_3 = \frac{.05\text{ v}}{.009\text{ amp.}} = 5.55\text{ ohms.}$$

Turning switch S_1 to the 100 ma position disconnects R_3 and connects shunt R_4 across the moving coil. For the 100 ma range, the current through R_4 is $100 - 1$ or 99 ma (.099 amp.). Since the voltage is still the same across the coil for this range, E_4 is .05 v and R_4 is:

$$R_4 = \frac{.05\text{ v}}{.099} = .505\text{ ohms.}$$

This is the shunt resistance calculated for the 100 ma range for a 1 ma, 50 ohm moving coil.

It is well to remember here that regardless of its magnitude, the current always divides between the moving coil and shunt in exactly the same ratio. Referring again to shunt R_3 of Figure 6, it carries nine times the moving coil current which is one tenth of the total current. As previously explained, with a total current of 10 ma, shunt R_3 carries 9 ma and the moving coil, 1 ma.

When the total current is reduced to 8 ma, the moving coil carries .8 ma and the shunt carries nine times .8 or 7.2 ma. Reducing the total current to 4 ma will cause the moving coil to carry .4 ma, and the shunt $9 \times .4$ or 3.6 ma. In this case, the moving coil always carries one tenth of the total current. This could be indicated directly on the scale by moving the decimal points until the scale reads the total current instead of the current through the coil.

With shunt R_4 in the circuit, the moving coil carries but one hundredth of the total current.

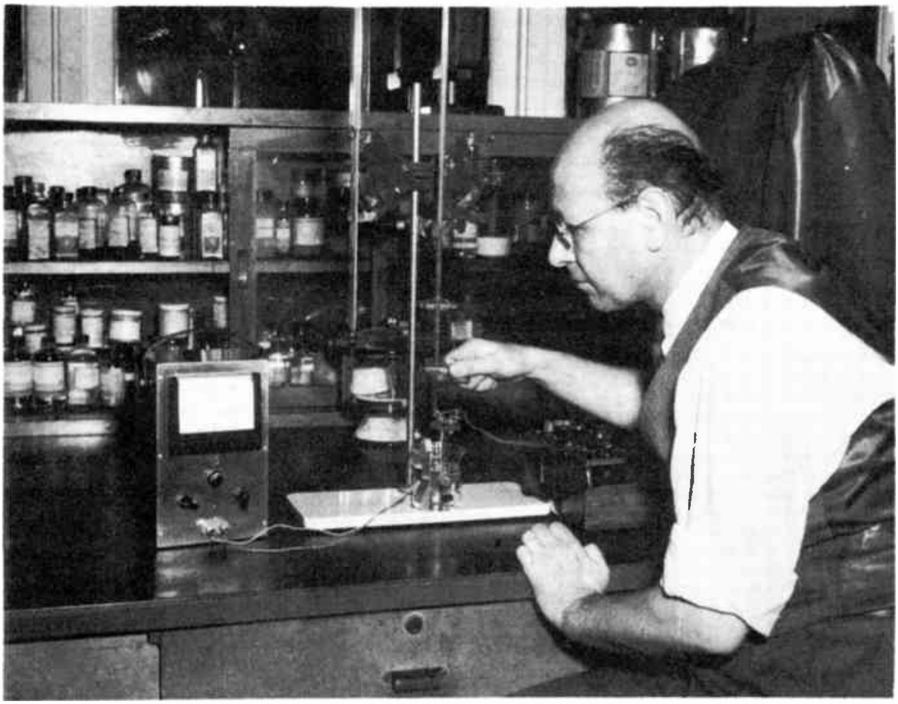
This could be indicated directly by making the scale of Figure 6 read 0-20-40-60-80-100.

By this method of using shunts, very large currents can be measured accurately by a low current meter, the moving parts of which are relatively small and sensitive.

This can be done only by rewinding the moving coil, a job which usually is more expensive than a new meter of the desired range.

VOLTMETERS

Voltmeters are designed to measure electric pressure and



To measure the electric potential of a chemical solution an ultra-sensitive d-c microammeter is used in this laboratory.

Courtesy Radio Corporation of America

Although shunts may be used to extend the range of a meter upward, they cannot be used to make the meter indicate by full scale deflection a current lower than that for which it was designed.

have their scales calibrated directly in volts. The D'Arsonval or moving coil type of meter, described in connection with ammeters and milliammeters, may be used in the construction of a voltmeter. However, there are a few things to consider. In the first place, voltage means a difference of potential between two points, such as the terminals of a battery, and to measure it, the meter must be connected directly across the two points.

A second point is that the coil of a D'Arsonval meter is moved by the magnetic effect of an electric current, therefore it is necessary to allow a current in the coil. Thus, a voltmeter really operates because of the current in it, but the scale is calibrated to read, not the current, but the voltage necessary to cause that current in the coil.

Voltmeter Multipliers

Actually, there is little difference between an ammeter and a voltmeter therefore, to simplify the explanation, the meter of Figure 5 can be adapted to operate as a voltmeter. Again let's assume that the moving coil has a resistance of 50 ohms and a current of 1 ma gives full scale deflection.

Connected directly across a source, or other two points of different potentials, the resistance of the voltmeter circuit must be sufficiently high to limit the current to that required for full scale deflection. Therefore, as shown in Figure 7, resistor R_1 is connected in series with the moving coil of the meter of Figure 5. In this position in the circuit, R_1 is known as a "multiplier resistor" or, more simply, a MULTIPLIER.

Suppose it is necessary that the voltmeter of Figure 7 read up to a maximum of 100 volts. As one milliampere of current in the moving coil produces full scale deflection of the pointer, the total resistance of R_1 and the moving coil must be such that the current is limited to 1 milliampere when 100 volts are applied. Substituting the known current and voltage into Ohm's Law, the total resistance must be:

$$R_T = E/I = 100/.001 = 100{,}000 \text{ ohms}$$

However, with 50 ohms of resistance in the moving coil, resistortor R_1 needs a value of 100,000 − 50 or 99,950 ohms so that the total circuit resistance is 100,000 ohms. Now 100 volts across the terminals causes 100/100,000 or 1 milliampere of current, a value just sufficient to pull the pointer all the way across the scale, and the number "100" can be marked on the scale directly under the pointer tip.

Additional values between 0 and 100 can be located on the scale by applying the proper voltages to the terminals and marking the scale each time. For example, by applying 50 volts, the number "50" can be placed at the point where the pointer stops.

After the scale is calibrated, any potential difference between 0 and 100 volts may be measured merely by applying it to the meter terminals and reading the indicated voltage.

A single range voltmeter is very limited in its scope of use. If 2 or 3 volts is applied to the 100 voltmeter of Figure 7, the resulting pointer deflection is so small that it is extremely difficult, if not impossible, to read it correctly on the scale. Then too, if 500 volts is applied across the terminals, the resulting current is greater than the full scale rating of the meter causing the pointer to deflect beyond the end of the scale. If the pointer swings hard enough, it will bend or possibly break. In most cases, this excessive current burns out the moving coil.

For use on electron apparatus, where voltages ranging from a fraction of a volt to several hundred volts are encountered, a multi-range voltmeter is most convenient. To obtain multi-range operation, a single meter movement is supplied with several multipliers, arranged so that the proper one can be selected by means of a switch or separate terminals. For example, in Figure 8, multipliers R_5, R_6, R_7, and R_8 are connected in series between the moving coil and the 1,000 volt terminal. The junctions between the resistors are connected to additional terminals to provide ranges of 10, 100, 500, and 1,000 volts.

The desired voltage range is selected by connecting one test lead into the "−" terminal, which is connected directly to one end of the moving coil, and the second test lead to one of the other terminals. A test lead is a flexible insulated wire with a metal plug on one end and a metal prod mounted in an insulated handle on the other end. It is used as a convenient way of making a temporary connection while measurements are being made.

Voltmeter Sensitivity

With reference to meter movements, the sensitivity is a measure of the current required for full scale deflection. Thus, a meter that requires a lower current to produce full scale deflection of the pointer is more sensitive than a meter that requires a higher current for the same deflection. For use on electron apparatus, voltmeters employ movements of relatively high sensitivity, since they require little current from the circuit under test and will produce less error in the reading.

Instead of referring to the sensitivity of voltmeters by the current required for full-scale deflection, it is stated as ohms per volt, meaning that the meter circuit must include so many ohms for each volt at full scale.

In the example of Figure 7, the total resistance of the meter circuit is 100,000 ohms for a full scale reading of 100 volts. Thus, its sensitivity is equal to 100,000 ohms divided by 100 volts or 1,000 ohms per volt. A meter movement that operates with less current for full-scale deflection requires more resistance in the circuit, and its ohms per volt rating is higher. Thus, the greater the sensitivity, the higher the ohms per volt rating of the meter.

As the ohms per volt rating of any meter tells how many ohms the circuit must have for each volt of the full scale reading; it may be calculated by dividing the full-scale current rating of the meter into one volt. That is:

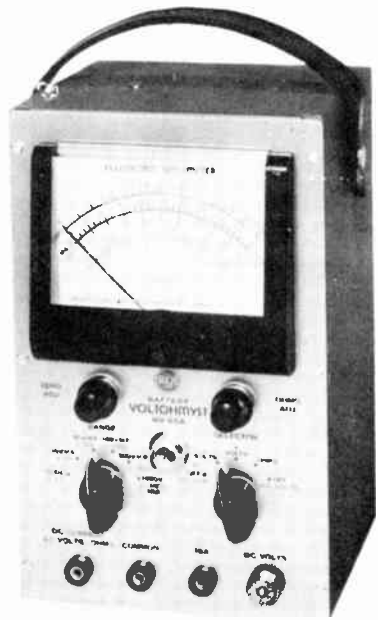
$$\text{Ohms per volt} = \frac{1}{\text{full-scale current}}$$

In Figure 7, the meter is a 0 to 1 milliammeter that requires 1 ma for full scale deflection and has an ohms per volt rating of 1/.001 or 1,000. In a like manner, if the movement of Figure 7 requires 100 microamperes (100 millionths of an ampere) for full scale deflection, the sensitivity rating is:

$$\frac{1}{.000100} = 10{,}000 \text{ ohms per volt}$$

Multiplier Calculations

The current to operate a voltmeter must be supplied by the circuit under test therefore, to cause the least possible change in circuit conditions, the meter current must be low. For this reason,



The sensitive electronic voltmeter has little effect on the circuits being measured. Therefore, more accurate voltage readings are obtained.
Courtesy Radio Corporation of America

most voltmeters used on electron equipment employ meter movements that require very little current for full scale deflection of the pointer.

The multirange voltmeter of Figure 8 makes use of the 1 ma meter movement of Figure 6 which has a resistance of 50 ohms and a sensitivity of 1,000 ohms per volt. To demonstrate the multiplier calculations, the resistances of R_5, R_6, R_7, and R_8 will be determined. Although Ohm's Law can be used directly in these calculations, the ohms per volt rating of the meter makes calculations simpler.

Looking at Figure 8, for the 10 v range the multiplier is R_5, for the 100 v range it is $R_5 + R_6$, for the 500 v range it is $R_5 + R_6 + R_7$. Finally, for the 1,000 v range it is $R_5 + R_6 + R_7 + R_8$. Because R_5 is a part of all the multipliers, its value can be found first. Then R_6, R_7, and R_8 may be determined in that order.

Since there must be 1,000 ohms per volt for full-scale deflection, the total resistance between the "−" and "10 v" terminals must be 10 times 1,000 or 10,000 ohms. The total resistance of a series circuit is equal to the sum of the individual resistances, therefore:

$$R_T = R_m + R_5$$

or:

$$R_5 = R_T - R_m = 10{,}000 - 50$$
$$= 9{,}950 \text{ ohms}$$

For the 100 v range, the total resistance must be $100 \times 1{,}000$ or 100,000 ohms. From the previous calculation, $R_m + R_5$ was found to be 10,000 ohms, therefore:

$$R_6 = R_T - (R_m + R_5)$$
$$= 100{,}000 - 10{,}000 = 90{,}000 \text{ ohms}$$

The same procedure is followed in calculating R_7 and R_8. Hence for the 500 v range:

$$R_T = 500 \times 1{,}000 = 500{,}000 \text{ ohms.}$$

$$R_7 = R_T - (R_m + R_5 + R_6)$$
$$= 500{,}000 - 100{,}000 = 400{,}000 \text{ ohms}$$

and for the 1000 v range:

$$R_T = 1{,}000 \times 1{,}000 = 1{,}000{,}000 \text{ ohms.}$$

$$R_8 = R_T - (R_m + R_5 + R_6 + R_7)$$
$$= 1{,}000{,}000 - 500{,}000 = 500{,}000 \text{ ohms}$$

METER ERROR

Every meter movement has a small but definite resistance. As has just been described, the current through this resistance produces a small voltage across it. As an end result, the current meter does affect the circuit being measured and actually a new circuit is created when a meter is inserted.

Shown in Figure 9A is a schematic of a series circuit consisting of R_1, R_m, and battery E.

If the meter resistance R_m was zero the circuit would have the same resistance that it had before the meter was inserted. Where E is 50 volts and R_1 is 10 ohms, the current would be 50 divided by 10 or 5 amp.

However, every practical meter does have some resistance. If it were 1 ohm the total circuit resistance would be increased to 11 ohms and the circuit current would be 50 divided by 11 or 4.55 amp. Thus, the meter indicates $5 - 4.55$ or .45 amps less than the circuit normally has. This difference is the error introduced by the meter due to its internal resistance.

A similar situation occurs in the circuit of Figure 9B due to the use of a voltmeter. If it was possible for the voltmeter to draw zero current the current in R_1 and R_2 would be the same since they are in series. However, the meter does draw some current, and thus there is more current in R_1 than in R_2 and the increased voltage drop across R_1 due to this added current means less voltage across R_2. This difference in voltage is the meter error.

For many purposes the meter error is small enough that it can be disregarded. For most purposes it is sufficient to know that the less internal resistance an ammeter has, the less error it introduces. Also, the more sensitivity or ohms per volt a voltmeter has, the less current it takes, and therefore, the less error it produces.

CALIBRATING METERS

By far, the easiest and simplest way to test or calibrate a meter is to compare it with a similar meter that is known to be correct. In Figure 10, two voltmeters are shown at "A" and two ammeters at "B". Notice the main difference is that the voltmeters are connected in parallel, while the ammeters are in series. This is based on the fact that all voltages across parallel branches are equal and the current is the same throughout a series circuit.

In both cases, the square meter is assumed to be correct and is used to check the calibration of the round one. In order to compare the readings at different points on the scales, at "A", a high resistance potentiometer is connected directly across the voltage source. Then, by changing the position of the movable contact, shown by the arrow, the voltage across the meters can be varied to check their readings at different points on the scales.

However, at "B", both meters and a rheostat type of variable resistor are connected in series across the voltage source. By changing the position of the movable contact, again shown by the arrow, the resistance of the circuit is changed and thus the current is varied to provide readings at various points on the meter scales.

OHMMETERS

In addition to measuring the voltage and current, often it is necessary that the resistance of a circuit or part be known before it is connected to a voltage source. Resistance may be measured by several methods, but the most simple and popular one is to use a meter that reads directly in ohms.

The electronic voltmeter above can be used for voltage, resistance, and capacitor measurements.

Courtesy Superior Instruments Co.

Ohm's Law states that the resistance of a circuit is equal to the applied voltage divided by the resulting current. Thus, if a known voltage is applied to a device and the electron flow is measured with a current meter, the resistance can be calculated. In fact, if the same voltage is used for all tests, the resistance readings can be printed on the meter scale instead of the current readings. When the scale is calibrated directly in ohms in this way, the instrument is called an OHMMETER.

The ohmmeter circuit shown in Figure 11, includes the same meter movement that was used in Figures 5, 6, and 7 with the exception that the meter scale now is calibrated directly in ohms.

The circuit includes a battery as a voltage source, the moving coil of the meter, fixed resistor R_1, variable resistor R_2, and two external terminals. When an unknown resistance, R_x, is connected across the terminals, a series circuit is completed and the resulting current causes a deflection of the meter pointer.

As the meter requires 1 ma, (.001 ampere) for full scale deflection and a 4.5 volt battery is indicated, the circuit must include 4,500 ohms of resistance to prevent excessive current when the R_x terminals are shorted. The total resistance consists of that in the moving coil, fixed resistor R_1 and variable resistor R_2. Known as the ohmmeter Ohm's Adjust or Zero Adjust, resistor R_2 is variable to compensate for voltage variations as the battery ages.

Although a single variable resistor could be used in place of R_1 and R_2, its adjustment would be extremely critical because of its wide range. With the arrangement shown, a fixed resistor of approximately 3,500 ohms, the meter resistance of about 50 ohms and a variable resistor of 1,000 ohms are placed in series. Thus the circuit resistance can be varied from slightly above to about 1,000 ohms below the required value during complete rotation of R_2 and so the adjustment is not critical. Moreover, by having 3,500 ohms fixed in the circuit, the possibility of an excessive current burning out the meter movement is reduced.

The terminals marked "unknown resistance" are in series with the battery, moving coil, and variable resistors. If the terminals are shorted and the circuit adjusted to place the 4½ volts across 4,500 ohms of resistance, by Ohm's Law, this condition will allow 1 ma, of current and the pointer moves all the way across the scale. Since the unknown resistance R_x is zero ohms, a "0" is marked opposite the pointer at the right end of the scale.

Now suppose a resistor of 1,000 ohms is connected across the R_x terminals. The total resistance of the meter circuit will be increased from 4,500 to 5,500 ohms, and the meter will indicate a current of 4.5/5,500 or .000817 amperes (.817 ma). However, when calibrating the scale, 1,000 is marked at this position since 1,000 ohms is the resistance added to the circuit. In the same way, resistances of 2,000, 5,000, 10,000, and 500,000 ohms, can be connected across the terminals and their resistances marked on the scale at the point where the pointer comes to rest when each resistor is in the circuit.

As shown in Figure 11, "0" is at the extreme right of the scale, with the numbers increasing toward the left and becoming more crowded as they approach the left end of the scale. At the extreme left, the resistance is read as "infinite" and is represented by the symbol for "infinity" which resembles a number 8 resting on its side. An infinity resistance reading is given by either an open circuit or a resistance well beyond the range of the meter.

The circuit shown in Figure 12 often is referred to as a BACK-UP OHMMETER. It receives its name from the fact that when resistances are measured, the pointer moves in a direction reversed to that explained for Figure 11. To obtain back-up operation, the 4.5-volt battery, the meter movement, resistors R_1 and R_2, and switch S_1 are all connected in series, and the R_x terminals are attached to each end of the moving coil. With this arrangement, any resistor connected between the R_x terminals is shunted across the moving coil and reduces the meter reading. Switch S_1 is included so that the circuit may be opened to prevent the battery from discharging when the meter is not in use.

With the switch closed and nothing connected between the R_x terminals, the circuit is the same as that of Figure 11 with the R_x terminals shorted. Thus, there is full-scale deflection of the meter hand and the "infinity" symbol is placed at the right end of the scale.

Assume as before that the moving coil has a resistance of 50 ohms and requires a current of 1 ma for full scale deflection. Then, with a 50 ohm resistor connected across the R_x terminals, the circuit current of 1 ma will divide equally between the moving coil and resistor.

Thus, with a moving coil current of ½ or .5 ma, the pointer will stop at the .5 division on the scale which can be marked 50, for in this case the "unknown resistance" is 50 ohms.

This is an interesting point to remember. The center marking on any "back-up scale" ohmmeter indicates the internal resistance of the moving coil unless shunts are internally connected across the moving coil. In that case the center scale marking is the resistance of the combination.

An ohmmeter of this type is calibrated exactly the same as explained for Figure 11. However, due to the fact that the resistance of the moving coil is comparatively low and that it determines the mid-scale value, the circuit of Figure 12 is used mainly for the measurement of low resistances. On the back-up ohmmeter scale, the resistance readings appear just opposite to that of the ohmmeter of Figure 11. Here, "0" ohms is at the left while infinity is at the right. Moreover, on this scale, the numbers are comparatively far apart near the left end and crowded at the right.

The circuit of Figure 11 is more flexible, as the resistance ranges can be varied to take care of any practical measurements. The ranges depend not only on the sensitivity of the meter movement, but also on the supply voltage. Although a battery is shown, any other source of d-c voltage may be employed. For example, in a number of commercial units, a high voltage d-c supply is obtained from an a-c power outlet by employing a rectifier built in as a part of the ohmmeter circuit.

Before making tests, the terminals of the ohmmeter of Figure 11 are shorted and variable resistor R_2 is adjusted until the meter pointer indicates exactly "0" ohms on the scale. Then the short is removed and when connected to the terminals, the unknown resistance R_x will be indicated on the scale.

For the back-up meter of Figure 12, the R_x terminals are left open and, with switch S_1 closed, resistor R_2 is adjusted until the pointer deflects full scale to the infinity mark. Then, when connected across the R_x terminals, the unknown resistance is indicated on the meter scale.

A COMPLETE MULTIMETER

Now that the various applications of a meter movement have been explained, in Figure 13 the individual circuits are shown combined to form a single multirange volt-ohm-milliammeter otherwise known as a **multimeter.** Provisions are made for the separate measurement of d-c voltage, current, and resistance with four ranges for volts, three ranges for milliamperes and two for ohms. A nine position selector switch connects this basic meter movement to the necessary circuits for the desired ranges. Since only one meter movement is used, it must be equipped with a dial face which includes all of the scales required for the individual ranges.

The circuits incorporated in this multimeter are those covered for the milliammeter, voltmeter, and ohmmeters of Figures 6, 8, 11 and 12. Any one of these circuits, may be selected by the 9-position switch S_1, which is of the rotary type with a knob attached to the shaft. Turning the knob causes the two contacts, S_{1_A} and S_{1_B}, to move in unison and make connection to the various points indicated by the small circles in Figure 13.

In the position shown, the meter circuit is in the 0-1000 volts d-c range and the four multipliers

Combination electronic voltmeter can be used to measure current, voltage, resistance, and capacitance.
Courtesy Radio Corporation of America

R_5, R_6, R_7, and R_8 are in series with the meter movement exactly as explained for the circuit of Figure 8. The circuit can be traced from the Black "−" terminal through the moving coil, resistors R_5, R_6, R_7, and R_8, and contact S_{1_B} to the Red "+" terminal.

Although the ohmmeter sections for both "hi" and "lo" ohms were described for Figures 11 and 12, a brief review of them along with an explanation of the modification introduced in this multimeter circuit may be of benefit.

With the switch contacts S_{1_A} and S_{1_B} in the "hi ohms" position, there is a circuit from the black terminal through the moving coil, through the battery from "+" to "−", through resistors R_1 and R_2, through the "hi ohms" and S_{1_B} contacts to the red terminal. This is the circuit of Figure 11 except for the slightly different positions of the battery and resistors.

The "lo ohms" section of the multimeter contains a back-up ohmmeter similar to that of Figure 12. With the selector switch in the lo ohms position, the red terminal is connected through S_{1_B} to the "+" terminal of the moving coil and battery, while the moving coil "−" and the black terminals are connected through S_{1_A} to R_2. Thus, the moving coil, R_1 and R_2 are placed in series across the battery and the red and black terminals are connected directly to the moving coil.

The example of Figure 13 is a very common multimeter circuit and it can be found in many commercial units on the market. With an 0-1 ma meter in its circuit, it is called a 1,000 ohms per volt instrument.

VACUUM TUBE VOLTMETER

We pointed out earlier in the lesson how the insertion of a meter in the circuit changes the circuit conditions sufficiently to give a reading different from the actual operating conditions.

For now it is sufficient to know that the more sensitive the meter circuit, the smaller the error. However, sensitive meter movements are costly and very fragile. Even though a meter movement operates satisfactorily within its design limits, it can be damaged readily by mechanical shock or accidental overloads.

One method to reduce error and at the same time have an economical, rugged multimeter with a D'Arsonval movement for troubleshooting purposes is to use a circuit which includes one or more electron tubes. Such a meter is called a **vacuum tube voltmeter** (VTVM) or an ELECTRONIC VOLTMETER.

The use of the VTVM is very similar to the multimeter and as shown in Figure 14, there are only two added controls. The on and off switch mounted on the "Ohm's Adj." control is needed to turn off the internal circuit when the meter is not in use and the zero adj. is needed to adjust the tube circuits to give a zero meter reading.

On the particular meter shown here, the range selector and function switches are shown separate instead of combined into one switch as used in the multimeter circuit of Figure 13.

The FUNCTION switch, located below the Zero Adj. on the left, selects the necessary internal circuits to measure d-c, a-c, and ohms. The desired range of the meter is selected by the RANGE switch located centrally below the meter face.

Below the Ohm's Adj. is the panel jack for the lead used for both AC and ohms measurements. Below it is the panel jack used for both d-c and r-f voltage measurements. Measuring high frequency a-c or r-f voltages poses new problems which are described later in your program. On the left side at the bottom is the common jack where the common or ground lead plugs into.

The common, d-c—r-f, and a-c-ohms test leads connect to the three meter terminals. The common test lead is merely an insulated wire with a convenient handling prod. The a-c and ohms lead is an insulated wire with test prods just like the common. The d-c lead is used for both + and − d-c measurements and in some models has a resistor inside the test prod. For ease in recognition, this test lead may be colored red. However, before considering the internal circuitry further, let's see how the meter is used.

READING THE SCALES

On the face of this VTVM meter are three scales which are shown in Figure 15. Starting at the top, we find a non-linear scale which is the Ohm's scale. Beginning with "0" on the left and ending with "∞" on the right, the Ohm's scale is identified by the words "ohms" at either end.

Normally in a VTVM of this type, the same scales are used for both a-c, and + or − d-c voltages. This is the reason why only "volts" appears at either ends of these scales. The upper volts scale goes from 0-5.0 while the lower extends from 0-15. Many VTVM's use colored scales for ease in distinguishing one scale from another.

With the function switch in the ohms position and the range switch set for the R × 1, the pointer indication is multiplied by one, or more simply, read as indicated on the ohm's scale. Switching to the R×10 range, the pointer directly over the 5 on the scale is 5 times 10 or 50. Switching to the R × 100 range the reading with the pointer still on 5 is 5 × 100 or 500.

With the pointer still at 5, and the range switch successively changed to R × 1,000, R × 10K and R $\times$ 100K, the readings become 5,000, 50K, and 500K.

With the function switch set at either + or − d-c or a-c the various possible ranges are 5, 15, 50, 150, 500, and 1,500. For 5, 50, and 500 volts the upper scale is more convenient since the multiplying factors are 1, 10 and 100. The lower scale is better adapted for reading 15, 150 and 1,500 since the multiplying factors are 1, 10, and 100. Briefly, the multiplying factor for the range selected is found by dividing that range selected by the maximum scale reading. For instance, if 50 were the chosen scale and 500 is the range, then the multiplying factor is:

$$\frac{500}{50} = 10.$$

ZERO PROCEDURE

As far as using the VTVM, there are two "zeroing" knobs to adjust: the Zero Adjust at the upper left and the Ohm's Adj. at the upper right. The Zero Adj. procedure is the same for each function when it requires it, while the Ohm's Adj. is required only for ohmmeter readings.

With the function switch set for ohms, and the range switch in one of the six positions, before any resistances are measured touch the ohms and common lead together and with the Zero Adjust, position the pointer directly over the zero on the ohm's scale. Separate the leads and let the pointer swing back to the right. If the pointer does not rest over the "∞" mark on the right, turn the Ohm's Adj. until it does. Always start by using the Zero Adj., since there is some interaction between the two when the Ohm's Adjust is used first. Having completed the zeroing, you can now measure resistances, but be sure all voltage sources are turned off.

