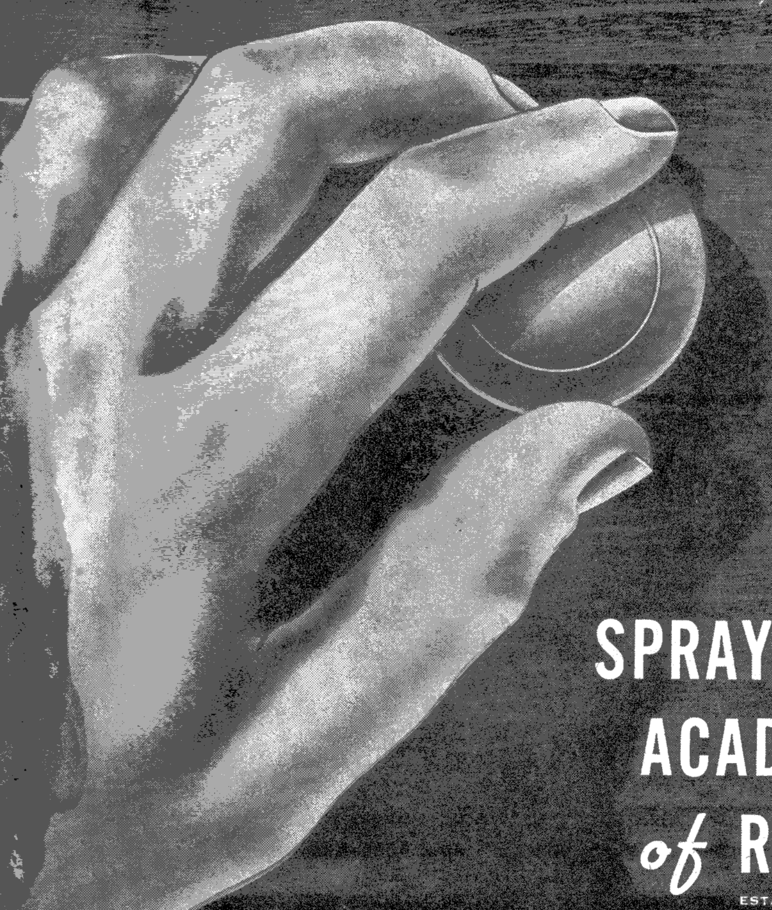
Resistance As a Property Of All Electrical Circuits

LESSON ND-6



SPRAYBERRY ACADEMY of RADIO

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RESISTANCE AS A PROPERTY OF ALL ELECTRICAL CIRCUITS

LESSON ND-6

If you have studied the previous lessons carefully, you have by this time assimilated considerable fundamental radio knowledge. This is your foundation material. The greatest mistake which most students of radio make is to *skip the fundamental principles.* Whatever you do, make very sure that you do not *skip or* merely read over these first few lessons.

This will certainly take time and patience, but it will be well worth your very best effort, and upon you alone depends the measure of success which you attain.

In this and the next two lessons, you will take up the detailed study of the three most important units in radio. These are *resistance, capacity* and *inductance.* If you undrstand the working principles of these three units, then you can grasp almost any radio problem. It can be said almost without contradiction that all radio circuits depend for their operation on the application of the principles of resistance, capacity and inductance.

LITTLE MATH NEEDED

A certain amount of mathematics is absolutely necessary in the study of radio if you are to be a *better-than-average* radio man. This does not mean that you will have to study a long and tedious amount of mathematical material. The essential math concerned with radio is quite simple and you should understand it thoroughly. Careful study of the math involved will enable you to solve radio problems which otherwise would be hopeless.

Before taking up the subject of resistance you should clearly understand *why* you must make a study of it and what particular significance it has in radio. Every electrical conducting path has resistance; thus it is a property of every electrical circuit. When no capacity or inductance is associated with resistance, it is affected alike by AC and DC. As you will learn later, when capacity or inductance is involved, radical changes take place and two new properties need to be considered; namely, *reactance* and *impedance.* This important fact is mentioned now *so that you will not assume that the contents of this lesson always hold true for AC.* All that you must remember now is that conditions change for AC when capacity and inductance are associated with resistance. *Thre is no such limitation as far as DC is concerned.*

