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CONDUCTORS AND RESISTORS

ASSIGNMENT 12

CONDUCTORS AND RESISTORS

We have seen in the preceding assignments that even the best electrical conductors, such as silver and copper, have some opposition to the flow of an electric current. This opposition is termed the **resistance** of the component or circuit. It was also pointed out, that there are no clear dividing lines between conductors, resistors, and insulators. It is thought that the atoms of good conductors hold on to their electrons more loosely than the atoms of resistors hold on to their electrons; and the atoms of good insulators hold on to their electrons **very** tightly. This will account, at least in an elementary way, for the low resistance of conductors, the higher resistance of resistors, and the very high resistance of insulators.

Of course, conductors will usually be found to have very low resistance; but what might be classed as a resistance in one circuit, might be an insulator in another. For example, it is not at all unusual to find resistors in vacuum tube circuits having a resistance of 10 million ohms; whereas, a component with that high a resistance value would be considered to be an insulator in the commercial power circuits supplying electricity to homes. Thus, conductors, resistors, and insulators differ in degree only; the same basic laws of electric current flow apply to each.

Resistance of Wire Conductors

There are several things which will affect the resistance of a wire conductor. The first of these which we will discuss is the **material** of which the wire is composed.

If we wished to use a wire with the smallest possible amount of resistance for a given size and length of wire, we would use wire made of silver. This is because silver is the best conductor of electricity known, and therefore, has the least resistance. Since silver is a rare metal, it is expensive and therefore is rarely used as a conductor. Instead, a compromise between conductivity and expense is made, and copper is used. Copper is almost as good a conductor as silver, and of course is much cheaper. Copper has other desirable features as far as wire manufacturing is concerned, since it can be "drawn" into the proper size and shape quite easily.

Another material which is sometimes used as a conductor is aluminum. It is not as good a conductor as copper, but is sometimes used because of its lightness in weight.

To compare the conductivity of these three materials, let us assume that we have a piece of silver wire, a piece of copper wire, and a piece of aluminum wire, all of identical size and length. If the piece of silver wire has 1 ohm resistance, we will find that the piece of copper wire will have approximately 1.06 ohms of resistance, and the piece of aluminum wire will have 1.75 ohms of resistance.

Another thing which affects the resistance of a piece of wire is the **length** of the wire.

If a piece of wire has some definite resistance, it stands to reason that a piece of the same wire twice as long, should have twice as much resistance. A piece of wire may be compared to a water pipe. Any pipe has opposition to the passage of water, but if the pipe should be twice as long, this opposition will be doubled. If a piece of wire one foot long has one ohm resistance, then 1000 feet of this same wire will have 1000 ohms of resistance.

Another factor which affects the resistance of a wire is its **cross-sectional area.** If you cut a piece of wire with a sharp tool, and looked at it "end-on", you would see a cross-section of the wire. Since most wire is round, the cross-section of the wire will be a circle. It can be seen easily, that if the area of this cross-section is increased, a larger path will be provided for the movement of the electrons which form the electric current. In other words, the larger the wire, the less the resistance. The cross-sectional area is proportional to the **square** of the **diameter** of the wire. Thus, if we double the diameter of a wire, the cross-sectional area will be increased **four** times, and the resistance will be one fourth.

Another thing which affects the resistance of a conductor is the temperature. All **pure metals** will **increase in resistance** as the temperature of the metal increases. This property is called **positive temperature coefficient.** In metals, this increase in resistance is about .4% per degree centigrade increase in temperature. For example, if the resistance of the filament of a light bulb is 20 ohms, when the bulb is not lighted, this resistance will increase to perhaps as much as 40 ohms, when this filament is connected to an electrical circuit and heated to incandescence.

Carbon, which is not a metal, has a negative temperature coefficient. That is, as the temperature increases, its resistance decreases.

Thus, we see that there are four things which affect the resistance of a conductor, namely: material, length, cross-sectional area, and temperature.

Wire Sizes

We would find it rather inconvenient to say that we were using a wire with a diameter of 403 ten thousandths of an inch, or 3196 hundred thousandths of an inch. For this reason, wire sizes have been assigned numbers.

There have been quite a few different systems for numbering wire, but the Brown and Sharp (B & S) Gauge is the most common one in use in this country and will be the one discussed here.

The Copper Wire Table at the end of this assignment will give you all the information you will ever need about the various sizes of wire which are in common use. Notice that there are eight columns, the first one at the left being marked "Gauge No." This is the number we mean when we talk about a number 20 or a number 36 wire. These numbers start at 0000 and end at 40, the larger the number, the smaller the wire. The second column from the left is the diameter in mils, which is the diameter of the wire in thousandths of an inch. This term "mils" is easy to remember, since it stands for milli-inch, which we know would mean thousandths of an inch. It is much simpler to say that a wire, No. 20 for example, has a diameter of 31.96 mils, than to say it is 31.96 thousandths of an inch in diameter.

The next column gives the cross-sectional area of the wire in circular mils. This is obtained by merely squaring the diameter in mils.

The fourth column shows the weight in pounds per 1,000 feet of the wire, without insulation.

The fifth column is very much like the fourth, but is turned around and gives the number of feet in a pound of the bare wire.

The last three columns list the resistance of the various sizes of pure copper wire in number of "Ohms per Foot", number of "Feet per Ohm", and number of "Ohms per Pound".

To use the wire table, you read down the left hand column to the size or gauge number you are interested in, and then read across to the right to determine the proper value. For example, suppose we wanted to find the resistance per foot of B & S Gauge No. 18 hook up wire. This is usually called "Number 18". Going down the left hand column to 18, and reading across to the proper column, we learn that it has a resistance of 0.006374 ohms per foot. We could also determine that this wire has a diameter of 40.3 mils, a cross-sectional area of 1624 circular mils, weighs 4.92 pounds per 1000 feet, and it would take nearly 157 feet of it to have a resistance of 1 ohm. A table of this type eliminates all calculations and makes available all of the commonly used information for the ordinary sizes of copper wire.

There are many different uses for such a table. For example, suppose you had a roll of wire and wanted to know how many feet of wire it contained. It would be quite a job to unroll it and measure it. Instead, you could weigh it, and then, turning to the table, determine the number of feet per pound for this size wire. All you need do then, is to multiply this number by the weight of the roll of wire, and you would have a very close approximation of its length.

Suppose someone asked you how many number 24 wires it takes to equal one number 9 wire. You can use the table to determine the circular mil cross-sectional area of the number 9 wire, which is 13,090. Then doing the same thing for the number 24 wire, we have 404. Dividing 13,090 by 404 gives 32 and a fraction. Thus, approximately thirty two No. 24 wires would be needed to replace one No. 9 wire.

Possibly, you are wondering how wire can be measured accurately when there is but a few thousandths of an inch difference in the diameter of various sizes. This is usually done with a wire gauge. These wire gauges are made in two popular designs. One is circular in shape and has a ring of holes drilled around the outside. The size of each hole corresponds to a wire gauge number. To measure a piece of wire with this gauge, you remove the insulation, and then find the smallest hole the wire will go through. The number corresponding to this hole is the wire size.

The other type of wire gauge has a "V" shaped slot in it and at the proper places on the "V", the sizes are marked. With this gauge, the bare wire is pulled down in the slot as far as it will go without forcing it, and the mark nearest it will give the size of the wire.

Stranded Wires

The B & S Wire Gauge applies to solid copper wires which, in general, are used for most permanent circuits. Solid copper, especially in the larger sizes, is not very flexible, so when it is desired to use the conductor in portable or moveable circuits, some other type of wire must be used. In order to obtain the necessary flexibility, yet have a proper size wire to carry the current, it is customary to make up a conductor of a number of smaller solid copper wires. These smaller size wires are more flexible and by combining a sufficient number of them into a cable, the resistance will be low. This is known as a **stranded** wire.