When the function switch is in +d-c, −d-c, or a-c, the pointer may not rest on zero. In that case the proper leads, common and d-c or common and a-c are touched together and the pointer is positioned over zero by the Zero Adj. It may not always be necessary to touch the leads together, but since voltages present in nearby equipment produce strong magnetic fields, these may induce enough voltage into the test leads to give an incorrect zero adjustment.

For the a-c, polarity need not be observed, but a good procedure is that the common of the VTVM should be connected to the common or chassis of the equipment under test.

POWER SUPPLY

Since the vacuum tube voltmeter has electron tubes in it, one of the main meter circuits is a power supply and practically all

VTVM's of the type used in laboratories and service work contain a built-in power supply similar to Figure 16. Note that it uses a half wave rectifier.

The primary circuit of T_1 is completed with the power line when switch S_3 is closed. Normally this switch is operated by the Ohm's Adj. knob. Transformer T_1 has two secondaries, one for supplying the high voltage to rectifier tube V_{2_B} and the other for the filament winding providing 6.3 volts a-c to the tube heaters.

The high voltage of T_1 is applied at the plate of V_{2_B} and the negative side of C_4. Remembering that the ground symbol indicates points of the same potential, R_{27} and R_{28} are really connected together. This places R_{27} and R_{28} in series with each other and in parallel with C_4. When the alternating voltage is such that the plate of V_{2_B} becomes positive, tube V_{2_B}

To obtain correct readings of low voltages across high resistance, a vtvm is used.
Courtesy Precision Apparatus Co.

conducts from cathode to plate. Electrons flow from the − of T_1 through R_{28}, then through R_{27}, to the cathode of V_{2_B}, inside the tube from cathode to plate, to the + end of T_1 and then back to its − end. At the same time electrons flow through R_{27} and R_{28}, C_4 is charged to the polarity indicated.

During the negative alternation, V_{2_B} does not conduct. Some of the charge on C_4 discharges through R_{27} and R_{28}, but since R_{27} is 47,000 ohms this discharge is slow and most of the voltage across C_4 still remains when the following positive alternation charges C_4 back to its full voltage. Since R_{28} is only 1,000 ohms, which is small compared to 47,000 ohms for R_{27}, the voltage developed across R_{28} is small compared to the voltage across R_{27}. Moreover, the direction of the current through R_{28} is such that the end connected to the capacitor is negative and its grounded end is positive. Thus, with ground as the reference, across R_{28} is a small negative voltage, part of which is fed through the slider to tube V_{2_A}. At the same time the larger positive voltage across R_{27} serves as B+ for the other circuits.

BALANCE AMPLIFIER

The heart of most VTVM's is the balance amplifiers shown in Figure 17A and the resistor circuit of Figure 17B can be used to explain the basic action. The same symbols and values are used in both diagrams except for one or two changes. In Figure 17B, R_M represents both the meter resistance and that of R_{22}, and R_{25} of Figure 17A is divided equally in Figure 17B and labeled R_{25_A} and R_{25_B}; both 1.5K ohms. R_{V1_A} and R_{V1_B} each represent sections of the tube V_{1_A} and V_{1_B}. Also the input grid resistor to V_{1_A} is not included since it is not part of the tube plate. Initially, let's suppose R_M is not connected in the circuit and so we have two circuits in parallel. Thus, R_{21}, R_{V1_A}, and R_{25_A} form one branch and each has an equal resistance in the other parallel branch labelled R_{26}, R_{V1_B}, and R_{25_B}. With a complete circuit from ground to B+, by Ohm's Law an equal current exists through both circuits since their resistance and voltage are the same. Thus, the voltage across R_{25_A} is identical to that of R_{25_B}, and for the sake of description let's assume it to be 6 volts. Therefore, points 1 and 2 are each +6 v to ground.

As a result, the potential difference between points 1 and 2 is $(6)-(6)=0$ v. Thus, even with R_m in the circuit there would be zero volts across it and without voltage across R_m no current exists through it. The circuit is "balanced" when no current passes through R_m.

Suppose resistance R_{V1_A} decreases so that the total resistance in that leg decreases. Then the current in the left branch is greater than in the right branch. With this in mind, the voltage across R_{25_A} is greater than 6 v since there is more current through it. Suppose the voltage increases to 7 v. Hence, point 1 is 7 v − 6 v or 1 v positive with respect to point 2 and there is a current through the meter. In this condition, the circuit is said to be "unbalanced". So long as the resistance change in the left branch is not too great, with the Zero Adj. potentiometer R_{25} of Figure 17A, the circuit can be "zeroed" or balanced as before by making R_{25_A} enough different than R_{25_B} to equalize the voltages across them.

Thus, we see how the Zero Adj. in Figure 17A balances the amplifiers so that there is no current through the meter or R_{22} when there is no signal on the grid of V_{1_A}.

The input grid resistor to V_{1_A} ties the grid to ground and since normally there is no current through it, V_{1_A} grid is at ground potential. However, when a voltage is applied to the input, the voltage across the grid resistor appears on the grid of V_{1_A}, and so the original bias for the tube is changed. When a positive voltage is placed on the grid, it is less negative and this reduces the internal resistance of tube V_{1_A}, thereby unbalancing the amplifiers. More current flows through the cathode resistor of V_{1_A} (R_{25}) which makes its voltage more positive with respect to ground.

With a difference of potential now existing between the cathodes, current passes through R_{22} and the meter. The current deflects the pointer, and the scale is calibrated to indicate whatever was applied to the input.

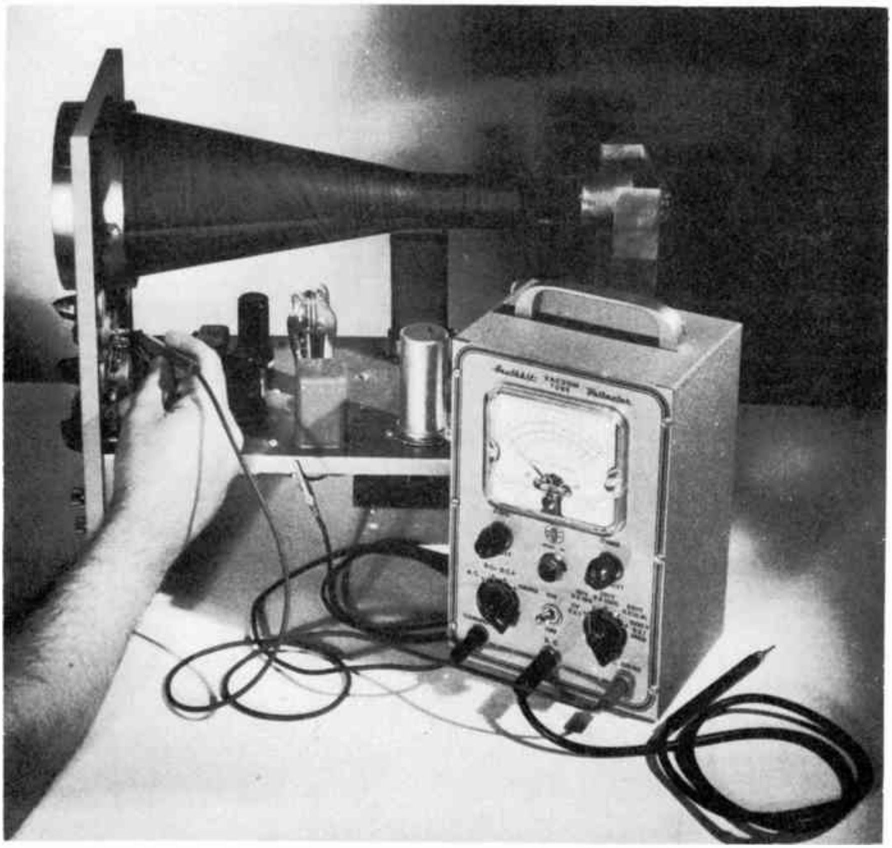
Resistor R_{22}, the d-c calibration resistor, is adjusted until the pointer indicates the standard voltage used to adjust the instrument. This is done for only one d-c voltage range. For a-c voltages R_{22} is replaced by R_{23} of Figure 22. This makes it possible to calibrate the meter for a-c voltages in the same manner.

The main purpose of these Calibrate and the Zero Adj. controls is that, as the parts age including tubes, any resistance changes easily can be compensated for without any component replacements. Whenever necessary, the meter can be quickly and accurately calibrated.

INPUT CIRCUITS

The VTVM has three main divisions: a power supply, balance amplifiers, and the input circuits needed to produce the necessary ranges and functions for the meter. The balanced amplifier was described in Figure 17, the power supply that supplies the B+ and heater voltages for this amplifier circuit were described in Figure 16. What remains is the input circuits.

By taking a quick look at Figure 22, it is easy to see that the major components in these input circuits are switches and resistors. In this particular circuit there are two wafer switches, S_1 and S_2. S_1 is the function switch and it has three wafers, S_{1_A}, S_{1_B}, and S_{1_C}. The range switch S_2 also contains three wafers, S_{2_A}, S_{2_B}, S_{2_C}. A good idea of how these switches work can be secured by looking at the two wafer switch in Figure 18.



The vacuum tube voltmeter is being used to measure a-c voltages in an oscilloscope which is used in dynamic testing.

Courtesy The Heath Co.

As shown in the side view of Figure 18A, the index mechanism and the wafers all mount on the same shaft. The index consists of a ball bearing pressing against the edge of a notched metal disc. This makes sure that the switch remains in position until rotated by the operator and then it moves by steps from one position to the next, never stopping half way between two positions.

Each wafer is a disc made of bakelite or a similar insulating material on which the terminals and sliders are riveted. The bakelite discs are held rigidly in position by posts running through the holes labeled C and D in the rear view of Figure 18B.

A smaller disc, free to rotate, is mounted on the shaft so that it moves between the large wafer and the contacts on the wafer. On this rotating disc are semi-circular conductors and the movable contacts are projections of these areas, labeled A and B. These reach out far enough to make contact with the terminals. The sliders are long enough to contact the semi-circular areas directly and therefore, do not depend on the switch position.

For example, in the position shown in Figure 18B, slider 8 connects to B and B is making contact with terminal 7. In like manner slider 1 connects to A which is making contact with terminal 6. Now if the switch was moved one position in the counterclockwise direction, A would contact 5 and B would contact 6. Therefore slider 1 would connect to 5 instead of 6 and slider 8 would connect to 6 instead of 7.

The actual number of sliders and terminals on each wafer of a switch are determined by the particular need of the switch. In Figure 22, the schematic diagram shows each wafer for the two switches separately so that 6 wafers are clearly in view. A quick glance will show differences even between wafers on the same switch. For example, although S_{2_A} and S_{2_B} each have six terminals, S_{2_C} has 12 terminals. Again S_{1_A} has one slider and 3 terminals, S_{1_B} has one slider and 5 terminals, and S_{1_C} has 2 sliders and 8 terminals.

In order to describe the input circuits accurately each one will be traced carefully in Figure 22 and then redrawn for explanation in a separate Figure. In Figure 22 the function switch is shown in the a-c position. When we trace the d-c voltmeter and ohmmeter circuit, be sure to remember these circuits are completed by the function switch when the meter is used for that purpose.

D-C Input

For the +d-c setting of the function switch we can trace the complete path from the d-c lead to V_{1_A} for the 5 v range because the movable contacts on S_{1_A}, S_{1_B}, and S_{1_C} connect with the +d-c terminals instead of the a-c terminals as shown. From + terminal of the voltage being measured, through the test lead through J_3, through R_2, to the + d-c terminal on S_{1_A}, and when this switch is in the + d-c position, from the slider on S_{1_A} to terminal 1 on S_{2_B}. From here it connects to the slider arm on S_{2_B}, to + d-c or terminal 2 on S_{1_B}, to the slider arm on S_{1_B}, and through R_{14} to the grid of V_{1_A}. From terminal 1 on S_{2_B}, the resistors R_8 through R_{13} are connected in series to ground. The common lead connects the − end of the voltage source to R_{13} through J_1, on the VTVM chassis.

As the range switch is advanced, the protruding contacts A, B, and C on the three wafers touch different terminals, while each "slider" arm connects to contacts A, B and C by means of the curved bar. The function switch S_1 contacts do not change from the +d-c position for changes in the ranges.

As shown by redrawing this portion of the circuit without the function switch in Figure 19, the voltage to be measured is applied through the d-c test lead, J_3, R_2, and R_{14} to the grid. The voltage to be measured is represented here by a battery. The common lead connects the negative end of the battery to the VTVM chassis. In this case R_2 and the S_{2_B} resistor string form a complete series circuit with the battery and the current makes Point B positive with respect to ground. Since no current passes through R_{14}, the grid of V_{1_A} is at this same positive potential. Referring to Figure 17, the positive grid makes V_{1_A} conduct more current. Assuming the amplifiers were already zero adjusted, the added current through R_{25} increases the voltage across it, making the cathode of V_{1_A} more positive. The cathodes then have a difference of potential and current passes through meter M and R_{22}.

To measure negative direct voltage, the function switch is set to the −d-c position. With this setting, the input circuits remain as they were for the +d-c position. However, the cathode of V_{1_B} now connects through terminal 3 of S_{1_C} and the lower slider to the + terminal of the meter. Variable resistor R_{22} connects through terminal 7 and the upper slider to the − of the meter. These connections to the meter are just the opposite of those shown in Figure 17. That is, in Figure 17, the meter + and − terminals should be interchanged to indicate the connections for measuring negative direct voltage.

Also, if the polarity of battery E were reversed, Figure 19 would illustrate the proper connections of the test leads for measuring negative direct voltage. That is, the d-c lead is placed at the negative terminal of the voltage source, and the common lead at the positive terminal. These connections make J_3 negative with respect to J_1 or ground. This negative voltage is applied through R_2 and R_{14} to the grid of V_{1_A}.

Referring again to Figure 17, with its grid more negative, V_{1_A} conducts less. With smaller plate current in this tube, the voltage across the left section of R_{25} is smaller. Therefore, the cathode of V_{1_A} is less positive than that of V_{1_B}. With the cathodes at different positive potentials with respect to ground, current is produced in the meter circuit. In this case, electron flow is from the left end of R_{25}, through R_{22} and meter M, to the cathode of V_{1_B}.

In either d-c position, higher ranges are selected by turning switch S_2 in Figure 22. Contact B on S_{2_B} successively makes contact with points 2, 3, 4, 5, 6. As higher voltages are measured on these ranges, a smaller portion of the total voltage must be applied to the grid of V_{1_A} for full scale deflection.

For example, in Figure 19 on the 1,500 volt range contact B is at terminal 6 instead of terminal 1. R_2, R_{13}, and the voltage source form a series circuit but only that portion across R_{13} is applied to V_1. Since the resistance of R_{13} is 18K ohms and the total resistance is over 10 megohms, only a small portion of the 1,500 volts is applied through R_{14} to the V_{1_A} grid. On the other hand for a 150 volt range, contact B is on ter-

Here the direct probe plugs into the d-c probe, thereby eliminating a third lead.
Courtesy Radio Corporation of America

minal 4. Now the voltage across R_{11}, R_{12}, and R_{13}, is applied through R_{14} to the grid of V_{1_A}. Since this is 10 times the resistance, it gives the same deflection for one tenth the voltage. Thus, the 150 volts now applied give the same meter deflection as 1,500 volts on the 1,500 volt range.

A-C Input

In Figure 22, the a-c input circuit can be traced through the a-c ohms test lead, to J_2, through C_1 and R_3 to S_{2_A} terminal 1, to the sliding contact arm of S_{2_A}, C_2 and R_7 to terminal 1 of S_{1_A}. From the contact arm of S_{1_A}, to S_{2_B} terminal 1, S_{2_C} terminal 1, S_{2_C} contact arm, S_{1_B} terminal 4, S_{1_B} contact arm, and finally through R_{14} to control grid of V_{1_A}. R_4, R_5, R_6, are in series from terminal 1 of S_{2_A} to ground. Also, from terminal 1 of S_{2_B}, resistors R_8, R_9, R_{10}, R_{11}, R_{12}, and R_{13} are in series to ground. Tube V_{2_A} also is part of the a-c input circuit.

This input circuit is drawn without the function switch S_1 in Figure 20. The numbers refer to the terminals on switches S_{2_A} and S_{2_C}. Mounted on S_{2_B}, resistors R_8 through R_{13} connect to S_{2_C} as shown.

Points A and C indicate the movable contact that moves along the various terminals for other ranges when the range switch is rotated.

The purpose of the a-c input circuit is to convert the measured a-c voltage to a positive d-c for the grid of V_{1_A}. If an alternating voltage were placed on the grid, then the current through the meter in the balance amplifier would follow this variation causing the pointer to oscillate. There would not be a stationary indication to read on the meter scale.

To avoid this fault, the entire circuit up to point C is required, and R_{14} and capacitor C_3 filter out any ripple before it reaches the grid of V_{1_A}. In addition R_{14} protects V_{1_A} from damaging current should the grid become positive with respect to the cathode. When no voltage is being measured the grid has a zero voltage with respect to ground but a negative voltage with respect to the cathode since the cathode is positive with respect to ground as explained in Figure 17A. Therefore, under normal conditions, a positive voltage at point C makes the grid positive with respect to ground but less negative with respect to the cathode, and does not produce grid current. However, a very large positive voltage could exceed the cathode bias and cause the grid to draw current. In this case, the resistance of R_{14} limits the current to a safe value.

When the function switch is placed in the a-c position with the a-c and common leads connected across an a-c voltage, the meter should indicate just this voltage. In some circuits, d-c may be present, and to keep the meter from reading it, it is blocked by C_1. This places C_1, R_3, and the entire S_{2_A} string in series across the a-c voltage being measured.

Without any voltage being measured, since the cathode of V_{2_A} is connected through R_7 and the S_{2_B} resistors to ground, the cathode should be at ground potential. However, since these resistances are very high, a very minute current caused by electrons striking the grid of V_{1_A} makes the cathode of V_{2_A} slightly negative with respect to ground. Therefore, an equal negative voltage must be applied to the plate of V_{2_A} to keep the tube from conducting except when an a-c voltage is being measured. As explained in Figure 16, this voltage comes from R_{28} in the power supply.

When an a-c voltage is measured, capacitor C_2 couples the voltage between point A and ground to the cathode of V_{2_A} and the string of resistors in S_{2_B}. When the negative alternation is applied to the cathode, the plate is more positive than the cathode and V_{2_A} conducts. As a result, current passes through the resistors in S_{2_A} into C_2 and from C_2 through the tube thus charging the cathode side of C_2 positive. Only a little current passes through R_7 and the resistors on S_{2_B}, since the total resistance of this series is very large.

On the positive alternation of a-c source, tube V_{2_A} does not conduct since the positive voltage, applied to the cathode, makes the plate negative with respect to the cathode. Capacitor C_2 will discharge very little through the high resistance path of the S_{2_B} resistors and R_7 during the positive alternation. Thus, a fairly constant d-c is applied to point C. Finally, R_7 lowers it to the value needed to unbalance the amplifiers and cause proper deflection of the pointer. This voltage is applied to the grid of V_{1_A} through R_{14}.

For the 15, 50, 150, 500, 1,500 v a-c ranges S_{2A} and S_{2C} are switched to terminals 2, 3, 4, 5, 6, and on terminals 5, and 6 a smaller portion of the measured voltage is rectified by V_{2_A} and passed to the grid of V_{1_A}. This keeps the voltage applied to V_{2_A} on the high voltage ranges from exceeding the tubes voltage limitations.

Ohms Input

The ohms input circuit is placed into operation when the function switch is placed in the Ohm's position. In Figure 22, the ohms lead connects through J_2 to terminal 5 on S_{1_B}. When the function switch is in the ohms position the movable contacts connect to terminal 5 and terminal 1. Therefore, the circuit is completed through terminal 1 to the contact arm of S_{2_C}, and in the $R \times 1$ position, movable contact C connects through terminal 12 to R_{20} and battery E. The slide contact on S_{1_B} connects to the grid of V_{1_A} through R_{14}.

The ohms input circuit on the $R \times 1$ range is shown in Figure

21, without all the switching. To measure the resistance of some resistor R_x, connect the ohms and common lead across it after being sure all of the external voltage is turned off and no other part is in parallel with it.

Keep in mind that there is a connection from the common jack through the chassis to the grounded end of the battery. R_x completes a circuit which includes R_{20} and the battery E. Current passes from battery negative through R_x, through R_{20}, and to battery positive. The voltage from point 12 to ground is positive since it is the battery voltage minus whatever appears across R_{20}.

This positive voltage at point 12 makes the grid bias for V_{1_A} less negative. This reduced bias upsets the amplifier balance, and the current through the meter deflects the pointer.

Since the unknown resistance R_x is in series with R_{20} and the battery, when R_x is equal to R_{20} or 10 ohms, half of the battery voltage appears across R_x and is applied through R_{14} to the grid of V_{1_A}. If a larger unknown resistance is used a larger portion of the battery voltage is applied to V_{1_A} and this causes a larger meter deflection.

When the range switch is rotated to new range positions new resistances replace R_{20}. For example in the $R \times 10$ position, R_{19} which is 100 ohms replaces R_{20} in the circuit. Therefore to have the same voltage across it and cause the same meter deflection R_x has to have 10 times the resistance. Hence, the readings are properly multiplied by 10. The same holds true for each other position of the range switch, the resistance that replaces R_{20} determines the multiplying factor.

Note that on $R \times 100K$, the highest range, the resistance, R_{20} is replaced by R_{15} which is 1 megohm as shown in Figure 22. If this range is used to measure a small resistance hardly any voltage appears across it. Thus, the grid bias on V_{1_A} is changed so slightly that little or no pointer deflection occurs. To measure this small resistance, you must switch to a lower range.

VTVM Rating

Unlike other meters, the VTVM is not rated by its ohms per volt sensitivity. As was pointed out earlier, the more current the meter draws, the more error a voltmeter has. The higher the input resistance of the meter, the less current drawn, and the less error. Moreover, unlike multimeters, the VTVM input resistance does not change for the various ranges. For example, the voltage being measured is applied to resistors R_2, R_8, R_9, R_{10}, R_{11}, R_{12}, and R_{13} in series for all d-c ranges of the VTVM.

Therefore, it is common practice to rate VTVM's according to their input resistance since it is this resistance that determines how much current is drawn by the meter. The higher this resistance, the better the meter; all other things being equal.

A typical input resistance is 10 megohms. By adding the values shown in Figure 22 for these resistors, this meter input slightly exceeds 10 megohms.

SUMMARY

Basically, a meter operates on the magnetic effects of an electric current. The meter movements described in this lesson operate due to the interaction of two magnetic fields. A pointer is attached to a moving coil which deflects. The stronger the magnetic field the greater the deflection.

To prevent a reduction of circuit current the resistance of an ammeter must be low. But to limit the current used for the operation of a voltmeter, its resistance must be high.

The greater the current required for full scale deflection of an ammeter, the less its sensitivity. An instrument which requires a small current for full scale deflection has high sensitivity. Selected resistors, called shunts, are connected across the terminals of an ammeter to extend its current range upward.

Voltmeter sensitivity is expressed in ohms per volt, and is found from:

$$\text{Ohms per volt} = \frac{1}{\text{full scale current}}$$

Selected resistors, called multipliers, are connected in series with the meter movement to extend the voltage range upward.

There are two basic ohmmeter currents: one is known as the series type in which the unknown resistance is placed in series with a meter, a battery and a limiting resistor. The decrease of current in the circuit is a measure of the added resistance. The scale markings of this type of ohmmeter decrease from a high resistance to zero resistance for full scale deflection of the pointer.

The second basic ohmmeter circuit is the back-up or shunt type in which the unknown resistance is placed in parallel with the meter movement. In this type, the current through the meter is an inverse measure of the shunt resistance. The scale markings of this type ohmmeter increase from zero to a high resistance for full scale deflection of the pointer.

A single multirange instrument, known as a multimeter, includes circuit arrangements for measurement of a-c/d-c voltages, direct current, and resistance. Similar in function to a multimeter, a vacuum tube voltmeter includes vacuum tubes and circuit arrangements which increase the accuracy of the instrument and make it less liable to damage on accidental overload.

A VTVM usually is rated according to its input resistance. A typical rating is 10 megohms.

IMPORTANT DEFINITIONS

D'ARSONVAL—[dahr son VAHL]—A type of direct current meter in which a lightweight coil of wire, supported on jeweled bearings between the poles of a permanent magnet, is rotated by the effects of an electric current in the coil.

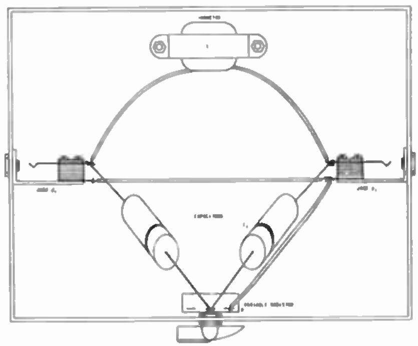
SENSITIVITY—[sen si TIV i ti]—As pertaining to meters, a measure of the current required for full scale deflection. For a voltmeter it is expressed in "ohms per volt".

VACUUM TUBE VOLTMETER—A circuit using a balancing circuit, which measures a voltage when the circuit is unbalanced.

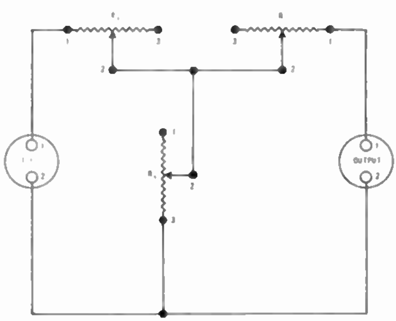
WATTMETER—[WAHT mee ter]—An electric instrument calibrated directly in watts and used for power measurements.

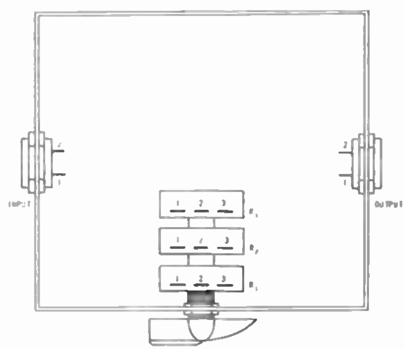
WORK DIAGRAMS

1. The drawing shows a circuit consisting of an iron core inductor, two capacitors, a variable resistor, and two jacks mounted in a chassis. Draw the schematic diagram and label the parts.



2. The schematic diagram shows the circuit of a control device containing three variable resistors connected between input and output sockets. These components are shown mounted in a chassis in the pictorial sketch. The three resistors are controlled by a single shaft. Use the schematic as a guide and sketch in the wiring to complete the circuit in the pictorial.





When you have finished, check with the solutions on the back of the foldout sheet.