IMPORTANCE OF RESISTANCE

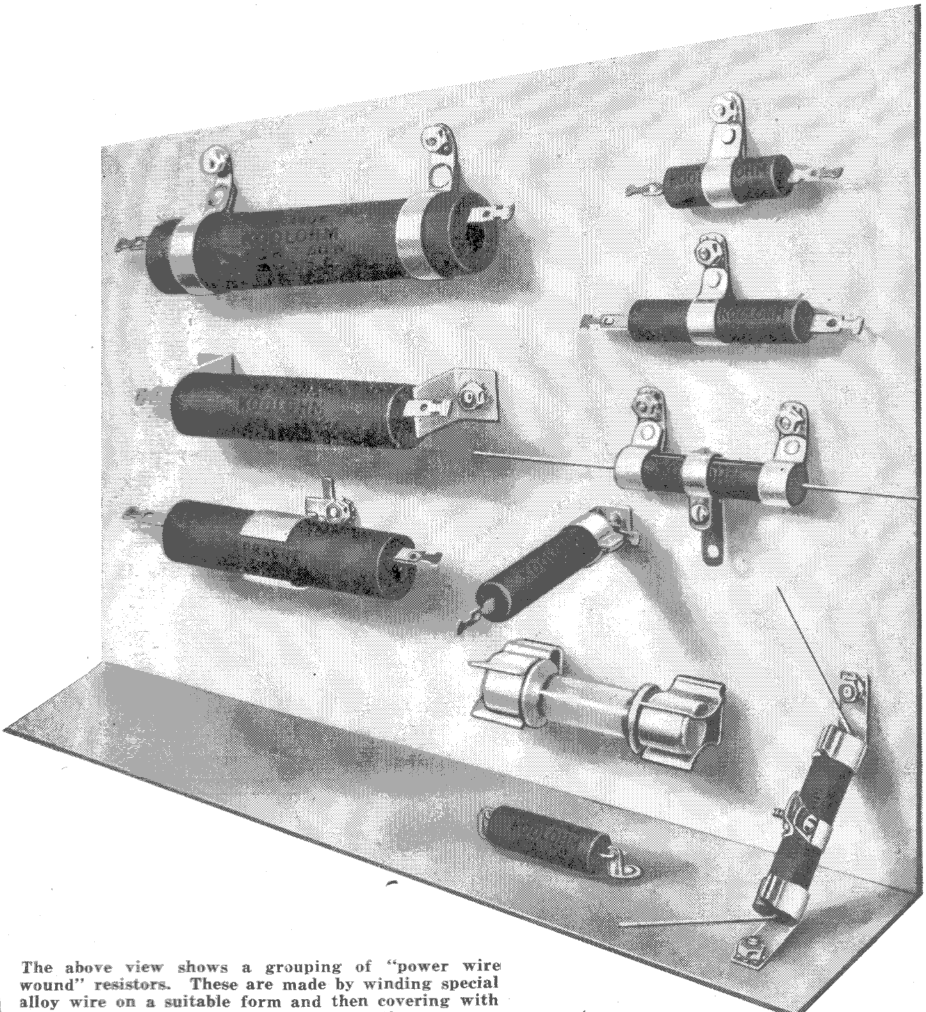
Next, consider why resistance is such an important subject in radio. It may be thought of as the *controlling element of electricity.* A certain quantity of electricity is not applied to a radio set or to an amplifier without some means of control. It is true, of course that operating power is obtained from the power line for most radio sets and amplifiers. Before a radio can be connected to the line, it must be *predetermined just how* much power is to be consumed, and once this is established resistance in one form or another must be employed to control the power consumption. The sum total of all the resistance elements within a given radio set represents the *load* connected to the power line, and this load limits the amount of current which can be drawn from the line.

Consider the average radio set and what occurs within it and you will get a good mental picture of why resistance and its correct value is so important. First, the voltage from the power line is stepped up in value from about 115 to a possible 600 or 700 volts. It is then rectified or changed from AC to effective DC. This is accomplished within a section of the receiver known as the *power supply.* From this point the voltage is fed to a multiplicity of circuits requiring (for diffrent reasons) several different values of voltage. The mere fact that different operating voltage values are required suggests that the separate resistors must have a definite value in ohms. Moreover, the resistors must be connected in series, parallel and series-parallel circuits. Resistors are also used for volume control, filtering, tone control, as a load for vacuum tube grid, plate, cathode and screen grid circuits and for many other purposes. From this brief description you will see that the study of resistance is important, and you no doubt realize that you must become thoroughly familiar with the basic laws which control its use. The purpose of this lesson is to give you this basic knowldge. If you study and learn the basic principles which apply, no resistance problem in the future can give you the least bit of trouble. So be patient and memorize the math formulas as you go along, for they are the key to a satisfying knowledge of resistance.

TWO ELEMENTS OF ELECTRICITY

All substances, from an electrical viewpoint, may be divided into two classes called *conductors* and *insulators. Conductors* are those materials, notably metals, through which electrons move with comparative ease. Conductors are so named, then, because they will *conduct* an electric current. A length of copper wire is an example of a conductor. *Insulators* are those materials such as glass, bakelite, mica, etc., which do not conduct an electric current except when subjected to terrific voltage pressure. They are so named because they insulate or prevent the movement of electrons when subjected to normal voltage pressures.

There are also good conductors and poor conductors. If you try sending a current through several pieces of wire of the same length and size but made of different metals by connecting a battery across their ends, you will find that the different currents are not the same. See Fig. 1. Some of the wires will conduct the current easily, and the current values will be large. The metals of which these wires are made are good conductors. Others will not conduct the current so well, and the current values will be small. These metals are poor conductors.



