HOW RESISTORS ARE USED

5B

RADIO-TELEVISION-ELECTRONICS

PIONEER HOME STUDY RADIO-TV SCHOOL

NRI

NATIONAL RADIO INSTITUTE

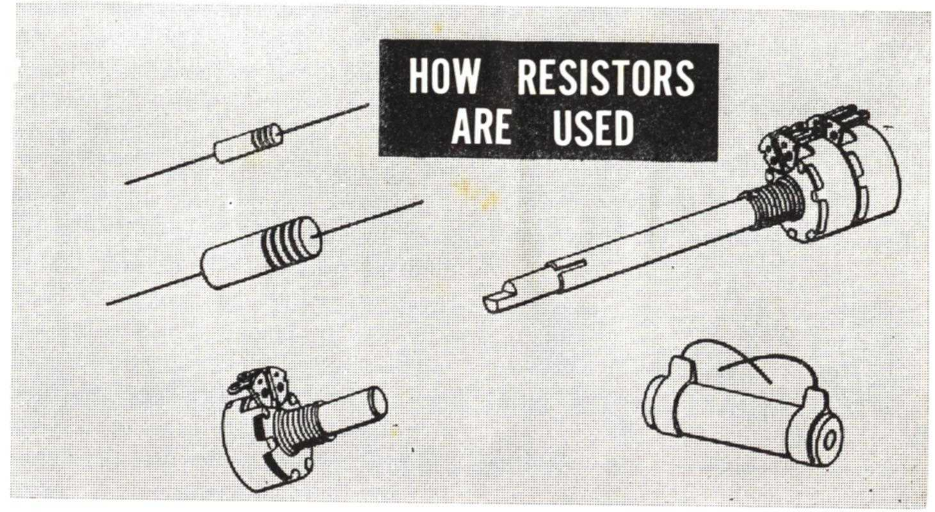
WASHINGTON, D. C.

ESTABLISHED 1914

STUDY SCHEDULE NO. 5

JD10M1157

Printed in U. S. A.



THIS is the first of three of the most important books in your NRI course. In this lesson you will study resistors, in the next lesson you will study coils, and in the following lesson you will study capacitors. Tubes, transistors, and these three parts, resistors, coils, and capacitors, are the most important components of electronic equipment.

It is important for you to study these parts, not only because they themselves are used in almost all electronic equipment, but also because understanding how these parts work will help you to understand how other parts work. For example, a transformer is nothing more than a group of coils wound on an iron core. If you understand how a single coil works, then you will be much better prepared to understand how several of them work when used together to make up a transformer.

You will learn how these parts work in both ac and dc circuits. Resistors act in essentially the same way in both dc and low-frequency ac circuits. A 1000-ohm carbon resistor will have a resistance of 1000 ohms when used in a dc circuit and when used in an ac circuit. However, this is not true at very high frequencies, nor is it true of coils or capacitors. In the next two books you will find that their operation in ac circuits is very different from their operation in dc circuits. In this group of books, in addition to presenting facts about these three parts, we will go into more detail about ac and how it acts in circuits in which coils and capacitors are found.

WHY RESISTORS ARE IMPORTANT

Resistors are found in practically every piece of electronic equipment. As a technician you will have to replace many resistors. Sometimes you will be able to refer to the schematic diagram of the equipment, find the value of the resistor, and simply go ahead and install a new one in the circuit. However, sometimes you may work on equipment for which there is no diagram available, and the original resistor may have been burned so badly you will not be able to tell what its value was. Then, you will fall back on your knowledge of electronic circuits to decide what size resistor to use. What you will learn in this lesson will prepare you for this type of work.

Uses of Resistors. There are many

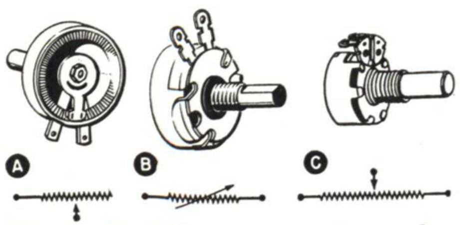


FIG. 1. Variable resistors and the schematic symbols for them. A and B are rheostats, and C is a potentiometer.

uses for resistors in electronic equipment.

Resistors are used to drop the voltage from a high value to a lower value to provide the correct operating voltage for a tube or some other part.

Resistors are used to isolate parts from each other, so that one will not interfere with the action or operation of the other.

Resistors are used as the load in vacuum tube circuits. For example, you will frequently find a resistor connected between the plate of a tube and B+. When a resistor is used like this it is called the *plate load.* You will learn more about this when you study tubes.

TYPES OF RESISTORS

There are many different kinds of resistors, but they can be divided into two general types, carbon and wire-wound. Carbon resistors are far more numerous than wire-wound resistors because they are cheaper. In most cases the current that flows in electronic circuits is extremely small, and carbon resistors are suitable for use in circuits when the current is low. However, in circuits where the current flowing is high, wire-wound resistors are almost always used.

Resistors can also be divided into fixed resistors and variable resistors. A fixed resistor is a resistor whose resistance cannot be changed; a variable resistor is one whose resistance can be changed. There are two types of variable resistors, one type is called a "rheostat." This type of resistor has two terminals, and the resistance between those two terminals is varied by rotating the control shaft. Another type is a potentiometer. This type of resistor has a fixed resistance between two terminals and a sliding contact that can be moved across the resistance so that the resistance between the center terminal of the resistor and the outside terminals varies as the shaft

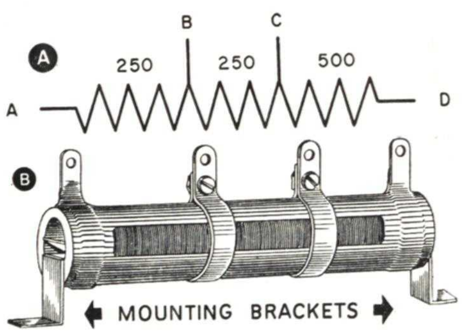


FIG. 2. A tapped resistor and its schematic symbol.

is rotated. Fig. 1 shows some variable resistors and the schematic symbols used to represent them. A and B are rheostats, and C is a potentiometer.

Another type of resistor is the tapped resistor. This type of resistor has a number of "taps" or connections. Different resistances can be connected into the circuit by using the different taps. A schematic of a tapped resistor is shown in Fig. 2A. Notice that the total resistance of the resistor is 1000 ohms, but between terminals A and B the resistance is 250 ohms, between terminals B and C the resistance is 250 ohms, and between terminals C and D the resistance is 500 ohms. A typical tapped resistor is shown in Fig. 2B.

Although these resistors may seem quite different in appearance, the way in which they affect the current flowing in a circuit is the same. In the following sections of this lesson, remember that the explanations given cover all types of resistors.

Resistance in Series and Parallel Circuits

You have already seen examples of both series and parallel circuits. Both types of circuits are important. Any circuit can be broken down into series circuits, parallel circuits, or a combination of the two. Understanding both series and parallel circuits is extremely important.

In a series circuit there is only one path through which current can flow. The current is the same at all points in a series circuit. In a parallel circuit there is more than one path through which the current can flow and the total current flowing in the circuit is the sum of the currents flowing in the individual branches.

You know that in a series circuit if the voltage remains constant but the resistance changes, the current must change. In the series circuit shown in Fig. 3, if the circuit is opened and a second resistor is added in series with R1, there must be a change in the current flowing in the circuit. If instead of opening the circuit, we connected a second resistor in parallel with R1, there would also be a change in the current flowing in the circuit.

In each of the two examples just mentioned, the current changed because the total resistance of the circuit changed. Often it is important to know the total resistance in a series or a parallel circuit. In this section

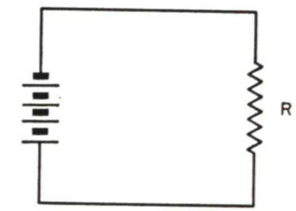


FIG. 3. A simple circuit consisting of a voltage source and a resistor.

of the lesson we will show you how to find the total resistance in both types of circuits.

SERIES CIRCUITS

The circuit shown in Fig. 3 is a series circuit because there is only one path through which current can flow. All current must flow through the battery, R1, and the leads connecting R1 to the battery. There is no other path through which current can flow; therefore, this circuit is a series circuit.

The current that will flow in this circuit will depend upon the battery voltage, the resistance of R1, and the resistance of the wires connecting R1 to the battery. The current will also be affected by the resistance of the battery itself. In other words, the

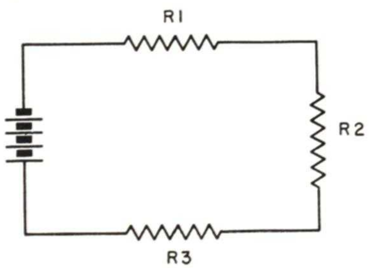


FIG. 4. A series circuit consisting of a voltage source and three resistors.

current will be affected by the total resistance in the circuit.