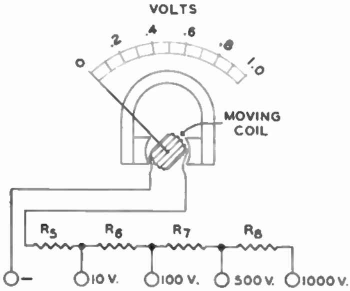


FIGURE 8

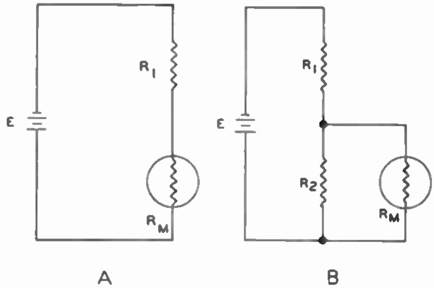


FIGURE 9

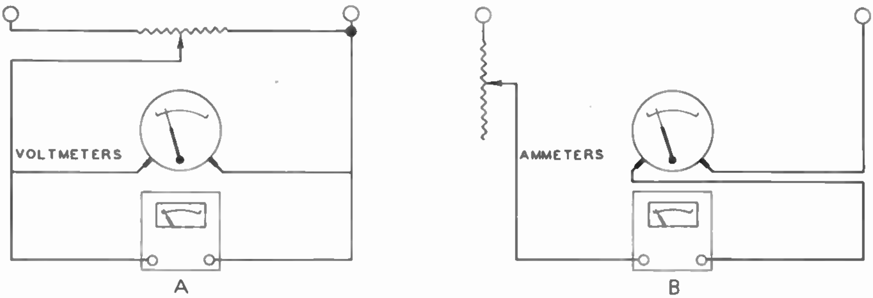


FIGURE 10

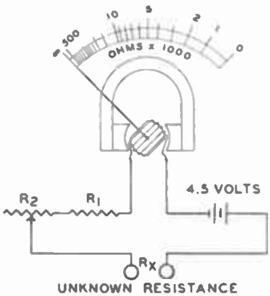


FIGURE 11

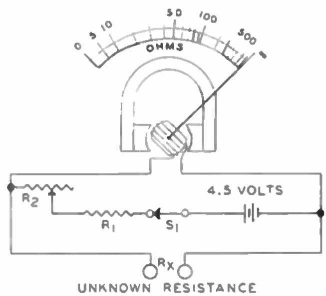


FIGURE 12

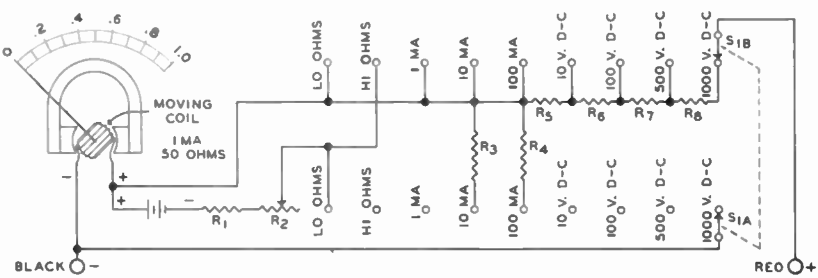


FIGURE 13

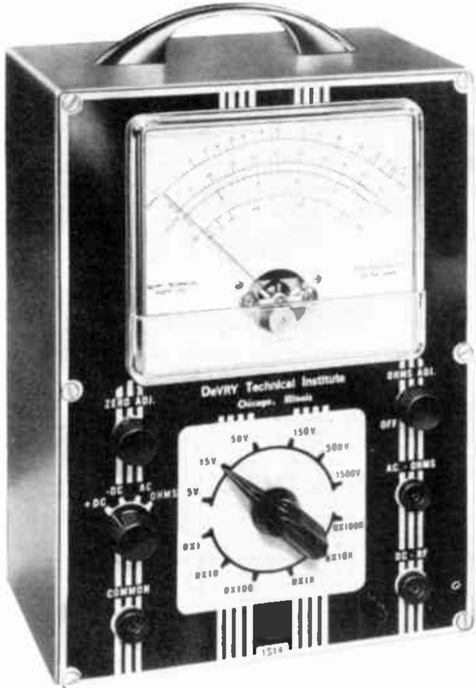


FIGURE 14

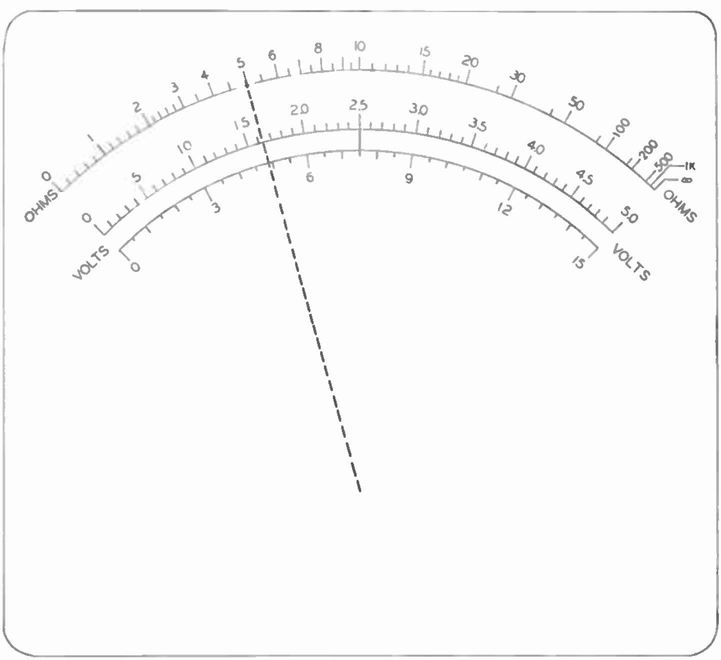


FIGURE 15

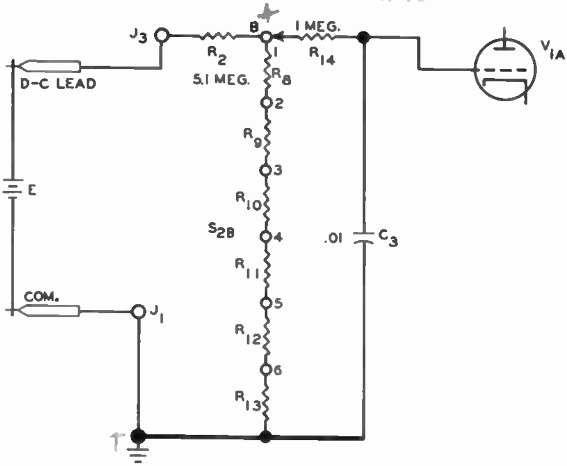


FIGURE 19

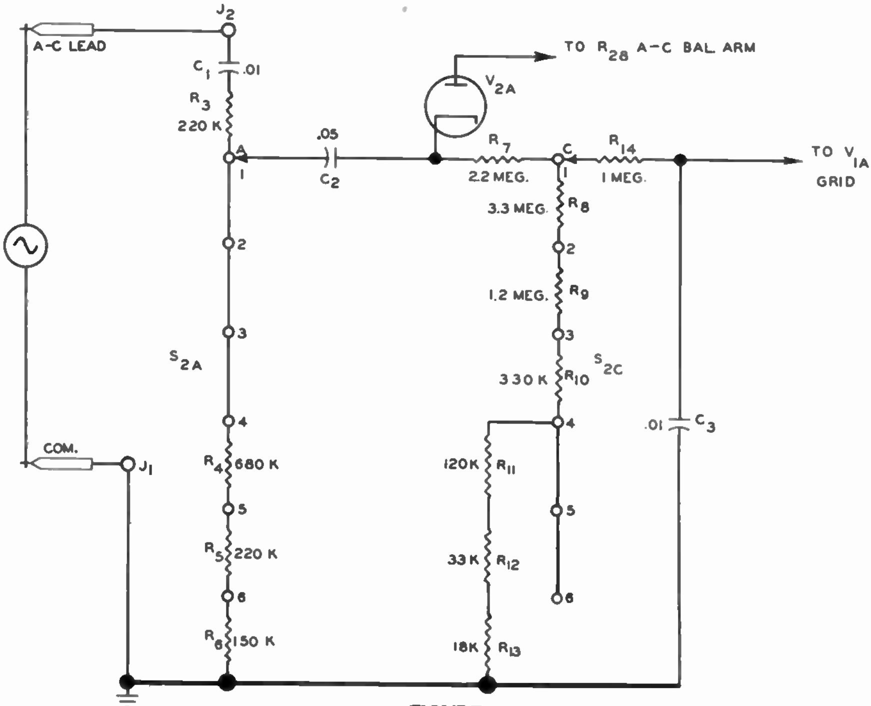


FIGURE 20

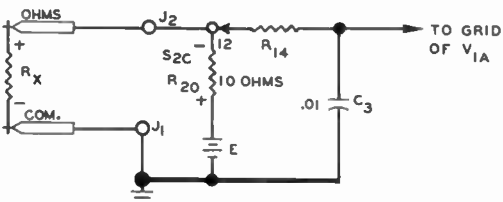


FIGURE 21

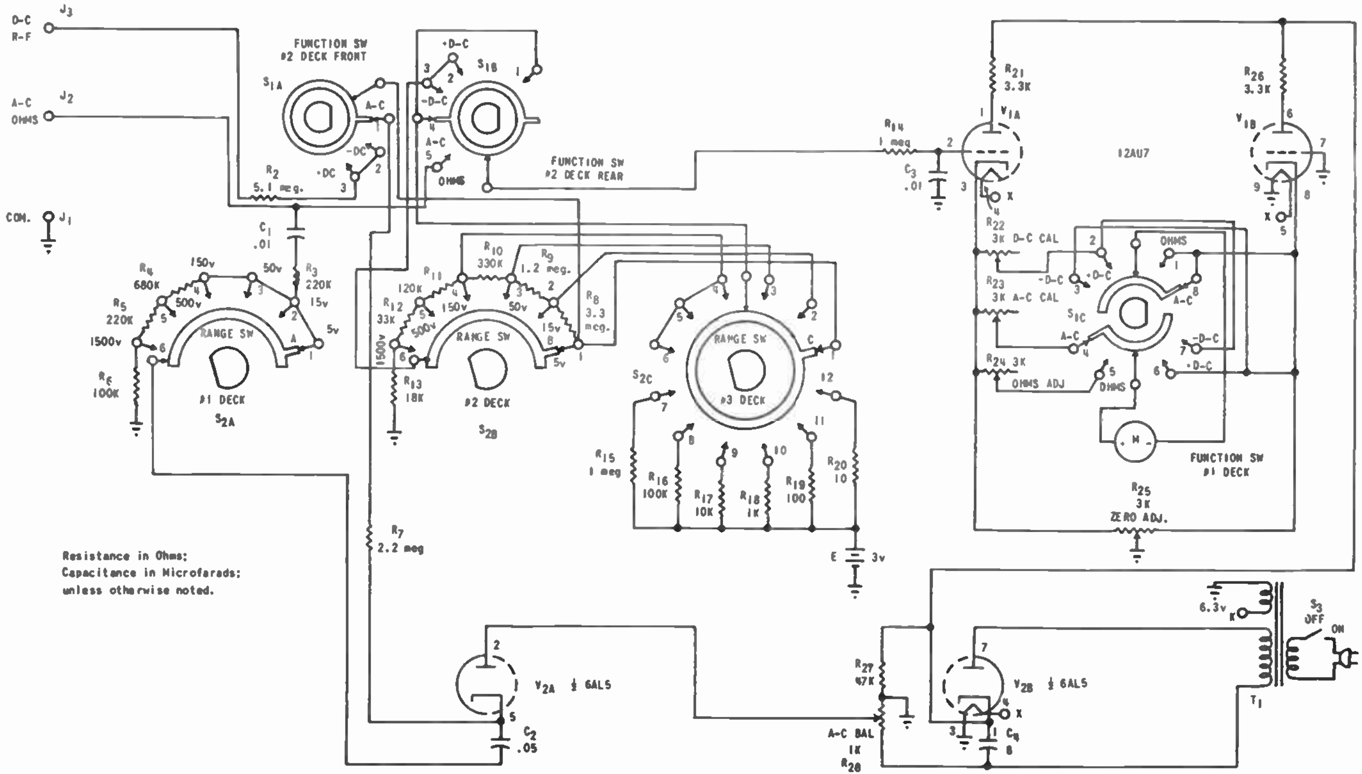

D-C
R-F
J3
A-C
OHMS
J2
COM.
J1
FUNCTION SW
#2 DECK FRONT
S1A
S1B
+D-C
-D-C
A-C
OHMS
-DC
+DC
R2
5.1 meg.
C1
.01
R3
220K
R4
680K
R5
220K
R6
100K
150v
50v
15v
500v
1500v
5v
RANGE SW
#1 DECK
S2A
FUNCTION SW
#2 DECK REAR
R10
330K
R9
1.2 meg.
R11
120K
R12
33K
R8
3.3 meg.
R13
18K
#2 DECK
S2B
S2C
RANGE SW
#3 DECK
R15
1 meg
R16
100K
R17
10K
R18
1K
R19
100
R20
10
E
3v
R7
2.2 meg
R14
1 meg
C3
.01
R21
3.3K
V1A
R26
3.3K
V1B
12AU7
R22
3K D-C CAL
R23
3K A-C CAL
R24 3K
OHMS ADJ
S1C
M
FUNCTION SW
#1 DECK
R25
3K
ZERO ADJ.
Resistance in Ohms;
Capacitance in Microfarads;
unless otherwise noted.
V2A ½ 6AL5
C2
.05
R27
47K
A-C BAL
1K
R28
V2B ½ 6AL5
C4
8
6.3v
S3
OFF
ON
T1

FIGURE 22

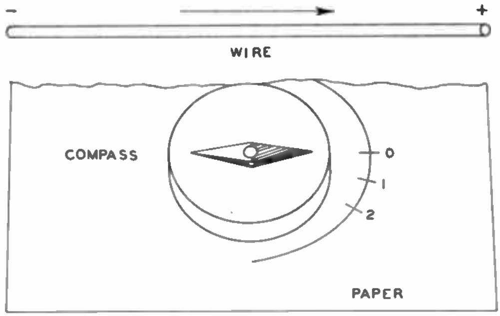


FIGURE 1

D, ARSONVAL,

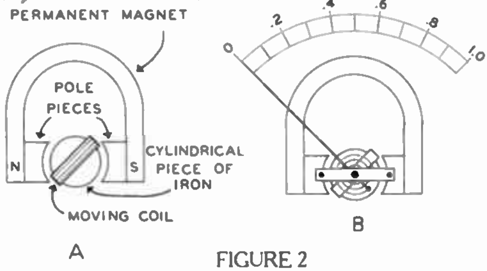


FIGURE 2

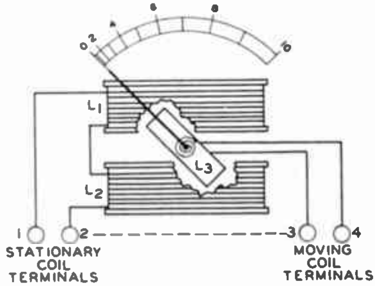


FIGURE 3

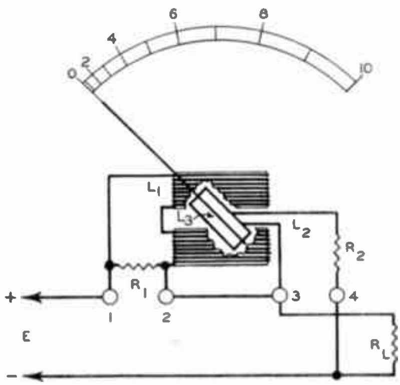


FIGURE 4

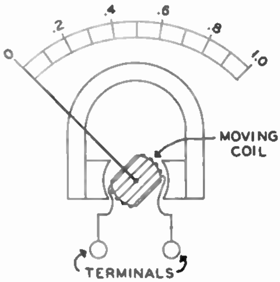


FIGURE 5

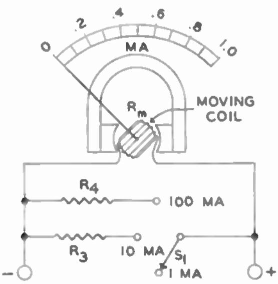


FIGURE 6

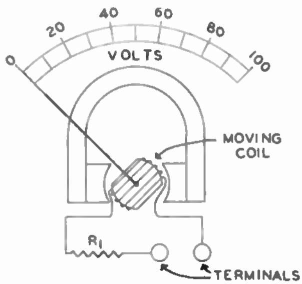


FIGURE 7

AEH-18

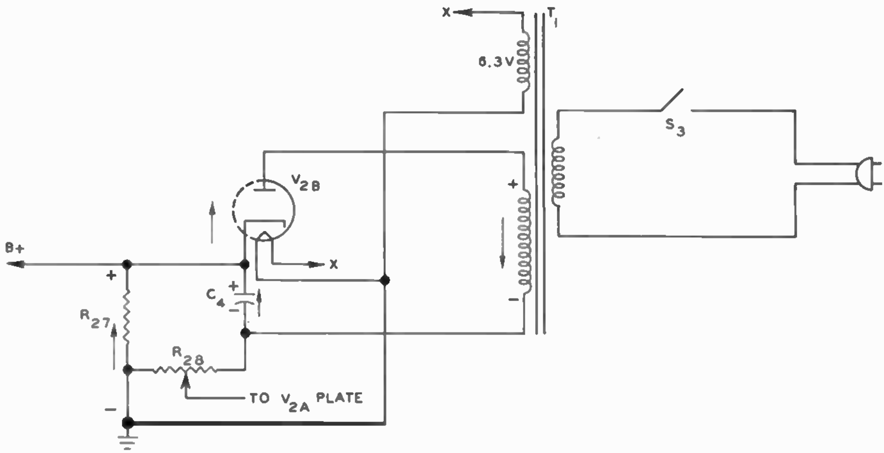


FIGURE 16

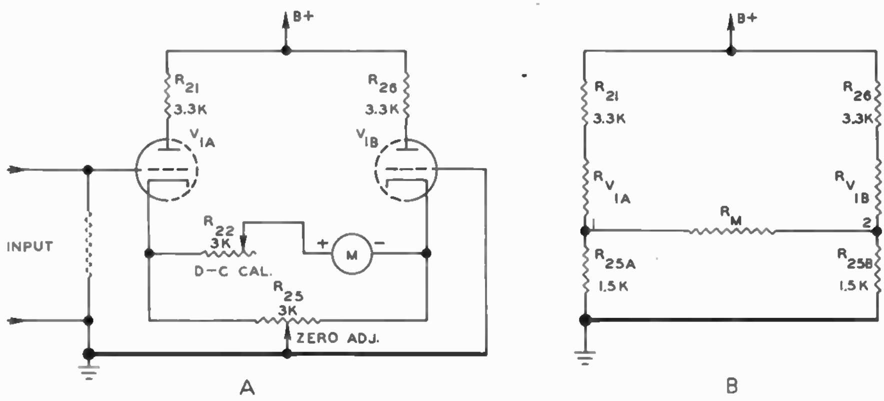


FIGURE 17

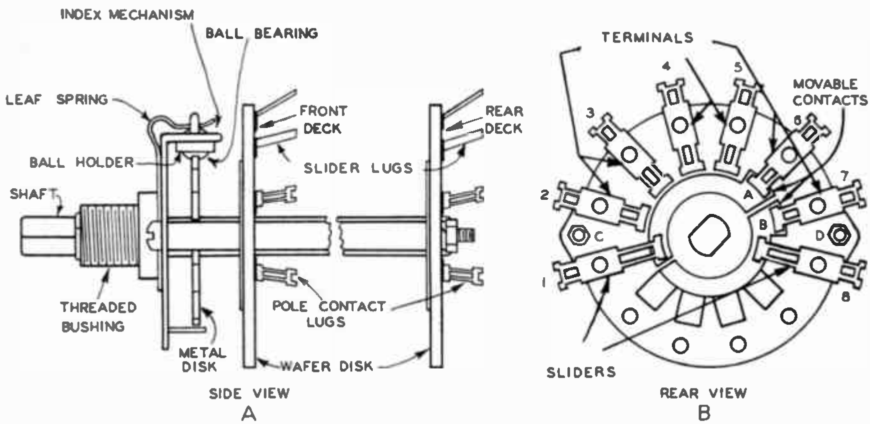
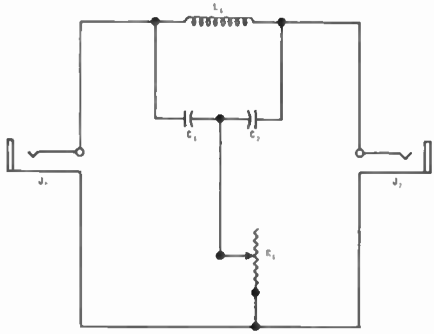


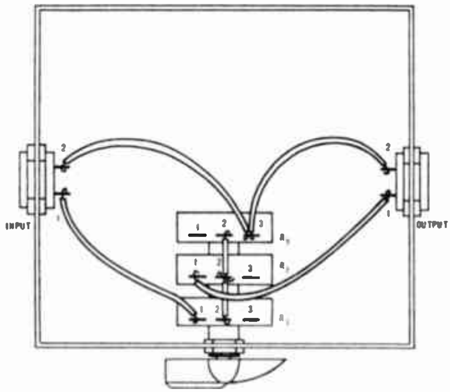
FIGURE 18

WORK DIAGRAM SOLUTIONS

1. The drawing shows a circuit consisting of an iron core inductor, two capacitors, a variable resistor, and two jacks mounted in a chassis. Draw the schematic diagram and label the parts.



2. The schematic diagram shows the circuit of a control device containing three variable resistors connected between input and output sockets. These components are shown mounted in a chassis in the pictorial sketch. The three resistors are controlled by a single shaft. Use the schematic as a guide and sketch in the wiring to complete the circuit in the pictorial.



FROM OUR *Director's* NOTEBOOK

IF—

If you can keep your head when all about you
Are losing theirs and blaming it on you;
If you can trust yourself when all men doubt you,
But make no allowance for their doubting too;
If you can wait and not be tired by waiting,
Or, being lied about, don't deal in lies,
Or being hated, don't give way to hating,
And yet don't look too good, nor talk too wise;

If you can dream—and not make dreams your master;
If you can think—and not make thoughts your aim,
If you can meet with Triumph and Disaster
And treat those two imposters just the same:
If you can bear to hear the truth you've spoken
Twisted by knaves to make a trap for fools,
Or watch the things you gave your life to, broken,
And stoop and build 'em up with worn-out tools;

If you can make one heap of all your winnings
And risk it on one turn of pitch-and-toss,
And lose, and start again at your beginnings,
And never breathe a word about your loss:
If you can force your heart and nerve and sinew
To serve your turn long after they are gone,
And so hold on when there is nothing in you
Except the Will which says to them: "Hold on!"
Yours is the Earth and everything that's in it,
And—which is more—you'll be a Man, my son!

—Rudyard Kipling

Yours for success,

W. C. DeVry

DIRECTOR

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R, L, and C

Lesson AEH-19B

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AEH-19B

R, L, and C

4141 Belmont Ave.

Chicago 41, Illinois

ELECTRONICS TELEVISION
DTI
DeVRY Technical Institute

ELECTRONS BAKE CAKES

Within 90 seconds after the batter is poured into the pan, it rises to form a smooth even texture, and the baking of a cake is completed. Instead of in the oven, the cake pan has been placed between two electrodes and an electric field generates the heat within the batter. Thus, it is unnecessary to wait the usual long period of time while heat penetrates inward slowly from the surface.

Known as dielectric heating, this process is used whenever quick, carefully controlled heating is required throughout the entire object. Other typical applications include molding plastics quickly from a powder, setting the glue quickly between thin sheets of wood to form plywood, curing rubber in tires and foam mattresses, "sewing" plastic cloth, and as diathermy, to reduce soreness, aches, and pains in the bodies of patients.

Fundamentals

R, L, and C

Contents

Our best friends and our worst enemies are our thoughts. A thought can do us more good than a doctor or a banker or a faithful friend. It can also do us more harm than a brick.

—Dr. Frank Crane

R, L, and C

Regardless of its particular application, every electron circuit contains at least a little of each of the three properties, resistance, inductance, and capacitance. Whether we want them there or not, these properties are always in a circuit due to the materials of which the circuit is constructed. In any given circuit, the properties due to its construction usually are not concentrated at a point. Instead, they are spread all along the circuit. For this reason, we call them the "distributed" properties. When concentrated in the form of resistors, inductors, and capacitors, these same properties are known as the "lumped" properties.

Since nearly all practical circuits contain lumped properties, it is this form which is understood ordinarily when the words resistance, inductance, and capacitance are used. The terms distributed and lumped are needed only when there is danger of misunderstanding in a particular case.

Normally, resistors, inductors, and capacitors contain a much larger amount of the respective properties than there is of the distributed type in a given circuit. Therefore, for most practical purposes, when a circuit contains one or more resistors, we simply assume that these resistors contain all of the circuit resistance. The same assumptions are made in the cases of inductors and capacitors. That is, in practice, we ignore the small distributed properties. The few exceptions to this rule are certain special cases which are better covered when the need arises.

Depending upon the meter measurement being made, certain circuit conditions result in erroneous indications of voltage or current. These errors are not the result of poor meter design. Instead, they are due to the effects which the meters have on the circuits in which the measurements are made. These effects are described in this lesson. Whenever a meter is connected to or into a circuit, the meter itself becomes a series or parallel section of the circuit. Therefore, to aid your understanding the various effects to be described, we shall begin with a review of the basic series and parallel circuits.

In such circuits, Ohm's Law can be employed to calculate either the resistance of, current in, or voltage across a single resistor. However, many practical circuits contain more than one re-resistor. Often, it is desirable to compute the circuit current which will be produced in such a circuit by a given applied voltage. Ohm's Law can be applied here too, once we have determined the resistance of the entire circuit. Similar calculations also are employed with circuits containing inductance or capacitance.

RESISTANCE OF SERIES CIRCUITS

Figure 1A shows a voltage E applied to the terminals of a circuit containing a resistor, R_1, and an ammeter, A. The applied voltage is obtained from any suitable source such as a battery or generator. As you will recall, Ohm's Law can be employed to find the value of either E, R_1, or I_1, providing the other two quantities are known.

As an example, suppose we desire to find the applied voltage, when R_1 is known to be 50 ohms, and the ammeter indicates a current of 3 amperes. We use Ohm's Law in the form which states that voltage is equal to current times resistance:

$$E = I_1 \times R_1$$

$$E = 3 \times 50 = 150 \text{ volts.}$$

For a second example, suppose the applied voltage is 250 volts, the circuit current measures 10 amperes, and we desire to know the resistance of the resistor. We then use the Ohm's Law form which states that resistance is equal to voltage divided by current:

$$R_1 = \frac{E}{I_1}$$

$$R_1 = \frac{250}{10} = 25 \text{ ohms.}$$

Finally, suppose we desire to check the accuracy of the ammeter reading by means of Ohm's Law. Here we employ the form which states that current is equal to voltage divided by resistance. If E is known to be 120 volts, and R_1 equals 10 ohms, the meter should read:

$$I_1 = \frac{E}{R_1}$$

$$I_1 = \frac{120}{10} = 12 \text{ amperes.}$$

As an experiment, suppose we replace resistor R_1 of this last example with a 20 ohm resistor, R_2, as shown in Figure 1B. The applied voltage is still 120 volts, but we have doubled the circuit resistance. With greater resistance in the circuit, current I_2 should be less than I_1 of Figure 1A. That this idea is correct is shown by the ammeter which read 12 amperes with R_1 but reads only 6 amperes with R_2 in the circuit. Checking with Ohm's Law:

$$I_2 = \frac{E}{R_2}$$

$$I_2 = \frac{120}{20} = 6 \text{ amperes.}$$

Thus, with the same applied voltage, increasing the circuit resistance resulted in decreasing the current. For the values used above, the current was halved when the resistance was doubled.