The above view shows a grouping of "power wire wound" resistors. These are made by winding special alloy wire on a suitable form and then covering with cement. Note the many forms of mounting.

Photo Courtesy of Sprague

All substances have a property known as *electrical resistance.* That is, when you send a current through any conductor by connecting a voltage across it, the conductor offers a certain *opposition* or *resistance* to the current flow. A good conductor, then, is one which does not offer much opposition to a current, and its resistance is low. A poor conductor, however, offers a large opposition to a current, and its resistance is high.

OHM'S LAW

In 1826, George S. Ohm established a very important *direct current* fact—that the ratio of the voltage across a conductor to the current flowing through it has a constant value. In other words, if you double the voltage which is connected across the ends of a length of wire, the current flowing in the wire will double in value; if you triple the voltage the current will

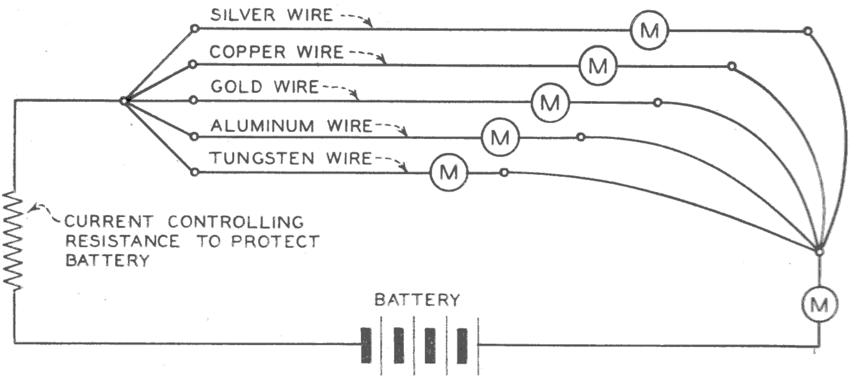


FIG. 1.

triple, etc. No exception to this relation has ever been found, and it has come to be known as Ohm's law. The latter may be expressed as a formula:

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

(which should be read as R equals E divided by I). In this case E represents the voltage in volts, I represents the current in amperes and R the resistance of the conductor in *ohms*. Thus, Ohm's law is a formula for the resistance of a conductor in terms of the applied voltage and the current.

Different metals vary in their conducting resistances. Suppose you had a one hundred foot length of No. 20 copper wire. This wire would have a resistance of one ohm. Now suppose you had other wires of the same length and diameter but made of different materials. Their resistances would have values according to table No. 1.

Copper is very widely used as a conductor. In consequence, it is assigned a *specific resistance* equal to unity (numerical value of 1). *All other materials then have specific resistances which indicate their resistance as compared with that of copper.* These are the values that are given in the table. The *specific resistance* of a given substance depends *only* on the substance, whereas the actual measured *resistance* of a length of wire made of the substance will depend, *in addition,* upon the length and diameter of the wire.

TABLE NO. 1

SUBSTANCE	SPECIFIC RESISTANCE
Silver	.945 ohms
Copper	1.000 "
Gold	1.414 "
Aluminum	1.655 "
Tungsten	3.48 "
Nickel	4.52 "
Brass	4.75 "
Iron	5.80 "
Bronze	7.83 "
Mercury	12.75 "
Carbon	56.70 "

You will see now how the size of the wire affects its resistance. If you had one thousand feet of No. 20 copper wire, the resistance would be 10 ohms. Six hundred feet would have 6 ohms resistance, and two hundred feet would have 2 ohms resistance. Thus the resistance of a given *wire* is directly proportional to its length. If, instead of No. 20 wire, you investigated a thousand feet of No. 17 wire, you would find the resistance to be 5 ohms. This is just one-half the resistance of an equal length of No. 20. If you look up the information in a wire table, you will find that No. 17 wire has just twice the cross section area of No. 20. Thus the resistance of a length of wire is *inversely* proportional to its *cross section* area.

The behavior of the resistance of a wire can now be summarized by saying that:

Resistance is directly proportional to *specific resistance* and *length* and inversely proportional to *cross section area.*

It should be noted that silver is a better conductor than copper. Its high cost prevents its general use as a conductor, but it is used in special applications were the lowest possible resistance is desired. Silver is often used for electrical contact points in switches and relays.

The temperature of any substance affects its resistance, and, for all conductors except carbon, maganin and a few of their alloys with metal, the resistance increases slightly with a rise in temperature (called *positive temperature coefficient*). For example, the resistance of copper will increase approximately 1/3 of 1% for each degree increase in temperature and carbon will *reduce* in resistance 1/20 of 1 per cent per degree increase in temperature (called *negative temperature coefficient*). It might be well to mention here that the tungsten filament of an ordinary electric lamp has quite a low resistance when cold, but when illuminated or operating at about a 3000 degree temperature, its resistance is some twelve times as great. Except for this example, temperature effects are unimportant. Temperature changes are usually small and the total resistance change amounts to very little.