These smaller wires are twisted together, somewhat like the threads in a piece of string, and therefore, each will carry a part of the total current in the circuit in which they are connected. For example, the attachment cord for the average radio receiver is called a No. 18 stranded wire, although it is actually made of sixteen No. 30 copper wires to provide the necessary flexibility.

By referring to the wire table, you will see that a No. 30 wire has a cross-sectional area of 100.5 circular mils, and that a No. 18 wire has an area of 1624 circular mils. To find the total cross-sectional area of the sixteen No. 30 wires, we multiply 16 times 100.5 and obtain 1608 circular mils. This is very nearly equal to the 1624 circular mil area of the No. 18 wire. Most stranded conductors employ No. 30 wires, and their number is varied to approximate the area of different sizes of solid wire. For example, No. 14 stranded wire is made up of 41, No. 30 wires, and No. 20 stranded wire is made up of 10, No. 30 wires.

For some uses, wire with greater flexibility than that of standard stranded wire is desirable. An example of this would be the wire used for test leads on most test instruments. It is desirable to have this wire very flexible. For this purpose, special flexible wire, Gauge No. 20 is made. This wire is composed of 41 strands of No. 36 wire. **Flexible wire** is made in several sizes for different uses.

Insulation for Wire

In many electronics applications, copper wire is wound on forms and spools, to form coils of various sizes and shapes. In most cases, the turns of the coils are wound tightly together and therefore the wire must be insulated. If the different turns actually touch, or make contact with each other, the electrical current would follow the shorter path from one turn to the next instead of passing through the entire length of the wire. Because a condition of this kind provides a shorter path for the current, we call it a "short circuit" or "short"; and to prevent this from happening, we put insulation on the wire.

The insulation on the type of wire used for coil windings is mainly of three materials: Enamel, silk, and cotton. For the first of these, the bare copper wire is run through a bath of special varnish, to apply a thin coat of insulation on its outer surface. This coating is known as "Enamel", and the finished wire as "enameled wire". Enameled wire is used widely in the winding of power transformers, output transformers, etc.

Cotton is a fairly good insulator when dry, and therefore, cotton threads, wound on the outside of a copper wire closely enough to completely cover the outer surface, form a layer of insulation. Wire of this type is known as single cotton covered and often abbreviated as S.C.C. When more insulation is needed, a second layer of cotton is wound over the first layer to produce double cotton covered (D.C.C.) wire. In addition to its own insulating qualities, the cotton helps to keep adjacent wires apart, and thus prevents them from touching.

On the smaller sizes of wire, silk is often used instead of cotton, as it can provide the same insulation in less space. Like the cotton covered wire, we have single silk covered (S.S.C.) and double silk covered (D.S.C.) wire. Cotton, or silk covered wire is used in winding R-F Coils, I-F Transformers, etc.

In addition to these three basic types, we often find wire with a coating of cotton or silk over enamel. These are called cotton enamel (C.E.) or silk enamel (S.E.), whichever the case might be. The enamel is a better insulator than the cotton or silk, but the cotton, or silk, provides the wire with more protection against mechanical injury, and this coating also acts as a spacer between adjacent turns. In general, the insulation of wire used for coil winding is comparatively thin; and, because the wire is usually permanently mounted (as in a coil), the conductors are solid. Wire used for winding coils is often called **magnet** wire.

With the exception of the various types of magnet wire, used in the coils and transformers, most electronics work is with conductors that are used to interconnect various circuit components. A great variety of insulation is found on these wires. A few of the more common types will be discussed here.

Perhaps the most widely used type of insulated wire, employed for interconnections in modern electronics equipment, is plastic coated wire. This wire is covered with a layer of plastic which has excellent insulating properties.

The type of insulation used often in hook-up wire is push back type. The insulation of this wire is made with a woven cloth which is often either waxed or varnished and which will not unravel. This insulation fits rather loosely and can be pushed back from one end to expose the conductor. Push-back insulation is available on either stranded or solid conductors.

Another type of wire which is sometimes used for interconnections uses rubber insulation. This insulation will not push back. Rubber insulated wire will be found on some circuit components, such as filter capacitors. In some cases a single layer of cotton insulation is placed directly over the conductor, and the rubber insulation placed on top of this.

Another type of wire which is used in certain applications in electronics work is shielded wire. This wire consists of a conductor, usually stranded, covered with a rubber or plastic insulation. The insulation is covered with a woven metallic sleeve which forms a metallic shield. Shielding of this type is used to prevent the conductor from picking up unwanted interference. In some cases, there is a woven cloth, or rubber, covering over the shield to protect it from mechanical damage. Wire of this type is used for the flexible conductor which connects to a microphone and, because the shielding is insulated on both the inside and outside, the shielding can act as a second conductor as well as a shield.

There are many applications, such as lamps and appliances, when it is necessary to run two conductors from the source of electricity to the unit using it. To take care of the many variations of circuits of this type, a large number of **double conductor** wires and cables are available. Most of these use rubber or plastic insulation. Double conductor wire can also be obtained in a metallic shield.

In certain cases, such as connections from one piece of electronics equipment to another, or between two sections of equipment, it is often desirable to have three or more wires in one cable. Cables are obtainable with almost any number of conductors and with or without a metallic shield. In these cables, the insulation of the various wires is of different colors, to identify the individual conductors.

There are hundreds of different types of wires, insulations, and cables, but the types discussed will familiarize you with the majority of those found in electronics work.

Resistors

Looking at the underside of an electronics or television chassis will quickly convince us that resistors of all types find extensive and extremely important applications in these circuits. As we shall learn later, they may be employed as current limiters, for obtaining bias voltages, for voltage-dropping, for controlling the volume and tone, and for many other uses. They are made in resistance values ranging from a fraction of an ohm to many million ohms, and have an accuracy ranging from as close as ½% to as much as plus or minus 20%.

Nearly all resistors in use today may be classified as "wire-wound" or "carbon-composition" type, with the composition type being the cheaper and more common. Carbon is a fair conductor and, therefore, has low resistance. Bakelite and some of the other plastics have a very high resistance. If we were to take powdered carbon and mold it into the shape of a resistor, we would find that this resistor would have a very low resistance. On the other hand, if we were to do the same thing with powdered bakelite, we would find that this resistor would have a very high resistance. We could mix the two powders in any proportion we wish, and by this means, produce any value of resistance that we wanted. The carbon-composition resistors used in electronics are actually made in this fashion, and connecting leads are attached to each end, as shown in Figure 1.

A cross-sectional view of a more modern type of construction of a carbon-composition resistor is shown in Figure 2. In this type of resistor, the carbon-composition element is located inside an insulated tube. By insulating the resistor, it is possible to mount it near metal parts without danger of a short circuit occurring.

Other types of composition resistors have been manufactured. One is known as the "metalized" type. These resistors have the carbon mixture baked on a small glass rod which is enclosed in a ceramic insulating material. Still another type is the "deposited composition" type in which the carbon composition is deposited on a non-conducting shell in such a manner as to produce the desired resistance value.

Resistor Color Code

Nearly all carbon resistors have their electrical value indicated by means of a special color coding, rather than by having the actual number of ohms marked on the resistor. This color code has become standard with all the resistor manufacturers and is known as the Standard Resistor Color Code.