A series circuit made up of a voltage source and three series resistors is shown in Fig. 4. Here again, the total current flowing in the circuit will depend upon the battery voltage, the resistance of the wires connecting the three resistors together and to the battery, and also upon the resistance of R1, R2, and R3. Increasing the resistance of any one of these resistors will reduce the total current flowing in the circuit; conversely, decreasing the resistance of any one of these will increase the total current.

From this you can see that the three resistors, R1, R2, and R3, actually act like one resistor having a resistance equal to the sum of the three resistances. Thus, in a series circuit we can say that the total resistance in the circuit is equal to the sum of the resistance of the individual resistors.

Electronic technicians usually express this by means of symbols. Using R_T to represent the total resistance, this expression is written as:

$$R_T = R1 + R2 + R3$$

To find the total resistance in a series circuit, all you need to do is add together the resistance of the individual resistors. If in Fig. 4 each of the resistors is a 100-ohm resistor, the total resistance in the circuit will be 300 ohms. If, on the other hand, R1 equals 100 ohms, R2 equals 600 ohms, and R3 equals 150 ohms, the total resistance in the circuit will be 100 + 600 + 150 = 850 ohms.

A practical example of a series circuit that might be found in a piece of electronic equipment is shown in Fig. 5. Here we have shown three resistors

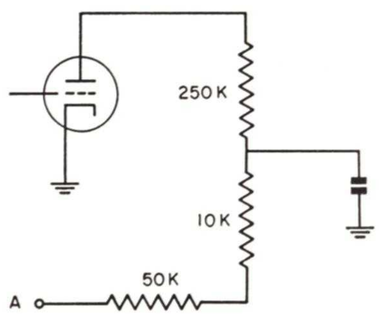


FIG. 5. A series circuit is often found in the plate circuit of a vacuum tube. Notice that the heater is omitted from the drawing. This is often done to simplify the drawing.

in the plate circuit of a vacuum tube. In servicing the equipment in which this circuit is used you might want to check the resistance between the plate of the tube and point A on the diagram. Perhaps this tube was not operating properly and you suspected that one of the resistors might be defective. It might be completely open so that no current flows through it, or the resistance of one of the resistors might change appreciably. Both defects are frequent in carbon resistors.

Before you can check the resistance of the plate circuit, you must know

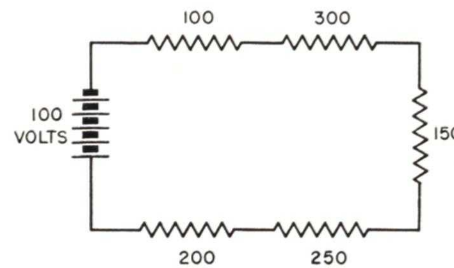


FIG. 6. To find the total resistance in this series circuit, add the individual resistances, R_T=100+300+150+250+200 =1000 ohms.

what it should be. From the diagram you can see the resistance of the individual resistors. The symbol K is used on diagrams to represent 1000. Thus the resistor marked 250K is a 250,000-ohm resistor. To find what the total resistance in the circuit should be, you simply add the values of the three resistors together. Therefore, the resistance between the plate of the tube and point A should be:

$$250K + 10K + 50K = 310K$$

which is 310,000 ohms. Once you have determined what this resistance should be, you can then use an ohmmeter to check the actual resistance in the circuit. If the resistance was only 60K ohms, you would know that the 250K-ohm resistor was shorted out of the circuit, or its value had dropped to zero.

Another example of a series circuit is shown in Fig. 6. Suppose you wished to determine the current flowing in this series circuit. You know that you can use Ohm's Law to find the current if you know the voltage and the resistance. The voltage is given on the diagram as well as the resistance of the individual resistors. To find the current you must first add the resistance of the individual resistors to get the total resistance. In this circuit the total resistance will be 1000 ohms. The current can be found from:

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

which in this case is:

$$I = \frac{100}{1000} = \frac{1}{10} \text{ amp}$$

The current flowing in the circuit shown in Fig. 6 will therefore be $\frac{1}{10}$ of an amp. This can also be written .1 amp, and it can also be expressed in milliamperes. Remember that there are 1000 milliamperes in an ampere, and therefore in $\frac{1}{10}$ of an ampere there will be 100 milliamperes. Another way of converting amperes to milliamperes is to move the decimal point three places to the right. Technicians would usually say the current is 100 milliamperes.

One question that you should consider is what will happen to the current flowing in a series circuit if one of the resistors is shorted out of the circuit. If one of the resistors is shorted out of the circuit, the total resistance in the circuit will be smaller, and the current will increase. On the other hand, if another resistor is added in the series circuit, the total resistance will increase, and the current will decrease.

Short Cuts. Another series circuit is shown in Fig. 7. Notice that in this circuit there are a total of 5 resistors. Two of the resistors are very large, R1 has a resistance of 1 megohm, which is one million ohms, and

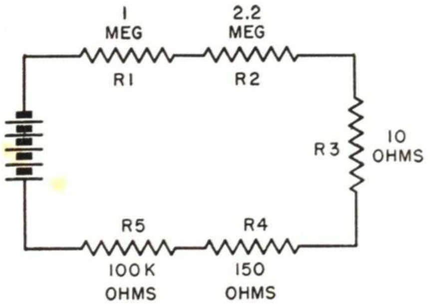


FIG. 7. In this series circuit, R3 and R4 are so much smaller than the other resistors, that they can be ignored when figuring the total resistance.

R2 has a resistance of 2.2 megohms, which is 2,200,000 ohms. Now look at R3; R3 has a resistance of only 10 ohms. Obviously in a series circuit where the resistance of R1 + R2 will be 3.2 megohms, or over 3,000,000 ohms, the 10-ohm resistor is so small that it will have no effect on the circuit at all. Therefore, in figuring the total resistance of the circuit, we can ignore R3 completely. Similarly since R4 is only 150 ohms, we can ignore it. R5, which has a resistance of 100,000 ohms should be considered if you are interested in considerable accuracy, because it is large enough to affect the total resistance of the circuit. The technician calculating the resistance of this series circuit would simply add R1, R2, and R5 to get a total resistance of 3.3 megohms, or 3,300,000 ohms. In most electronic circuits any resistor that has a resistance that is less than 10% of the resistance of the largest resistor can be ignored because its effect on the total current flowing in the circuit will be small. In this case it would include only R1 + R2, which will give you a resistance of 3.2 megohms. This is usually abbreviated 3.2 megs.

PARALLEL CIRCUITS

Finding the total resistance in a circuit consisting of two or more resistors in parallel is not as easy as finding the total resistance of a number of resistors connected in series. However, it certainly is not a difficult problem either; it should not give the average technician any serious trouble.

To see what happens in a parallel circuit, let us go back to the simplest possible circuit consisting of a single voltage source and a single resistor connected across it, as shown in Fig. 8. Here we have a 10-volt battery and a 10-ohm resistor. Notice the symbol we have used to represent ohms. This is the Greek letter "omega."

Ohm's Law tells us that the current that will flow in this circuit can be found from the formula:

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

which in this case, is:

$$I = \frac{10}{10} = 1 \text{ amp}$$

Now let us stop and consider for a minute what we must do in order to get more current to flow while at the same time the battery voltage remains constant at 10 volts. If the battery voltage remains constant, the only way we can get more current to flow

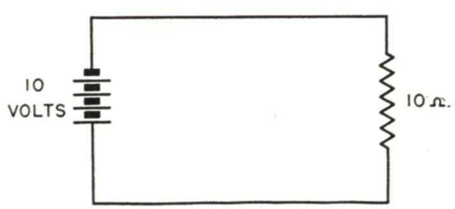


FIG. 8. A simple circuit with one resistor across a voltage source.

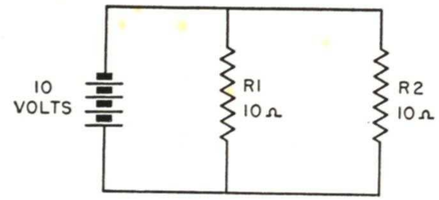


FIG. 9. When a second resistor is added in parallel with R1, the total current flowing in the circuit increases, hence the total resistance must decrease.

in this circuit is to reduce the resistance. Thus, if we make the 10-ohm resistor smaller, the current will increase. Conversely, if we make the 10-ohm resistor larger, the current will decrease. The way in which we can reduce the resistance is to put another resistor in parallel with the 10-ohm one already in the circuit. At first glance, it may not seem logical that putting in another resistor will reduce the resistance. However, the reason it does, is that the second resistor provides a second path through which current can flow.