Now, if we replace R_2 with R_1, to return to the circuit of Figure 1A, we reduce the resistance from 20 ohms to 10 ohms. As a result, the current increases from 6 amperes to 12 amperes. Notice that,

An AM/FM radio-phono combination. Equipment such as this incorporate a considerable number of each of the types of circuits described in this lesson.

Courtesy Admiral Corporation

whichever way the resistance is changed, the current changes in the opposite direction. That is, a resistance increase reduces the current, while a resistance decrease permits greater current. When related quantities change in this manner, we say they are INVERSELY PROPORTIONAL to each other. With voltage constant, CURRENT IS INVERSELY PROPORTIONAL TO RESISTANCE.

To continue our experiment, we next use both resistors to form the series circuit of Figure 2. Here, the applied voltage E produces current I which is carried by both resistors and the ammeter. Although there are two resistors in the circuit, there is only one path for current. Coming from the voltage source, electrons enter one terminal, flow through the circuit, and leave by the other terminal to return to the source. Polarity signs are not shown since it matters not whether the electrons enter by the upper or the lower terminal. In either case, the opposition offered by the resistors is the same. That is, the ammeter indicates the same current regardless of whether the electrons enter the upper terminal and flow through the meter first and then through R_1 and R_2 to the lower terminal, or enter the lower terminal and flow through R_2 and R_1 and then through the meter to the upper terminal.

With E equal to 120 volts as before, R_1 equal to 10 ohms, and R_2 equal to 20 ohms in the circuit of Figure 2. we find that our ammeter indicates a circuit current of 4 amperes. That is, the entire series circuit of Figure 2 has a resistance that permits only 4 amperes of current when 120 volts is applied. The current, here, is less than in either circuit of Figure 1. Since current and resistance are inversely proportional, the entire circuit resistance of Figure 2 must be greater than Figure 1A or Figure 1B.

To use Ohm's Law for Figure 2, we can think of the entire resistance as being lumped in one component, R_T. Thus, R_T represents the total resistive effect offered by R_1 and R_2 connected in series. Then substituting the known values of voltage and current in the Ohm's Law equation:

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

$$R_T = \frac{120}{4} = 30 \text{ ohms.}$$

That is, the entire series circuit of Figure 2 has a resistance, R_T, equal to 30 ohms.

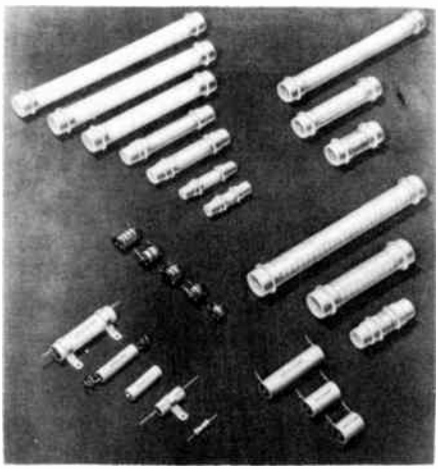
Also, when the resistances of R_1 and R_2 are added, we obtain a total of 30 ohms:

$$R_1 + R_2 = 10 + 20 = 30 \text{ ohms.}$$

Since both R_T and $R_1 + R_2$ are equal to the same value, 30 ohms, they are equal to each other also. This idea can be expressed briefly as follows:

$$R_T = R_1 + R_2 \qquad (1)$$

Stated in words, this equation tells us that THE TOTAL RESISTANCE R_T OF A SERIES CIRCUIT IS EQUAL TO THE SUM OF THE SEPARATE RESISTANCES, R_1 and R_2. Notice that there are no numbers in the equation: only the symbols, R_T, R_1, and R_2 are used. This fact enables us to use the equation for any series circuit like that of Figure 2, regardless of the resistances used.



Resistors are made in a variety of sizes, compositions, resistances, and wattage ratings to accommodate the different current, voltage, and other requirements of the circuits employed in the various types of electron equipment.

Courtesy Sprague Electric Co.

As an example, in Figure 2, suppose E and I are not known, but we know that R_1 equals 25 ohms and R_2 equals 60 ohms, and we desire to find the total resistance of the circuit, R_T. We substitute the known resistances into the above equation:

$$R_T = R_1 + R_2$$

$$R_T = 25 + 60 = 85 \text{ ohms.}$$

Now that we have a means of calculating the total resistance of a series circuit, we can employ it to solve Ohm's Law problems as mentioned in our introduction to this lesson. That is, we can employ Ohm's Law to compute the current which is produced in a series circuit by a given applied voltage.

An example is illustrated in Figure 3. Here, it is desired to know what current I is produced when 60 volts are applied to a series circuit containing two resistors with resistances of 10 ohms and 15 ohms. Since the current is limited by both resistors, the total resistance of the circuit must be known to compute the current. The total resistance is, $R_T = 15 + 10 = 25$ ohms. Now, with R_T known, the current is,

$$I = \frac{E}{R_T} = \frac{60}{25} = 2.4 \text{ amperes.}$$

In Figures 2 and 3, the applied voltage E is across both resistors in series. However, this voltage is not applied to each individual resistor. For example, in Figure 3, if 60 volts were applied across the terminals of the 15 ohm resistor alone, the current in this unit would be $I = E/R = 60/15 = 4$ amperes. As explained above, the current in this circuit, and therefore in this resistor, is only 2.4 amperes. Due to the circuit current, the voltage E_1 across the 15 ohm resistor is found from Ohm's Law as follows:

$$E_1 = I \times R_1 = 2.4 \times 15 = 36 \text{ volts.}$$

Likewise, the voltage E_2 across the 10 ohm resistor is:

$$E_2 = I \times R_2 = 2.4 \times 10 = 24 \text{ volts.}$$

Notice that the sum of E_1 and E_2 is $36 + 24 = 60$ volts, the total applied voltage. This situation is true in all series circuits. Therefore, we can state this general rule in the form of an equation:

$$E = E_1 + E_2 \qquad (2)$$

where E is the voltage applied to the entire series circuit, and E_1 and E_2 are the voltages across the individual components.

In words, this rule states that, IN A SERIES CIRCUIT, THE APPLIED VOLTAGE IS EQUAL TO THE SUM OF THE COMPONENT VOLTAGES.

Also in Figure 3, the voltage E_1 across the 15 ohm resistor is greater than the voltage E_2 across the 10 ohm unit. This fact illustrates another rule which is true for all series resistance circuits. This rule is: IN A SERIES CIRCUIT, THE VOLTAGES ACROSS THE RESISTORS ARE DIRECTLY PROPORTIONAL TO THE RESISTANCES. That is, the higher the resistance of a given resistor in a series circuit, the greater the voltage across it.

RESISTANCE OF PARALLEL CIRCUITS

In Figure 4, resistors R_1 and R_2 are connected to switches which enable us to apply voltage E to either resistor alone or to both in parallel. When switches S_1 and S_2 are both closed, we obtain the parallel circuit shown in Figure 5. With E applied, electrons from the source enter either the upper or the lower terminal, flow through the circuit, and leave by the other terminal. As before, the meter indicates I_T to be the same with either current direction.

If electrons enter by the upper terminal, the current passes through the meter to point A. Here, it divides into two parts. One part, I_1, passes through S_1 and R_1 to point B. The other part, I_2, passes through S_2 and R_2 to point B. At point B, I_1 and I_2 join to become a single current equal to the value I_T read by the meter. Finally, the electrons flow from point B to the lower terminal, from which they return to the source. On the other hand, if electrons enter by the lower terminal, the current splits at point B, each resistor carries a part of the total current, and the parts join at point A to pass through the meter and leave by the upper terminal.

Suppose, in Figures 4 and 5, the applied voltage $E=120$ volts, $R_1=20$ ohms, and $R_2=30$ ohms. With both switches open, as in Figure 4, there is no path for current. Now, if S_1 is closed, there is a path from the upper input terminal, through the ammeter, switch S_1, and resistor R_1 to the lower terminal. Thus, with S_1 closed, and S_2 open, the circuit is like that of Figure 1A. The applied voltage produces a current I_1 which is determined by the values of E and R_1. I_1 can be calculated by employing the given E and R_1 values in the Ohm's Law equation:

$$I_1=\frac{E}{R_1}=\frac{120}{20}=6 \text{ amperes.}$$

Therefore, with only switch S_1 closed in Figure 4, the ammeter indicates a current of 6 amperes.

Now if S_1 is opened and S_2 closed, the circuit is like that of Figure 1B. The applied voltage produces a current I_2 which is determined by the values of E and R_2. Using Ohm's Law:

$$I_2=\frac{E}{R_2}=\frac{120}{30}=4 \text{ amperes.}$$

Thus, with only switch S_2 closed in Figure 4, the ammeter indicates a current of 4 amperes.

In these examples, closing S_1 permitted voltage E to be applied to R_1, while closing S_2 applied E to resistor R_2. In each case, the produced current depended upon the value of E and the resistance of only the resistor thus connected.

However, when both S_1 and S_2 are closed, as in Figure 5, then voltage E is applied to both resistors. Along with its switch, each resistor forms a "branch" of the parallel circuit.

Thus, THE VOLTAGE ACROSS EACH BRANCH OF A PARALLEL CIRCUIT IS THE SAME AS THAT APPLIED ACCROSS THE ENTIRE CIRCUIT. The branches are independent of each other. That is, branch current I_1 is the same whether switch S_2 is open or closed. Likewise, branch current I_2 is the same when S_1 is closed as when S_1 is open. This point is important to remember. Stated in general terms, regardless of the number of branches IN A PARALLEL CIRCUIT LIKE THAT OF FIGURE 5, THE CURRENT IN A GIVEN BRANCH DEPENDS ONLY UPON THE RESISTANCE IN THAT BRANCH AND THE APPLIED VOLTAGE.

Therefore, in Figure 5:

$$I_1 = \frac{E}{R_1} = \frac{120}{20} = 6 \text{ amperes, and}$$

$$I_2 = \frac{E}{R_2} = \frac{120}{30} = 4 \text{ amperes.}$$

Notice here, that current I_1 in the 20 ohm branch is greater than current I_2 in the 30 ohm branch. Stated as a rule: IN A PARALLEL CIRCUIT, THE BRANCH CURRENTS ARE INVERSELY PROPORTIONAL TO THE BRANCH RESISTANCES. That is, the branch with the lowest resistance carries the largest branch current, and that with the highest resistance the smallest branch current.

As mentioned, when current direction is such that electrons enter the lower input terminal, for example, in Figure 5, then the current divides at point B. Part is carried by the R_1 branch; the other part by the R_2 branch. As explained above, branch current I_1 is equal to E/R_1 and branch current I_2 is equal to E/R_2. At point A, these currents, I_1 and I_2, rejoin to form the current I_T indicated by the ammeter. The source supplies sufficient current for all the branches of the parallel circuit. Called the total current, I_T, this supplied current is equal to the sum of the branch currents. In Figure 5, I_T is carried by the portion of the circuit between point A and the upper terminal, and also by the portion between the lower terminal and point B. Using the values of the above example:

$$I_T = I_1 + I_2 \qquad (3)$$

$$I_T = 6 + 4 = 10 \text{ amperes.}$$

Thus, with both switches closed to form the parallel circuit of Figure 5, the ammeter A indicates a total circuit current of 10 amperes.

Combination circuits form the majority of those employed in electron equipment such as this table model television receiver.

Courtesy Sentinel Radio Corp.

We can think of the entire circuit of Figure 5 as though it were a single component, R_{eq}, in which all of the resistance is lumped. In this case, R_{eq} is the "equivalent" resistance of the circuit. It is not equal to the sum of R_1 and R_2. Instead, R_{eq} is the resistance which will allow a current equal to I_T when a voltage E is applied. When E and I_T are known, R_{eq} can be calculated from Ohm's Law: $R_{eq}=E/I_T$. Using the values of the above example, the equivalent resistance of the circuit of Figure 5 is:

$$R_{eq}=\frac{E}{I_T}=\frac{120}{10}=12 \text{ ohms.}$$

Thus, THE EQUIVALENT RESISTANCE OF A PARALLEL CIRCUIT IS LESS THAN THE RESISTANCE IN ANY BRANCH. As shown in the Figure, the same voltage, E is applied to each branch and also to the entire circuit. With the same applied voltage, the branch with the highest resistance carries the smallest current. As R_{eq} is less than the lowest branch resistance, I_T is greater than any branch current. Of course, this condition is necessarily true since I_T is the sum of all the branch currents.

As with series circuits, sometimes it is necessary to calculate the equivalent resistance of a parallel circuit when E and I_T are not known. By a method explained in Appendix A of this lesson, we can derive an equation which gives R_{eq} in terms of the branch resistances. For a two-branch parallel circuit like that of Figure 5, this equation can be expressed as follows:

$$R_{eq}=\frac{R_1\times R_2}{R_1+R_2} \qquad (4)$$

In words, this equation states that THE PRODUCT OF THE BRANCH RESISTANCES DIVIDED BY THEIR SUM GIVES A VALUE WHICH IS THE EQUIVALENT RESISTANCE OF THE ENTIRE PARALLEL CIRCUIT OF TWO BRANCHES.

As an illustration, we can employ this equation to check the value of R_{eq} obtained in the above example. The branch resistance values given were, $R_1=20$ ohms, and $R_2=30$ ohms. Substituting these values in equation (4):

$$R_{eq}=\frac{R_1\times R_2}{R_1+R_2}$$

$$R_{eq}=\frac{20\times 30}{20+30}=\frac{600}{50}=12 \text{ ohms.}$$

This result checks with that obtained above using $R_{eq}=E/I_T$.

With equation (4) providing a means of finding R_{eq}, we can employ Ohm's Law to compute the total current produced in a parallel circuit by a given voltage. An example is illustrated in Figure 6. Here, 60 volts are applied to the terminals of a parallel circuit in which one branch consists of a 10 ohm resistor and the other of a 15 ohm resistor. Using equation (4), the equivalent resistance of this circuit is:

$$R_{eq}=\frac{R_1\times R_2}{R_1+R_2}=\frac{10\times 15}{10+15}=\frac{150}{25}=6 \text{ ohms}$$

Then, to find the total current, we use this calculated value of R_{eq} and the given value of E in Ohm's Law:

$$I_T=\frac{E}{R_{eq}}=\frac{60}{6}=10 \text{ amperes.}$$

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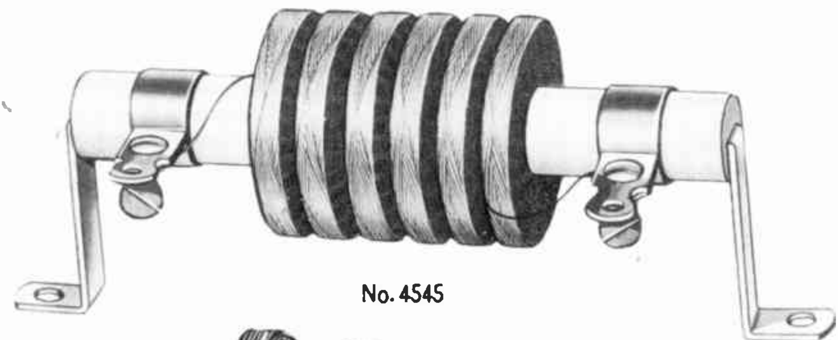

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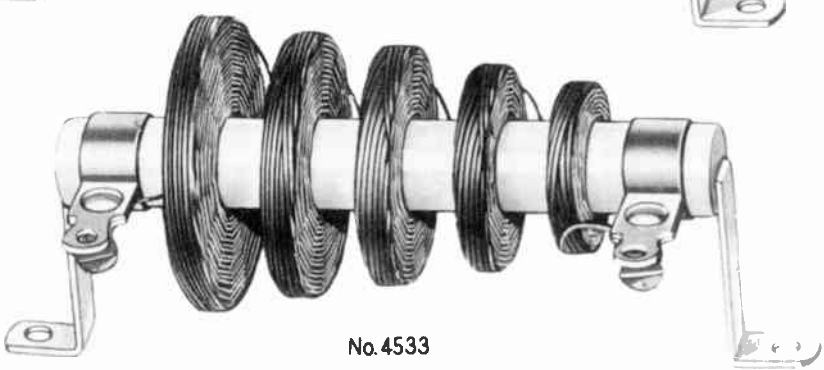

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Inductors. The lower two are made up of sections connected in series.

Courtesy of J. W. Miller Co.

Comparing the parallel circuit of Figure 6 with the series circuit of Figure 3, although the resistors have the same values, and the same voltage is applied to both circuits, the total current of 10 amperes in the parallel circuit is much greater than the 2.4 amperes in the series circuit. Also, in Figure 3, the total resistance R_T is 25 ohms, while in Figure 6 the equivalent resistance R_{eq} is only 6 ohms.

An alternative method of computing the total current in the circuit of Figure 6 is that which we used in explaining Figure 5. That is, since 60 volts is across each resistor, we can use Ohm's Law first to find the branch currents:

$$I_1 = \frac{E}{R_1} = \frac{60}{10} = 6 \text{ amperes}$$

$$I_2 = \frac{E}{R_2} = \frac{60}{15} = 4 \text{ amperes.}$$

Then, we can add the branch currents to obtain the total current:

$$I_T = I_1 + I_2 = 6 + 4 = 10 \text{ amperes.}$$

Of course, the same result is obtained by either method.

MEASURING ELECTRON TUBE VOLTAGES

In the above explanations, we gave equations concerning the total resistance and the voltages in series circuits and the currents and equivalent resistance in parallel circuits. Strictly speaking, these equations apply only to circuits like those of Figures 3 and 6. In the case of Figures 1, 2, 4, and 5, we included meters and switches to aid our explanations. Such components, especially the ammeters, have some resistance. Although relatively small, this resistance alters the circuit currents and voltages by a slight amount. As a result, whenever ammeters are inserted into circuits, the current readings obtained are slightly lower than the values calculated by the equations. In most practical cases, however, the circuit resistances are much greater than the ammeter resistance, and the errors are very small. For this reason, the preceding explanations ignored the effect of the ammeters.

Errors are obtained also when meters are connected to measure voltage. Often, these errors are considerably greater than the ammeter errors explained above. Figure 7 shows a triode employed as an amplifier. Here, C_1 and R_g are the input coupling components by means of which the signal is applied to the grid-cathode circuit of V_1. In the plate circuit, the output signal is developed across load resistor R_L. R_K and C_2 provide cathode bias for the tube. The plate supply voltage E_{bb} is applied to the terminals of the plate circuit as indicated.

When checking the operating voltages in a circuit like that of Figure 7, it is normal practice to touch the voltmeter prods to the plate and cathode of the tube, as shown. All tube voltages are measured using the cathode as the reference point. Therefore, in the Figure, the voltmeter is measuring the plate voltage. As the plate is positive with respect to the cathode, the positive meter terminal is connected to the plate of V_1, and the negative terminal to the cathode. These connections provide an added current path through the meter, external to the tube. Electrons flow from the cathode through the meter to the plate without passing through V_1. This current operates the meter, and the pointer deflects to indicate the plate voltage. It is this conduction by the meter which causes the error.

In Figure 8, the plate circuit of V_1 is redrawn to show that E_{bb} is applied to R_L and V_1 in series. Compared with R_L and V_1, cathode resistor R_K has very low resistance. For this reason, we have omitted R_K and its bypass capacitor C_2 in Figure 8. Tube V_1 conducts plate current in the direction from cathode to plate, and in this respect, may be considered a resistor. Therefore, we have redrawn the plate circuit again in Figure 9 where V_1 is replaced by the resistor labeled r_b. Here, we have a series circuit like that of Figure 3. Voltage E_{bb} is across both R_L and r_b. The portion of this voltage across R_L is labeled E_L, and the remainder, across r_b, is the plate voltage E_b. As in all series circuits, E_{bb} is equal to $E_L + E_b$. Therefore, the plate voltage is the difference between E_{bb} and the voltage E_L across the load resistor. That is,

$$E_b = E_{bb} - E_L.$$

Figure 9 represents the conditions without a meter connected to the circuit.

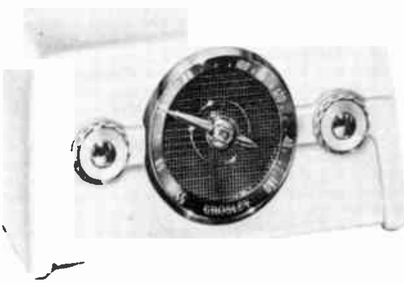
The plate circuit arrangement of Figure 8 is repeated in Figure 10 where voltmeter V is connected to measure the plate voltage of V_1. Since the voltmeter conducts current, it can be represented as a resistor also. In Figure 10, the voltmeter and tube V_1 are in parallel with each other. Therefore, these units are represented by resistors R_V and r_b, respectively, in Figure 11. Here, load resistor R_L is in series with the parallel circuit consisting of R_V and r_b.

Equation (4) can be employed to calculate the equivalent resistance of the two parallel units. Thus,

$$R_{eq} = \frac{R_V \times r_b}{R_V + r_b}$$

In Figure 12, this equivalent resistance is represented by resistor R_{eq}. Again, E_L is the voltage across R_L, but the voltage across R_{eq} is indicated as E_V, since this is what the voltmeter scale reads.

As explained for parallel circuits, the equivalent resistance is less than that in any branch. Therefore, R_{eq} in Figure 12 is less than r_b. As a result, the voltage E_V indicated by the meter is less than the voltage E_b of Figure 9.



This popular type radio receiver contains a number of series circuits, parallel circuits, and combination circuits.

Courtesy Crosley Div. of Avco Mfg. Corp.

To illustrate how this error comes about, we can employ typical voltages and resistances as an example.

In the circuit of Figure 7, suppose $E_{bb}=250$ volts, $R_L=100{,}000$ ohms, and the plate current I_b is .001 ampere. This current is carried by R_L, therefore we can use Ohm's Law to calculate the voltage E_L, indicated in Figure 9.

$$E_L = I_b \times R_L$$

$$E_L = .001 \times 100{,}000 = 100 \text{ volts.}$$

Subtracting E_L from the total applied voltage E_{bb} gives the actual plate voltage E_b which is present when there is no meter connected:

$$E_b = E_{bb} - E_L$$

$$E_b = 250 - 100 = 150 \text{ volts.}$$

Suppose a 1,000 ohms-per-volt meter is set to its 250 volt range to measure the plate voltage as shown in Figure 10. The meter resistance R_V is equal to $250 \times 1{,}000 = 250{,}000$ ohms. With $E_b = 150$ volts, and $I_b = .001$ ampere, the resistance r_b presented by the tube is:

$$r_b = \frac{E_b}{I_b} = \frac{150}{.001} = 150{,}000 \text{ ohms.}$$

With R_V and r_b in parallel, as shown in Figure 11, they have an equivalent resistance of,

$$R_{eq} = \frac{R_V \times r_b}{R_V + r_b}$$

$$R_{eq} = \frac{250{,}000 \times 150{,}000}{250{,}000 + 150{,}000}$$

$$R_{eq} = \frac{37{,}500{,}000{,}000}{400{,}000} = 93{,}750 \text{ ohms.}$$

In the circuit of Figure 12, the total resistance of R_L and R_{eq} in series is $R_T = R_L + R_{eq} = 100{,}000$

+ 93,750 = 193,750 ohms. The current in the circuit is increased to

$$I = \frac{E_{bb}}{R_T} = \frac{250}{193{,}750} = .0013 \text{ ampere. (approx.)}$$

With this larger current in the load resistor, the voltage E_L is equal to

$$E_L = I \times R_L = .0013 \times 100{,}000 = 130 \text{ volts.}$$

Subtracting E_L from E_{bb} gives the voltage E_V in Figure 12.

$$E_V = E_{bb} - E_L = 250 - 130 = 120 \text{ volts.}$$

As E_V is the voltage that the voltmeter indicates, the meter reading is 120 volts, since this is the voltage across the tube with the meter connected as in Figure 10. As explained, the actual plate voltage without the meter connected is 150 volts. Therefore, connecting the meter to the circuit, in this example, results in an error of 30 volts.

Summarizing this action briefly, touching the voltmeter test prods to the plate and cathode of tube V_1 in Figure 7 results in an equivalent resistance between the points of connection which is less than the resistance of the tube alone. The total resistance of the plate circuit thereby is reduced, allowing the circuit current to increase. With the larger current, the voltage E_L across the load resistor is greater. As the applied voltage E_{bb} is unchanged, there is less of this voltage available to appear across the tube, since the plate voltage E_b is equal to $E_{bb} - E_L$.

As mentioned, it is common practice to measure plate voltage in the manner shown in Figure 7, even though we know the reading obtained is not exactly correct. When such a measurement is made therefore, it is necessary to keep in mind the fact that the actual voltage present is somewhat higher than indicated by the voltmeter scale. If the voltmeter had infinite resistance, it would not decrease the resistance of the circuit to which it is connected. Then, R_{eq} in Figure 12 would be equal to r_b in Figure 9, the circuit currents and E_L would be the same in both cases, and E_V would be equal to E_b. To approach this ideal condition with a given voltmeter, it is a good idea to EMPLOY THE HIGHEST VOLTAGE RANGE WHICH WILL PERMIT REASONABLY EASY READING OF THE SCALE.

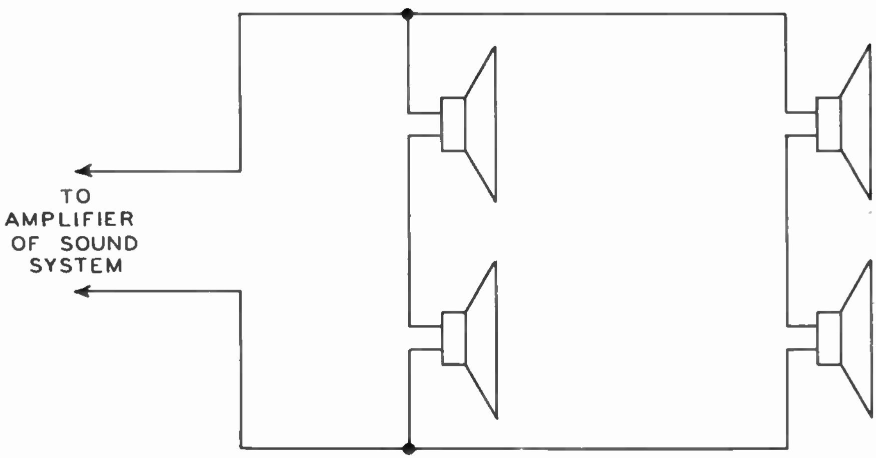
To illustrate the smaller error obtained when a high resistance voltmeter is employed, suppose a vacuum tube voltmeter is connected to measure the plate voltage as shown in Figure 7. If the VTVM has an input resistance of 10 megohms, then, in Figure 11, R_V and r_b have an equivalent resistance of

$$R_{eq} = \frac{R_V \times r_b}{R_V + r_b}$$

$$R_{eq} = \frac{10{,}000{,}000 \times 150{,}000}{10{,}000{,}000 + 150{,}000}$$

$$R_{eq} = \frac{1{,}500{,}000{,}000{,}000}{10{,}150{,}000} = 147{,}783$$

or approximately 148,000 ohms.



In certain public address systems the loudspeakers are operated as a combination circuit to provide proper sound coverage.