The present method of coding resistors consists of painting 3 or 4 bands around the resistor, and closer to one end of it than the other, as shown in Figure 3. Each of these bands represents a number, as shown in the table accompanying Figure 3. To obtain the ohmic value of the resistor, we should first look at the color nearest the end of the resistor—which in this case is Red. We refer to our table and learn that Red represents the number 2, so we write down 2. Next, we go to the second color which is Green, and by referring to the table, we find that this represents five. This gives us 25 so far. Finally, we go to the third color (Yellow) and, by referring to the table, we see that Yellow represents four. However, for the third color we do not add 4 to the other two numbers, but rather, we add **four zeros**. This would make our resistor have the value 250,000 ohms. If there is a fourth color it would be Silver or Gold and will always represent the tolerance, which will be discussed later.

As another example to illustrate the use of the resistance color code, suppose we have a resistor which has these three bands on it: Orange, Black, and Red. (In each of these examples, the colored band nearest the end will be mentioned first, then the 2nd band and then the third band.) The resistance color code table shows us that the Orange band stands for three, the Black band for zero and the Red band for two, or two zeroes in this example, since it is the third color. Combining these figures, we have a value of 3,000 ohms resistance.

Let us take another example. Suppose, we wish to find the ohmic value of a resistor color coded, Gray, Blue, Green, and Gold. From the chart we find:

Gray stands for 8
Blue stand for 6
Green stands for 00000 (not 5, but 5 zeroes since it is the third color.)

Gold—Tolerance—will be discussed later.

Combining these values, we find the value of the resistor to be 8,600,000 ohms, or 8.6 megohms.

To further demonstrate the use of the resistor color code, we will list the colors of several resistors and the ohmic value directly below each. Check each example against the color code to make sure you understand each.

(1). Green — Black — Orange 5 0 000	(2). Violet — Red — Brown 7 2 0
(3). Yellow — Green — Yellow 4 5 0000	(4). Blue—White—Red 6 9 00
(5). Brown — Black — Brown 1 0 0	(6). Yellow — Violet — Orange 4 7 000
(7). Green—Gray—Red 5 8 00	(8). Brown — Black — Green 1 0 00000
(9). Red — Red — Red 2 2 00	(10). Yellow — Violet — Black 4 7

Notice the ohmic value for the resistor in Example 10. The Yellow and the Violet gave us the 47. The third color is Black, since the third color tells us how many zeroes to add, Black tells us to add 0 zeroes or no zeroes. Thus, the ohmic value of this resistor is 47 ohms.

For very small values of resistance, the **third** band may be either Silver or Gold. In this case, it represents a decimal multiplier, as shown in the chart. For example, suppose we wish to find the value of a resistor color coded, Orange, Green, Gold.

This Orange and Green, of course, stand for 35, and the Gold as the **third band** stands for a multiplier of .1. Thus, the ohmic value of this resistance is $35 \times .1 = 3.5$ ohms.

As another example, suppose we wish to find the ohmic value of a resistor color coded Red, Violet, and Silver. The Red and Violet would give us 27, and the Silver, as the **third band**, indicates a multiplier of .01. Thus, the ohmic value of the resistor is $27 \times .01 = .27$ ohms.

An older method of color-coding carbon resistors did not mark the colors in bands, but rather had the entire resistor body painted one color, a second color splashed on one end, and the third color in the form of a dot somewhere on the resistor. This is shown in Figure 4. These resistors are read in exactly the same way, except that the **Body color is read first**, the **End color second**, and the **Dot tells us the number of zeroes to add.** This is easy to remember because the first letter of each word in order spells "BED". The resistor of Figure 4 would have a rated value of 500 ohms.

Suppose you needed to know the value of a resistor which was painted entirely Red. It has a Red body, so the first number is 2; a Red end, so the second number is 2; and a Red dot on a Red body would still look Red, so we would add 2 zeroes, making it 2200 ohms.

At this point, it is worth while to go back to the radio you used in Assignment 2, and find the size of each resistor in it. While it is not absolutely necessary to become completely familiar with the Resistor Color Code, all good electronics technicians know it by heart, and it is possible that, by not being completely familiar with it, you might brand yourself as an inexperienced or careless worker. If you will practice using this color code, you will soon find that you have memorized the code.

Accuracy of Resistors or Tolerance

One percent of any amount is one one-hundredth of this amount. Ten percent is 10/100 of the amount being considered, and so on. Most commercial carbon resistors are accurate to within plus or minus 10% of the marked or coded value; which means that the resistor may have a resistance value 10% higher or lower than its indicated value and still be within the manufacturers' guarantee. Such resistors have a fourth color painted on them which is Silver. If the fourth color is Gold, the manufacturer has guaranteed that the resistor has an actual value within 5% higher or lower than its marked value. If there is no fourth color on the resistor—that is, there are only three colors —the manufacturer has guaranteed that the resistor will be within plus or minus 20% of its indicated value. Thus, a resistor marked 50,000 ohms with an accuracy of 10% (this is usually called 10% tolerance), may have a value anywhere between 45,000 ohms and 55,000 ohms. However, since the manufacturer has guaranteed that it is between these two values, there is a good chance that it will be quite close to the indicated value. The resistor shown in Figure 3 is within plus or minus 10% of 250,000 ohms, or between 225,000 ohms and 275,000 ohms.

Perhaps you are somewhat surprised that electronics parts can be this much off the required value and yet give good results. Not all electronics equipment circuits permit such variation of resistance values, but carbon resistors are usually employed in those circuits where the resistance value is not so critical. The fact that a piece of equipment is intricate or expensive does not indicate that very accurate resistors are needed. The application of the part itself determines this. For example, if we wished to make a meter accurate to within ½%, the shunt resistors and multiplier resistors would have to be that accurate, whereas, the same instrument using the same circuit, could be made 5% accurate if this accuracy were sufficient for the application. Most electronics equipment is so designed that the resistor values are not critical to within plus or minus 20%.

Carbon-composition resistors are made in several wattage ratings. One-quarter watt, one-half watt, one watt and two watt resistors are the types generally used. The larger the wattage rating, the larger the resistor will be physically. Figure 5 shows the actual size of resistors with these four wattage ratings.

Wire-Wound Resistors

When resistors must handle greater power, or have better accuracy, they are made of a high-resistance wire such as nichrome. Commercially, these resistors are made by winding the resistance wire on strips of fiber, or on porcelain tubes. The turns are separated from each other, and the type of resistance wire used, its diameter and total length, determine the resistance of the resistor. These resistors are usually enclosed in a protective coating of baked enamel or special cement which serves to protect the fine resistance wire and prevent resistance change which might occur due to moisture. The majority of these resistors have a metal band around them on which the resistance value is stamped. Figure 6 shows a wire-wound resistor.

Usually, the resistance wire is started and terminated in suitable connector lugs, and sometimes extra connections are made in the middle of the resistor by means of extra terminal lugs. Semi-variable wire-wound resistors have a bare strip along the length, which is not covered with the insulating cement, and permits contact with the resistance wire. Sliding lugs are used to make contact with the wire, and the connections may be adjusted for the resistance value needed. Such a resistor is shown in Figure 7.

Wire-wound resistors are made in resistance values from a fraction of an ohm to about 100,000 ohms, but it is not practical to make these resistors in higher resistance values. They are made in various physical sizes to serve different heat or power dissipating requirements. Wattage ratings from three watts to one hundred watts are common.

Variable Resistors

In many electronics applications, the value of a resistor must be changed for the purpose of adjusting the circuit. You saw in Assignment 2, that when you turn the knob to control the volume of a radio, you are really adjusting a resistor. Some variable resistors are made so that a sliding contact, easily controlled by means of a knob, permits the changing of the resistance value between zero ohms and the maximum resistance incorporated in the resistor. Such units have but two terminals. One terminal is the end connection; the other is the sliding contact. When the slider is near the fixed terminal, the resistance is at a minimum, and as the slide moves away, the amount of resistance between the two terminals increases. These units are called rheostats and are usually made in low resistance values; from a few ohms minimum to several thousand ohms maximum. Figure 8 shows a typical rheostat.