Let's take an example to demonstrate this. In the circuit shown in Fig. 9, we have a 10-volt battery with two 10-ohm resistors connected in parallel across it. We can find the current flowing through each resistor by using Ohm's law, which says:

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

The battery voltage is 10 volts, and the resistance of each resistor is 10 ohms, so we divide 10 by 10 to find the current through each resistor. This tells us that the current that will flow through each resistor will be 1 ampere. If 1 amp flows through R1 and 1 amp flows through R2, the total current flowing in the circuit must be 2 amps. In other words, by connecting a second 10-ohm resistor across the original 10-ohm resistor shown in Fig. 8, we can increase the current flowing in the circuit. Remember what we said, that in order to increase the current flowing in a circuit without increasing the voltage, we had to reduce the resistance in the circuit. Therefore, connecting the second 10-ohm resistor in parallel with the first 10-ohm resistor must have reduced the total resistance in the circuit. This leads us to an important rule, *whenever two resistors are connected in parallel, the total resistance of the combination is always less than the resistance of the smaller resistor.*

If you have a 10-ohm resistor connected in parallel with another 10-ohm resistor, the resistance of the combination will be less than 10 ohms. If you have a 1-ohm resistor connected in parallel with a 100-ohm resistor, the resistance of the combination will be less than 1 ohm. Similarly if you have a combination of three resistors, a 5-ohm resistor, a 10-ohm resistor, and a 100-ohm resistor, the resistance of the parallel combination will be less than that of the smallest resistor, which in this case, is less than 5 ohms.

Now let us go back to the example shown in Fig. 9 to find out exactly what the resistance of the parallel combination is. We know that a current of 1 amp will flow through each branch of the parallel circuit. R1 is one branch of the circuit, and R2 is the other branch. Since 1 amp will flow through R1 and 1 amp through R2, the total current flowing will be 2 amps. Now we can use Ohm's Law in another form to find out what the resistance of the parallel combination is. We know that:

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

In this case E is 10 volts, and I is the total current flowing, which is 2 amps. Therefore:

$$R = \frac{10}{2} = 5 \text{ ohms}$$

Notice that in this case we connected two 10-ohm resistors in parallel, and found that the resistance of the combination was 5 ohms. This means that putting two equal resistors in parallel gave a total resistance equal to half the value of each resistor. This is always true when two resistors of equal value are connected in parallel. If you connect two 10,000-ohm resistors in parallel, the resistance of the combination will be 5000 ohms. If you connect two 1-megohm resistors in parallel, the resistance of the combination will be .5 megohm; .5 megohm is another way of writing one-half megohm. It can also be written 500K ohms, since a megohm is a million ohms. K means a thousand, so 500K means 500,000 or half of one million.

This system can always be used to find the resistance of any parallel combination when you know the voltage across the resistors. However, frequently you will be interested in finding the resistance of resistors connected in parallel when you do not know the exact voltage across them. In that case, you will have to use a different scheme to find the total resistance in the circuit.

The total resistance of two resistors in parallel can be calculated from a simple formula. This formula is particularly useful when the voltage across the resistors is unknown. The only two values you need to know in order to determine the total resistance is the resistance of the two resistors themselves. The formula is:

$$R_T = \frac{R1 \times R2}{R1 + R2}$$

Now let us see how this works by using this formula to calculate the resistance of R1 and R2 in parallel in Fig. 9. You have already calculated the resistance and found it to be 5 ohms; now let us see if we get the same answer by using this formula. Substituting in the formula we get:

$$R_T = \frac{10 \times 10}{10 + 10}$$

10×10 is equal to 100, and $10 + 10$ is equal to 20. Therefore:

$$R_T = \frac{10 \times 10}{10 + 10} = \frac{100}{20}$$

Dividing 100 by 20 gives us 5, so the total resistance in the circuit is 5 ohms. This agrees with our other answer.

You might try this formula using two equal resistors of some other value. You will find that you always end up with a total resistance equal to one half the value of the two individual resistors. This will give you a good chance to check yourself using this formula if you wish to do so, and at the same time help you remember the fact that when two equal resistors are connected in parallel, the total resistance will be equal to half the resistance of the individual resistors.

Now let us try this on two resistors whose values are not equal, and see if the total resistance is less than that of

the smaller resistor. Let's take as an example an 80-ohm resistor connected in parallel with a 20-ohm resistor. The total resistance will be:

$$R_T = \frac{80 \times 20}{80 + 20} = \frac{1600}{100} = 16 \text{ ohms}$$

Notice that the resistance of the parallel combination is less than 20 ohms, in other words less than the resistance of the smaller resistor.

Sometimes there are more than two resistors connected in parallel. If they are all of equal value, you can find the combined resistance simply by dividing the resistance of one by the number of resistors in parallel. For example, three equal resistors in parallel will have a combined resistance equal to one-third of the resistance of one of them; four equal resistors in parallel will have a combined resistance equal to one-quarter of the resistance of one of them.

If there are more than two resistors in parallel, and they are not of equal value, the easiest way to find the resistance of the combination is usually to work the problem by grouping the resistors in pairs.

As an example, look at Fig. 10A. Here we have three resistors in parallel. Find the resistance of the three in parallel by first finding the resistance of R1 and R2 in parallel. Once you have found this value, you then have a circuit like the one shown in Fig. 10B. Here you treat the combination of R1 and R2 in parallel as a single resistor R and find the value of this resistor in parallel with R3. This simply means using the equation or formula for two resistors in parallel twice. For example, suppose R1 and R2 are both 10-ohm resistors, and R3 is a 5-ohm resistor. You can find the value of R1 and R2 in parallel from the formula, and you will find that the resistance is equal to 5 ohms. Now you have a problem of a 5-ohm resistor in parallel with another 5-ohm resistor and again you apply the formula for two resistors in parallel, and you will find that the resistance of the combination is 2.5 ohms. Thus you have found the resistance of a combination of two 10-ohm resistors and a 5-ohm resistor in parallel.

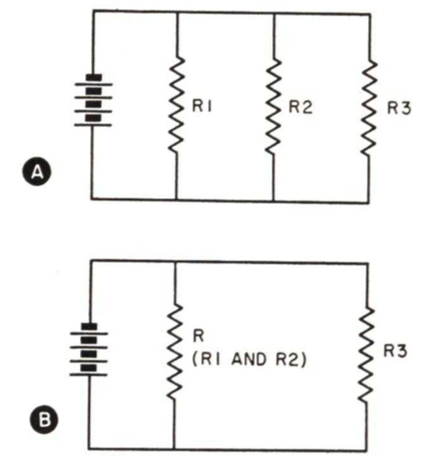


FIG. 10. To find the total resistance of three resistors in parallel, you first find the combined resistance of two of them, then combine that with the third resistance.

If there were four resistors in this circuit, you would find the combined resistance of R1 and R2 in parallel, and also the combined resistance of R3 and R4 in parallel, and would then find the resistance of the two combinations in parallel.

There is another way to find the resistance of any number of resistors in parallel with one formula. Although this might at first seem to be a simpler way of attacking this problem, it is actually much more difficult. This formula is:

$$\frac{1}{R_T} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \cdots\cdots$$

This formula can be expressed in another form, which is:

$$R_T = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \cdots\cdots}$$

It is very unlikely that you will ever have to calculate the resistance of a large number of resistors in parallel. On some occasions you might want to find out the resistance of two resistors in parallel, and occasionally you might want to find the value of three parallel resistors, but this is probably about as far as you will have to go.

One practical point to keep in mind is that when resistors are in parallel, the greatest current will flow through the smallest resistor. Thus, if a 2-ohm, a 3-ohm, and a 4-ohm resistor are connected in parallel, more current will flow through the 2-ohm resistor than through either of the other two. The smallest current will flow through the 4-ohm resistor.

Sometimes when a number of resistors are connected in parallel, some of the resistors are so large that the current flowing through them is extremely small compared to the current flowing through the other resistors. For example, if a 1-ohm resistor is connected in parallel with a 1-megohm resistor, there will be 1,000,000 times as much current flowing through the 1-ohm resistor as through the 1-megohm resistor. The 1-megohm resistor is so large that for all practical purposes it has no effect whatsoever on the total current flowing in the circuit. In determining the resistance of this parallel combination you could ignore the 1-megohm resistor entirely. Usually if the resistor has a resistance ten times the resistance of the smallest resistor in a parallel circuit, the current flowing through it will be small enough to be ignored. Thus, if you have a 10-ohm resistor, a 17-ohm resistor, a 50-ohm resistor, a 150-ohm resistor, and a 10,000-ohm resistor all in parallel, in determining the resistance of the parallel combination, you can ignore the 150-ohm and the 10,000-ohm resistors. Their effect on the total resistance of the parallel combination will be so small that in practical electronic circuits it can be ignored. However, remember that each resistor is put into a circuit for a definite purpose. If you wanted to check the resistance of the individual resistor, you would disconnect it from the circuit.

SERIES-PARALLEL CIRCUITS

Some circuits are combinations of series and parallel connections. A circuit like the one shown in Fig. 11 can be broken down into a series circuit and a parallel circuit. First, let us consider resistors R3, R4, and R5. These three resistors are connected in parallel. If we want to find the total resistance in the circuit, we must first find the resistance of these three resistors.