A *resistor* is the name applied to a unit which displays the property of resistance to an exceptional degree. All conductors, of course, have resistance. Sometimes this is undesirable. An ordinary radio receiver, for example, could be made more efficient if its connecting wires had no resistance. But in radio circuits there are many places where a definite, large amount of resistance is needed. It is in these applications that *resistors* are use. Resistors appear in many forms. There are *wire wound* resistors, made by winding on a form many turns of fine wire having a high specific resistance (nichrome wire, for example). *Carbon* resistors are simply cylindrical rods of carbon with wire terminals affixed to the ends. *Metalized* resistors are made by sputtering a thin layer of molten metal on a small cylindrical core. You will learn more about the applications of these different resistor types in later lessons.

As a unit of measurement, the ampere is quite large when dealing with radio circuits, as most of the currents are small fractions of an ampere. A more convenient unit is the milliampere, abbreviated ma. Since there are 1000 milliamperes in one ampere, a value in amperes may be changed to milliamperes by multiplying by 1000.

Here is a most important fact that you should take pains to remember—practically all radio formulas are usually stated or given in fundamental units as in the case of Ohm's law. Thus these are voltage, current and resistance. In radio, current values below 1 ampere are more common than above this value. Thus, if you followed Ohm's law literally, you would always be working with decimal values. To avoid this, it is common practice to use the words milliampere (meaning one-thousandth of an ampere) and microampere (meaning one-millionth of an ampere). Use is also made of these prefixes in a limited way when dealing with voltage but never with resistance since most resistance values are above 1 ohm.

The mere fact that milliamperes of current are used most of the time leads many students to use a milliampere value when employing Ohm's law. This is incorrect. *The equivalent in amperes must be used instead.* For example, suppose you have a problem where the current value is 15 milliamperes and the voltage value is 60 and you want to find the resistance value. Ohm's law says $R = \frac{E}{I}$. Therefore, it appears that the answer would be $\frac{60}{15} = 4$ ohms. A little reflection, however, will show that this is the wrong solution because 15 milliamperes is $\frac{15}{1000}$ part of an ampere because 1 ampere is equal to 1000 milliamperes. Arithmetically, therefore, $\frac{15}{1000}$ must be changed to a decimal value before the application of Ohm's law will give a true answer. This is done by dividing 15 by 1000 which gives .015 ampere. With this change, Ohm's law will hold true and the problem becomes $\frac{60}{.015} = 4000$ ohms which, as you can see, is quite different from 4 ohms—the answer obtained when the milliampere value was used. This same principle holds true for microamperes and for voltage, frequency and other values when sub-multiples of the fundamental units are employed. So it is an important point to remember. *Always remember when you use a radio formula to make sure your values are the same as called for in the fundamental units of the formula.*

Here is a convenient guide for your reference. To change a milliampere value to an equivalent ampere value, multiply by .001. Thus 22 milliamperes is equal to 22×.001 or .022 ampere. To change an ampere value to an equivalent milliampere value, muitiply by 1000. For example, .19 ampere is equal to .19×1000 or 190 milliamperes. If you are dealing with microamperes use the following:

TO CHANGE	TO	MULTIPLY BY
Microamperes	Amperes	.000001
Microamperes	Milliamperes	.001
Amperes	Microamperes	1,000,000
Milliamperes	Microamperes	1,000

The same general principle is involved when dealing with voltage although not to such a great extent because in radio most values are above 1 volt. A millivolt is changed to volts by multiplying by .001. A microvolt is changed to volts by multiplying by .000001. To change volts to millivolts, multiply by 1000 and to change volts to microvolts multiply by 1,000,000. If you want to change from millivolts to microvolts multiply by 1,000, and if you want to change from microvolts to millivolts, multiply by .001.

In the matter of resistance usually values much higher than 1 ohm are involved. In fact, the values go on up to several million ohms. In this case the word *megohm* is often employed, meaning one million ohms. Thus 6 megohms means 6,000,000 ohms. Often resistor units are given as decimal parts of a megohm. Thus .25 megohm means 250,000 ohms. To change megohms to ohms, multiply by 1,000,000. For example, .65 megohms is equal to .65×1,000,000 or 650,000 ohms. To change ohms to megohms, multiply by .000001. An example—240,000 ohms equals 240,000×.000001 or .24 megohm.

On radio diagrams, it is common practice to use the abbreviation MEG. for megohm and M or K for a value of 1,000. Thus .85 MEG. or 850M or K means the same thing, both referring to 850,000 ohms. Be sure to remember this principle.

RESISTANCE SYMBOLS

The last letter of the Greek alphabet is the accepted standard symbol for resistance. It is pronounced *omega*. The capital letter symbol is Ω, and the small letter symbol is ω. Both represent resistance and appear on many diagrams.