In the circuit of Figure 12, the total resistance is $R_T = R_L + R_{eq} = 100{,}000 + 148{,}000 = 248{,}000$ ohms. Therefore, the current in the circuit is

$$I = \frac{E_{bb}}{R_T} = \frac{250}{248{,}000} = .001008 \text{ ampere.}$$

With this current in R_L, the voltage across this resistor is

$$E_L = I \times R_L = .001008 \times 100{,}000$$
$$= 100.8 \text{ volts.}$$

Subtracting E_L from E_{bb} gives the voltage indicated by the meter

$$E_V = E_{bb} - E_L = 250 - 100.8 = 149.2 \text{ volts.}$$

Since the plate voltage without the meter connected is 150 volts, this meter reading of 149.2 volts is much more accurate than that obtained with the 1,000 ohm-per-volt meter.

Figure 13 shows a voltmeter V connected to measure the bias voltage between the grid and cathode of an electron tube. In this circuit, the cathode bias voltage E_{cc} is developed across the cathode resistor, R_K, with the polarity indicated. This Figure illustrates one method sometimes employed to measure the grid bias. However, due to the normal grid-cathode circuit conditions, a voltmeter connected as shown provides a reading with considerable error, unless the meter resistance is very high.

To explain the cause of this error, we have redrawn the grid-cathode circuit in Figure 14. Here, the cathode bias voltage E_{cc} is represented as the applied voltage with polarity such that the upper terminal is negative, and the lower terminal positive. By careful inspection, you will see that this circuit is exactly like the grid-cathode circuit of Figure 13, insofar as electric connections are concerned.

In Figure 14, there is a conductive path from the negative terminal of R_K through the grid resistor R_g to the grid of V_1. The cathode is connected directly to the positive terminal of R_K. Therefore, the cathode bias voltage E_{cc} is applied to R_g and the grid-cathode portion of V_1 in series. However, when the tube is operated so that there is no grid current, the resistance between the cathode and grid within the tube can be considered infinite. Thus, there is NOT a complete circuit through the tube and R_g. This condition is illustrated in Figure 15.

Here, the tube has been removed entirely to show that it does not provide a path for current in the grid circuit.

With no current in R_g, there is no voltage across this resistor, as indicated. With no difference of potential across R_g, both of its terminals are at the same potential. Therefore, point G in Figure 15 is at the same potential as the negative terminal of resistor R_K. Also, point K is at the same potential as the positive terminal of R_K. Thus, points G and K, the grid and cathode of V_1, have a difference of potential E_c equal to E_{cc}. This situation exists when there is no meter connected to the grid and cathode.

Figure 14 is repeated in Figure 16, but now a voltmeter V is connected to measure grid bias voltage in the manner of Figure 13, and the meter provides a conductive path between points G and K. Therefore, now a current path exists from the lower terminal of R_g to the positive terminal of R_K.

Again we do not show the tube in Figure 17, since only the meter V forms a complete series circuit with R_g. In Figure 18, resistor R_V represents the meter resistance, and with a circuit thus completed, the applied voltage E_{cc} causes current in R_g and R_V. With current in this circuit, there is a voltage E_{R_g} across the grid resistor and a voltage E_V across the meter as indicated.

As in all series circuits, the applied voltage is equal to the sum of the voltages across the individual components. Thus, in Figure 18,

$$E_{cc} = E_{R_g} + E_V.$$

Hence, the voltage E_V indicated by the voltmeter is equal to the difference between the applied voltage E_{cc} and the voltage E_{R_g}:

$$E_V = E_{cc} - E_{R_g}$$

Therefore, because the current allowed by the voltmeter produces a voltage across the grid resistor R_g, the voltage E_V indicated on the meter is less than the actual bias E_c.

Using typical circuit values in an example, suppose the circuit of Figure 13 operates with an applied bias $E_{cc} = -5$ volts, and the grid resistor R_g has a resistance of 1,000,000 ohms. As explained for Figure 15, with no voltmeter connected, the full bias voltage appears between points G and K. That is, the grid bias E_c on V_1 is 5 volts negative with respect to the cathode.

Suppose a 1,000 ohms-per-volt meter, set to its 10 volt range, is connected to measure the grid voltage as in Figure 13. The meter resistance then is $10 \times 1,000 = 10,000$ ohms. As explained for Figures 16 and 17, the meter completes the circuit between the grid end of R_g and the cathode end of R_K. In Figure 18, the grid resistor and meter form a series circuit which has a total resistance R_T equal to:

$$R_T = R_g + R_V$$

$$R_T = 1,000,000 + 10,000 = 1,010,000 \text{ ohms.}$$

Applied to this series circuit, the voltage E_{cc} produces a current equal to:

$$I = \frac{E_{cc}}{R_T} = \frac{5}{1,010,000} = .00000495 \text{ ampere.}$$

With this current in the circuit, the voltage E_V indicated by the voltmeter is:

$$E_V = I \times R_V$$

$$E_V = .00000495 \times 10,000 = .0495 \text{ volts, or approximately .05 volts.}$$

Thus, the meter reading is only .05/5, or 1/100, of the actual bias present when the meter is not connected. With the voltmeter in the circuit, practically all of E_{cc} appears across the grid resistor. Thus:

$$E_{R_g} = I \times R_g$$

$$E_{R_g} = .00000495 \times 1,000,000 = 4.95 \text{ volts.}$$

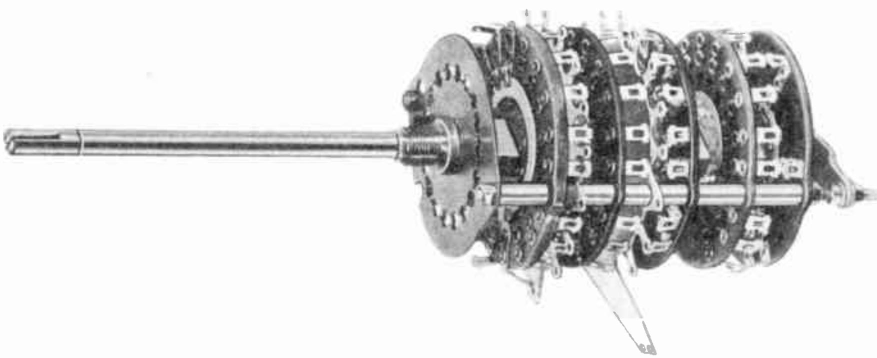
As when measuring plate voltage, less error is obtained if a high resistance voltmeter is employed to measure grid voltage in the manner of Figure 13. For example, suppose the meter used is a vacuum tube voltmeter with an input resistance of 10 megohms. In this case, in Figure 18, R_G and R_V have a total resistance of

$$R_T = R_G + R_V$$

$$R_T = 1{,}000{,}000 + 10{,}000{,}000$$
$$= 11{,}000{,}000 \text{ ohms.}$$

Thus, even with the higher resistance meter, an appreciable error is obtained when the connection of Figure 13 is employed to measure grid bias.

As explained for Figures 14 and 15, the voltage between the grid and cathode is equal to E_c, and this voltage is also across the cathode resistor R_K. Therefore, to measure the grid bias in a circuit of this type, the voltmeter may be connected across the cathode resistor. The test lead from the (+) meter terminal is touched to the positive end of R_K, and the lead from the (−) meter terminal to the negative end of R_K. The grid to cathode measurement is used as a rough check to make sure that the voltage applied to the grid isn't positive and close enough to the cathode resistor



In many electron instruments, multi-terminal switches, operated by a common shaft, are mounted to form a single unit as shown here. These switches permit changing connections in several combination circuits at the same time.

Courtesy Oak Mfg. Co.

In this series circuit, the applied voltage E_{cc} produces a current of

$$I = \frac{E_{cc}}{R_T} = \frac{5}{11{,}000{,}000} = .00000045 \text{ amp.}$$

and the voltage indicated by the meter is

$$E_V = I \times R_V$$

$$E_V = .00000045 \times 10{,}000{,}000 = 4.5 \text{ volts.}$$

voltage to indicate a good grid resistor.

Referring again to Figures 7 through 12, when the meter resistance is 250,000 ohms, the reading obtained is in error by

$$\frac{30}{150} \times 100 = 20\%.$$

When the VTVM is used with a 10 megohm input resistance, the per cent of error is only

$$\frac{.8}{150} \times 100 = 0.53\%.$$

In the case of Figure 13 through 18, when the meter resistance is 10,000 ohms, the meter reading is in error by

$$\frac{4.95}{5} \times 100 = 99\%.$$

and with the 10 megohm input resistance of the VTVM, the error percentage is

$$\frac{.5}{5} \times 100 = 10\%.$$

These percentages show two things: (1) for a given circuit, the higher the meter resistance, the more accurate the reading. (2) For a given meter, greater accuracy is obtained when the meter resistance is high compared with that of the circuit component in parallel or series with the meter.

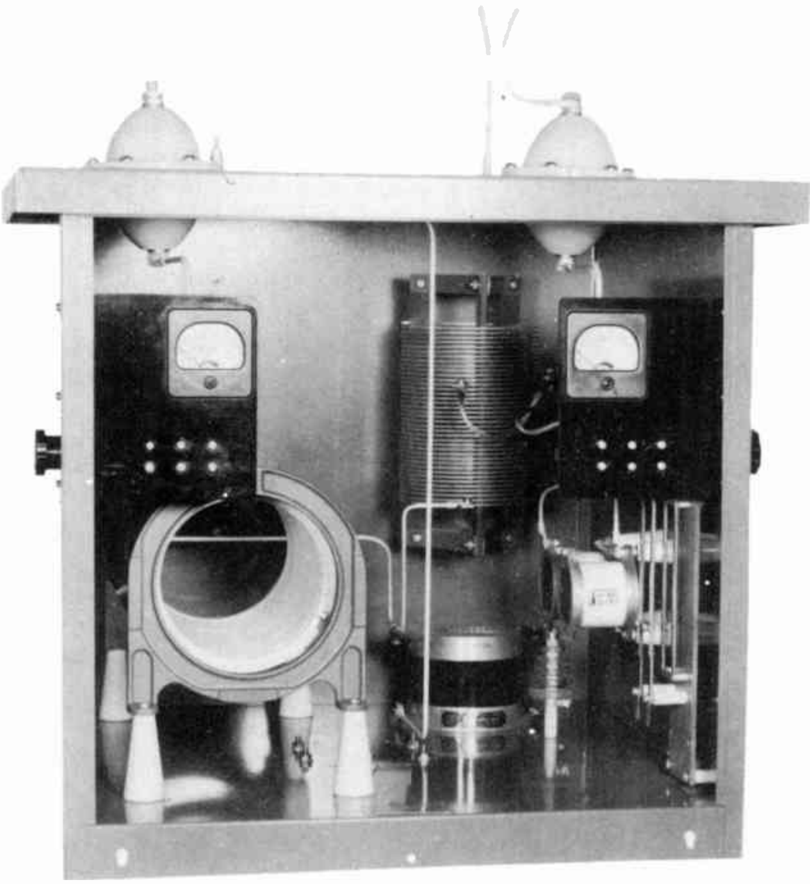
Generally, it is considered that sufficient accuracy is obtained for most practical purposes when a voltmeter has resistance at least 10 times that of the resistance of the component which the meter is connected in parallel or in series with. In Figure 11, the meter resistance R_V is connected in parallel with the resistance r_b of the tube. In Figure 18, the meter resistance R_V is connected in series with the grid resistor R_g. Thus, R_V should be at least 10 times r_b or R_g for these two examples.

RESISTOR COMBINATION CIRCUITS

Referring to Figure 11, resistors R_V and r_b are connected in parallel. As explained, these parallel units are represented in Figure 12 by a resistor R_{eq} equal to their equivalent resistance. However, R_{eq} is in series with R_L. Therefore, the circuit of Figure 11 is not a parallel circuit only, nor is it just a series circuit; it is a combination of both. Consequently, a circuit of this type is called a combination circuit. In this case, we produced a combination circuit by connecting a voltmeter in parallel with an electron tube. This arrangement is only one example of a general form which is shown in Figure 19A. Here, we show resistors R_1 and

R_2 in parallel, and this parallel section of the circuit is in series with resistor R_3.

like that of Figure 19A. However, should you desire, you can use the method we employed with Fig-



Antenna tuning unit uses inductors in series and parallel circuits. On the upper coil, the tap can be adjusted to vary the inductance to the desired value.

Courtesy Collins Radio Co.

In the various electron circuits to be studied, you will encounter many more combination circuits

ures 11 and 12 to convert this type of combination circuit to a simple series circuit like that of

Figure 19B. That is, in Figure 19A, the resistances of R_1 and R_2 can be substituted in equation (4) to give R_{eq} of Figure 19B. Since Figure 19B is a series circuit, all the rules and conditions apply to it which were explained for Figure 2.

Figure 18 is an example of another type of combination circuit. Resistors R_g and R_V form a series circuit, and this series circuit is in parallel with resistor R_K. Again, we produced the combination circuit of Figure 18 by connecting a voltmeter to an electron tube circuit. However, as you advance in your studies, you will encounter many more combination circuits of this type also. The general form is shown in Figure 20A. Here, resistors R_1 and R_2 in series form one branch of a parallel circuit. R_3 is the other branch. Whenever you desire, you can substitute the resistances of R_1 and R_2 in equation (1) to obtain R_T of Figure 20B. As the circuit of Figure 20B is a parallel circuit, all the rules and conditions apply to it which were explained for Figure 5. Thus, together with Ohm's Law, the four equations given in the earlier sections of this lesson provide you with means of computing voltage, current, and resistance in any circuit composed of resistors, regardless of whether the resistors are connected in series, in parallel, or in a combination circuit.

Often, when solving problems concerning combination circuits, you will find that you cannot obtain the values desired directly from the information given. In such cases, the best plan is to study the circuit carefully and decide exactly what additional information you need in order to use some equation that will give you the voltage, current, or resistance desired. Then, you begin by using the given data in one or more equations which will give the additional information needed. With this information thus obtained, you can complete the solution of your problem. Stated briefly, several steps are generally required to solve problems dealing with combination circuits.

As an example of this procedure applied to the circuits of Figures 19A and 20A, suppose, in both of these circuits, the applied voltage E is 100 volts, $R_1 = 20$ ohms, R_2 is 30 ohms, R_3 is 8 ohms, and we desire to know the current in R_2 in Figure 19A, and the voltage across R_2 in Figure 20A.

For Figure 19A, we can use Ohm's Law in the form $I_2 = E_2/R_2$ to find the desired current. However, to do so, we need to know the voltage E_2 which is across R_2. This voltage E_2 is across both branches of the parallel section. If we determine the equivalent resistance R_{eq} of R_1 and R_2 in parallel, and the circuit current I, we can compute the voltage E_2 from Ohm's Law in the form $E_2 = I \times R_{eq}$. Since the values of R_1 and R_2 are given above, we first use equation (4) to find R_{eq}:

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{20 \times 30}{20 + 30} = \frac{600}{50} = 12 \text{ ohms.}$$

This step changes the circuit to the simple series arrangement of Figure 19B. Now, we can use equation (1) to find the total resistance of this circuit:

$$R_T = R_3 + R_{eq} = 8 + 12 = 20 \text{ ohms.}$$

Since the applied voltage is 100 volts, we can use Ohm's Law to find the circuit current I:

$$I = \frac{E}{R_T} = \frac{100}{20} = 5 \text{ amperes.}$$

Next, we can use Ohm's Law to find the voltage across R_{eq} in Figure 19B. However, since R_{eq} represents the parallel resistors R_1 and R_2 in Figure 19A, the voltage across R_{eq} is also the voltage E_2 across R_2. Thus:

$$E_2 = I \times R_{eq} = 5 \times 12 = 60 \text{ volts.}$$

Finally, we use Ohm's Law to obtain the current in R_2:

$$I_2 = \frac{E_2}{R_2} = \frac{60}{30} = 2 \text{ amperes.}$$

To find the voltage across R_2 in Figure 20A, we can use Ohm's Law in the form $E_2 = I_2 \times R_2$, where I_2 is carried by the R_1, R_2 branch of the circuit. Since the voltage E is applied across R_1 and R_2 in series, we can find I_2 by using Ohm's Law in the form $I_2 = E/R_T$, in which R_T is the total resistance of the series resistors R_1 and R_2. Since the resistances of R_1 and R_2 are given, we first use equation (1) to find R_T:

$$R_T = R_1 + R_2 = 20 + 30 = 50 \text{ ohms.}$$

This step changes the circuit to the simple parallel arrangement of Figure 20B. Next, we use Ohm's Law to find the current in R_T. Since R_T represents the series resistors R_1 and R_2 in Figure 20, the current in R_T is also the current I_2 in R_2. Thus:

$$I_2 = \frac{E}{R_T} = \frac{100}{50} = 2 \text{ amperes.}$$

Finally, we use Ohm's Law to obtain the voltage across R_2:

$$E_2 = I_2 \times R_2 = 2 \times 30 = 60 \text{ volts.}$$

SERIES INDUCTORS

Two independent inductors are shown connected in series in Figure 21; that is, there is no magnetic coupling between them. When such inductors are connected in this manner, the total inductance of the circuit is the sum of the individual inductances. This rule is the same as that for series resistors. Stated as an equation:

$$L_T = L_1 + L_2 \qquad (5)$$

Thus, if L_1 is 8 henrys and L_2 is 4 henrys in the circuit of Figure 21, the circuit has a total inductance of:

$$L_T = 8 + 4 = 12 \text{ henrys.}$$

Also, as in resistor circuits, the voltages across the series inductors are directly proportional to the individual inductances, and their sum is equal to the applied voltage.

PARALLEL INDUCTORS

Two independent inductors parallel connected are shown in Figure 22. Again, the rule for the inductance presented by the entire circuit is the same as with resistors. That is, the equivalent inductance of two inductors in parallel is equal to the product of the individual inductances divided by their sum. As an equation:

$$L_{eq} = \frac{L_1 \times L_2}{L_1 + L_2} \qquad (6)$$

Thus, if $L_1 = 15$ henrys and $L_2 = 10$ henrys in Figure 22, the circuit presents an equivalent inductance of:

$$L_{eq} = \frac{15 \times 10}{15 + 10} = \frac{150}{25} = 6 \text{ henrys.}$$

As with resistors, the inductance of the entire parallel circuit is less than the inductance in any branch.

A voltage applied to the terminals of the circuit of Figure 22 is applied to both L_1 and L_2. Thus, in any parallel inductance circuit, the voltage across each branch is equal to the applied voltage. Also, the branch currents are inversely proportional to the branch inductances, and the total current equals the sum of the branch currents. Again these situations are the same as in resistor circuits.

SERIES CAPACITORS

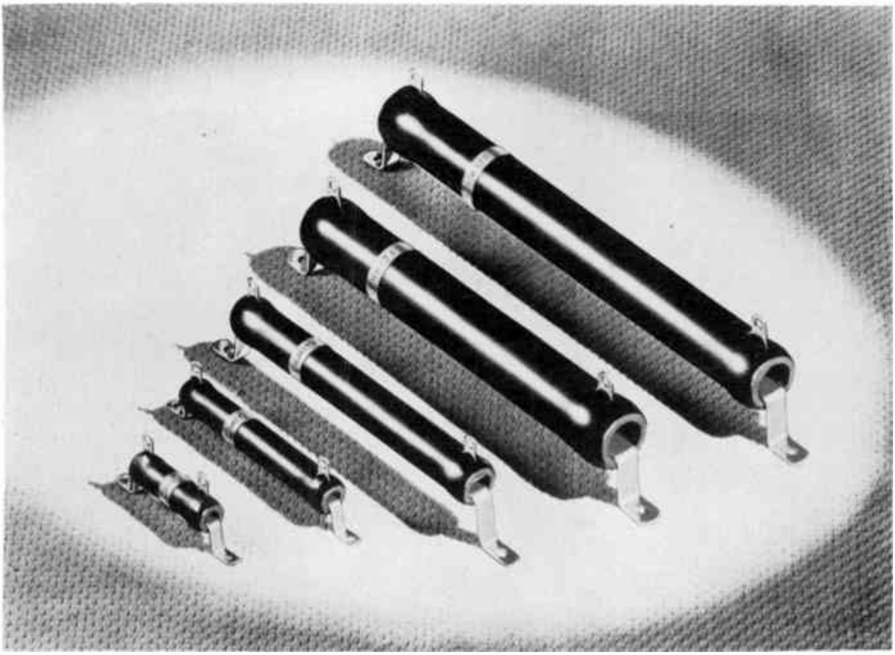
A series circuit made up of two capacitors is shown in Figure 23. As you may recall, the nearer the plates of a capacitor are to each other, the greater the capacitance. Connecting capacitors in series has the same effect as moving the plates of a single unit farther apart. That is, it decreases the capacitance. A series capacitor circuit has an equivalent capacitance which is less than the capacitance of the smallest capacitor.

The equation for computing the equivalent capacitance of two capacitors in series is like that used for two resistors in parallel. Thus, for a circuit like that of Figure 23:

$$C_{eq} = \frac{C_1 \times C_2}{C_1 + C_2} \qquad (7)$$

For example, if $C_1 = .002\ \mu f$, and $C_2 = .003\ \mu f$, then the equivalent capacitance of these capacitors in series is:

$$C_{eq} = \frac{.002 \times .003}{.002 + .003} = \frac{.000006}{.005} = .0012\ \mu f.$$



On these wire-wound resistors, the adjustable bands provide a third terminal, and often connections are made so that part of the resistor becomes a branch of a parallel circuit which is in series with the remainder of the resistor.

Courtesy Ohmite Mfg. Co.

PARALLEL CAPACITORS

With a given spacing between them, the larger the plates of a capacitor the greater its capacitance. Connecting capacitors in parallel has the same effect as increasing the area of the plates of a single unit. It increases the capacitance. Two capacitors connected to form a parallel circuit are shown in Figure 24. A circuit like this has a total capacitance equal to the sum of the capacitances of the individual capacitors. The equation is like that for series resistors:

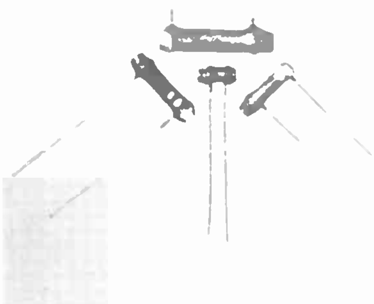
$$C_T = C_1 + C_2 \qquad (8)$$

To illustrate the use of equation (8) for the circuit of Figure 24, suppose $C_1 = .001\ \mu f$ and $C_2 = .005\ \mu f$. Then the total capacitance of the circuit is:

$$C_T = C_1 + C_2 = .001 + .005 = .006\ \mu f.$$

VOLTAGES ACROSS CAPACITORS

When a voltage E is applied to the terminals of the circuit of Figure 23, it produces electron flow which charges the capacitors. For example, if E has polarity such that the upper terminal is made positive and the lower terminal negative, electrons flow from the voltage source to the lower plate of C_2, from the upper



These ceramic tubular capacitors are a type commonly found in the circuits of television and radio receivers as well as many other electron instruments.

Courtesy Centrolab Division of Globe Union, Inc.

plate of C_2 to the lower plate of C_1, and from the upper plate of C_1 to the voltage source. Since the electrons do not pass through the capacitors, they "accumulate" on the lower plates to produce a negative charge on these plates. Also, as the electrons leave the upper plates, the electron "deficiency" produces a positive charge here. Electron flow in this manner is known as "displacement current."

Due to its plates having obtained opposite charges, each capacitor has a voltage across it. As in all series circuits, the electron flow is the same in every part of the circuit. Therefore, in Figure 23, both capacitors receive the same charge. For any capacitor, the voltage across its plates is equal to the number of electrons displaced measured in coulombs divided by its capacitance in farads. Thus, in Figure 23, where Q represents the number of coulombs in the charge, the displaced electrons produce a voltage on capacitor C_1 equal to:

$$E_1 = \frac{Q}{C_1},$$

and a voltage on capacitor C_2 equal to:

$$E_2 = \frac{Q}{C_2}.$$

As an example, suppose a voltage E is applied to the terminals of the circuit of Figure 23 such as to cause a charge Q of .0036 coulombs to be produced on each capacitor. If $C_1 = 20\ \mu f$, the voltage across this capacitor is:

$$E_1 = \frac{Q}{C_1} = \frac{.0036}{.00002} = 180 \text{ volts.}$$

If $C_2 = 30\ \mu f$, the voltage across this unit is:

$$E_2 = \frac{Q}{C_2} = \frac{.0036}{.00003} = 120 \text{ volts.}$$

Notice here that the voltage E_1 across the 20 μf capacitor is greater than the voltage E_2 across the 30 μf capacitor. This condition exists whenever capacitors are connected in series. That is, IN A SERIES CIRCUIT, VOLTAGES ACROSS THE CAPACITORS ARE INVERSELY PROPORTIONAL TO THE INDIVIDUAL CAPACITANCES. This relation is exactly opposite that found in series resistance and series inductance circuits.

As in all series circuits, the sum of the voltages across the capacitors in Figure 23 is equal to the total voltage applied to the terminals of the circuit. Therefore, to produce the voltages E_1 and E_2 calculated in the above example, the voltage applied to the circuit must be equal to:

$$E = E_1 + E_2$$
$$E = 180 + 120 = 300 \text{ volts.}$$

When a voltage E is applied to the terminals of the circuit of Figure 24, this voltage is applied to both capacitors. Each capacitor is a branch of the parallel circuit. The applied voltage produces a displacement of electrons in each branch which charges the capacitors in the manner explained above. When the capacitors are charged, voltage E_1 across C_1 and voltage E_2 across C_2 are both equal to the applied voltage E, and therefore to each other also.

As in all parallel circuits, the total electron flow supplied from the source is equal to the sum of the electrons displaced in the branches of a parallel capacitor circuit. Therefore:

$$I_T = I_1 + I_2$$

For example, if 300 volts is applied to the terminals of the circuit of Figure 24 in which $C_1 = 20\ \mu f$ and $C_2 = 30\ \mu f$, the voltage $E_1 = E = 300$ volts, and the charge on C_1 is:

$$Q_1 = C_1 \times E_1 = .00002 \times 300$$
$$= .006 \text{ coulombs.}$$

Also, the voltage $E_2 = E = 300$ volts, and the charge on C_2 is:

$$Q_2 = C_2 \times E_2 = .00003 \times 300$$
$$= .009 \text{ coulomb.}$$

Here, as in all parallel capacitance circuits, the branch with the largest capacitance has the largest displacement current. That is, the branch currents are directly proportional to the branch capacitances.

Since current in amperes is the total number of electrons that flow each second measured in coulombs, if both capacitors are charged in 1 millisecond of time, the displacement current in the C_1 branch is:

$$I_1 = \frac{Q_1}{t} = \frac{.006}{.001} = 6 \text{ amperes.}$$

and that in the C_2 branch is:

$$I_2 = \frac{Q_2}{t} = \frac{.009}{.001} = 9 \text{ amperes.}$$

Equal to the sum of these displacement currents, the total current supplied by the source to charge the capacitors is:

$$I_T = I_1 + I_2 = 6 + 9 = 15 \text{ amperes.}$$

The circuit principles outlined in this lesson form the foundation upon which you can base your analysis of the various practical circuits which may be encountered in service and maintenance work. Most electron equipment is made up of nothing more than series circuits, parallel circuits, and combination circuits.

SUMMARY

In all series circuits, the sum of the voltages across the individual components, is equal to the applied voltage. In those made up of resistors or inductors, the component voltages are directly proportional to the individual resistances and inductances. In capacitor series circuits, the capacitor voltages are inversely proportional to the capacitances. In all series circuits, the current is the same in all parts of the circuit.