Since the resistance of the 235-ohm resistor R5 is over ten times as much as the resistance of the 17-ohm resistor, R3, we can ignore R5. It will not appreciably affect the total resistance in the circuit. Therefore the first

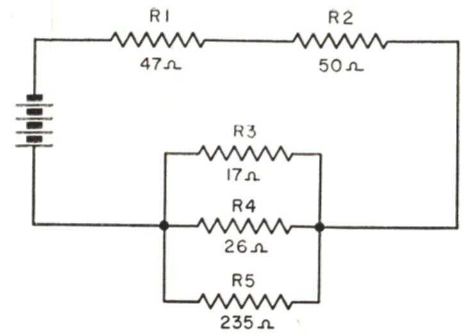


FIG. 11. A combination series-parallel circuit.

step is to find the resistance of the parallel combination of R3 and R4.

$$R = \frac{17 \times 26}{17 + 26} = \frac{442}{43} = 10.3 \text{ ohms (approx.)}$$

Now to find the total resistance of the circuit, we treat the circuit as a series circuit with three resistors, a 47-ohm, a 50-ohm, and a 10.3-ohm resistor in series. To find the resistance of a series circuit you simply add the value of the resistances in the circuit:

$$R_T = 47 + 50 + 10.3 = 107.3 \text{ ohms}$$

From the preceding you can see that to find the resistance in a series-parallel circuit, you simply work in steps. First, you determine the total resistance of the parallel branch, and then you treat this branch like a single resistor. The circuit then breaks down to a simple series circuit where you can add the individual resistances.

Many of the circuits in electronic equipment are series-parallel circuits. When you have to figure the total resistance of a circuit like this, remember to take one part of the circuit at a time until you have the resistances in a form that can be handled like a simple series circuit.

SUMMARY

Series and parallel circuits are extremely important. You are going to meet them time and time again in electronic equipment. You should remember the following rules for finding the total resistance for both types:

1. In a series circuit, the total resistance is equal to the sum of the resistance of the individual resistors.
2. In a parallel circuit, the total resistance is always less than the resistance of the smallest resistor.
3. The total resistance of two resistors in parallel is equal to the product of the resistance of the resistors in ohms divided by the sum of the resistance in ohms.
4. To find the resistance of a number of resistors in parallel, start by grouping the resistors in pairs.
5. In a parallel circuit consisting of a number of resistors, resistors ten or more times as large as the smallest resistor can be ignored in most cases.
6. In a parallel circuit, the highest current will flow through the smallest resistor, and the lowest current through the largest resistor.
7. When two equal value resistors are connected in parallel, the total resistance is equal to one half the resistance of either resistor.

Using Resistors to Reduce Voltage

In most pieces of electronic equipment a number of different operating voltages are required. The operating voltages in electronic equipment are obtained from a section called the power supply. The power supply provides the voltage needed throughout

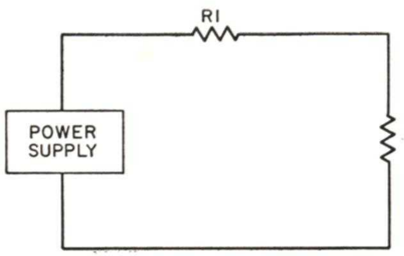


FIG. 12. A simple series circuit.

the equipment. Usually the voltage is obtained from an ac power line; the power supply changes the voltage from ac to dc.

It would be completely impractical to build a separate power supply to provide each different operating voltage needed in a complex piece of electronic equipment. This would be too costly, and in addition the equipment would be many times as large as it needed to be.

This problem is solved by building a power supply capable of supplying the highest voltage needed and then by using resistors to reduce this voltage to the lower levels needed in some parts of the electronic equipment. One of the most important uses of resistors is to drop voltage from a high value to a low value to provide the correct operating voltages at the various points in the equipment. Sometimes this can be done by means of a comparatively simple circuit; sometimes elaborate circuits are used. In this part of the lesson you will study two of the simpler methods.

SERIES DROPPING RESISTORS

You already know that in any series circuit there will be a voltage drop across the resistors in the circuit. The sum of the voltage drops will be equal to the source voltage. In the circuit shown in Fig. 12, if the power supply voltage is 250 volts, the voltage drop across R1 plus the voltage drop across R2 must be equal to 250 volts.

Now if R2 represents a load in a piece of electronic equipment and we need a voltage of 100 volts across this load, we can get it by installing a series dropping resistor like R1 of Fig. 12. We will choose the size of R1 so that 150 volts will be dropped across it, and we will then have 100 volts left across R2. The circuit will look like Fig. 13. Notice that this is exactly like the circuit shown in Fig. 12. R1 has been selected so that it has exactly the right resistance to use up 150 volts of the available 250 volts so that the desired voltage of 100 volts will appear across the load.

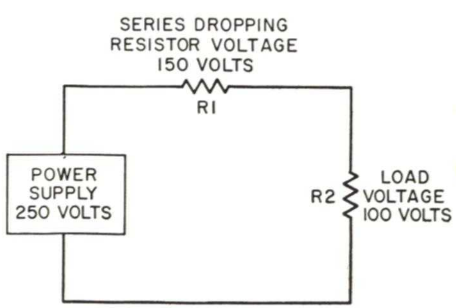


FIG. 13. To get a load voltage of 100 volts from a 250-volt power supply, we use a series-dropping resistor, R1.

You might wonder how to figure the correct size for R1. There are two easy ways of doing this. If you know the resistance of R2, and often this value is easy to find, you can figure out the value for R1 quite easily. First, remember that we want 100 volts across the load, and 150 volts across the series dropping resistor. In other words, there must be 1½ times as much voltage across the series dropping resistor as across the load. To get this, we must have a series dropping resistor 1½ times the size of the load resistance. If the load resistance is 1000 ohms, the series dropping resistor must have a resistance of 1500 ohms.

Another way you can find the required resistance for R1 is to calculate its value using Ohm's Law. You can do this if you know the current that will flow in the circuit. For example, if the current flowing in the circuit is 100 mils (mils is the abbreviation for milliamperes), you can use the formula $R = \frac{E}{I}$ to find the value of R1. In this case, I is 100 mils, which is .1 amp, and E is the voltage we want to drop across the series resistor, which is 150 volts. Therefore:

$$R = \frac{150}{.1} = 1500 \text{ ohms}$$

Thus, you can find the resistance of a series dropping resistor R1 if you know either the resistance of the load or the current that will normally flow through the load and the series resistor.

Let's take another example. Suppose we again want 100 volts across the load, but the current will be only 10 mils (.01 amp). Let's use our formula to see what size series dropping resistor we would need. The voltage to be dropped across it again equals 150 volts, so we have:

$$R = \frac{150}{.01} = 15{,}000 \text{ ohms}$$

Series dropping resistors are used in many places in electronic equipment. You already know that a triode tube has a cathode, a grid, and a plate. Another tube that you will soon study is a "tetrode", meaning a four-element tube. Still another tube is a "pentode" which is a five-element tube. In both of these tubes, between the grid and plate, there is a second grid, called a "screen grid." This grid is operated with a positive voltage applied to it. As you remember the plate voltage is also positive. However, the positive voltage for the screen grid is somewhat less than the plate voltage. Series dropping resistors are often used to provide the screen-voltage required.

BLEEDER RESISTORS

The series dropping resistor shown in Fig. 13 works quite satisfactorily as long as the current through the load does not vary. If the current flowing through the load varies, the current flowing through the series dropping resistor will also vary. If the current through the series dropping resistor varies, the voltage drop across it will vary, and as a result the load voltage will vary because the sum of the voltage drops must equal 250 volts at all times.

Frequently in electronic equipment the load is a vacuum tube. You know that when the voltage applied to the grid of a vacuum tube varies, the current flowing through the tube will vary. Hence there will be a varying current flowing through the series resistor, which will result in a varying voltage across the series dropping resistor with the result that the load voltage will vary. In some circuits a certain variation in the voltage across the load can be tolerated, but in other instances, the load voltage must be held reasonably constant if the equipment is going to work properly.

First, let's investigate the effect of a varying current in the load on the voltage dropped across the series dropping resistor and hence the voltage applied to the load resistance. In Fig. 14 we have shown the same circuit as

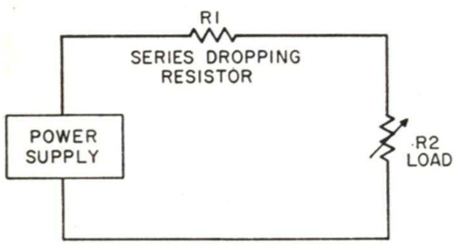


FIG. 14. A series circuit in which the resistance of the load is variable.

in Fig. 13, but in this case we have represented the load, R2, as a variable resistor. This is to show that the current through this resistor varies. Let's assume that R2 represents the resistance of a vacuum tube and that when no signal is applied to the grid of the tube, the current that will flow through the vacuum tube is 10 milliamperes. The power supply voltage is 250 volts, and the voltage required across the load is 100 volts. These are the same conditions as in our second example in Fig. 13, except that the load resistance is variable.

We can represent the vacuum tube resistance by a variable resistance because the current through the tube changes when the grid voltage changes. The grid actually has the effect of changing the resistance between the cathode and plate of the tube to cause the change in current through the tube.