Potentiometers are very similar to rheostats, but have three connecting terminals. Both end terminals are used and the arm connects to the third terminal. As the resistance between the arm and one of the fixed terminals is increased, the resistance between the arm and the other fixed terminal is decreased. These two sections of resistance always add up to the total resistance of the potentiometer.

Most potentiometers are mounted on the side of the chassis and require a single ½ or ⅜ inch hole. Several makes of potentiometers have an extra rib which requires a small hole beside the larger one. This protruding rib prevents the entire unit from revolving as the shaft is turned. The shafts of replacement potentiometers are supplied quite long and must be cut to size, but since they are made of soft metal, this is easily done with a hack-saw. Sometimes the shaft comes notched in sections, permitting breaking off the extra length with a pair of pliers. Some manufacturers make replacement potentiometers without shafts; separate shafts of all descriptions being available and quickly installed.

Potentiometers are often called volume controls, since they are used for this purpose in radio receivers. However, this is not a particularly good name, since potentiometers are also used in many other applications such as tone control circuits, oscilloscopes, test instruments, etc.

Some potentiometers are made with resistance wire in a manner similar to wire-wound resistors. Wire-wound potentiometers are used primarily where low value resistance units are needed and electrical power is handled by the circuit. A wire-wound potentiometer, with the dust cover removed, is shown in Figure 9.

The maximum values of wire-wound potentiometers are between several ohms and about 20,000 ohms. Potentiometers using a carbon deposit as the resistance element are used more commonly, and are obtainable in resistance values between 1000 ohms and 20 megohms.

In some potentiometers, the arm having the center terminal for its connection is grounded to the shaft and the metal framework of the unit, but in most cases, the elements of the potentiometer are entirely insulated from the metal framework.

An "on-off" switch is often mounted on the back of potentiometers, so that the first rotation of the shaft will operate this switch. Figure 10 shows a potentiometer with the switch mounted on it. In many cases the switches are installed on the potentiometer at the time of manufacture, and are a permanent part of the unit. In some cases, to install the switch, it is only necessary to remove the dust cover, as shown in Figure 9, and install the switch assembly in its place. There is no electrical connection between the switch and the resistance element of the potentiometer.

Connecting the Potentiometer

We have seen that a potentiometer has three terminals, the center terminal being connected to the movable arm. When a potentiometer is to be connected into a circuit, the manner in which the other two terminals are connected in the circuit is important. Let us assume that you are holding a potentiometer in your left hand with the shaft pointing directly at your face, and the connecting terminals at the bottom of the unit. This would appear as in Figure 11. Now turn the shaft all the way to the left; counter-clockwise. There is now almost no resistance between the terminal on the left and the center terminal; but between the right hand terminal and the center terminal there is a maximum resistance. Now as you rotate the shaft to the right, or clockwise, you increase the resistance between the left and the center terminals, and decrease the resistance between the right terminal and the center terminal.

Usually the output of any electronics equipment is increased as the control knob (on the shaft of the potentiometer) is turned to the right or clockwise. Consequently, the potentiometer must be connected so that the circuit will be changed to produce an increased output by a clockwise rotation of the slider. You will be able to apply this knowledge when you begin to study complete electronics circuits.

Let us now consider what resistance we will get between the left-hand terminal and the center terminal for different positions of rotating arm. If we start with the rotating arm in the extreme counter-clockwise position, we should have about zero resistance. Actually, in high-resistance potentiometers, this minimum resistance may be as much as several hundred ohms, but this is so small compared to the total resistance of the unit, that we may ignore it. Since we have not turned the shaft, we can call this position of the rotating arm 0% of the effective rotation from left to right.

If the potentiometer we are using for our example, is made up of **a uniform** deposit of resistance-carbon material, at the mid-point of the rotation (corresponding to 50% of the effective rotation) we would have one-half of the total resistance of the unit. We say, then, that this potentiometer has a "linear taper", which means that the resistance between the terminals we are considering varies linearly (directly) with the rotation. At 75% effective rotation, or three-quarters of the way around to the right, we would have three-quarters of the total resistance. Thus, if we are using a potentiometer having a total resistance of 1,000,000 ohms, we would have 750,000 ohms between these terminals.

For most control applications, non-linear taper types of potentiometers are needed. These potentiometers do not have equal resistance changes for equal changes of rotation. In some of these units, the first 50% of rotation brings only a very small change in resistance between a set of terminals, and the bulk of the resistance change occurs at the end of the rotation. In other units, a great deal of resistance change occurs as the rotation is started, but then the change becomes gradual. Figure 11 shows the tapers for a series of potentiometers made by the P. R. Mallory Company. Taper No. 1 has very little resistance change for the first half of the effective rotation, whereas, taper No. 2 has very little resistance change for the last half of the effective rotation. Taper No. 4 is a linear taper.

Servicing Potentiometers

Since potentiometers usually receive considerable mechanical wear in addition to the normal component electrical heating, they often wear out or become quite "noisy", and thus require replacing or reconditioning.

Of course, there is little that can be done to repair a potentiometer that has become worn out, since this usually means that the resistance element is worn through. It is possible to repair this breakage in a wire-wound control by soldering a small strip of copper or brass foil across the open section, but this procedure is not recommended except in a case of absolute necessity, since, the wearing through of any section indicates that the whole strip is probably badly worn and likely to break in other places. In cases of emergency, it is sometimes possible to patch up a carbon control, until a replacement can be obtained, by rubbing a piece of pencil lead on the worn spot. However, it is never possible to obtain the same taper and total resistance by this method, and the control should be replaced as soon as possible.

One of the most frequent symptoms of trouble in potentiometers, used as volume controls and tone controls in radios, is "noise". When a "noisy" control is turned, a crackling-scratching sound will be heard in the loudspeaker. The cause of the noise is usually an accumulation of oxidation on the wiper arm. To properly clean the control, a small amount of contact cleaner (available at electronics parts houses) should be applied by means of a small syringe (also available at electronics parts houses) and the control shaft should be rotated through its range several times.

The Measurement of Resistance

In the discussion of the multimeter in Assignment 11, we saw how it is possible to measure resistances with a fair degree of accuracy by properly connecting a milliammeter, a battery, and a resistor in series.

If we attempt to design an ohmmeter so that a wide range of resistance can be read, we find that the instrument will not be very accurate at the extreme low end or the extreme high end of the scale. The error on the extreme low end is due to the meter movement inaccuracy; the error on the high end of the scale is due to the crowding of the scale. For these reasons, ohmmeters are usually made with more than one range and in several main types. The principal types are: (1) The series ohmmeter, (2) the shunt ohmmeter, and (3) the combination series-shunt ohmmeter. In the series type, the resistance to be measured is connected in series with the meter and the battery; in the shunt type, it is connected in parallel with them; and in the combination type, the circuit is so arranged that it is connected as a series type for the high resistance ranges and as a shunt type for the low resistance ranges—thus using each type of circuit for the resistance range it is best suited to measure.

Figure 12 is the basic circuit of the series type ohmmeter which we studied in the last assignment. R is the zero-resistance current limiting resistor and is made variable, so that when the battery ages and its voltage drops, this resistance can be decreased in order to make the instrument read zero when the test leads are shorted. In many cases, this resistor is composed of a fixed and a variable resistor in series, for in this way, a fine adjustment is obtained with the variable resistor, inasmuch as a given movement of its shaft changes the resistance of the entire circuit by only a small percentage.

Another arrangement for the "zero-ohms" adjusting resistor (R) is shown in Figure 13. Here it is connected in series with a fixed resistor (N) of low resistance, and the two of them together are connected in parallel with the meter. A current limiting resistor (P) is connected in series with the meter and battery. In this case, when the battery ages, the value of R must be increased so that it shunts less current away from the meter, thereby, making it possible to bring the reading up to full-scale value when the test leads are touched together. This latter arangement is the one most frequently used in commercial instruments, since it provides a greater degree of accuracy, when several resistance ranges are used, than does the arrangement shown in Figure 12.