In all parallel circuits, the total current is equal to the sum of the branch currents. In the resistor and inductor circuits, the branch currents are inversely proportional to the branch resistances and inductances. In the case of capacitor parallel circuits, the branch currents are proportional to the branch capacitances. In all parallel circuits, the voltage is the same across all branches and equal to the applied voltage.

The various equations given for computing resistances, inductances, and capacitances have a form which states that the total circuit value is equal to the sum of the individual values in the case of:

1) resistors in series
2) inductors in series
3) capacitors in parallel,

and a form which states that the equivalent circuit value for two components is equal to the product of the individual values divided by their sum in the case of:

1) resistors in parallel
2) inductors in parallel
3) capacitors in series

The explanations regarding voltmeter error were given to illustrate the actual conditions encountered when you are troubleshooting electron equipment.

SUMMARY

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APPENDIX A

EQUIVALENT RESISTANCE OF PARALLEL RESISTORS

In this lesson, equation (4) is given as, $R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$. This equation applies to parallel circuits containing two resistors only, and is a special form of a more general equation for circuits with any number of resistors in parallel. This general equation is derived as follows:

Assume a parallel circuit composed of a number of branches having resistances R_1, R_2, R_3 and so on. If a voltage E is applied to the terminals of this circuit, each branch carries a current, and the sum of these branch currents is the total circuit current I_T. Thus:

$$I_T = I_1 + I_2 + I_3 + \ldots$$

Since the voltage across each branch is equal to E, branch current $I_1 = E/R_1$, branch current $I_2 = E/R_2$, and so on. We can substitute these E/R terms for I_1, I_2, etc. in the above expression to give:

$$I_T = \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3} + \ldots$$

By Ohm's Law, the total current I_T is equal to the applied voltage E divided by the equivalent resistance R_{eq} of the circuit:

$$I_T = \frac{E}{R_{eq}}$$

Therefore, as they are both equal to I_T, the right members of these equations are equal to each other:

$$\frac{E}{R_{eq}} = \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3} + \ldots$$

Factoring out the E in the right member, we can write this expression as:

$$\frac{E}{R_{eq}} = E\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\right)$$

APPENDIX A—(Continued)

Dividing both members of this equation by E, we obtain the general equation for R_{eq} which may be applied to a parallel circuit with any number of branches:

$$\frac{1}{R_{eq}}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\ldots$$

For two branches, the above equation is written as:

$$\frac{1}{R_{eq}}=\frac{1}{R_1}+\frac{1}{R_2}$$

To simplify the right member, we can multiply the numerator and denominator of the first term by R_2, and the numerator and denominator of the second term by R_1, thus obtaining a common denominator:

$$\frac{1}{R_{eq}}=\frac{R_2}{R_1\times R_2}+\frac{R_1}{R_1\times R_2}$$

Adding the terms of the right member gives:

$$\frac{1}{R_{eq}}=\frac{R_1+R_2}{R_1\times R_2}$$

Inverting both members, we have:

$$R_{eq}=\frac{R_1\times R_2}{R_1+R_2}$$

which is the form shown for equation (4) in this lesson.

As for resistor circuits, there are general equations for parallel inductor circuits and for series capacitor circuits which are derived in a manner similar to that for R_{eq}. These general equations are:

For parallel inductors: $$\frac{1}{L_{eq}}=\frac{1}{L_1}+\frac{1}{L_2}+\frac{1}{L_3}+\ldots$$

For series capacitors: $$\frac{1}{C_{eq}}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+\ldots$$

ESSENTIAL SYMBOLS AND EQUATIONS

C_{eq}	— equivalent capacitance	(farads)
C_T	— total capacitance	(farads)
C_1, C_2	— individual capacitances	(farads)
E	— applied voltage	(volts)
E_1, E_2	— individual voltages	(volts)
I_T	— total current	(amperes)
I_1, I_2	— individual currents	(amperes)
L_{eq}	— equivalent inductance	(henrys)
L_T	— total inductance	(henrys)
L_1, L_2	— individual inductances	(henrys)
R_{eq}	— equivalent resistance	(ohms)
R_T	— total resistance	(ohms)
R_1, R_2	— individual resistances	(ohms)

$$R_T = R_1 + R_2 \quad (1)$$

$$E = E_1 + E_2 \quad (2)$$

$$I_T = I_1 + I_2 \quad (3)$$

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2} \quad (4)$$

$$L_T = L_1 + L_2 \quad (5)$$

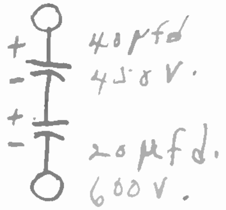
$$L_{eq} = \frac{L_1 \times L_2}{L_1 + L_2} \quad (6)$$

$$C_{eq} = \frac{C_1 \times C_2}{C_1 + C_2} \quad (7)$$

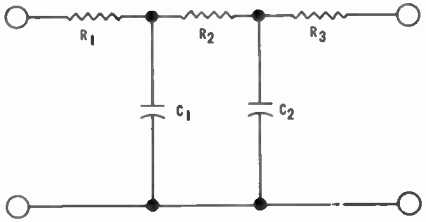
$$C_T = C_1 + C_2 \quad (8)$$

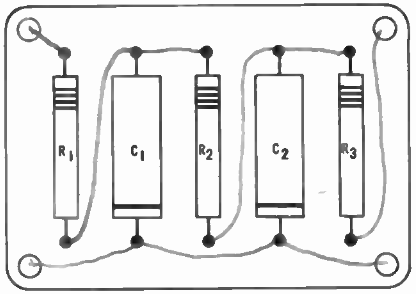
WORK DIAGRAMS

1. A 20 μfd, 600 volt capacitor is needed. The only units available are rated at 40 μfd, 450 volts. Draw a schematic diagram showing how two of the available capacitors can be connected to satisfy the stated requirements. Indicate the capacitor positive and negative plates.



2. In the pictorial drawing, sketch in the wiring needed to connect the resistors and capacitors to form the circuit given in the schematic diagram.





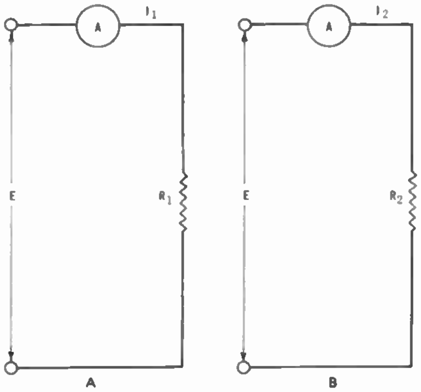


FIGURE 1

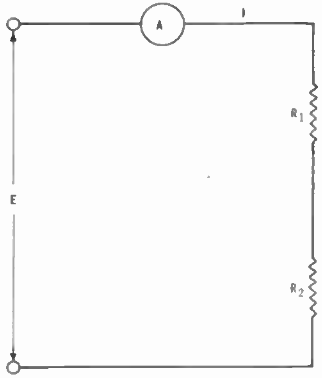


FIGURE 2

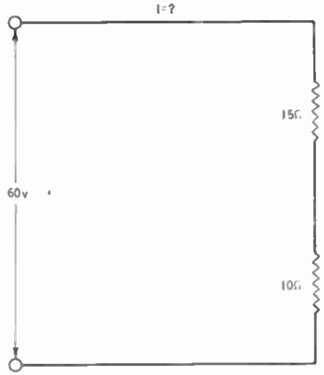


FIGURE 3

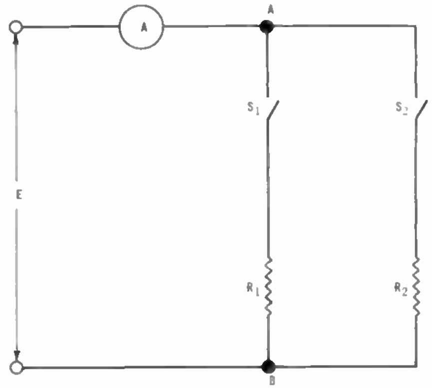


FIGURE 4

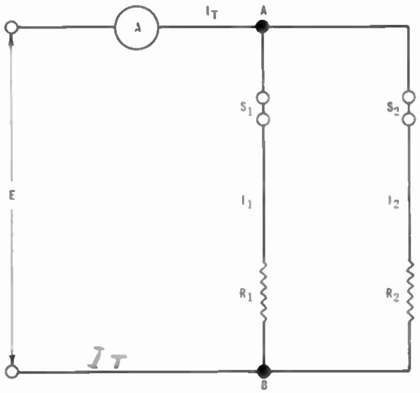


FIGURE 5

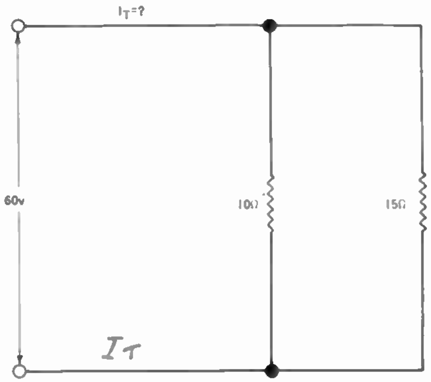


FIGURE 6

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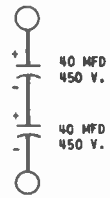
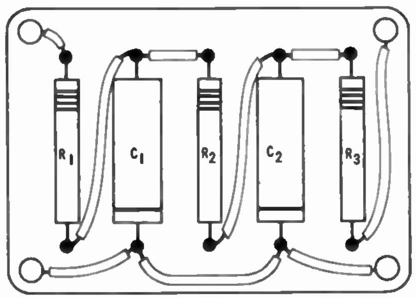
WORK DIAGRAM SOLUTIONS

1. A 20 μfd, 600 volt capacitor is needed. The only units available are rated at 40 μfd, 450 volts. Draw a schematic diagram showing how two of the available capacitors can be connected to satisfy the stated requirements. Indicate the capacitor positive and negative plates.



2. In the pictorial drawing, sketch in the wiring needed to connect the resistors and capacitors to form the circuit given in the schematic diagram.



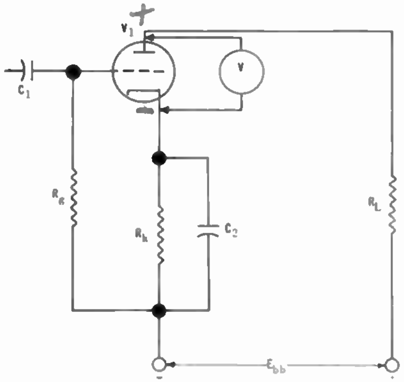


FIGURE 7

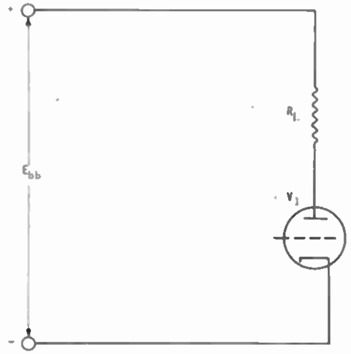


FIGURE 8

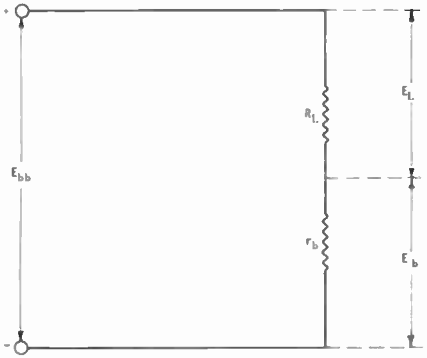


FIGURE 9

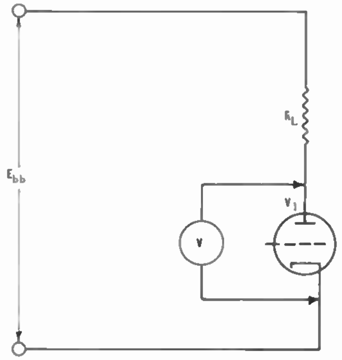


FIGURE 10

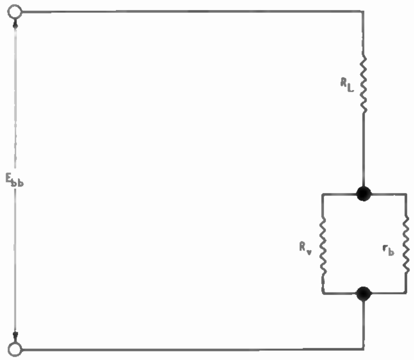


FIGURE 11

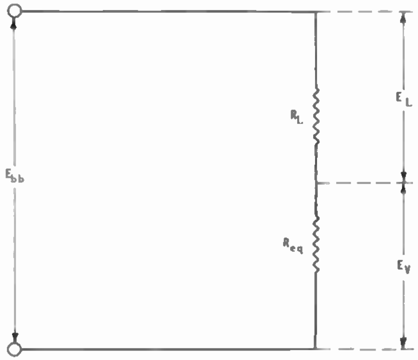


FIGURE 12

AEH-19

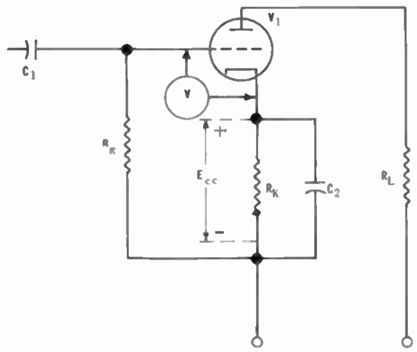


FIGURE 13

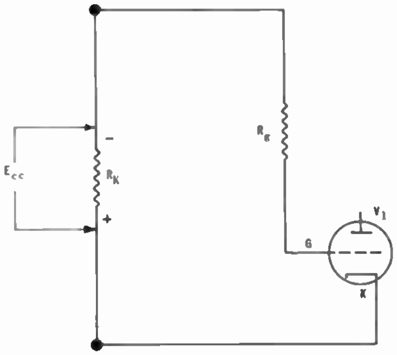


FIGURE 14

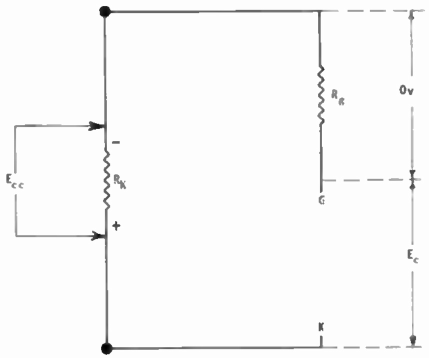


FIGURE 15

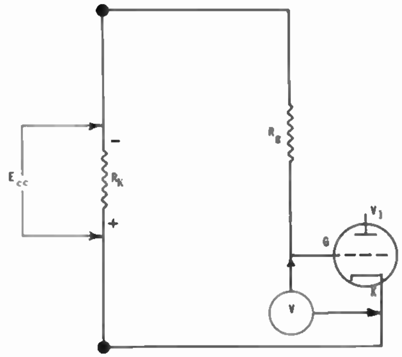


FIGURE 16

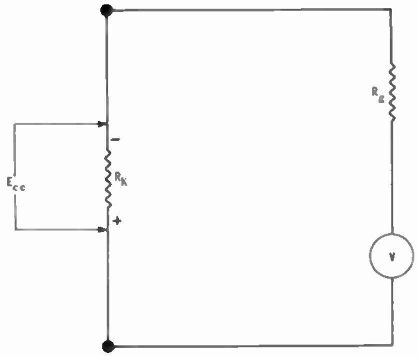


FIGURE 17

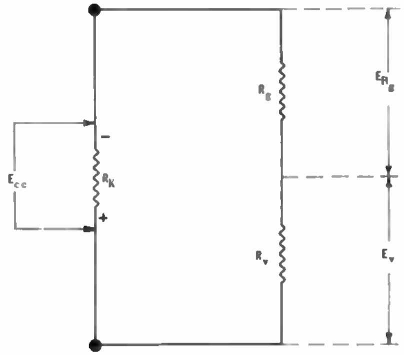


FIGURE 18

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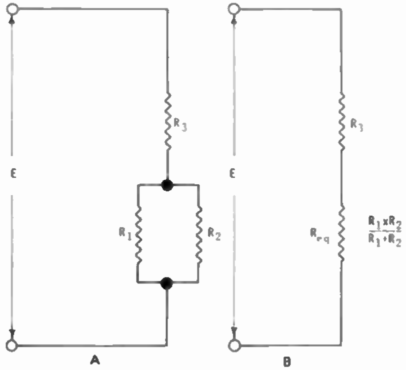


FIGURE 19

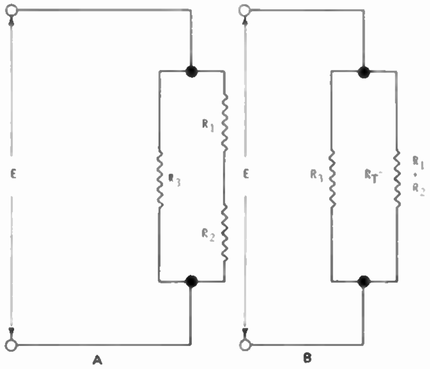


FIGURE 20

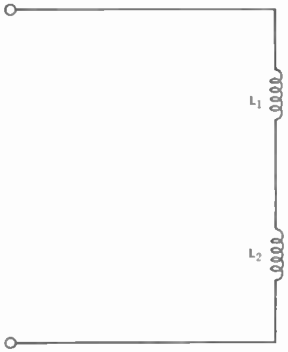


FIGURE 21

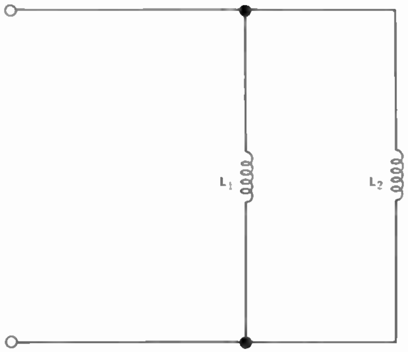


FIGURE 22

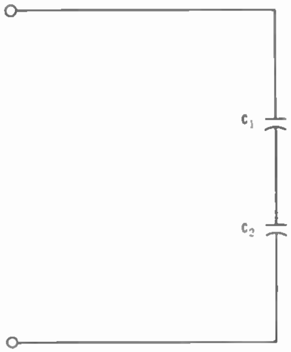


FIGURE 23

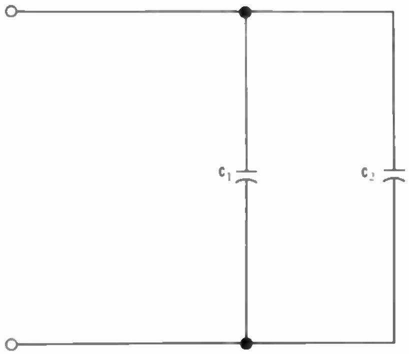


FIGURE 24

AEH-19

FROM OUR *Director's* NOTEBOOK

THE MAN WHO STICKS

The man who sticks has this lesson learned;
Success doesn't come by chance—its earned
By pounding away; for good hard knocks
Will make steppingstones of the stumbling blocks.
He knows in his heart that he cannot fail,
That no ill effects can make him quail
While his will is strong and his courage high,
For he's always good for another try.
He doesn't expect by a single stride
To jump to the front; he is satisfied
To do every day his level best,
And let the future take care of the rest.
He doesn't believe he's held down by the boss—
It's work, and not favor, that "gets across",
So his motto is this: "What another man
Has been able to handle, I surely can",
For the man who sticks has the sense to see
He can make himself what he wants to be,
If he'll off with his coat and pitch right in—
Why, the man who sticks can't help but win!

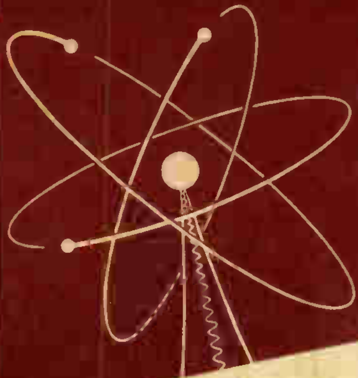
—Charles R. Barrett

Yours for success,

W. C. DeVry

DIRECTOR

PRINTED IN U.S.A.



TROUBLESHOOTING PROCEDURES

Lesson AEH-20B

DeVRY Technical Institute

4141 W. Belmont Ave., Chicago 41, Illinois

Formerly DeFOREST'S TRAINING, INC.

AEH-20

AEH-20B

TROUBLESHOOTING A RADIO

4141 Belmont Ave.

Chicago 41, Illinois

ELECTRONS PENETRATE FOG

Fog was so thick that 60 vessels were forced to anchor and remain immobile for more than 14 hours in the winding St. Mary's River. Suddenly, the captains and crews on these ships were astonished to hear the 600-foot A. H. Ferbert steam past them at full speed ahead. These men did not know that this ship had been equipped with radar, and thus, electronically could "see" the shoreline, docks, and other ships.

Radar can detect the distance to, the size, the direction, and speed of travel of objects which are beyond the visual range or hidden by darkness, fog, clouds, or rain. Developed originally for military use, radar now is employed for marine navigation, airfield tower control, blind landing of aircraft, by fishing boats to spot their catch, by the weather bureaus to locate and measure the velocity of approaching storms, and even by highway police to measure the speed of automobiles.

Fundamentals

TROUBLESHOOTING A RADIO

Contents

Opportunity comes like a snail and once it has passed you, it changes into a rabbit and is gone. What is opportunity? It is a chance to do something, to give something, to achieve something, to climb out of the rut. To be somebody of value in the world. Opportunity is life itself.

—Arthur Brisbane

TROUBLESHOOTING A RADIO

Every technician needs to know how to find trouble. The radio and television serviceman makes his living doing just that, but every other technician frequently needs to locate and set aright a defective circuit. He has either installed or built some equipment and it does not work as expected.

After examining a typical radio receiver a couple of lessons back, it should be apparent that troubles can be caused by any one of a number of parts in each of the different circuits. To find this fault by a haphazard "try this to see if it works" approach would be very time consuming and, in some cases completely ineffective.

Therefore, to be an efficient technician, one who seems to lay his finger right on the defect, you have to have a plan of attack that uses the minimum time and effort to determine the trouble.

This type of approach usually is composed of two major steps: First, find the circuit within the equipment that is not operating properly. Second, determine what in the circuit is defective and needs replacing. Everyone has a slightly different troubleshooting method, but efficient technicians all end up by using this basic approach to the problem. Don't lose sight of it or you will find yourself wasting time testing things that have nothing to do with the problem at hand.

Another good rule of thumb to use is when more than one component is equally likely to be at fault always check the one most available; it saves time. Naturally, if one particular component of two is very prone to cause the fault observed, you check it first.

FIRST INSPECTION

Finally, troubleshooting starts immediately by being alert for little clues. All of your natural senses can be used to detect faults. Don't assume that your test equipment must be laid out before the job begins. With the use of all your senses, except taste, and a good understanding of what each component and circuit can do, many faults can be discovered by being aware of exactly what is happening.

For example, suppose the receiver in Figure 12 plays intermittently when some one walks across the room. Here is likely what a good technician does. First he notices whether the dial light blinks too. If it does the power is being interrupted inside or outside of the receiver cabinet. If it doesn't something inside the receiver makes intermittent contact.

Next he would wiggle the volume knob to which the switch is attached. If that produced a similar effect and the light blinked, likely the trouble is in the switch, if the light didn't blink the volume control might have bad contact. Rotating it slowly up and down and listening for noise checks this point.

On the other hand, if no effect came from wiggling the control the fault either lies elsewhere in the receiver or outside. Since outside is handy, he would carefully check the cord and plug for defects and try a different outlet.

Only when these effects didn't yield results would the technician turn his efforts to the inside of the receiver. It would be a terrible waste of time to pull the receiver out of the cabinet when only the plug or outlet is at fault. From this description it should be apparent that a good technician services by being alert to little details as well as making effective use of instruments.

Without instruments, you can use your natural senses. With the exception of taste, these senses are important troubleshooting tools. There are the familiar parts which can be defective: resistors, capacitors, transformers, inductor, coils of all types, tubes, and batteries. Less noticed but equally as important, and often the most difficult to locate trouble in, or at, are such things as: mounting brackets, shielding cans, jacks, tube sockets, solder joints (especially ground connections), terminal strips, loudspeakers, cones, and foreign materials such as dirt, bugs, and moisture. Therefore, before going into a description of how to service with a meter, we will just describe some things to look for.

Common defects which develop in most components are "shorts" and "opens". A short is any condition which produces a lower than normal resistance between two given points in a circuit. An open is a condition in which conductors are separated so that current cannot pass.

To make it easy to carry, this multi-band radio has a number of circuits in a small space. Point-to-Point testing is a very effective means of servicing it.
Courtesy Zenith Radio Corp.

Resistors

When some circuit fault causes too heavy current in a resistor, the resistor overheats and becomes discolored. Some get so charred they are "dead black". Others may not discolor, but break or turn powdery and fall apart when jarred. Other signs of a too hot resistor are smoke or odors of burning paint. Usually, another component is faulty also.

Capacitors

Capacitors are just a little more troublesome to locate. They can short, be leaky, change value, or open completely. In air dielectric jobs, such as a variable capacitor, bent plates touching together may be the fault.

Leaky capacitors conduct d-c all the time so they heat. This is especially true of electrolyte types. Capacitors handling enormous power such as liquid filled units found in transmitters and industrial equipment do heat normally, but never enough to ooze or boil out the contained liquid. Cracked housing, chips, or even pencil cracks must be examined closely.

When the equipment is completely inoperative, very likely the power supply is at fault and the most likely fault is a leaky or shorted electrolytic capacitor. Therefore, the first check to make for a completely "dead" piece of equipment is to remove all power immediately and measure the resistance from the cathode of the rectifier to ground. This can be made without even pulling the chassis by removing the rectifier tube and placing one ohmmeter lead in the socket hole for the cathode, and then using the other lead to touch the chassis of a receiver with a transformer or one side of the a-c plug on the a-c/d-c models. If the resistance is below normal or zero, the chassis should be pulled and the individual electrolytic capacitors checked to locate the faulty unit. This should be done before even replacing the tubes. Otherwise, good components will be ruined by the short.

Never lay capacitors on resistors, tubes, or any elements generating heat in electronic equipment. Moreover, since some capacitors are parts of tuned circuits, in servicing these should not be disturbed from their original position. The change can detune the circuit.

Transformers

Transformers, particularly power transformers, heat up normally. However, when overheated the odor of lacquer or varnish exists. When you detect such an odor, turn the power off promptly; you may save an expensive component. Usually an overheated transformer is due to a shorted electrolytic capacitor. Therefore, check the resistance from the rectifier cathode to ground. Only when the resistance from cathode to ground checks normal, should the transformer be suspected.

One shorted turn in a primary acts like a secondary. Since the ampere turns for the primary equals the secondary, then the shorted turn carries a heavy current. The result is over heating, low voltages, or the blowing of fuses.

Signal carrying transformers with a shorted turn ordinarily reduce the signal. In fact, sometimes the signal is blocked altogether since this one shorted turn tunes the circuit to another frequency. Inductors behave somewhat the same as transformers in so far as faults are concerned.

Tubes

The component most frequently at fault is the electron tube. About 70 to 80% of the trouble is here. Many of the tubes have glass envelopes through which you can see when the heaters are on or not. Sometimes just feeling tubes to see if they are warm is enough, but don't expect tubes having type numbers such as 1B3GT, 1R5, or 1S5 to be warm. Tubes in this 1 volt filament class operate cold. These are rated to operate at about 1.2 or 1.4 volts, usually d-c. On the other hand power rectifier tubes and power pentodes should be hot, but the plates shouldn't turn red or sparks fly in small equipment.