In the second example in Fig. 13, we figured that a 15,000-ohm series dropping resistor was needed. The voltage drop across the 15,000-ohm series dropping resistor will be 150 volts as long as the current through the load remains 10 milliamperes.

Now let us see what happens when the load current varies from 5 milliamperes to 15 milliamperes when the signal is applied to the grid of the tube. When the load current is 5 milliamperes (.005 amp), the voltage drop across the series dropping resistor can again be found from Ohm's Law:

$$E = IR$$

Substituting 15,000 ohms for the resistor value and .005 amp for the current, we get:

$$E = 15{,}000 \times .005 = 75 \text{ volts}$$

Thus, the voltage drop across the series dropping resistor will be only 75 volts, and therefore the voltage across the load will be 250 — 75 = 175 volts.

When the current through the load increases to 15 milliamperes (.015 amp), the voltage drop across the series dropping resistor will be:

$$E = 15{,}000 \times .015 = 225 \text{ volts}$$

This means that the voltage applied to the load will be 250 — 225 = 25 volts. From this you can see that as the current through the load varies from 5 milliamperes to 15 milliamperes, the voltage across the load will

vary from 25 volts to 175 volts—a total variation of 150 volts.

This variation can be reduced by adding the resistor shown marked R3 in Fig. 15. This is called a "bleeder" resistor. Here the bleeder resistor is connected in parallel with the load, and its size is selected so that it will draw a reasonably large current. This means that its resistance must be fairly small compared to that of the load. Then, the varying current through the load will not have as much effect on the voltage drop across the series dropping resistor. The exact

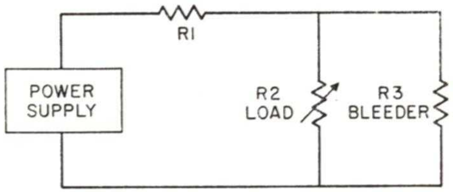


FIG. 15. A bleeder resistor connected across the load to reduce the variation in the current through the series dropping resistor.

current that we should have flowing through R3 will depend upon how closely we want to maintain the voltage across the load.

Let's see exactly how this works. Suppose that as before, the current through the load is 10 milliamperes when no signal is applied to the grid. Let's see what happens if we choose R3 so that a current of 20 milliamperes flows through it. When no signal is applied to the tube, the current flowing through R2 will be 10 milliamperes, and the current flowing through R3, 20 milliamperes. Since both of these currents flow through the series dropping resistor, the total current through it will be 30 milliamperes (.03 amp).

If we want 100 volts across the load as before, we must have a voltage drop of 150 volts across the series dropping resistor. Using Ohm's Law to calculate the size of the series dropping resistor we get:

$$R = \frac{150}{.03} = 5000 \text{ ohms}$$

Now let us see what happens when the current through the load resistor varies from 5 milliamperes to 15 milliamperes as the signal applied to the grid of the tube varies. When the current drops to 5 milliamperes, the total current flowing through the series dropping resistor will be the 5 milliamperes flowing through R2, plus the 20 milliamperes flowing through the bleeder resistor R3 or a total of 25 mils (.025 amp). The voltage drop across R1 will be:

$$E = .025 \times 5000 = 125 \text{ volts}$$

The voltage across the load would then be 250 volts — 125 volts = 125 volts.

When the current through the load increases to 15 milliamperes, the load current flowing through R1 will be 35 milliamperes, and the voltage drop across R1 will be:

$$E = .035 \times 5000 = 175 \text{ volts}$$

The voltage across the load will therefore be 250 — 175 = 75 volts. From this you can see that the voltage across the load will vary from 75 volts to 125 volts or a total of only 50 volts. This is much less than the variation of 150 volts that we had without the bleeder.

To find the value of the bleeder resistor R3 that will draw 20 mils, we divide the voltage across it (100 volts since it is in parallel with the load) by the current through it, 20 milliamperes, or .02 amp. Dividing 100 by .02 gives us 5000, so the size of the bleeder should therefore be 5000 ohms. The voltage across the load resistor can be held still more constant by using a smaller bleeder resistor, which will draw current so that the current variation in the load will become a smaller percentage of the total current flowing, and the voltage across the series dropping resistor will vary less and hence the load voltage will be more constant.

Another way of looking at bleeder action is to consider the voltage drop across the series dropping resistor. This voltage drop is equal to I x R. For a given voltage across the series resistor, we can use a smaller R if we increase the current. In the example given, to get a voltage drop of 150 volts with a current of 10 mils, we needed a resistance of 15,000 ohms. But when we added a bleeder which draws a current of 20 mils, the total current through the series resistor became 30 mils. Since we have increased I, R can be reduced in size. In this case, we need only a 5000-ohm series resistor.

Now, with the smaller series resistor, the current variations produced by the varying load have a much smaller effect on the voltage across the series resistor. A change of 5 mils in the current through a 15,000-ohm resistor results in a voltage change of 75 volts, but the same current change through a 5000-ohm resistor gives us a voltage change of only 25 volts. With a bleeder in the circuit, the load current changes the same as it does without a bleeder, but the voltage change across the series resistor will be smaller because the resistor is smaller.

If the voltage across a tube remains constant we say it is well "regulated." Adding a bleeder resistor helps to improve the voltage regulation, or keep the voltage more constant. When we say that the voltage regulation is good, we mean that the voltage varies only a small amount; if we say that the voltage regulation is poor, we mean that the voltage varies appreciably.

Bleeders are often used in electronic equipment in order to help maintain constant voltage in a circuit. However, there are places where it is a definite advantage to have the voltage change when the current through the load changes, and in these places, a bleeder is not used.

SUMMARY

Now let's sum up what you have studied in this section on reducing voltage. Resistors are frequently used as voltage-dropping devices. You'll find many instances in electronic equipment where a resistor is connected between one element of a tube and the power supply to reduce the voltage. The size of resistor needed to reduce the voltage in the circuit can be determined from Ohm's Law, by dividing the amount of voltage you want to drop across the resistor by the current that will flow through the resistor.

Bleeders are used to stabilize or regulate the voltage across a load. The bleeder consumes or wastes a certain amount of current, but this extra current flowing through the bleeder resistor does not change appreciably while the current flowing through the load does. The current through the series dropping resistor is made up of both the varying current flowing through the load, and the almost constant current through the bleeder. Because the current through the bleeder is larger, the variations in the current through the load are only a small percentage of the total current through the series dropping resistor. Therefore the voltage across it will vary only a small amount, and the voltage across the load will remain reasonably constant.

Bleeders are used in circuits where the voltage should be held reasonably constant. Series dropping resistors are frequently used without bleeders in circuits where a constant load voltage is not important, or where we want the voltage across the dropping resistor to change when the current through the load changes.

Power in Electrical Circuits

So far in your NRI course you have studied three electrical quantities: voltage, current, and resistance. The voltage in a circuit is the force available to send electrons through the circuit. Current is the rate at which electrons are moving through the circuit, and resistance is the opposition to the flow of current through the circuit. There is another quantity that is important. This is the amount of electrical energy or power being used or expended in a circuit. The unit of this measurement is the watt.

THE WATT

You have probably already encountered the term watt in everyday life. You know that the size of electric light bulbs is given in watts. You know that a 100-watt bulb will give considerably more light than a 60-watt bulb. This is because the 100-watt bulb consumes more electrical energy than the 60-watt bulb, and converts more electrical energy into light and heat. The 100-watt bulb will use a power of 100 watts, a 60-watt bulb will use 60 watts.

In a dc circuit, the power is the product of the voltage times the current in the circuit. Thus, if the voltage across a resistor is 100 volts, and the current flowing through the resistor is 1 ampere, the power is $100 \times 1 = 100$ watts. Similarly, if the voltage is 1000 volts and the current flowing in the circuit is ½ amp, the power used in the circuit will be $1000 \times \frac{1}{2} = 500$ watts.

By using Ohm's Law we can find the power in two other ways. For example we know from Ohm's Law that:

$$E = I \times R$$

If we substitute $I \times R$ for E in the power equation:

$$P = E \times I$$

we get:

$$P = I \times R \times I = I \times I \times R$$

The expression $I \times I$ is written I^2. This is called I squared and it means the current times the current. Thus, the equation becomes:

$$P = I^2 \times R$$

By using this form of the power equation we can find the power in a circuit where we know the resistance and the current.

We can get the power formula into another form by again making use of Ohm's Law. We know that:

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

and if we substitute this in the expression:

$$P = E \times I$$

we get:

$$P = E \times \frac{E}{R} = \frac{E^2}{R}$$

By using this expression we can calculate the power in a circuit when we know the voltage and the resistance. This gives us three power formulas:

$$P = E \times I;\ P = I^2 \times R;\ P = \frac{E^2}{R}.$$

These three power formulas are important. You should remember them because you will need them over and over again. The three formulas make it possible for you to find the power in a circuit if you know any two of these three circuit values: voltage, current, and resistance.