Somtimes the capital letter Ω is used to symbolize megohms and the small letter ω is used for ohms. This is usually true where both symbols appear on the same diagram, but the capital letter Ω is most often used for the *general resistance symbol of ohms*. By examining a given diagram you can usually tell which style is followed. Thus on many diagrams you may see such figures as 1200 Ω or 1200 ω, both meaning 1200 ohms. And on some few diagrams, both symbols may appear in which case 1200 ohms would appear as 1200ω and for megohms it would appear as .0012Ω.

Now return to Ohm's law and note how it is used in a simple circuit. Observe that by changing the original formula algebraically, Ohm's law can be written in three ways:

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

These three forms of Ohm's law are extremely useful. By knowing any two of the three quantities (voltage, current or resistance) of a given circuit, you can find the third quantity. Suppose a 45 volt battery is connected across a variable 5000 ohm resistor, as shown in Fig. 2. Using the second form of Ohm's law:

$$I = \frac{E}{R} = \frac{45}{5000} = .009 \text{ ampere.}$$

If you had known that the voltage was 45 volts and the current .009 ampere, you could have found the resistance by using the first form:

$$R = \frac{E}{I} = \frac{45}{.009} = 5000 \text{ ohms.}$$

Now you will see that if a 40 volt battery is connected across the same resistor, the current will be .008 amperes. This is proven as follows:

$$I = \frac{40}{5000} = .008 \text{ ampere.}$$ (For principles of dividing a small num-

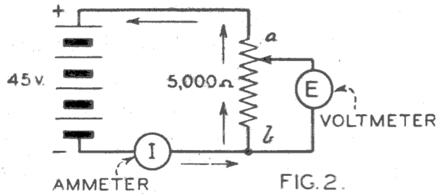


FIG. 2.

ber by a larger number see your SAR math book on fractions and decimal fractions).

Thus any voltage will produce a proportional current where the resistance is constant. Several voltage values are given in Table No. 2, with corresponding currents for this 5,000 ohm resistance, and it will be noticed that the relation between voltage and current is constant—that is, any voltage divided by its corresponding current will always give 5,000 for an answer. For constant resistance, the current varies directly with the voltage or $I = \frac{E}{R}$.

TABLE NO. 2

Volts (E)		Resistance (R)		Current (I) Amp.	Ma.
45	divided by	5,000	equal	.009	9.
40	" "	5,000	"	.008	8.
35	" "	5,000	"	.007	7.
20	" "	5,000	"	.004	4.
90	" "	5,000	"	.018	18.
200	" "	5,000	"	.040	40.

Now suppose you pass the same value of current through resistors of various sizes. You will find that the voltage will vary directly with the resistance. A variable contact has been provided on the 5000 ohm resistor of Fig. 2. This particular resistor is called a *potentiometer*—two stationary terminals and one movable. A continuous and steady current will flow through this resistor (neglecting the effect of the voltmeter) at any position of the variable contact along the resistance. Divide the resistance into section (A) above the variable element (arrow) and (B) below it —Fig. 2. In every case A + B will equal 5000 ohms. Now if you move the slider so that A is equal to 1000 ohms, B will be equal to 4000 ohms and the voltmeter will read an effective value of $\frac{4000}{5000} \times 45$ or 36 volts. If A is 2000 ohms and B 3000 ohms, the meter will read $\frac{3000}{5000} \times 45$ or 27 volts, or, if A is 1250 ohms, the voltage will be $\frac{3750}{5000} \times 45$ or 33.75 volts. You can see from this that where the current is constant, the voltage varies directly with the resistance.

Finally, with the circuit of Fig. 2, consider a constant voltage of 45 volts, and assume you can vary the total resistance, noticing the effect on the current flow.

At 2500 ohms, the current will be 18 milliamperes or double that for 5000 ohms. For 1000 ohms, the current will be 5 times that for 5000 ohms or 45 milliamperes. (Use the formula $I = \frac{E}{R}$). The current in this case (constant voltage) will *vary inversely as the resistance.* In proportion to the reduction in value of the resistance, you will have an increase in current.

Now place two 5000 ohm resistors in series with any battery or voltage source, as in Fig. 3A. If you have a length of wire whose resistance is one ohm, and you add to it another piece of the same size and length, the total resistance will, of course, be two ohms. In

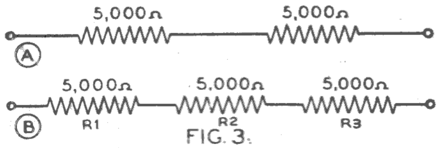


FIG. 3.

the same way, the resistance of the combination of Fig. 3A is 10,000 ohms. If you add another 5000 ohm resistor to the circuit in series with the first two, the total resistance will be 15,000 ohms, as in Fig. 3B. In fact, any number of resistors connected in series will have a total resistance equal to the sum of the individual resistances. Thus, the *total* circuit resistance formed by connecting resistors, R_1, R_2, R_3, etc., in series is

$Rt = R_1 + R_2 + R_3 + etc.$

An example of this is given in Fig. 4 where there are 5 radio tubes with their heaters (filaments) conncted in series. The resistance of each heater is given. To find the total resistance of the circuit, simply add the value of each of the separate resistors. In this case, there will be 366 ohms. Now part of this resistance is in the form of wire wound on asbestos or mica, and part of it is in the form of *tube filaments,* but it is all electrical resistance. At 110 volts, the current through this circuit would be $\frac{110}{366}$ or .3 ampere. The circuit of Fig. 4 is not intended as an explanation of radio tubes for that will come to you in a later lesson.