Not all faulty tubes have visible effects, and since they plug in easily and are so frequently at fault, it is a sound practice to replace the tubes with a set known to be good. If the trouble is cleared up, replace each old tube until the trouble appears. Thus the defective tube is found. This usually is done when preliminary inspection doesn't reveal any evidence of the fault. It saves removing and installing the chassis in many cases.

Hardware

Mounting brackets sometimes are at fault. Other parts may be mounted on them, one side of which is grounded to the bracket, it in turn being grounded to the metal chassis. The connection becomes loose, corroded, or even broken. In any case, the circuit will not work normally.

Shielding cans on IF transformers are anchored with snap-on clips or threaded lugs and sometimes are soldered to the chassis for a good ground connection. If the can gets loose, then with each jar of the equipment, tuning will change, and the set will operate erratically, fading in and out.

Any connector elements, such as jacks, tube sockets, and terminal strips have insulation material which ages and becomes leaky. Normally, checked with an ohmmeter their resistance reads close to "∞", but when the insulation resistance drops enough to obtain a reading definitely less than infinite, then they are suspects for causing trouble.

Of course foreign materials such as dirt, bugs, and moisture are great headaches. Dust or dirt on all components is harmful to their normal operating conditions. Compared to other troubles in electronic devices, these are difficult to find and cure. As a result, the good technician removes such things as a general servicing practice no matter what other troubles exist.

These are items to watch for when you first pull the chassis. However, observation doesn't stop here. Often the performance indicates the nature or general location of the trouble. In fact, deliberately injecting a signal and observing what happens, helps to locate the faulty circuit.

DYNAMIC TESTING

Using the radio receiver in Figure 12 as an example, since a 60 cycle sound can be heard, part of the heater voltage can be coupled into the circuit to see if a signal comes through.

By connecting a capacitor to the ungrounded or "hot" side of a heater you can couple this signal voltage to the plate of the power amplifier at pin 5 of V_5. You should hear a hum through the speaker, if both speaker and transformer are good.

A harsh or weak sound would indicate a faulty part. Next the capacitor can be used to couple the heater voltage to the grid of the power amplifier at pin 7 of V_5 and then the grid of voltage amplifier at pin 1 of V_4. In each case the sound should be louder but sound the same. Any loss of sound would indicate the added circuit was faulty. Finally when coupled between volume control R_8 and resistor R_7, the sound should remain the same as on the grid of V_4 when the volume control is rotated clockwise, and diminish smoothly as the volume control is turned down.

Going back further than the volume control with the 60 cycle voltage wouldn't work since V_1, V_2, and V_3 amplify only radio frequency signals.

Another variation of this procedure is the screwdriver test. When two metal surfaces are rubbed together, small electric voltages or noises making up many frequencies are produced. Therefore, rubbing the grids of V_1, V_2, and V_3 with a screwdriver blade often produces signals that can be heard as noises. When these come through, it is a fair indication that the circuit does amplify although it might not perform some of its other functions.

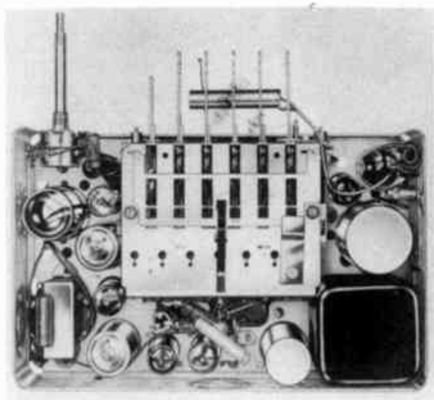
Tracing the signal through the radio receiver in this manner to see what each tube does to the signal is called DYNAMIC TESTING. To make full use of the dynamic testing procedure, you must know a lot about how the circuit is supposed to work so that an improper operation can be recognized and traced to its cause.

For example, a good serviceman can tell by looking at what is on the screen of a television receiver just about which tube circuit out of 16 or more can cause the particular trouble seen. Therefore, he can go immediately to that part of the receiver for further troubleshooting. However, to do this, the technician must know exactly how each circuit performs. For this reason most dynamic trouble shooting procedures are applied to the particular type of equipment you are interested in later in your study program.

STATIC TESTING

Once the general nature of the trouble has been found by dynamic testing, STATIC TESTING procedures are used. These include measuring the voltages and resistances in a circuit, rather than watching how the circuit handles the signal. To use static testing first would not be an efficient method. Rather than measure all of the voltages and resistances in the circuit of Figure 12, it is much better to locate the general area of the trouble by dynamic testing, and then measure these values only in this one area.

Static testing uses two important steps. First, the voltages are measured to see if they are normal. Once an abnormal voltage is found, the technician analyzes the situation to determine what most likely would cause the voltage to be high or low. This first step is called VOLTAGE ANALYSIS.



Shown with the top cover removed is an auto radio. It has circuits very similar to table model receiver, and so almost identical servicing procedures are used.

Courtesy Motorola, Inc.

In the design of electronic equipment, the voltages are selected to provide optimum circuit operation. So long as these remain within about 20% of the design value, usually no appreciable change in operation is noted. However, when the voltage changes are greater, the circuit no longer performs as designed. Hence, measuring these various voltages and comparing them with the design values often locates that part of the circuit which is faulty.

However, in order to compare, the designed values must be known. Those listed in tube manuals only suggest possible voltages as a guide for designers. The actual voltages used may vary widely from these suggested values. Consequently most equipment manufacturers publish instruction booklets, schematic diagrams, and service data sheets containing part specifications, voltages, and resistances. The one exception to this general policy are some radio and television receiver manufacturers.

A common source of information subscribed to by many radio and television receiver service men are the manuals published by John F. Rider, Inc. of New York, and Howard W. Sams Co., Inc. of Indianapolis, Indiana. These manuals give exact values for specific makes and models, and should be referred to whenever available.

Once the abnormal voltage is found, the serviceman measures the resistance of the suspected part to make sure it is the one at fault. This last step is made with the circuit turned off. Frequently these resistance measurements are called CONTINUITY TESTING.

Possibly the best way to describe voltage analysis and continuity testing is to use individual circuits from Figure 12 as examples and Charts 1 and 2 at the end of this lesson list the voltages and resistances for this receiver. In fact, these are quite typical for a table model receiver. In order to establish a common starting point, the conditions prevailing at the time the measurements were made are listed on the chart. For the technician to be sure his voltage or resistance readings give him a true indication of circuit conditions, he should strive to duplicate the listed conditions. Also, he should use a meter of the same sensitivity as that employed originally. If he does not, he must bear in mind that the meter itself may cause the circuit voltages to read lower than those listed due to the increased meter reading error.

VOLTAGE ANALYSIS

Power Supply

Since the power supply is the source of the operating voltages in any electron unit, it is good practice to test the power supply circuits first whenever the entire unit is inoperative or is operating improperly. Of course, when some sections or stages of a unit are observed to be operating properly, it is unlikely that the power supply is at fault, and the voltage testing may begin in the faulty stage or section.

To illustrate the method of power supply voltage tests, the transformer type power supply used in Figure 12 is shown in Figure 1. Each plate of the full-wave rectifier tube V_6 connects to one end of the high voltage center tapped secondary and the filament is connected across the heater secondary of power transformer T_6 as indicated by the letters X and Y. A pi type filter includes resistor R_{14} and capacitors C_{18} and C_{19}.

We pointed out earlier that the electrolytic capacitors are very likely leaky or shorted when the receiver is completely "dead" or the transformer smokes. Therefore, the first test on the power supply in Figure 1 is made while the chassis is still in the cabinet by pulling rectifier tube V_6 and measuring the resistance from pin 7 to the chassis. According to Chart 2 this resistance should be 100 K ohms. If it is substantially less than this then very likely C_{18} or C_{19} is very leaky or shorted and needs to be checked individually. However, if the reading is near normal or above, it is safe to turn the power on and proceed with the voltage tests.

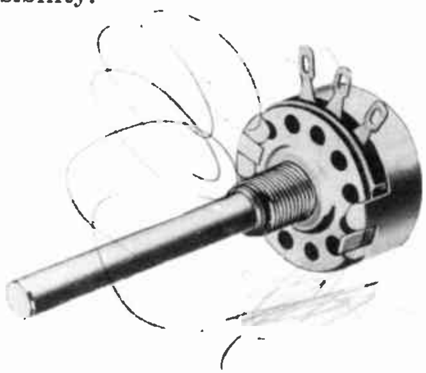
Therefore, assuming the initial inspection and tests have been made and the heaters of all the tubes light up to normal brilliance or heat to normal temperature, the primary and heater windings of the power transformer are very likely in good condition. Therefore, with the receiver power turned on, the first check is made with the voltmeter prods at point A and ground, as shown in Figure 1.

Since the power supply provides a d-c output across points A and B−, the voltmeter must be a d-c instrument or a multimeter or VTVM set for d-c voltages. The exact voltage which should be present across these points may be found in a service manual or data sheet for the particular unit. In this case it is Chart 1 at the end of this lesson. However, for equipment of the same general type the power supply output voltages do not vary a great deal. Using radio receivers as an example, most power supplies of this type develop a normal output of 250 volts, plus or minus about 50 volts. Therefore, the voltmeter switch of the VTVM should be set on its 500 volt range. If the meter reading is more than 10% above or below the value specified or is beyond the general limits just given, it indicates a defect in either the supply or the external circuits to which it is connected.

The two most likely causes of a higher than normal voltage at Point A are an a-c line voltage above normal or one of the exterior circuits is not drawing normal current.

The first possibility can be checked by measuring the a-c voltage at an outlet or across transformer T_1 primary at points

P_1 and P_2. It should be the same as that used for obtaining the chart voltages. If it isn't, allowance must be made for the variation. If the fault is due to low current, the exterior circuits, that is the circuits around tubes V_1 through V_5 in Figure 12, need checking. Moreover, since V_1, V_2, V_3 and V_4 normally draw a small current, V_5 is the most likely possibility.



Controls, especially the volume control, eventually become noisy in radio and TV sets. Sometimes, a commercial contact cleaning fluid placed in the slot immediately behind its terminals washes away loose particles causing noise.
Courtesy Ohmite Mfg. Co.

On the other hand, three different reasons can cause a lower than normal voltage: a low a-c voltage at the wall outlet, a defective power supply, or, some circuit connected to the power supply is drawing excessive current.

To determine the location of the defect causing the low voltage at point A, move the test prod from point A to point C. According to Chart 1, pin 7 of V_6 is 250 volts and pin 6 of V_5 is 240 volts, and since these are connected directly to points C and A, the voltage should increase about 10 volts when going from A to C. A larger voltage change indicates that too much current is passing through R_{14} or the resistance of R_{14} has increased. A normal change would indicate that the fault lies before R_{14}.

Let's take the first condition first.

Open filter capacitor C_{18} may cause a greater reduction of output voltage than an open C_{19} but usually when either one is open it is indicated by a noticeable increase of hum. Completely shorted capacitors cause excessive heating of the rectifier tube and capacitor, a defect which should be observed during the initial inspection. But, filter capacitor defects which allow excessive leakage current can cause voltage drops like those explained for a high current in an external circuit.

To determine definitely whether the low voltage at point A is due to a large resistance in R_{14}, a leaky capacitor C_{19}, or excessive current in the external circuits, the B+ wire connecting all exterior circuits to point A should be disconnected. If the voltage returns to normal the external circuits need testing or the resistance of R_{14} is too high. If the voltage remains low, very likely C_{19} leaks. As explained later in the lesson, R_{14} and C_{19} are checked by continuity test and replaced where necessary.

When point A is about 20 volts below point C, the fault is not very likely R_{14}, C_{19}, or the exterior circuits connected to B+. Either the B++ line connected directly to point C draws too much current or the fault lies elsewhere.

Since the power line voltage may be low or an a-c component in the power supply may be defective, check the a-c voltages. If the voltage at points P_1 and P_2 reads lower than normal, or zero, the power cord should be removed from the receptacle and a voltage test made at that point. With a low voltage at the receptacle, the trouble is in the house wiring. With normal voltage at the receptacle and low voltage at points P_1 and P_2, there is a defect in the line cord, switch, or plug.

A visual check of the line cord chassis connections will locate the fuse which would be inspected. The usual procedure is to make a continuity test of the line cord and fuse. This method is explained later in this lesson.

Next, check the secondary a-c voltages from H_1 to H_2, from H_2 to H_3, and from X to Y. If any of these are below those listed in the chart, as the V_6 plate and heater voltages, remove the plug and check the transformer windings by continuity test as described later. However, when these a-c voltages are normal three possibilities are left; Tube V_6, capacitor C_{18}, or the circuit connected to B++ is defective. V_6 is checked during the preliminary inspection by replacing it. By removing B++ from point C the exterior circuits and C_{18} are checked. If the voltage returns to normal, the exterior circuit is at fault; if it remains below normal, then C_{18} must be checked for leakage.

As an example of the effects of an external circuit on the power supply voltages, suppose in Figure 2 that the voltages at points A and B were low but the difference in the voltages between these two points were about normal. This would indicate that normal current was being conducted by R_{13}. Since tubes V_1, V_2, and V_3 all draw their plate and screen currents through this resistor, the short must be in the circuits about V_4 or V_5. An extra large voltage drop across R_{13}, on the other hand, would point to a short in the V_1, V_2, or V_3 circuits.

For example, tube V_2 has a screen bypass capacitor C_8, which is in series with R_{13} and R_5. Therefore, a leakage or short in this capacitor will result in the abnormally low voltage reading at point

B as well as pin 6. Therefore, a continuity or resistance check of these components also is necessary.

A short between the screen and grid in V_1, V_2, V_3 or V_5 all could produce the low voltage at point A. However, since it is sound policy to replace the tubes as a matter of routine in the preliminary steps, it isn't very likely the fault. On the other hand, if one of the tubes wasn't replaced because you didn't have the type on hand, a quick check is to pull the tube out of the socket and see if the voltage returns to normal.

A more likely source of trouble is a leaky or shorted bypass capacitor like C_{20} or C_8, or a coupling capacitor like C_{15} or a short in the tube sockets between terminals, or between primary and secondary windings of transformers like T_1, T_3, T_4 or T_5. Also, there is always the possibility of defective insulation on wiring, bad tie points, etc. Once suspected, most of these can be traced down by continuity testing although by temporarily disconnecting the component from the B+ line to see if the voltage returns to normal is a positive check.

Regardless of the order in which the power supply voltage tests are made, when proper voltage readings have been obtained at all of the key test points described for Figure 1, the power supply is in good condition, and any trouble that exists is in some other section.

Although variations of these circuits and other types of power supplies are in use, in every case they contain key test points which correspond to those in the diagrams of this lesson. The above outline of power supply testing has been given on the basis of using a minimum number of tests either to eliminate quickly the power supply section as the source of trouble, or to determine that the defect is in the power supply or in any B supply or heater circuits that are capable of affecting the power supply voltages.

If the trouble does lie in the supply or in circuits which affect the supply voltage readings, the chances are that this will be the only defect in the entire electron device. After it is corrected, further tests of the unit will be unnecessary. Just turn the receiver on for awhile to see if the operation remains normal. On the other hand, if the power supply and closely associated circuits and components are in proper condition, this knowledge is gained quickly by means of these voltage tests, after which the technician can turn his attention to checking the other sections of the receiver.

Signal Circuits

The various power supply checks described for Figure 1 indicate the nature of the B+ and heater voltages at the output of the supply, but do not show that the required voltages reach the desired points in the other circuits of the unit, such as at the tube socket terminals. Since not more than one or two defects occur at a time, troubleshooting time is wasted when voltage and continuity tests are made in stages which are not defective. Therefore, after tests have been made as explained, it is good practice to employ dynamic testing to isolate the trouble, to a particular section or stage of the unit and to make voltage and continuity tests only in the circuits so located.

Once it has been determined which stage is faulty, the first voltage tests are made at the tube socket lugs to determine the operating voltages applied to the plate, screen grid, control grid, and cathode of each tube in the defective section or stage.

The circuit of a typical amplifier stage is shown in Figure 3 in which the signal is coupled by input transformer T_3 to the grid of amplifier tube V_3, and from the plate of V_3 to the following stage by means of output transformer T_4.

To make these tests, first the common or negative test prod is placed at a B− point in the circuit, as shown in Figure 3.

When the chassis is at B− potential, the voltmeter negative test lead may be applied at any convenient point on the metal chassis

As shown by the solid line 1 and dashed lines, 2 and 3, Figure 3, the voltmeter positive test prod is touched to the appropriate tube socket lugs in turn to check the plate, screen grid, and cathode voltages. In each case, the readings obtained are checked against

This vacuum tube voltmeter and capacitance checker is used not only to service radios, but TV sets, and other electronic equipment as well. The capacitance checker is just added scales for the ohmmeter to indicate the proper kick for each size capacitor.

Courtesy Hickok Electrical Inst. Co.

the values given in a service manual or manufacturer's data sheet like chart 1, or those known to be approximately correct for the particular type of equipment.

These sources usually give values as measured from the various tube socket lugs to the receiver common B− point. Technically speaking, plate, screen, and grid voltages are those existing respectively from plate to cathode, screen to cathode, and grid to cathode. Thus, on this basis, a plate voltage should be measured with the negative test prod at the cathode socket lug. However, when readings of B+ voltages at points in the circuit other than tube elements are to be made, the B− point is the proper reference, and so to simplify the entire process, MOST SERVICE MANUALS LIST ALL VALUES WITH REFERENCE TO B−; therefore, the tube voltage tests are made as shown in Figure 3. This removes the need to move the common or negative lead from one tube cathode to another and is the method used for measuring the Chart 1 voltages.

Since the control grid usually is operated negative with respect to the cathode of a tube, and negative or at zero potential with respect to B−, the test leads must be reversed to make this measurement. That is, the positive test prod is placed at B− and the negative prod at the grid socket lug, as shown by the solid lines in Figure 4. Actually, the total grid-to-cathode negative bias includes the voltage across cathode resistor R_6, when this voltage drop is to be included in the measurement, the positive test lead must be placed at the cathode socket lug as indicated by the dashed line in Figure 4.

Most vacuum tube voltmeters incorporate a polarity reversing switch which makes it unnecessary to reverse the test leads to check negative voltages. With this arrangement, the test leads are used the same as for the positive voltage tests of Figure 3, except that the reversing switch is turned to "−D.C. VOLTS" when the control grid voltage is checked.

As explained earlier, since the various voltage charts normally give all voltages as measured from the tube socket lugs to B−; the method of measuring grid operating voltages usually is used as indicated by the solid-line test leads in Figure 4.

Plate and Screen Voltages

Once a tube voltage has been found to be abnormal, the technician is well on his way to discovering the circuit defect. For example, in the circuit of Figure 3, suppose the check at the plate of tube V_3 results in a reading of zero on the meter although the chart lists 112 volts for that point. As the preliminary tests have shown that the proper B+ voltage is present at the output of the power supply, it now is evident that a defect must exist in some component, wire, or connection forming a part of the circuit between the plate of V_3 and B+.

Further isolation of the fault may be obtained by making a second voltage test as shown at point P, Figure 3. At this point, the reading should be practically the same as the voltage specified in the chart for the tube plate, since normally there is very little drop due to the plate current in the primary of T_4.

If the proper voltage is found to be present at point P, then an open exists in the primary of T_4 in the leads, or connections between this winding and the plate of tube V_3 or between the winding and point P are open.

If a zero voltage reading is obtained at point P, then there may be a short in V_1, V_2, or V_3 plate or screen circuits, or an open in the circuit between this point and B+ such as in R_{13}. Any of the components, wiring, or the circuit connections upon which the voltage tests have thrown suspicion may be given a continuity or resistance test, using an ohmmeter in the manner explained later in this lesson.

Many circuits do not employ resistors such as R_5, Figure 12, and the plate voltage of the tube normally is at B+ potential less the small drop across the transformer primary as shown by V_3 in Figure 3. In such a case, the plate voltage test does not disclose much.

However, for any tube where the plate circuit contains a series resistor R_5 as in Figure 12 or in the case of a resistance coupled amplifier stage, an abnormally low reading indicates an excessive plate current. One common cause of this condition is lack of grid bias due to some defect. Also, an open cathode circuit will be indicated by a higher than normal plate voltage reading.

Figure 5 shows why measurement of the plate voltage indicates these conditions. The plate to B− voltage for V_4 is indicated as E_B. E_L represents the voltage due to plate current in resistor R_{10}.

Since the total voltage between B+ and B− remains essentially constant, the increase in voltage E_L is accompanied by a corresponding decrease in E_B. And as mentioned, E_B is measured by the meter in checking the tube plate voltage.

Since the decrease in E_B is due to an increase in voltage across R_{10} in the case of stages in which the plate circuit does not contain a series resistor, a defect may not be discovered until the cathode or grid voltage is measured.

If the original plate voltage test results in an abnormally high reading, then it is likely that the cathode resistor, which carries both the plate and screen currents, is open. Thus, with an open in cathode resistor R_1 of Figure 12, the plate and screen currents will be zero, there will be no voltage drop across R_2 and at the plate of V_1 the voltage will equal that at B+.

A second cause for the abnormally high reading is an open grid circuit. For example, if antenna loop is open, the grid of V_1 in Figure 12 has no cathode d-c path to ground. The few electrons

A signal tracer is a detector, amplifier, and speaker used to trace a signal through every stage of a radio.

McMurdo Silver Co., Inc.

that hit the grid on the way from cathode to plate would collect on the grid until it became so negative that the tube cuts off.

This condition is referred to as a "floating grid". Frequently when a temporary connection is made to ground by means of a screwdriver or even the meter, the radio will play after the connection is removed until enough electrons collect to bias the tube beyond cut-off again.

Similar circuit defects may be the cause of an abnormal screen voltage reading. That is, a zero reading indicates an open somewhere in the d-c circuit between the screen socket lug and B+, or a shorted bypass capacitor. A high screen voltage reading indicates that some circuit defect is causing the screen current to be low or zero, while an abnormally low reading is indicative of excessive screen current due to some circuit fault, such as a shorted bypass capacitor.

Cathode Voltage

Insufficient or complete lack of cathode voltage may be due to a snorted or leaky bypass capacitor or to some condition which limits or prevents the screen current, plate current, or both. If there is an open in the cathode circuit, such as in R_1 of Figure 12, there is no current and very little voltage drop in the tube or the resistors between the tube plate or screen and B+. Therefore, the cathode voltage will be very high; practically equal to B+.

Grid Voltage

In the case of stages employing self bias as in Figure 3, lack of or excessive negative grid bias voltage may be due to defects in the cathode circuit components or abnormal plate and screen currents. For equipment where a fixed bias is used, it may be necessary to take voltage readings at various points in the grid bias supply circuit as described for the power supply of Figure 1 in order to locate the component or connection which is causing the trouble.

A positive voltage reading may be obtained at a control grid due to leakage of the capacitor which couples the signal voltages to this grid from the plate of the preceding stage. The rare exceptions are amplifier stages designed to operate with the control grids positive with respect to B−. However, even in these cases normal operating conditions prevail, since the cathodes of these tubes are operated still more positive than the grids.

Detector and AVC

The detector performs two things. It removes the audio signal by rectifying the r-f. Once this is performed, there is an additional function: it provides part of the rectified voltage as an automatic volume control for the incoming signal. In Figure 12, the detected signal is fed by C_{14} to the audio amplifier and the AVC voltage from the top of R_8 is fed through a filter consisting of R_{15}, R_3, C_{22}, and C_3 to the previous three tube grids.

Returning to Figure 5, with no signal into the circuit, the voltage measured from pin 5 to ground is due to a tube noise. As a result, the voltage at the junction of R_7 and R_8 is usually about −0.4 volt d-c as shown in Chart 1. In addition, any voltages measured at the grids of V_1, V_2, V_3 is due to their own self-bias properties.

And the only way to tell that the AVC is operating properly is to have a signal passing through the radio. However, unless this signal is controlled there may be improper AVC action due to other causes. Here is one specific service technique which requires the very thorough knowledge of a-c circuits.

RF Amp and Converter

Most of the comments on voltage checks hold true for RF AMP of Figure 12 as shown in Figure 6. In addition, some comments should be noted on the oscillator action within tube V_2. You may recall that V_2 has a tuned-grid oscillator. The tuned circuit of the oscillator consists of C_{2C}, C_5, C_6, C_7, and T_2. Primarily, C_6 and R_4 provide the grid-leak bias for V_2. In the cathode circuit, the winding of T_2 is the feedback winding to maintain the oscillations. Since grid-leak bias is produced by rectifying the signal applied to the grid, and in an oscillator the only signals are the oscillations, a bias indicates that the circuit is oscillating. This d-c check is shown in Figure 6 using ground and the dotted connection line to pin 1 of V_2.

Power Amplifier

Frequently, the power amplifier tube in Figure 7 causes trouble since it handles more power than several of the other tubes in Figure 12 put together. Other than the tube itself, capacitor C_{15} breaks down about as often since it has the plate voltage of practically all of V_4 across it. When this happens, the positive grid for V_5 is a sure sign of such trouble. Since it does handle so much power, the tube will draw enough current to cause damage very quickly were it not for the cathode self bias of C_{16} and R_{12}. C_{16} may be leaky and, for a low cathode to chassis voltage, a continuity check should be made to determine whether this is the defect.

Note that the plate voltage is applied through the primary winding of T_5 from the junction of C_{18} and R_{14} labelled B++. This enables the tube to operate at a higher voltage. Figure 7 shows the VTVM connections for measuring the plate voltage from pin 5 to ground.

In each of the Figures 1 through 7, once the voltage check has been completed in a stage and an incorrect reading is obtained, further checks are necessary to locate the exact component. Thus, the voltage checks in general tell whether the trouble is in the cathode, control grid, screen grid or plate circuit. To pin point the exact part causing the trouble, continuity checks must be performed.

CONTINUITY TESTING

Modern chassis design makes it impossible to trace most connecting wires visually, moreover a defective resistor, coil or capacitor may appear to be in perfect condition. Therefore, electric tests must be made to determine which parts are defective. Fortunately, most of this work can be done with very simple equipment using continuity testing.

The word CONTINUITY means uninterrupted connection, and in regard to electric and electron circuits, is defined as the presence of a complete, or continuous path for current. For service work, this definition usually means a complete, or closed, circuit for direct current only, and depending on the purpose of the circuit, it may contain a large, moderate, small, or zero resistance.

Because of the range of resistance that may be employed in the various circuits, most service manuals include charts like Chart 2 that list the resistance between two selected points, usually but not always the socket lugs and the chassis or common B− point. Like voltage measurements, resistance measurements are made under certain conditions, and the technician must duplicate those conditions if the readings he obtains are to have real meaning. Variations up to about 20 per cent between the actual resistance and those listed in any circuit may be caused by resistor and other component tolerances. Greater variations are due to component failures which may be discovered by checking each component and wire between the points with the abnormal reading.

Point to Point

As one form of continuity testing, POINT-TO-POINT testing consists of checking the resistance or continuity between two points in a circuit.

The wiring of the majority of modern radio and television receivers especially those using printed circuits and other electronic equipment is very compact, and many of the component parts are shielded so that they are out of sight. In such cases, continuity or point-to-point tests are the practical method.