In some electronic equipment large amounts of power are used. The power may be several thousand watts. Instead of expressing the power in thousands of watts, we use the term kilowatts. A kilowatt is 1000 watts. Thus if we say that the power of a radio transmitter is 5 kilowatts, we mean that the power is 5000 watts. Kilowatt is frequently abbreviated kw.

WATTAGE RATING OF RESISTORS

Both carbon and wire-wound resistors are designed to handle a certain amount of power. Carbon resistors are made in one-third, one-half, one, and two-watt sizes. Occasionally you might see three-watt carbon resistors, but carbon resistors are not commonly made with large wattage ratings. As a matter of fact, the great majority of carbon resistors are half-watt resistors.

When we say that a resistor is a half-watt resistor we mean that the power it can safely dissipate is ½ watt. Another way of saying this is that the product of the voltage across the resistor times the current flowing through it will give a power of ½ watt or less. As a matter of fact, when engineers design equipment they usually allow a safety factor. For example if a resistor will have to dissipate or handle a power of ½ watt, they will probably use a 1-watt resistor. If a ½-watt resistor were used, the resistor would be operating right at its rated capacity, and since carbon resistors are relatively inexpensive, it is more economical to use a larger resistor and avoid the possibility that it will burn out.

You will notice that we have used the expression "dissipate ½ watt." The product of the voltage across a resistor times the current flowing through the resistor represents electrical power that is converted into heat by the resistor. The heat serves no useful purpose insofar as operating the equipment is concerned, and therefore the power is simply wasted, or as

we say, it is "dissipated". This means that the power is given off by the resistor in the form of heat. This expression is used frequently when discussing electrical energy that is wasted and given off in the form of heat.

Wire-wound resistors can be made to handle large amounts of power. In large pieces of electronic equipment such as radio and television transmitters, 50-watt and 100-watt wire-wound resistors are frequently found. These resistors are much larger than carbon resistors and they convert large amounts of electrical energy into heat.

When replacing a resistor in a piece of electronic equipment, you must select a resistor that has not only the correct resistance, but also that is capable of handling the power that will be dissipated by the resistance. In other words, if the product of the voltage times the current through the resistor is 2 watts, then you must use a resistor in the circuit that is able to handle this power, otherwise the resistor will burn out. If you put a ½-watt resistor in a circuit where the power dissipated by the resistor is 2 watts, the resistor will last only a short time. On the other hand, if you put a 5-watt wire-wound resistor in the circuit, the resistor should last a long time, because it is capable of dissipating considerably more power than it actually will be called upon to dissipate.

In most pieces of electronic equipment ½-watt resistors are used. When a resistor of larger wattage rating is needed, the wattage rating of the resistor is usually marked on the diagram of the equipment. If you are servicing a piece of electronic equipment and you find that some of the resistors have the wattage rating marked on them but the majority do not, you can assume that the resistors that do not have any wattage rating, are ½-watt resistors. Also, after you have worked with your experimental kits and started servicing electronic equipment you'll soon learn to recognize the sizes of the various resistors and you can usually tell the approximate wattage of a resistor from its physical size.

In replacing a resistor, there is no harm done if you use a resistor having a higher wattage rating than the resistor originally used in the circuit. The resistor having a higher wattage rating will usually be somewhat larger than the original resistor, but in most pieces of electronic equipment you'll be able to find room to mount the larger resistor.

GETTING MAXIMUM POWER

A common problem in electronic circuits is that of getting the maximum possible power from one part to another. For example, suppose you wanted to connect a resistor across a battery and dissipate or use up as much power as possible in that resistor. What size resistor would you use? The power in the resistor will be equal to the voltage across the resistor times the current flowing through it. Therefore, you might at first think that since the battery supplies a fixed voltage, you can get maximum power by getting as high a current as possible to flow through the resistor. This would mean using the lowest value resistor that you can locate. Unfortunately, the problem is not as simple as this.

You already know that there is no

such thing as a perfect conductor. Even the copper wire used to connect parts in electronic equipment has some resistance. In a complete circuit consisting of a battery and a resistor, current flows in all parts of the circuit. Current must flow through the battery itself. While the electrons leave the negative terminal of the battery and flow through the circuit back to the positive terminal of the battery, they must then flow from the positive terminal through the battery to the negative terminal. In flowing through the battery, they meet a certain amount of resistance. Thus, the battery has resistance, just as the conductors do.

In Fig. 16 we have shown a simple circuit consisting of a resistor, R1, connected across a 10-volt battery. We have drawn a second resistor RB in series with the battery. This resistor represents the internal resistance of the battery. The terminals marked 1 and 2 represent the — and + terminals of the battery. Let's assume that the internal resistance of the battery is .5 ohm. This is a reasonable figure for a carbon battery.

Now, let us first consider what happens when current starts to flow through the battery. When we say that the battery is a 10-volt battery, we mean that the voltage between the battery terminals is 10 volts when there is no current being used from the battery. As soon as current begins to flow through the battery, there will be a voltage drop across the internal resistance of the battery, which is shown as RB in Fig. 16. Since this resistance is right inside the battery, the voltage that will be available at the terminals of the battery is less than 10 volts. We say that the electromotive force

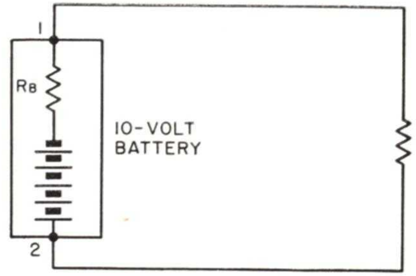


FIG. 16. A simple circuit with a resistor connected across a battery. RB represents the internal resistance of the battery.

(emf) of the battery is 10 volts. This is the voltage actually being produced inside the battery by the chemical action. However, because the battery has internal resistance, the terminal voltage of the battery will be equal to the emf minus the voltage drop across RB. From Ohm's Law we know that the voltage drop across the resistance RB will be equal to the current in the circuit in amperes times the resistance RB. The terminal voltage will therefore be 10 volts minus I × RB. Since we know the resistance of RB is .5 ohm, we can say that the terminal voltage will be 10 — .5 × I.

In the series circuit shown in Fig. 16, the voltage drop across RB plus the voltage drop across R1, must be equal to the 10-volt emf of the battery.

Now let us see what value of resistance will give us the maximum amount of power in R1. Let's start with a 10-ohm resistor, and see what the power will be. With a 10-ohm resistor, the total resistance in the circuit will be 10.5 ohms, and the current flowing in the circuit will be 10 volts divided by 10.5 ohms, which equals .952 ampere. The power across R1 will be equal to the voltage across it times the current flowing through it. We can find the voltage across the

resistor by first finding the voltage drop across RB and then subtracting it from 10 volts. The voltage drop across RB will be .952 × .5 = .476 volt, and therefore the voltage across the resistor will be 9.524 volts. The power dissipated by the resistor will be the voltage times the current, or 9.524 × .952, which is slightly over 9 watts.

Now let us check the other two formulas for finding the power to see if we get the same result. One form is:

$$P = I^2 \times R$$

From the preceding we know that I = .952 amp. Therefore:

$$P = .952 \times .952 \times 10$$

.952 × .952 = .9063 so we have

$$P = .9063 \times 10 = 9.06 \text{ watts}$$

This is the same result that we got before, slightly over 9 watts.

Using the other power formula:

$$P = \frac{E^2}{R}$$

we should get the same answer. We know that E = 9.52 volts and R = 10 ohms. Therefore:

$$P = \frac{9.52 \times 9.52}{10} = \frac{90.6}{10} = 9.06 \text{ watts}$$

Thus we have seen that the same result is obtained from the three power formulas. Using the one for which the values are known will save some calculation.

Now let's go to the problem of the resistor across the battery and see what happens when we connect a 5-ohm resistor across the battery and see if power dissipated by the resistor R1 increases or decreases. The total resistance of the circuit will be .5 + 5 or 5.5 ohms. Current flowing in the circuit will be 10 volts divided by 5.5 ohms, which is about 1.8 amps. Now we have all we need to determine the power in the resistor from the formula

$$P = I^2R$$

The power in the resistor R1 is therefore 1.8 × 1.8 × 5 = 16.2 watts. The power for different values of R1 in Fig. 16 is given in Fig. 17. If we continue to reduce the size of resistor R1, we will find the power in the circuit continues to increase until finally we make R1 equal to RB. At this time the power in R1 will be 50 watts. However, if we reduce the size of R1 still further, the power in R1 will start to go down again. When the resistance of R1 is .1 ohm, the power in R1 will be only slightly over 25 watts.

The explanation of this is simple. As we reduce the size of R1, the total current that will flow in the circuit continually increases as the resistance of the circuit is made smaller. However, we eventually reach a point where R1 becomes smaller than the internal resistance of the battery. Then more power will be lost in the battery itself than we will be able to get over to the resistor. Thus, we can get maximum power from the battery into the resistor when we make

R1 IN OHMS	POWER IN WATTS
10	9+
5	16.2
.5	50
.1	25+

FIG. 17. Power for different values of R1 in Fig. 16.

the resistor exactly equal to the internal resistance of the battery.