SERIES CIRCUIT

In a series circuit, the current has the same value everywhere in the circuit. Using the third form of Ohm's law, E=IR, you can find the voltage, called the *voltage drop,* across any individual resistor in a series circuit. The sum of all of these voltage drops must equal the applied voltage across the entire circuit. If you refer to a manufacturer's tube manual, you will find that the rated filament current for each of the tubes in Fig. 4 is 0.3 ampere. If the rated currents were different for the different tubes, then these tubes *could not be expected to operate properly* when connected in series. In the same manual you will find the rated filament voltage, this voltage being the voltage drop for the particular tube when it is connected as in Fig. 4. The *voltage drop* for the 137 ohm line cord resistor (R_1)) in Fig. 4 is calculated from Ohm's law,

$E = IR = 0.3 \times 137 = 41.1$ volts.

Now add the voltage drops around the entire circuit of Fig. 4. Thus the sum of the voltage drops equals the *applied line voltage.* If you wished, you could calculate the filament resistance of each tube by dividing its filament voltage by the current. You would then find that the sum of all of the resistances in

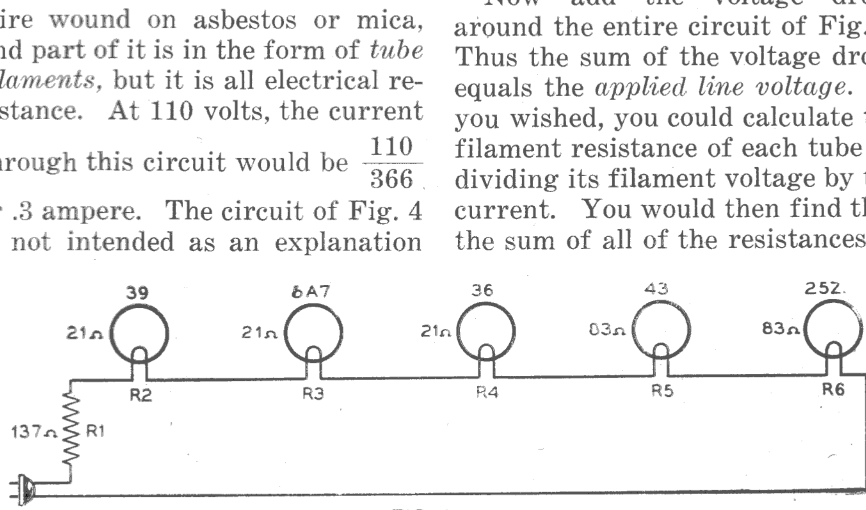


FIG. 4.

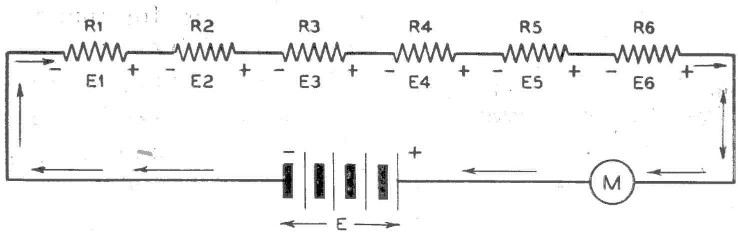


FIG. 5.

Resistor	Voltage Drop
R_1	41.1 volts
R_2	6.3 "
R_3	6.3 "
R_4	6.3 "
R_5	25.0 "
R_6	25.0 "
	110.0 volts

the circuit would be 366 ohms, which is the value obtained by dividing 110 volts by 0.3 ampere.

This matter of a *series connection* deserves your close attention, and it is highly important that you understand just what it means. An electrical circuit can only be called a series circuit when *all current of the circuit flows through each and every unit in the circuit*—that is if there is any way for the current to divide and go through another circuit it cannot be called a series circuit. Thus in Fig. 5 all current which flows through resistor R_1 must also flow through R_2, R_3, R_4, R_5 and R_6 for the simple reason there is no other circuit or path for it. A meter inserted anywhere in this circuit will register the value of current at every other point in the circuit. Thus a current meter may be properly connected in a series circuit at any point. This is not true for a voltmeter, for it must be connected across or in parallel to a voltage source to properly measure it (You will get instruction later on meters.)