An example of a test of this kind is illustrated in Figure 8A where an ohmmeter is being used to check the continuity between the terminals of two tube sockets. Since terminal Number 3 of socket S_1 is connected directly by a wire to terminal 3 of socket S_2, the resistance between these terminals should be almost zero. The resistance of the connecting wire is so low that it will not be indicated by the usual service type ohmmeter.

The lowest ohmmeter range should be used for this type of test, and the test prods should be held tightly against the socket terminal lugs rather than on the soldered joints. If a reading of

Shown is one type of tube checker. It tests the tube while operating in a circuit built in the instrument.

Courtesy Hickok Electrical Instruments Co.

zero resistance is obtained under these conditions, the connection may be considered in good condition. Should a higher resistance reading be obtained, a "high-resistance" soldered joint or a break in the wire is indicated. However, before proceeding, the test prods should be touched together to make sure the "zero adjustment" of the meter is still correct.

In the case of a connection of this kind, the soldered joints are the most likely offenders. The solder may cover the joint, but the wire is loose inside of it, or not even connected. These are called "cold" solder joints. These may be checked by placing one test prod on the bare wire and the other on the socket lug, as indicated in Figure 8B. A zero reading should be obtained, but if the meter indicates resistance, a hot soldering iron should be held against the joint until the solder melts and flows. After cooling, the joint should be re-tested.

The connecting wire itself may have broken inside the insulation to cause a very high, if not infinite resistance. In any case, the continuity of the wire may be checked by placing the ohmmeter test prods on the ends in such a way as not to include the solder joints.

Instances of broken wires in cases of connections of the type shown in Figure 8A are rather rare; it is more frequently encountered in wires that may be moved. Examples of these are the a-c power cord, and tube grid cap wires.

In Figure 8A, a short wire of sockets S_1 and S_2 is connected from terminals 4 to ground. Each connection from the terminal to ground should have zero resistance. A zero resistance indication using the Rx1 VTVM range shows that the connections between these points are all right. To check the connection at S_1, remove the tube from socket S_2. This is done since the heaters which are pins 3 and 4 of the two tubes are in parallel. Thus, one parallel connection may be good while the other may not and checking the two connected together is no check at all.

When the tube pins are exposed, the surest check is to touch pin 4 of the tube with the other ohmmeter lead touching the chassis at a place not on the solder connection. You may meet up with a cold solder joint, but by placing the test lead on the solder ground point, you press the lead against it and complete the connection. As for touching the tube pin, the socket lug itself may be making poor contact with the pin. Thus, the sure check is to check from pin to chassis.

A high resistance requires a further check to isolate the poor connection. For instance, pin 4 to chassis ground reads 1 megohm. Checking from pin 4 to socket lug of S_1, you read zero. From lug 4 to the solder on the chassis, you still read zero. From the solder on the chassis to the chassis, you read 1 megohm.

To cure a cold solder joint, take your soldering iron, properly cleaning off old solder and corrosion are necessary, and resolder the wire properly. As a final check, make an ohmmeter test from pin

4 to the chassis. You should read zero.

Then replace the tube in socket S_2 and remove the tube from socket S_1 to perform the same point to point check for the S_2 connection to ground.

Let us suppose that with dynamic checking we have isolated the trouble to tube V_5 and the underchassis view of this part of receiver looks like Figure 9. We can check the continuity of the resistors, transformer T_5, and other components. We can check the continuity of R_{11} by placing the ohmmeter test leads from the bare wire attached to pin 7 of V_5 and the bare lead of R_{11} connected to the chassis by the solder lug. To include these connections, the same procedure outlined for heater checks is followed. That is, check from chassis to pin 7. In our receiver, the grid resistor is about 1 megohm, so if the range selected is $R \times 100{,}000$, the pointer should indicate about 10 on the dial.

Resistor R_{12} can be checked the same way, that is from pin 2 to solder lug, but this time using the $R \times 100$ range. The pointer should indicate about 2.7 or read as 270 ohms.

To check the continuity of the primary of T_5, connect the ohmmeter leads to lug 5 of J_5 and to the junction of C_{18} and R_{14}.

A reading of several hundred ohms should be obtained. If not and a high resistance of say 1,000 ohms is obtained, the transformer has been damaged.

When a part changes value, further checks should be undertaken to be sure another part failure did not cause the change. For example, a burnt out transformer winding would lead one to suspect lug 5 of the V_5 socket of being shorted to ground.

Capacitor Testing

When in proper operating condition, a capacitor consists of two conductors, in the form of plates, rolled sheets or electrodes, insulated from each other by a dielectric. When the dielectric breaks down or is punctured, so that the plates come in contact with each other, the capacitor is shorted. When an external lead wire becomes disconnected from its plate, the capacitor is open and again, in most cases, it must be replaced.

Capacitors are classed in several ways: According to their use as filter, coupling, tuning, bypass, trimmer, and padder; according to their shape as tubular, disc, button, postage stamp, and bathtub; or according to their dielectric such as paper, mica, oil, air, ceramic, and electrolytic. Also, they are rated in capacitance, μf, or $\mu\mu$f and d-c working volts, "WV" or "WV DC".

However, insofar as tests are concerned, the main distinction must be made between electrolytic capacitors and others. Not only are electrolytics polarized when in good condition, but they allow leakage current which would indicate a short for capacitors with other dielectrics.

Although special testers are available, capacitors can be checked for leakage by applying the test prods of a series type ohmmeter across the terminals as

This service type instrument generates a wide range of frequencies which are needed to tune oscillators and i-f transformers to their proper frequencies.

Courtesy Jackson Electrical Instrument Co.

shown pictorially in Figure 10A and schematically in Figure 10B. For good paper type capacitors, the capacitance of which is greater than .01 microfarad, the meter pointer will jump or "kick" slightly, when the test prods are touched to the leads, and then at once drop back toward the high end of the ohms scale. This shows that the direct current from the meter battery charges the capacitor, but as the pointer drops back toward infinity on the ohms scale it indicates that the dielectric is in good shape and the capacitor is all right. No pointer deflection indicates a probable fault of an "open". In most cases the terminal lead has broken loose from the capacitor foil or plate.

With the capacitor charged in this manner, removing and replacing the test prods on its terminals should cause no deflection of the meter pointer. However, a recheck of the condition of the capacitor can be made by reversing the test prods and touching them again to the capacitor terminals. This will allow the capacitor to discharge and then charge again in the opposite direction, causing an even greater initial kick of the meter pointer.

A back-up type ohmmeter is not satisfactory because the meter pointer is at full scale and the capacitor charging current is so small that its shunting effect will not cause a change of the pointer position.

Although giving a reading of infinite resistance on ordinary ohmmeters, good capacitors of this type do indicate a definite resistance after the initial needle kick, when they are checked with very sensitive ohmmeters of the VTVM type. The dielectric of a capacitor is not a perfect insulator, and therefore, it has some finite resistance. The present standard insulation has a resistance of around 500 megohms for a one microfarad paper capacitor and this rating can be used as a rough check as to whether or not a capacitor has a leaky dielectric.

In the event the capacitor dielectric is defective or broken down so that the plates touch each other, the ohmmeter will read a steady low or zero resistance.

For tests of this type, be sure to disconnect one capacitor lead to avoid inaccurate readings due to parallel connected units. For example, in the circuit of Figure 11, capacitor C_1 is connected as a by-pass in parallel with bias resistor R_1. With the test prods in the positions shown, both R_1 and C_1 affect the meter reading, thus making it useless for testing either one separately.

Sometimes the plate of a variable capacitor is bent out of shape sufficiently to touch and provide a low resistance d-c path. To test for this trouble, first disconnect any coils that may be connected across the capacitor, and then touch one of the ohmmeter test prods to the rotor and the other to the stator of the capacitor section that is suspected of being defective. Then the rotor is turned slowly, and if and when it touches the stator plates, the ohmmeter will indicate very low or zero resistance. If the capacitor plates are correct and do not touch, the ohmmeter reads infinite resistance during the full turn of the rotor.

Electrolytic capacitors present a little different problem because they are polarized, and also because they allow a small leakage current even though they are in good condition. Therefore, when a capacitor of this type is tested with an ohmmeter, the prod connected to the positive of the meter battery should be placed on the positive terminal of the capacitor.

The dielectric of an electrolytic capacitor consists of an insulating oxide film which has the property of allowing heavy current to pass in one direction and very little in the opposite direction. Thus, when one of these capacitors is subjected to reversed polarity, the heavy current will raise its internal temperature and may cause serious damage to the unit.

However, the oxide film on the capacitor anode plate is not harmed by reversed polarity except when sufficient heat is generated. Therefore, a short application of reversed polarity does not injure the capacitor.

When ohmmeter test prods are placed across the terminals of a good electrolytic capacitor, C_{16} in Figure 9, and its ground is disconnected, the meter indicates a comparatively low resistance, but almost immediately the deflection of the meter pointer changes slowly until a fairly high resistance is indicated. As explained above, this action is due to the current which charges the capacitor. It is heavy at first and then drops gradually to a final value determined by the leakage resistance of the unit.

A capacitor analyzer, as illustrated here, can be used for checking paper (or mica) and electrolytic capacitors for capacitance and leakage. Leaky capacitors cause intermittent and erratic receiver performance.

Courtesy Solar Manufacturing Corporation

When making this test, always take a second reading, with the ohmmeter test prods in a reversed position, to check the polarity of the test voltage. The highest indicated resistance can be considered as correct but be sure the meter hand has stopped moving before taking the final reading.

While it is difficult to make a general statement as to what resistance a good electrolytic capacitor should have, field observations indicate that the average 20 μf filter capacitor rated at 150 WV DC has a resistance of 150,000 up to perhaps 500,000 ohms. An 8 μf capacitor rated at 450 WV DC usually has a resistance of between 250,000 ohms and 1 megohm. In either case, a new capacitor shows a somewhat lower resistance, but the value increases as the capacitor has been in operation for a short time.

If the ohmmeter pointer shows little or no deflection when the prods are placed on the terminals of an electrolytic capacitor, it indicates that the capacitor is either open or has low capacitance. In either case it should be replaced. On the other hand, when the meter pointer indicates low or zero resistance and retains this reading for a minute or so, it is safe to say that the capacitor is shorted internally and should be replaced. Thus by watching the ohmmeter pointer, the condition of an electrolytic capacitor can be checked quite accurately. SUMMARIZING: (1) when the meter shows an initial low resistance but changes quite rapidly to a higher resistance reading, the electrolytic capacitor is presumably in good condition, (2) when the meter shows little or no deflection, or gives a continuous low resistance reading, the unit can be presumed to be in need of replacement.

In this lesson we have described for you an effective method for troubleshooting the radio receiver in Figure 12. However, bear in mind that the very same methods used here apply equally well to every other type of electronic equipment. An organized approach along with an alertness to the significance of each reading soon leads one to the defective part.

Only one type of test equipment was shown in this lesson. There are others. These are described after the fundamentals are presented which make it possible to use this added equipment effectively.

Take a look at the lessons studied and notice how much you have learned already. As you progress, you find this information increasingly valuable to you.

SUMMARY

Troubleshooting procedures for locating and correcting a fault in any electronic device require a planned and systematic approach. First, it is necessary to isolate the circuit containing the fault. Then, determine what part or parts cause failure or unsatisfactory operation of that circuit. Next, the part is checked, and if a satisfactory repair cannot be made, it is repaired. Finally, an operational check is made to confirm normal operation.

In such a planned procedure, the first step is a careful inspection of the device using the natural senses of sight, hearing, and smell—these are very valuable aids in the detection of trouble.

When the initial inspection doesn't provide a clue as to the nature of the fault, dynamic tests are made. These tests consist usually of tracing a signal through the various stages of the electronic equipment being serviced. An abnormal signal indicates a faulty stage.

Once the general location of the fault is known, static tests are made to isolate the particular part causing failure or abnormal operation. Static tests include voltage analysis, resistance measurements, and continuity tests, the latter usually done with an ohmmeter.

Complete failure of a part or a component is due to an "open", which is a broken current path, or a "short" or unwanted current path. Abnormal operation of a device usually means the desired characteristic of a component has changed beyond its normal tolerance.

Effective troubleshooting is the result of correctly interpreting the meaning of tests or measurements made in a logical sequence.

CHART 1

VOLTAGE MEASUREMENTS

All voltages measured with an electronic voltmeter from socket lugs to the chassis.

Volume control turned to maximum clockwise position, no signal applied.

Line = 117 v a-c.

Tube No.	*Socket Lug No.* 1	2	3	4	5	6	7
V_1	— .2 v	0	0	6.3 v a-c	85 v	50 v	.4 v
V_2	—7.4 v	0	0	6.3 v a-c	100 v	100 v	—.1 v
V_3	— .1 v	0	0	6.3 v a-c	112 v	112 v	2.4 v
V_4	— .6 v	0	0	6.3 v a-c	—.4 v	—.4 v	100 v
V_5		12 v	0	6.3 v a-c	250 v	240 v	0
V_6	225 v a-c		6.3 v a-c	0		225 v a-c	250 v

CHART 2

RESISTANCE MEASUREMENTS

All resistances except as noted measured from the socket lugs to the chassis.

* Measured from lug 7 of socket V_6.

Line cord removed from a-c outlet and volume control turned to maximum clockwise position.

Tube No.	*Socket Lug No.* 1	2	3	4	5	6	7
V_1	2 Meg Ω	0 Ω	0 Ω	0 Ω	* 50 Ω	* 10K Ω	100 Ω
V_2	22K Ω	.6 Ω	0 Ω	0 Ω	* 5.7K Ω	* 5.7K Ω	2 Meg Ω
V_3	1. Meg Ω	0 Ω	0 Ω	0 Ω	* 4.7K Ω	* 4.7K Ω	330 Ω
V_4	10 Meg Ω	0 Ω	0 Ω	0 Ω	547K Ω	547K Ω	*470K Ω
V_5		270 Ω	0 Ω	0 Ω	*400 Ω	*820 Ω	1 Meg Ω
V_6	132 Ω		0 Ω	0 Ω		132 Ω	100K Ω

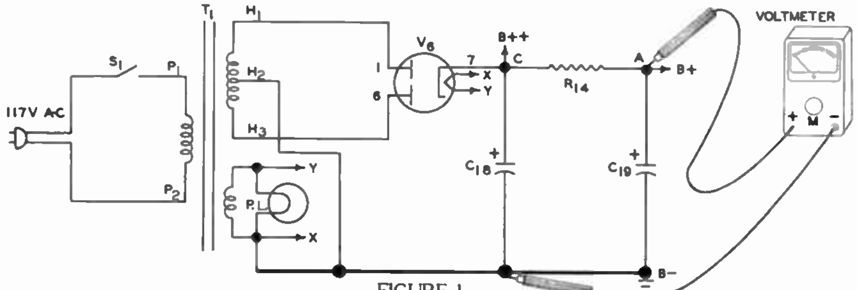


FIGURE 1

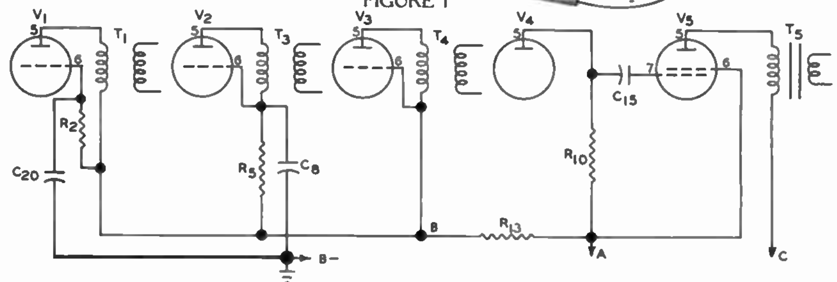


FIGURE 2

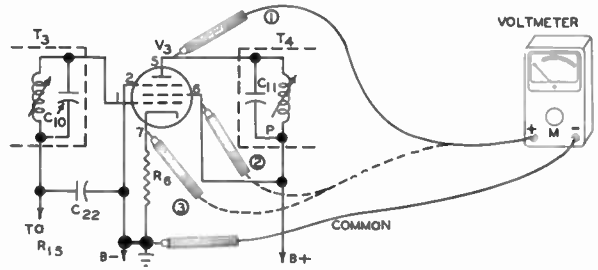
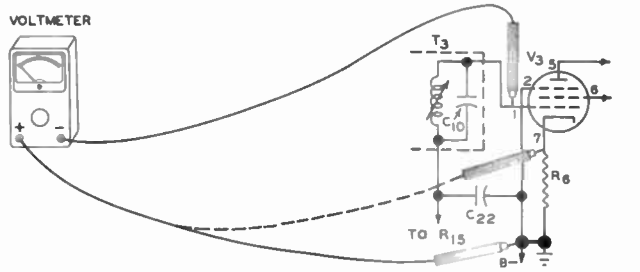


FIGURE 3



AEH-20

FIGURE 4

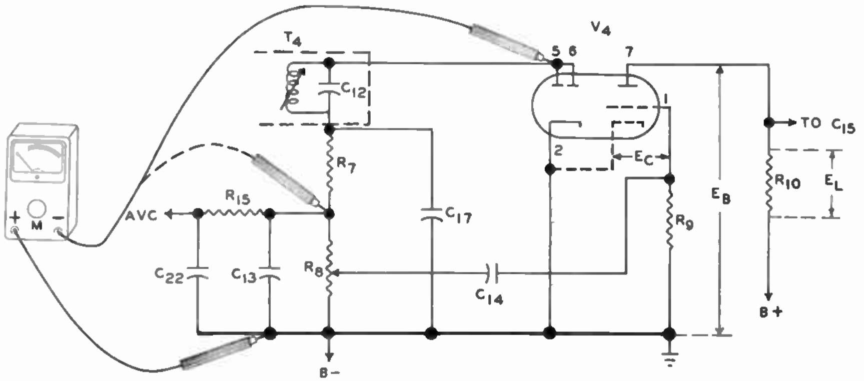


FIGURE 5

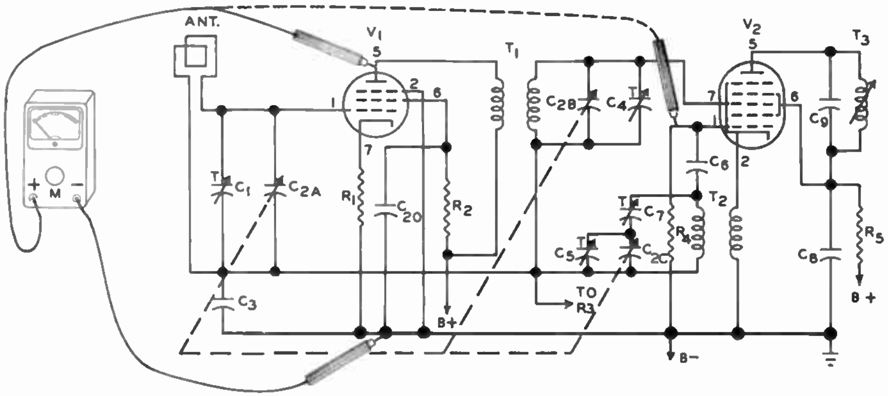


FIGURE 6

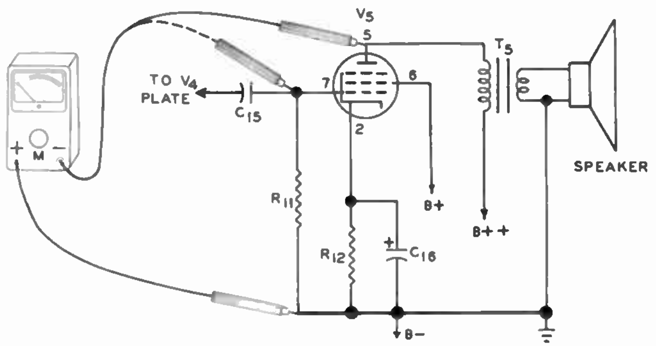


FIGURE 7

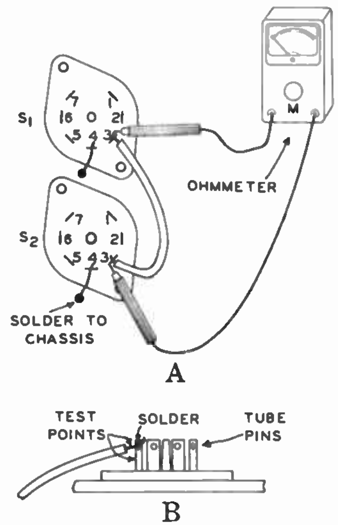


FIGURE 8

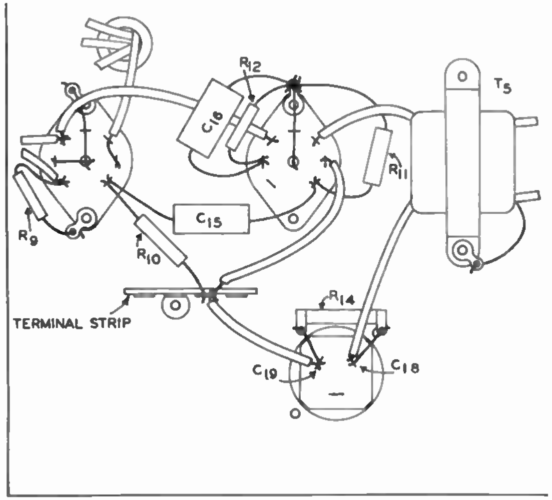


FIGURE 9

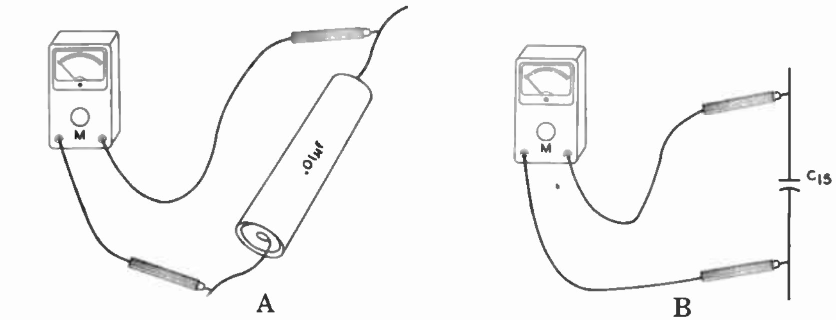


FIGURE 10

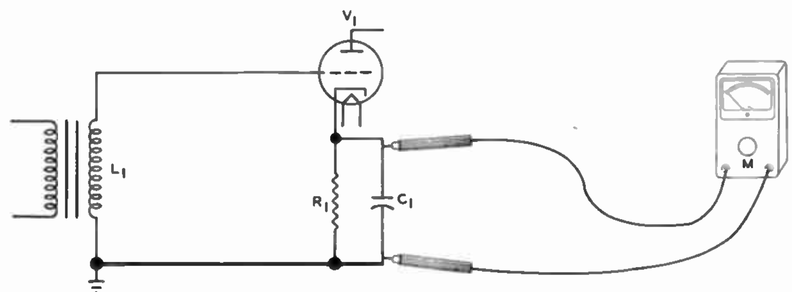


FIGURE 11

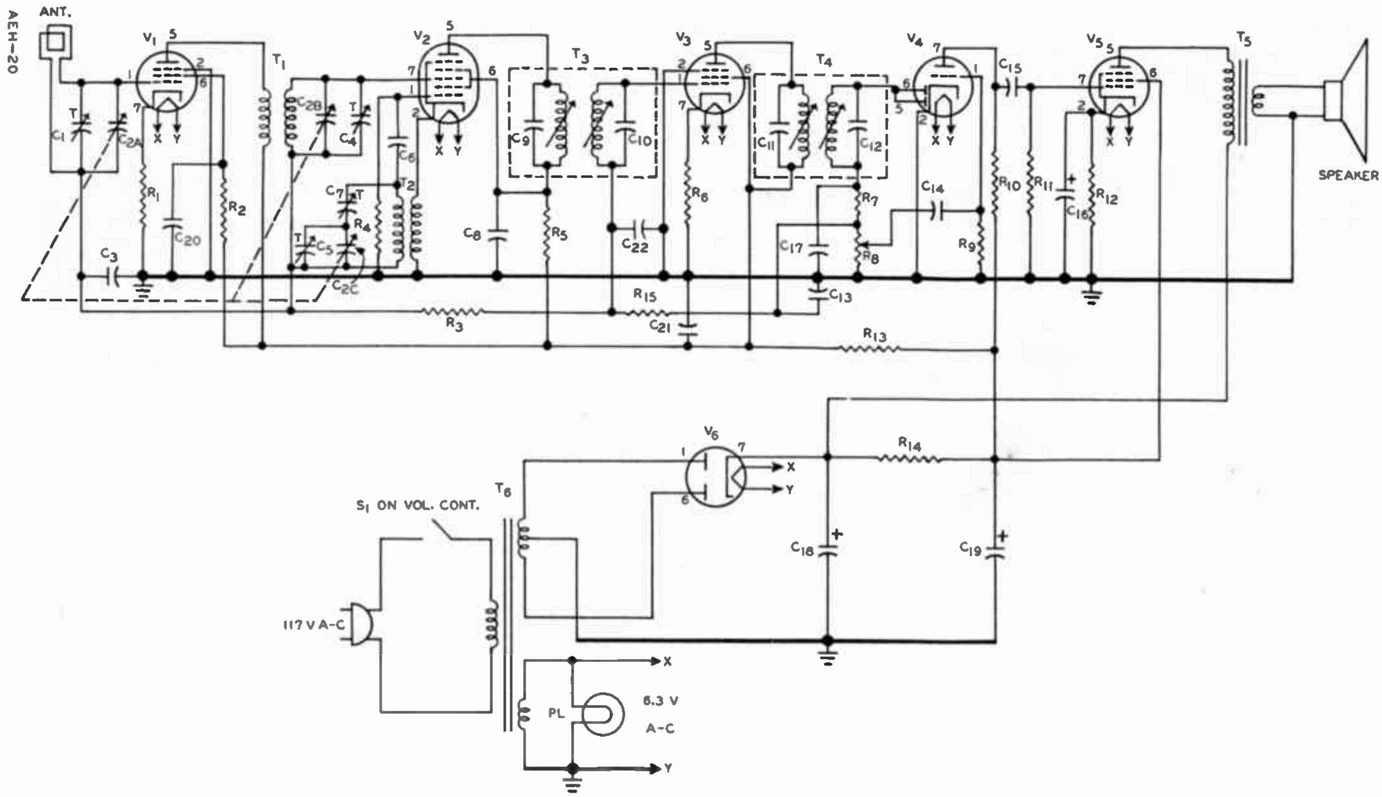


FIGURE 12

FROM OUR *Director's* NOTEBOOK

THE MAN WHO QUITS

The man who quits has a brain and hand
As good as the next; but he lacks the sand
That would make him stick, with a courage stout,
To whatever he tackles, and fight it out.
He starts with a rush, and a solem vow
That he'll soon be showing the others how;
Then something new strikes his roving eye,
And his task is left for the bye and bye.
It's up to each man what becomes of him;
He must find in himself the grit and vim
That brings success; he can get the skill,
If he brings to the task a steadfast will.
No man is beaten till he gives in;
Hard luck can't stand for a cheerful grin;
The man who fails needs a better excuse
Than the quitter's whining "What's the use?"
For the man who quits lets his chances slip,
Just because he's too lazy to keep his grip.
The man who sticks goes ahead with a shout,
While the man who quits joins the "down and
out."

—Charles R. Barrett

Yours for success,

W. C. DeVry
DIRECTOR

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