Let us suppose that the series ohmmeter of Figure 13 will accurately indicate resistances over the range of from 100 to 100,000 ohms. If we wished to use this same instrument to measure resistances over the range of from 1.0 to 1000 ohms, we could connect a shunt resistor (S) of the proper value to shunt the proper amount of current away from the meter circuit as shown in Figure 14.

With this arrangement, when a **small** unknown value of resistance is connected between the test leads, the meter deflection will be much less than in the circuit shown in Figure 13. (Remember that in the circuit shown in Figure 13, if a small resistance is connected between the test leads, the meter deflection will be nearly full scale). Thus, by choosing the correct value of S, it is possible to calibrate a scale for the meter which will accurately indicate small values of resistance. This circuit is an adaptation of the series type of ohmmeter, since the unknown value of resistance is connected in series with the battery and meter.

The Shunt-Type Ohmmeter

The basic circuit of the shunt-type ohmmeter is simply one containing two parallel resistors and having a constant applied voltage. One of these parallel resistors is the meter itself, which will measure the current in that branch. The other branch, which is the unknown resistor, carries the remainder of the full-scale current. Again, in this type of instrument, the meter scale can be calibrated in ohms of resistance rather than in current.

An examination of Figure 15 should help you understand the shunt ohmmeter. Suppose a milliammeter and a battery are connected in series with a current limiting resistor as in (A). Let the internal resistance of the meter be 50 ohms and the battery voltage 3 volts. If the meter has a full-scale reading of 1 ma. (0.001 ampere), then the resistance of the complete circuit must be 3,000 ohms, and the resistance of the variable current-limiting resistor is 2,950 ohms. $(R = \frac{E}{I} = \frac{3}{.001} = 3000\ \Omega.)$

The unknown value of resistance, R_X, is connected in parallel with the meter as shown in Figure 15(B).

Now, suppose that the meter is shunted by a resistor, R_X, of 50 ohms, as in (B) of Figure 15; then if R is 2950 ohms, the total circuit resistance becomes 2950 plus 25 (the equivalent of the 50 ohm resistor and the 50 ohm internal resistance of the meter in parallel), or 2975 ohms. The current flowing from the battery will be given by Ohm's Law, or $I = E/R = 3/2975$, or 0.001008 ampere, or 1.008 ma. This is very nearly the same current as before we added the 50 ohm resistor in parallel with the meter, but the important point is that now only **half** of this current is flowing through the meter, and the other half is flowing through the 50 ohm resistor. Consequently, since the meter will always read ½ ma. with a 50 ohm resistor connected between the test leads, we could mark the half-scale point on the scale "50 ohms".

If we replace the 50 ohm resistor at R_X by a 25 ohm resistor, the meter will only take ⅓ of the total series current and will, therefore, read 0.333 ma. This point on the scale could be marked "25 ohms".

If the external resistor, R_X, is made 75 ohms, the current through the meter would be 0.6 ma. and this point on the scale could be marked "75 ohms".

Figure 16 shows a diagram of the scale for this meter. Additional ohms readings have been added to make the scale complete. Examination of Figure 15 will show that when the test leads on this type of ohmmeter are shorted together, there will be a short circuited path directly around the meter, and therefore, no current will flow through the meter. Zero ohms on this meter will be on the **left** end of the scale, as shown in Figure 16.

If there is no resistor connected between the test leads, as in Figure 15(A), there will be one ma., or full scale current, through the meter. This is when the only resistance between the test leads is the resistance of the air. Thus, infinity on this ohmmeter is at the right end of the scale. Therefore, the scale on this type of meter has the **low** resistance values at the **left** and the **high** resistance values at the **right**. Compare this meter scale to the scale for the series type ohmmeter in Assignment 11. Notice that this shunt-type ohmmeter will read lower values of resistance, and also, that its scale increases from left to right, which is opposite to the series type of ohmmeter scale.

If Figure 15 is examined, it will be noticed that the meter in the shunt type of ohmmeter is always in series with the battery, whether or not an unknown resistance is being measured. Consequently, we would always have a drain on the battery. To avoid this, this type of ohmmeter should have a switch in series with the meter and the battery, and this switch should be opened when the instrument is not in use.

A number of commercial multimeters use an arrangement whereby a series type ohmmeter is used for high resistance measurements, and a shunt type for low resistance measurements.

The Wheatstone Bridge

The ohmmeters we have described provide a quick, easy method of checking resistors, but it is exceedingly difficult to design and build an ohmmeter which will have a consistent accuracy of 5% or better. Consequently, laboratory technicians and engineers, who wish to measure resistances with a high degree of accuracy, resort to a circuit known as the Wheatstone bridge. Fundamentally, the Wheatstone bridge is a method by which an unknown resistor is compared to a known resistor, and in its simplest form, is shown in Figure 17. The meter of Figure 17 is known as a galvanometer. A galvanometer is nothing more than a very sensitive milliammeter with the pointer so arranged that it indicates in the center of the scale when there is no current through the instrument; it reads to the left when a current passes through the instrument in one direction; and it reads to the right when a current passes through the instrument in the other direction.

Three known resistances (R_1, R_2, R_3), and the unknown resistance (R_X) are connected in the form of a diamond, with a battery connected across the opposite corners of the diamond and a galvanometer connected between the remaining corners. Each resistor is known as an "arm" of the bridge.

To make a measurement, the two "ratio arms", R_1 and R_2, are set at some fixed ratio, usually 1 : 1, 10 : 1, 100 : 1 or 1000 : 1, and allowed to remain that way. The arm, R_3, is adjustable and is ordinarily calibrated directly in ohms. Rx is the unknown resistor to be measured. If we examine Figure 17 carefully, we see that as far as the battery is concerned, the circuit is nothing more than two groups of resistors in parallel, and so if we follow the current from the negative side of the battery through the circuit and back to the positive side, we see that as the current reaches point **A**, it will branch out or split up. Some current will flow through the R_2R_1 branch, and the rest of the current will flow through the R_3Rx branch. These two currents will unite again at the point **C**, and flow back to the battery together.

In order to get a clear picture of how the Wheatstone bridge circuit works, let us draw an analogy from the stream of water shown in Figure 18. We will let **ABC** and **ADC** be the branches of a stream flowing around an island, Is. Further, let us imagine that, beginning at the point **D**, a ditch, **G**, is dug across the island. Evidently, if this ditch is joined to the upper branch of the stream at the proper point, there would be no tendency for water to flow in it in either direction. Let us see why this is so. If the end of the ditch marked **B** is connected too far upstream, water would flow in the ditch in the direction **B** to **D**. If, on the other hand, we were to connect it too far downstream, water would flow in it in the direction from **D** to **B**. There must be, therefore, some point across which we can dig the ditch, so that this point would be neither too far upstream nor downstream, and there would be no flow of water in the ditch in either direction. We all know that water flows from a higher to a lower level, so if we dig the ditch in such a way that both points **D** and **B** are on the same level, no water will flow through it.

This is exactly what happens to the electron current in the Wheatstone bridge. Looking again at Figure 17, let us concern ourself with the adjustable resistor R_3. This arm of the bridge is adjusted until, at some point, there will be no current flowing through the galvanometer. At any other point, the galvanometer will indicate a flow of current in one direction or the other. When there is no current flow in either direction through the galvanometer, we can say that each end of the galvanometer is at the same level of voltage or at the same potential, and at this point, the bridge is said to be "balanced" and the galvanometer is at the "null" point.