This is extremely important. When R1 is exactly equal to the internal resistance of the battery, we say that R1 is "matched" to the battery. Another way of saying this is that the load, which is R1, is matched to the source, which is the battery. Maximum power can always be transferred from a voltage source to a load when the load is matched to the source. This is true whether the source is a battery such as we have used in this example, a generator such as might be found in a power station, or an electron tube or transistor such as you will find in radio, television, and in all types of electronic equipment. Maximum transfer of energy is obtained when the load is matched to the source.

The fact that a battery has internal resistance explains why it is possible to get a much higher current from a large 6-volt battery than you can get from another smaller 6-volt battery. The larger battery will have a lower internal resistance than the smaller battery, and thus the total resistance in the circuit will be lower. For the same reason it is possible to get a much higher current from a 6-volt storage battery than it is from a 6-volt dry cell. A storage battery has a very low internal resistance. The internal resistance of a dry cell is much higher than that of a storage battery. Thus, the high internal resistance of a dry cell will limit the current that it can supply. The 6-volt dry cell can therefore supply considerably less current than a 6-volt storage battery. The storage battery can be used to supply the energy needed to start an automobile because it can supply very high current for a short time. A 6-volt dry cell would be totally unsuited for this purpose, because its high resistance would limit the amount of power it could supply.

Resistance in AC Circuits

Earlier in this lesson we mentioned that parts such as coils and capacitors do not act in the same way in ac circuits as they do in dc circuits. In fact, a capacitor is not supposed to let any dc at all flow through it, but it is supposed to let ac flow through it. The higher the frequency of the ac, the more current that can flow. Coils act in exactly the opposite way. They will permit dc to flow with little or no opposition, but they oppose the flow of ac, and the higher the frequency of the ac, the greater the opposition will be.

In general, resistors perform in very much the same way in ac circuits as they do in dc circuits, but there are some special problems that you will encounter, particularly at higher frequencies, with wire-wound resistors.

AC IN WIRE-WOUND RESISTORS

To understand why wire-wound resistors are a special problem in ac circuits, you must first know something about how they are made. They are made of resistance wire. Resistance wire is wire made of nichrome or some similar substance that has a

fairly high resistance. Copper wire is not suitable for wire-wound resistors because you would need a very long piece of wire to get an appreciable resistance. Nichrome, however, has a much higher resistance than copper, so we can get a high resistance with only a short piece of wire.

Wire-wound resistors are made by winding nichrome wire on a round form. The resistor is wound like a coil and therefore it acts not only like a resistor, but also somewhat like a coil.

Usually wire-wound resistors are made with only a comparatively few turns of wire so they do not cause too much trouble at the lower ac frequencies encountered on power lines or at audio frequencies. However, at high radio frequencies, the resistor has enough turns of wire to act very much like a coil, and therefore is unsuitable.

AC RESISTANCE

There are other problems that you will encounter when considering ac resistance. For example, you might measure the resistance of a wire with an ohmmeter and get a resistance of .1 ohm. This is the dc resistance of the wire. However, this is not the ac resistance. The resistance of the wire will be much higher at high radio frequencies.

The increase in resistance is due to several factors. One of the most important is called *skin effect*. This is the name given to an effect in which the current flows on the outside of the wire instead of being distributed evenly throughout the entire diameter of the wire. When the current flows on the outside of the wire, this results in a much higher current density in the part of the wire being used, and this in turn means that the wire offers a much higher resistance to the flow of current than it would if the current were distributed evenly.

Another factor that causes the ac resistance to be higher than the dc resistance is that there are losses which occur with ac that do not occur with dc. For example, part of the ac is radiated, just as a radio signal is radiated from the transmitting antenna of a radio transmitter. This loss shows up as an increase in ac resistance.

Another loss that causes trouble is due to leakage through the supports or terminals used to hold the wire in place. This results in current flowing in a path other than through the wire. This loss can become so high at high frequencies that wires and connecting leads used in high-frequency circuits are usually large wires that are stiff enough to be self-supporting.

In some instances the losses we have described in this section can be quite high. In most cases they result in an appreciable difference between the ac resistance and the dc resistance of the coil. However, the additional resistance is just like the resistance found in a resistor such as a carbon resistor. In the next lesson you will study another effect which is called "reactance". Reactance acts something like resistance to oppose the flow of current in a coil. However, reactance is found only in ac circuits. You will also learn another term, "impedance". Impedance is the total opposition to the flow of current. It is made up of resistance and reactance. Remember these two new terms, reactance and impedance, both are very important.

Resistor Values

In most pieces of electronic equipment, you will find more resistors than any other single part. Perhaps the two pieces of electronic equipment with which you are most familiar are radio and television receivers. The average radio has somewhere between 10 and 15 resistors. Television receivers usually have somewhere between 50 and 100 resistors. Some of the older TV sets may have considerably more than 100 resistors.

There are many ways of expressing the value or resistance of a resistor. The resistance can be expressed in ohms, thousand (K) ohms, or in megohms. Thus, if you see a resistor on a diagram marked 2.2K you know that the K stands for thousands. This value can be converted to ohms by moving the decimal point three places to the right. In order to do this, you move it two places to the right beyond the 2 and then add two zeros, and 2.2K becomes 2200 ohms.

A 100K resistor is a 100,000-ohm resistor. But 100,000 ohms is one-tenth of a million ohms. Therefore, a 100 K resistor might also be marked .1 megohm or .1M. This is one-tenth of a million ohms.

On some older diagrams M was used to represent thousand. This may seem a little confusing. But if you look at such a diagram carefully, you should have no trouble telling which is meant. If M is used for thousand, meg is usually used for megohm. If M is used for megohm, K is used for thousand. M and K are never both used for thousand on the same diagram.

To summarize, to convert K ohms to ohms, you multiply by 1000, or move the decimal point three places to the right. To convert megohms to ohms you multiply by one million, or move the decimal point six places to the right.

TOLERANCES

On a diagram you might see a resistor marked 220K. This means 220,000 ohms. However, does the resistor actually have to be exactly 220,000 ohms? Suppose it was 220,100 ohms. Would this affect the operation of the equipment? The answer is no; as a matter of fact in most pieces of electronic equipment the actual value of a resistance is not at all critical. Most resistors have an allowable variation of at least 10%. We say they have a "tolerance" of at least 10%. For example a 220K-ohm resistor with a tolerance of 10% can vary up to 22,000 ohms above or below 220,000 ohms. Therefore a resistor measuring anywhere between 242,000 ohms and 198,000 ohms will usually be satisfactory in the circuit. As a matter of fact, resistors color-coded 220K usually have a tolerance of 10%, and the actual resistance of the resistor if it is measured accurately might fall anywhere between these two limits.

In some circuits the actual value of the resistance is more critical than it is in others. When a 10% variation would be too high, the manufacturer of the equipment may use a resistor having a tolerance of 5%. The 220K-ohm, 5% resistor will have a tolerance of 11,000 ohms, and therefore its value would lie somewhere between 209,000 and 231,000 ohms. Since 5% resistors are more expensive than 10% resistors, manufacturers use 10% resistors in place of 5% wherever it is possible to do so.

In some electronic devices, resistor values must be held in very close tolerance. In these circuits, 1% resistors are used. A 1%, 220K resistor will have an actual resistance within 2200 ohms of 220,000 ohms. As you might expect, 1% resistors are even more expensive than 5% or 10% resistors, and therefore they will be found only in very critical circuits. The 1% resistors are frequently found in test equipment, where the accuracy of the equipment depends upon having the correct value resistance.

COLOR CODE

Carbon resistors are identified by means of a color code. There are usually four colored bands on a carbon resistor. Three of the bands give the resistance of the resistor, and the fourth band indicates the tolerance of the resistor. A silver band indicates a 10% resistor, and a gold band a 5% resistor. In 1% resistors, the value of the resistor is usually stamped on the resistor along with the marking 1%.

We are not going into the resistor color code here, because it's far easier to learn when you actually have resistors to work with. However, it is extremely important that you learn the color code. It may take a little time to learn it, but once you have learned it you'll save a great deal of time. If you do not know the color code, each time you have to install a resistor in a piece of equipment you'll have to look up the color code in order to find the correct value. Sometimes, when you know the color code to some extent, and do not know it as well as you should, you may actually install the wrong value resistor in the piece of equipment. Needless to say, this can lead to a great deal of extra work because the error might not be readily detectible. Learn the color code as you work on your experimental kits; it will save you a great deal of time.

How Temperature Affects Resistance

A certain amount of heat is generated in most electronic circuits even under normal operating conditions. Sometimes this heat will affect the resistance in the circuit and thus affect the performance of the circuit. In fact, if a resistor gets hot enough, its resistance may change considerably or in some cases the resistor may burn out completely. In most cases the small changes in the value of a resistor due to heating in normal usage will be of no concern to the electronics technician, but in some cases, these changes are important because they may result in an appreciable change in the current flowing in the circuit.