VOLTAGE DROPS

Now for another important principle about Fig. 5. Whenever current flows through a resistance a *voltage drop* occurs across it. This is true because the voltage *lost* across a resistance subtracts from the source voltage. A voltage drop is that voltage existing across the ends of a resistor, and this can only occur when current flows through the resistance. *If there is no current flow, there can be no voltage drop.*

In Fig. 5 the source voltage is the battery E. The sum of all the voltage drops across R_1 to R_6 must equal E. Thus $E_1+E_2+E_3+E_4+E_5+E_6=E$. If all six resistors have the same value each will have the same voltage drop across it. The chances are, however, that in a practical circuit, the resistance values will be unequal. Thus the voltage drops will be unequal. In Fig. 5 or a similar circuit, to calculate exact values, at least two of the factors of Ohm's law must be known. For instance, if you were given the value of current the meter M registered, the value E could be found if you knew the total resistance value. Likewise, if, for example, you knew the E_5 and R_5 values, you could get the value of I. Once you have I, any voltage value between E_1 and E_6 could be found by multiplying I by the separate resistor values. Unknown values in a resistance network must often be found by indirect methods, as explained in the foregoing. In making any of these calculations, it is only necessary to apply Ohm's law.

POLARITY

A *resistor has polarity* in the same sense as a battery. Current flow through the resistance establishes a voltage drop across it, and, consequently, *one end of a resistance is negative and the other is positive.* This is true for every resistance through which there is a DC current flow. This is another highly important principle which you should remember because it has a common application in radio work.

Refer to Fig. 5 again and note the plus and minus signs at the resistor ends. You will see, reading from left to right, that the plus of one resistor is connected to the minus of the next one and so on. This is the same principle you would employ if you connected a group of dry cells in series to form a battery. Six 1.5 volt dry cells in series would give a total of 9 volts because in a series battery circuit voltages are additive if polarity is observed. Applying this principle to Fig. 5, you can readily see that the sum of the separate voltage drops must equal E as it is the source of all of the voltages. Since the voltage drop across any one of the resistors in Fig. 5 can be considered as a separate voltage source, it follows that you can connect a circuit across either one or a group of the resistors and obtain an operating voltage of correct value. This is exactly what is done in most radio circuits; the group of resistors in Fig. 5 is called a *series voltage divider* because it divides the source voltage into lower values. It is possible to divide the source voltage into any proportion by selecting the proper resistance values.

The meaning of a voltage drop should now be clear, and you should understand about the polarity of a resistor. There is one more point to consider about polarity. This is a relative term when it is applied to a group of resistors. For example, consider R_3 of Fig. 5. It, of course, has its own negative and positive ends, but, in relation to the other resistors in the group, it is *both positive and negative.* For instance, R_3 is positive in relation to R_1, but it is negative in relation to R_6. This is because of its position in the group. From this you should observe that a resistor can be both positive and negative, depending on what polarity is used as a reference. If, as in the foregoing ex-

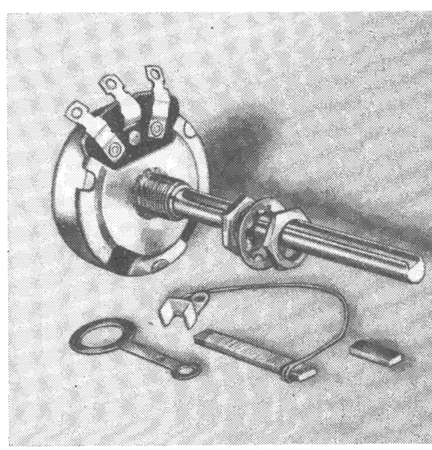


Photo Courtesy of Mallory

This view shows the component parts of a carbon type potentiometer used as a volume control. Included with it are parts used as a minimum bias fixed resistor. The shaft is extra long and is supposed to be cut to the required length by the serviceman.

ample, the negative end of the voltage divider is referred to, R_3 is negative. Study over this principle carefully and make sure you understand it.

If the foregoing principle is understood, you are ready to see how this works out in actual radio circuits. Refer to Fig. 6 where there is shown an ordinary *triode tube* connected to the usual voltage divider. The voltage E represents the power unit for the receiver which may be thought of as a battery having a certain definite voltage. *Current is considered to flow from negative to positive.* In flowing through R_1 it causes a voltage drop to occur across it. Since it exists here, the grid return of the tube is connected to the negative end of R_1, and the voltage across it is applied to the grid to act as a negative grid voltage. As you will learn later when you study tubes, the grid does not draw current; hence no current path can be shown in its circuit.

After leaving R_1, the current divides, a part of it going through the tube via the cathode and plate while the remainder goes through R_2. At the positive end of R_2 the two curcents come together again and flow through R_3 back to the source, E. This is a practical example of a series voltage divider *with a parallel branch circuit.* Note carefully the arrangement of the resistors to divide the voltage. Note, too, that the cathode is positive in relation to the grid but that it is negative in relation to the plate. You can prove this by noting where the grid, cathode and plate connect to the divider. This is the same principle involved when reference was

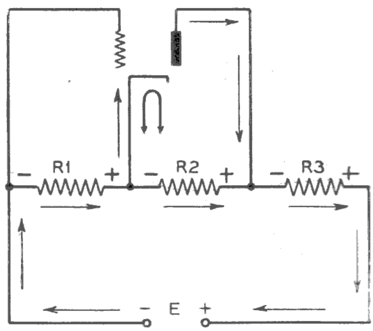


FIG. 6.

made to R_3 of Fig. 5. In tube circuits, it is a necessary condition that the cathode be negative in relation to the plate but positive in relation to the grid. The technical reasons for this will be brought out in your tube lessons, plus more details along this same line.