If we had chosen R_1 and R_2 to have exactly the same values, then we could immediately tell the value of the unknown resistor by adjusting the bridge for a balance and reading the scale giving the value of R_3. This is so, because when R_1 equals R_2, R_X equals R_3. However, most of the time the values of R_1 and R_2 are not the same, and R_X would therefore, not equal R_3 when the bridge is balanced. In such cases, the ratio of R_1 to R_2 will be the same as the ratio of R_X to R_3. This can be expressed in the formula:

$$\frac{R_1}{R_2} = \frac{R_X}{R_3} \text{ or } R_X = \frac{R_1 \times R_3}{R_2}$$

To illustrate the use of a Wheatstone bridge, let us assume that R_1 is 10,000 ohms, R_2 is 100,000 ohms, and when the bridge is **balanced** (when R_3 is adjusted for a zero reading on the galvanometer), R_3 reads 3376.2 ohms. We wish to know the value of the unknown resistance R_X.

Substituting the known values in the formula, we have:

$$R_X = \frac{R_1 \times R_3}{R_2}$$

$$R_X = \frac{10{,}000 \times 3376.2}{100{,}000}$$

$$R_X = \frac{1 \times 3376.2}{10}$$

$$R_X = 337.62 \text{ ohms.}$$

As another example, let us assume that R_1 is 1,000 ohms, R_2 is 100,000 ohms, R_3 is 734.3 ohms when the bridge is balanced. We wish to know the value of the unknown resistance R_X. Substituting the known values in the formula, and solving, we find $R_X = 7.343$ ohms.

$$R_X = \frac{R_1 \times R_3}{R_2}$$

$$R_X = \frac{1{,}000 \times 734.3}{100{,}000}$$

$$R_X = \frac{1 \times 734.3}{100}$$

$$R_X = 7.343 \text{ ohms.}$$

Figure 19 is a photograph of a good commercial Wheatstone bridge. This Wheatstone bridge, with its self-contained galvanometer and battery, can be used to read resistances from 0.001 to 1,000,000 ohms with an accuracy of ½%.

In this assignment, we have learned a great deal about conductors and resistors. Resistors are perhaps the most numerous of all the components in electronics equipment, and resistance is one of the three main properties of any electrical or electronic circuit. For these reasons therefore, this subject will be encountered time and time again in all of our future work. Consequently, you should study this assignment until you are familiar with it, and then review it as often as necessary.

Test Questions

Use the enclosed answer sheet for your answers to this assignment.

The questions on this test are of the multiple-choice type. In each case four answers will be given, one of which is the correct answer. To indicate your choice of the correct answer, **mark out** the letter opposite the question number on the answer sheet which corresponds to the correct answer. For example, if you feel that the answer (A) is correct for Question No. 1, indicate your preference on the answer sheet as follows:

1. (X) (B) (C) (D)

Submit your answers to this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. The bands on a carbon resistor are painted Red—Green—Yellow—Silver, in that order. Its ohmic resistance and tolerance is:

   (A) 25,000 ohms, 5%
   (B) 25,000 ohms, 10%
   (C) 250,000 ohms, 5%
   (D) 250,000 ohms, 10%

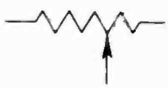
2. The bands on a carbon resistor are painted Yellow—Violet—Orange—Gold, in that order. Its ohmic resistance and tolerance is:

   (A) 47,000 ohms, 5%
   (B) 47,000 ohms, 10%
   (C) 470,000 ohms, 5%
   (D) 470,000 ohms, 10%

3. The body of a carbon resistor is Green, the end of the resistor is Black, and the dot on the resistor is Red. Its ohmic resistance is:

   (A) 100 ohms
   (B) 1,000 ohms
   (C) 2,000 ohms
   (D) 5,000 ohms

4. The symbol for a variable resistor is:

   (A) 
   (B) 
   (C) 
   (D) 

5. A No. 8 wire is:

   (A) Larger than a No. 18 wire
   (B) Smaller than a No. 28 wire
   (C) Twice as large as a No. 16 wire
   (D) Half as large as a No. 20 wire

6. Copper is:

   (A) A poorer conductor than aluminum
   (B) A better conductor than aluminum
   (C) Equal in conduction to aluminum
   (D) A good insulator

7. A spool of wire is marked: No. 22 S.C.C. The S.C.C. means:

(A) Silk and Cotton Covered
(B) Silk and double Cotton Covered
(C) Single Cotton Covered
(D) Silk Covered with Cotton

8. The best wire (of these listed) with which to make ordinary connections between components in a piece of electronic equipment is:

(A) Shielded wire
(B) Rubber insulated wire
(C) Enameled wire
(D) Plastic coated wire

9. Wire A has a diameter of 1 mil and Wire B has a diameter of 2 mils.

Both are copper. The resistance of a 10-foot length of Wire B is:

(A) Greater than the resistance of a 10-foot length of Wire A.
(B) Greater than the resistance of a 15-foot length of Wire A.
(C) The same as the resistance of a 10-foot length of Wire A.
(D) Less than the resistance of a 10-foot length of Wire A.

10. If 500 feet of wire has 2 ohms resistance, what will be the resistance of 250 feet of this same wire?

(A) 1 ohm
(B) 2 ohms
(C) 4 ohms
(D) 250 ohms

EARLY CARBON COMPOSITION RESISTOR

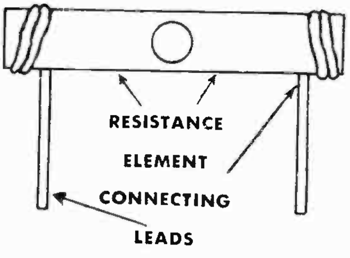


Figure 1

MODERN CARBON COMPOSITION RESISTOR

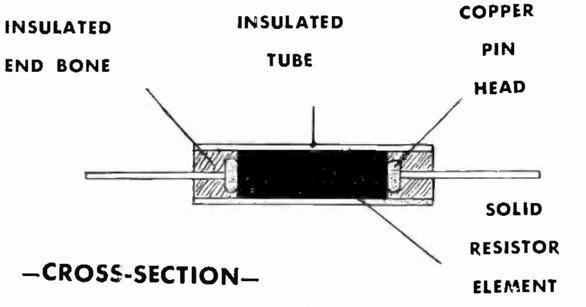


Figure 2

MODERN COLOR CODING

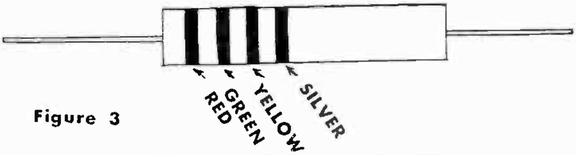


Figure 3

0 BLACK	5 GREEN
1 BROWN	6 BLUE
2 RED	7 VIOLET
3 ORANGE	8 GRAY
4 YELLOW	9 WHITE
Silver as Third Band	.01
Gold as Third Band	.1
Silver as Fourth Band	10%
Gold as Fourth Band	5%