TEMPERATURE COEFFICIENTS

All materials have what is known as a "temperature coefficient". The temperature coefficient of a material is an indication of how the resistance of the material changes with changes in temperature. It is expressed in a number that shows how much the resistance will change for each degree centigrade of temperature change. For example, if the temperature coefficient of a certain material is .0001, this means that the resistance of the material will change one ten-thousandth for each degree centigrade of change in the temperature of the material. If the resistance of this material at a temperature of 20 degrees centigrade is 10,000 ohms, if the temperature increases to 21 degrees, the resistance will change 1 ohm.

There are two types of temperature coefficient, one is a positive temperature coefficient and the other is a negative temperature coefficient. If the material has a *positive* temperature coefficient, the resistance increases as the temperature increases, and if the material has a *negative* temperature coefficient, the resistance decreases as the temperature increases. In the example of the 10,000-ohm resistor with a temperature coefficient of .0001, if the temperature increases from 20°C to 21°C, and the temperature coefficient is positive, the resistance of the resistor will be 10,001 ohms; on the other hand, if the temperature coefficient is negative, the resistance will be 9,999 ohms.

The temperature coefficient of most materials is comparatively small. Pure metals have a positive temperature coefficient; the resistance of wires such as copper wire will increase as the temperature increases. However, carbon has a negative temperature coefficient. Since carbon resistors are made of a carbon compound, most carbon resistors have a small negative temperature coefficient.

Under normal operating conditions the resistance of a resistor in a piece of electronic equipment changes so little with changes in temperature that is of no concern to the electronics technician. However, carbon resistors can be overheated so that there is a chemical change in the resistor and the resistance decreases appreciably. A 1000-ohm resistor that has been seriously overheated due to a temporary overload, may have a resistance as low as 5 or 10 ohms once the overload has been removed and the resistor has cooled. A resistor that has been overloaded in this way will frequently be damaged so that it cannot be used, and must be replaced.

In general, the materials used in making resistors have low temperature coefficients. Thus, resistance changes with changes in temperature are extremely small.

However, there are devices used in electronic equipment that have a high temperature coefficient and their resistance does change appreciably with changes in temperature. These devices are used for special applications and are called "thermo-sensitive" elements. A thermo-sensitive element is a part whose resistance varies appreciably with changes in temperature. One of these devices is the "thermistor". The word thermistor is a

contraction of the words "thermo-sensitive resistor". Let us see how thermistors are used.

THERMISTORS

A thermistor is made of a semi-conductor material whose resistance value varies with changes in temperature. In an earlier lesson we defined a semiconductor as a material having properties somewhere between those of a conductor and those of an insulator. Sometimes a semi-conductor may act like a conductor and sometimes it may act like a resistor.

A thermistor has a negative temperature coefficient. This means that as its temperature increases, the resistance decreases. Thermistors are usually made of special materials that have a very high temperature coefficient so that the change in resistance with small changes in temperature can be quite large.

Several different thermistors are shown in Fig. 18. Notice that one type is made in the form of a disc. Other thermistors look very much like resistors. However, you will find that thermistors are not color coded as resistors are. In addition, the word thermistor is usually stamped on a thermistor so that it is not difficult to identify. The schematic symbol used to identify a thermistor is also shown in Fig. 18. Notice that it looks like a resistor symbol with a circle around it. The T beside it identifies it as a thermistor. Sometimes the word thermistor is written near the symbol.

Thermistors are made with resistance values ranging from a few ohms up to several megohms. The higher resistances are particularly useful in some electronic circuits.

One important application of thermistors is in sensitive temperature-measuring devices. For example, if a thermistor is placed in an oven and leads are connected to it, we can use the thermistor to measure the temperature of the oven. The thermistor is connected to a voltage source and the current flowing in the circuit is measured. As the temperature of the oven increases, the resistance of the thermistor decreases, and therefore the current flowing in the circuit will increase. A meter will indicate this increase in current and if the characteristics of the thermistor are known, the temperature of the oven can be determined from the current flowing in the circuit. Thermistors can be found in many temperature-indicating applications.

Thermistors are used in other electronic circuits where it is important to keep the circuit current constant with changes in temperature.

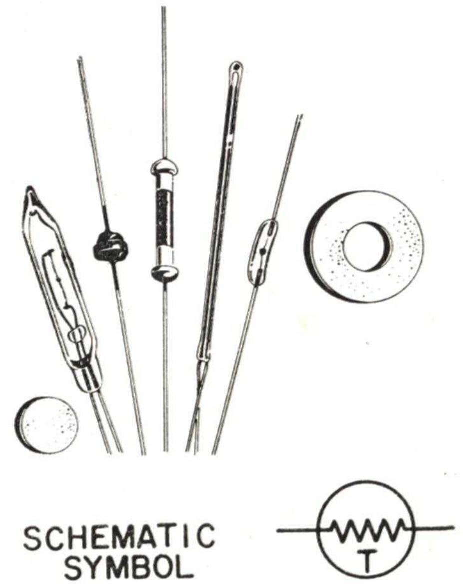


FIG. 18. Some typical thermistors and the schematic symbol used for them.

In some circuits, the resistance of the parts may increase as the temperature increases. This would result in a decrease in the current flowing in the circuit. However, if a thermistor having a negative temperature coefficient equal to the positive temperature coefficient of the other components is used in the circuit, the decrease of resistance in the thermistor will counteract the increase in resistance in the other parts. As a result, the total resistance in the circuit will remain essentially constant, and the current flowing in the circuit will not change.

SUMMARY

The important point to remember from this section of the lesson is that the resistance of most materials varies somewhat as the temperature changes. The amount of change in resistance can be determined from the temperature coefficient of the material. Most materials used in electronic equipment have a comparatively small temperature coefficient so that the change in resistance is usually small.

Thermistors are devices that are sensitive to heat. The resistance of a thermistor changes appreciably as the temperature changes. Thermistors have a negative temperature coefficient, which means that the resistance decreases as the temperature increases.

ANSWERING THE QUESTIONS

The questions in this lesson are designed to test your understanding of the material you have studied in this lesson. Do not expect to find these questions as easy as those in the earlier lessons. You're reaching a point in your course where you must understand the material in order to go on successfully with the next lesson. Some of the questions in this lesson are not answered directly in the book, but if you understand the material, you should have no difficulty in answering them. You are not expected to get a perfect paper from each and every lesson. If you could answer all the questions quickly and get every one of them right, the questions would not be teaching you anything. The important thing for you to do is try to work out each question. You'll find that this will help you to understand the information in this lesson. Even if you have difficulty answering one or more of the questions, but make an effort to answer them, you'll find a short time later when you have studied a few more lessons that if you look back at the questions in this book they will seem much easier than they do now.

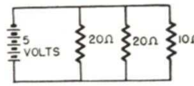
Lesson Questions

Be sure to number your Answer Sheet 5B.

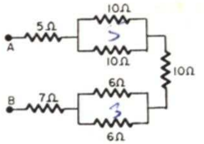
Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. What is the total resistance in a series circuit made up of a 17-ohm, a 21-ohm, and a 14-ohm resistor?
2. If one of the resistors in a series circuit made up of four resistors is shorted out of the circuit, which would you expect the current flowing in the circuit to do, (1) increase, (2) decrease, (3) remain the same?
3. If two equal resistors are connected in parallel, what will the total resistance be?
4. What is the total resistance of a 30-ohm resistor connected in parallel with a 20-ohm resistor?
5. What is the total current flowing in this circuit?



6. What is the total resistance that would be measured with an ohmmeter between terminals A and B of this series-parallel circuit?



7. What value of series dropping resistor should be connected in series with a 1000-ohm load if the power supply voltage is 300 volts and the voltage required for the load is 100 volts?
8. What is the purpose of a bleeder?
9. If the voltage across a 50-ohm resistor is 10 volts, what is the power being dissipated by the resistor?
10. Change the following to ohms:
    (a) 2.2K ohms
    (b) 100K ohms
    (c) .47 megohm
    (d) 2.2 megohms

A PLAN FOR YOUR FUTURE

In a radio interview a few minutes after a championship heavyweight boxing match, one of the fighters stated his plans for the future as follows:

"I'm going to get myself in shape, fight my own fights, and listen to nobody!"

You can use these dynamite-packed words as your plan for the future, too. Here's the way:

"GET MYSELF IN SHAPE." You're doing this right now, because the NRI Course gets you in shape for a career in electronics. But remember that it takes the *complete* NRI Course, with all its associated practical work, to get you *completely in shape.*

"FIGHT MY OWN FIGHTS." In real life, the only person who can bring you success is YOU yourself. Expecting somebody else to do your work and fight for your success is just wishful thinking.

"LISTEN TO NOBODY." Even friends and relatives will at times ridicule your studies—they can't help it, because seeing you get ahead makes them feel uncomfortable about their own laziness. So, remember human nature, and don't give anyone a chance to discourage you.

J.E. Smith