OLDER METHOD OF COLOR CODING

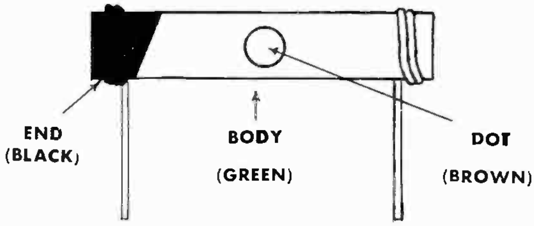


Figure 4

FIXED

COMPOSITION

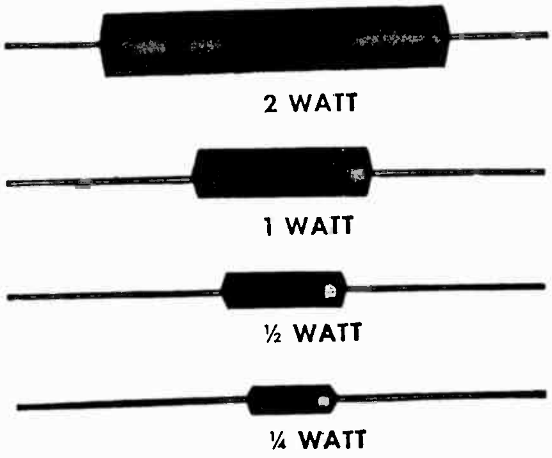


Figure 5

FIXED

WIREWOUND

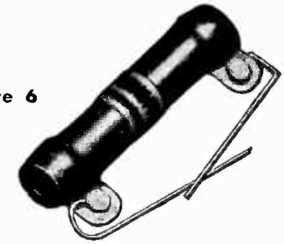


Figure 6

WIRE WOUND SEMI-VARIABLE

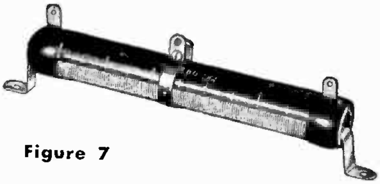


Figure 7

RHEOSTAT

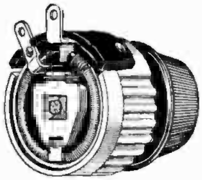


Figure 8

WIRE WOUND

POTENTIOMETER

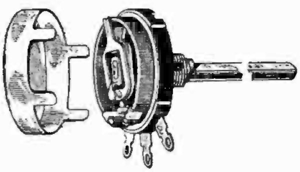


Figure 9

POTENTIOMETER

WITH SWITCH

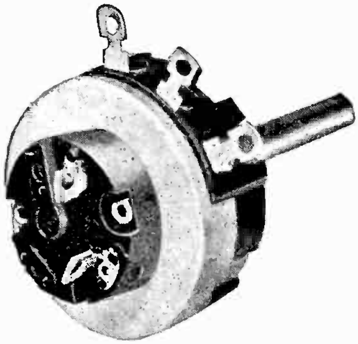


Figure 10

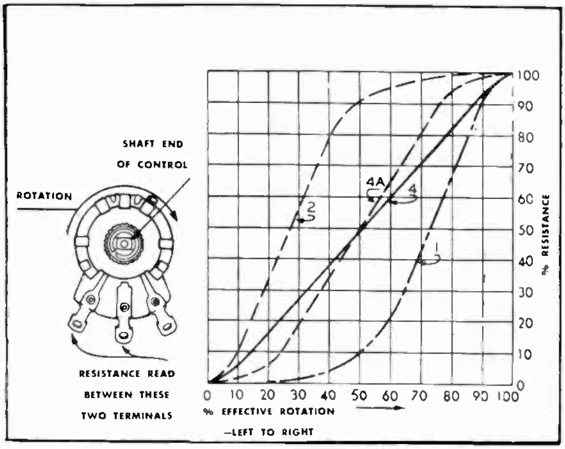


Figure 11

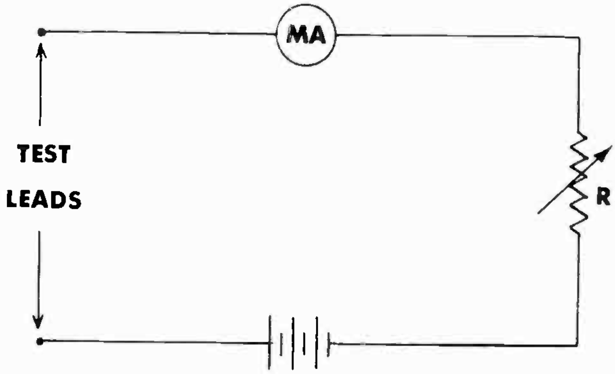


Figure 12

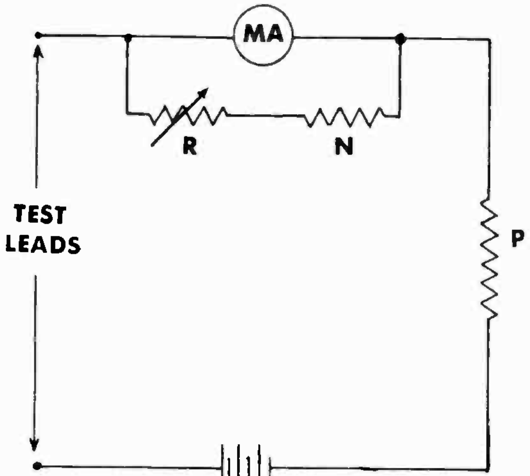


Figure 13

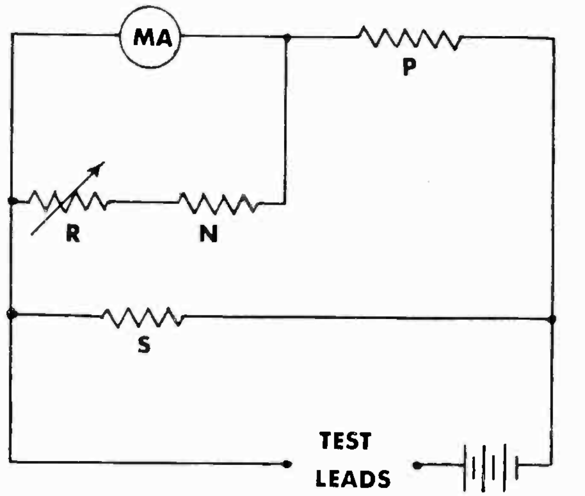


Figure 14

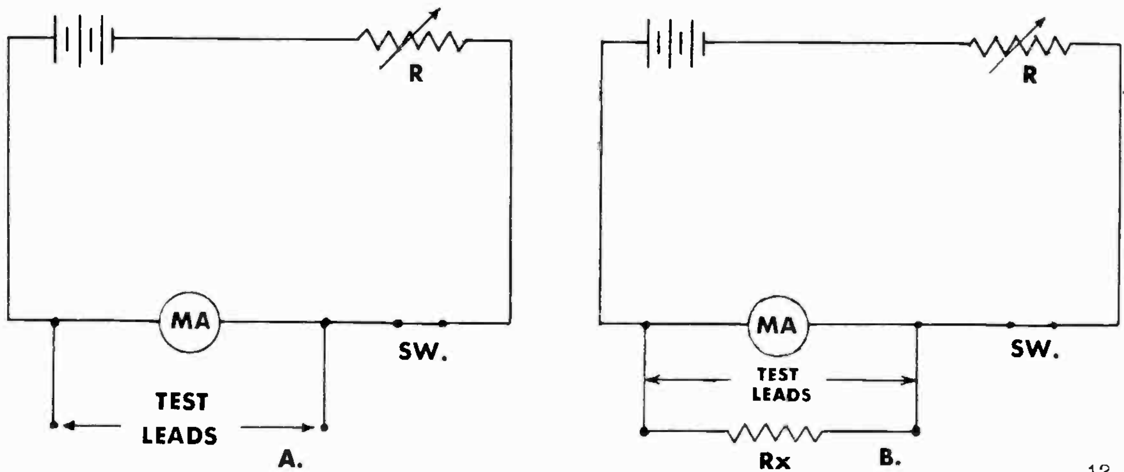


Figure 15

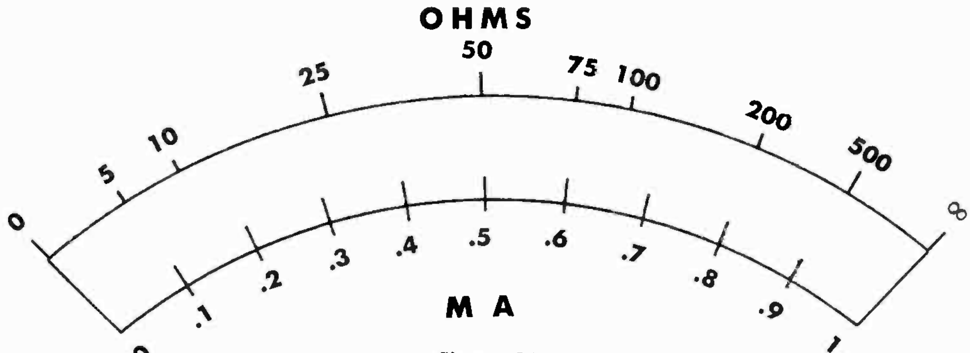


Figure 16

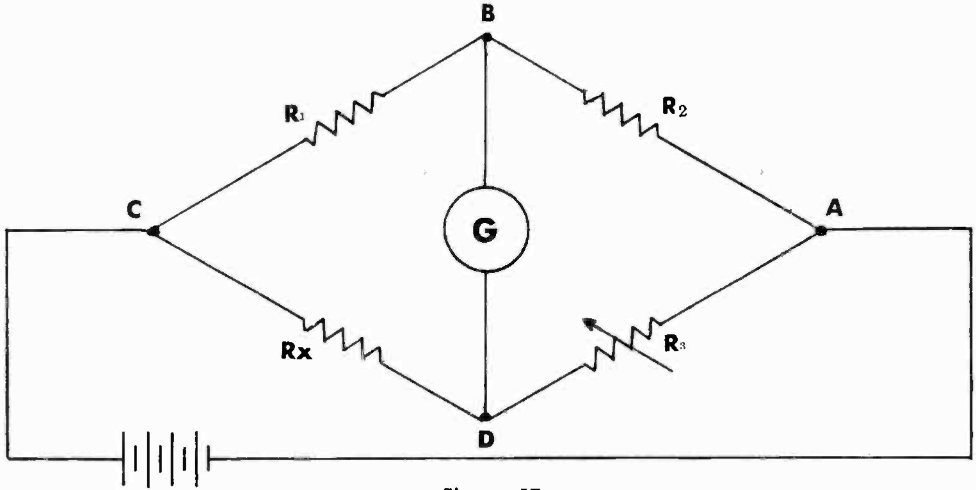


Figure 17

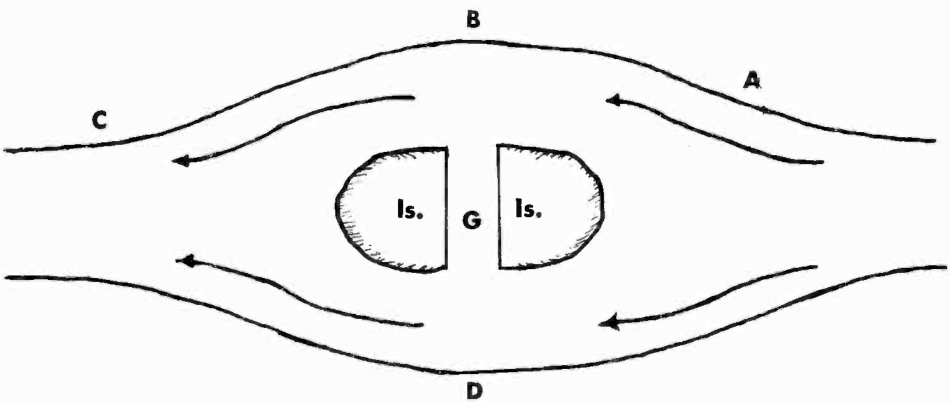


Figure 18

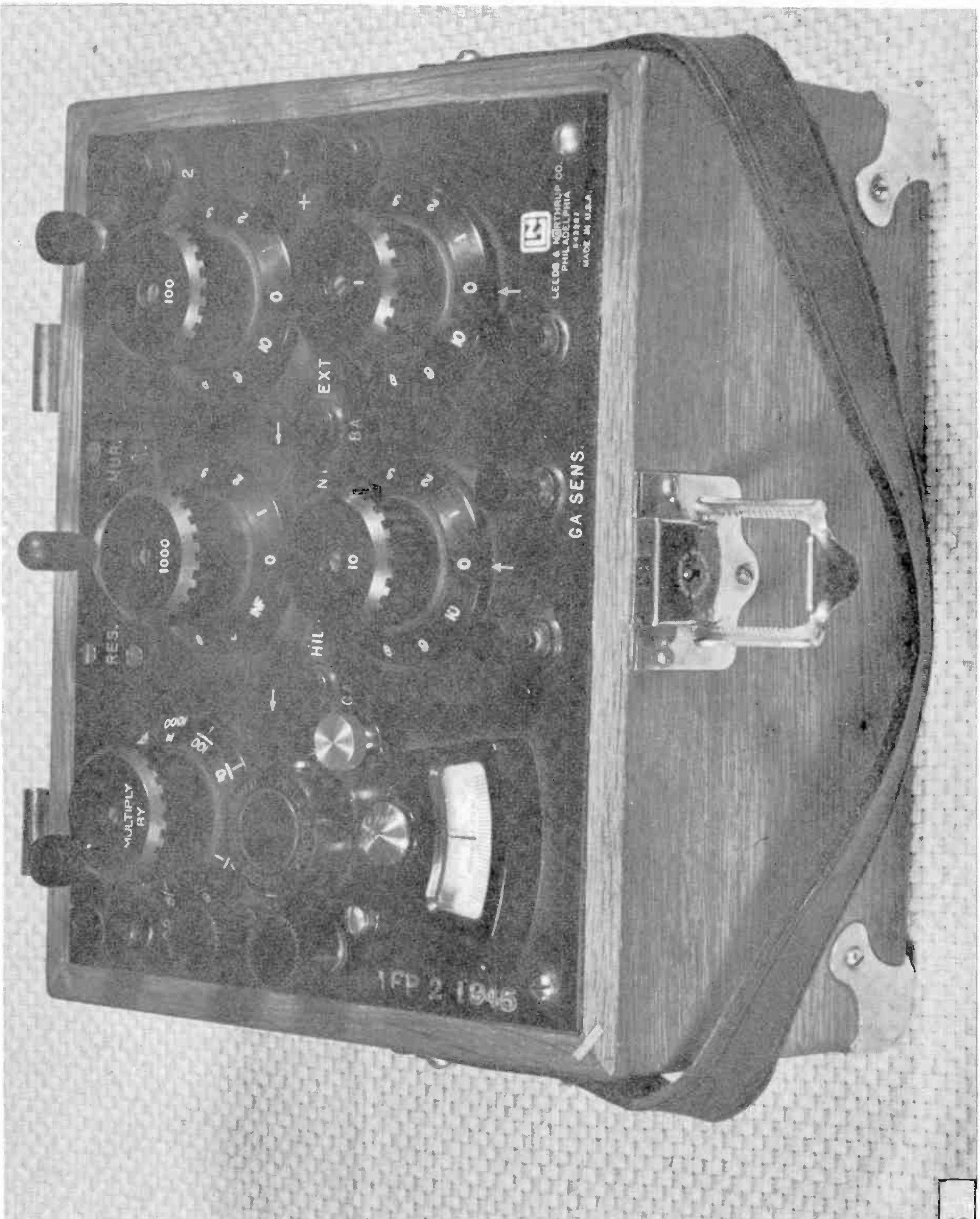

MULTIPLY BY
RES.
EXT
GA SENS.
LEEDS & NORTHRUP CO.
PHILADELPHIA
MADE IN U.S.A.

Figure 19