PARALLEL CONNECTIONS

Another way of combining resistances is to *connect them in parallel or shunt.* Two 5000 ohm resistors are connected in parallel in Fig. 7. For a given applied voltage between terminals A and B, for example 100 volts, 20 milliamperes (.02 amp.) will flow through both R_1 and R_2. ($I = \frac{100}{5000} = .02$). But the total current in meter I will be 20 plus 20 or 40 milliamperes, and the first form of Ohm's law gives

$$R = \frac{E}{I} = \frac{100}{.04} = 2500 \text{ ohms.}$$

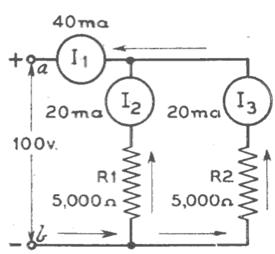


FIG. 7.

This figure shows how current may be divided in two paths to form a shunt or parallel circuit.

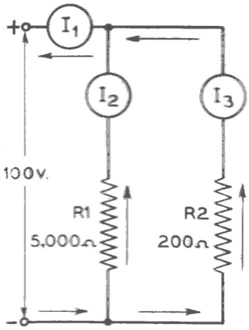


FIG. 8.

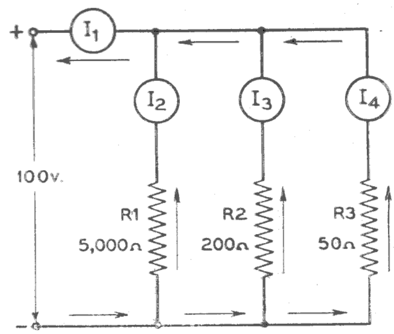


FIG. 9.

There is no individual 2500 ohm resistance in the circuit, but the two 5000 ohm resistors in parallel give the same effect as a single 2500 ohm resistor.

Now assume R_2 to be 200 ohms instead of 5000, as Fig. 8. This time you will find that I_2 is still 20 ma., but 100 divided by 200 equals 0.5 ampere for I_3. The total current I_1 will then be 20 ma. plus 500 ma. or .52 amp. (520 ma.) The total resistance therefore is equal to $R = \frac{100}{.52} = 192.3$ ohms which is less in value than the lowest single resistor in the circuit.

By placing still another resistor of 50 ohms in parallel with these two, as in Fig. 9, an additional current of 2 amperes will be added to I_1. The total resistance will therefore be equal to $R = \frac{100}{2.52} = 39.7$ ohms which is less than 50 ohms. *Note that the total equivalent resistance of a parallel combination is always less than the resistance of the lowest unit in the circuit.*

If a number of resistors having the *same value* are connected in parallel, the total resistance is equal to the value of one resistor divided by the total number. Thus if four 10,000 ohm resistors are connected in parallel, the resistance of the combination is equal to 10,000 divided by 4 or 2500 ohms.

If all of the resistors in a parallel combination are of different value, then the total resistance must be calculated differently. In Fig. 9, I_1 is equal to $I_2+I_3+I_4$, and I_1 is also equal to $\frac{E}{R}$ where R is the total resistance. But since $I_2 = \frac{E}{R_1}$ and $I_3 = \frac{E}{R_2}$, etc., then—

$$\frac{E}{R} = \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3} \text{ and}$$

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

To find Rt (total R) directly for a parallel group of re-

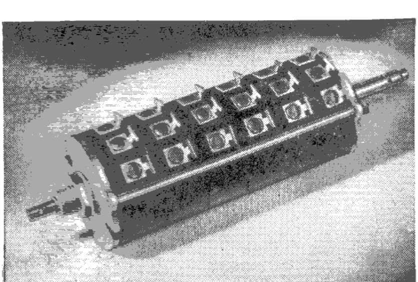


Photo Courtesy of Clarostat

The above photo shows a tandem type of resistance control, wherein six potentiometers are ganged together and controlled from a common shaft. This type of control has application in Public Address and Theatre installations.

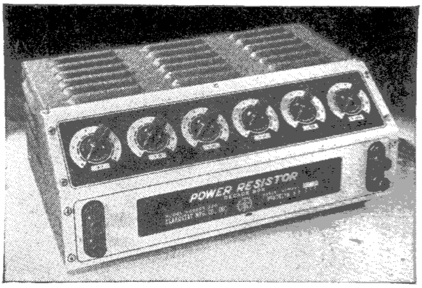


Photo Courtesy of Clarostat

Shown above is a variable power resistor for the distribution of voltages. The control elements are wire wound on insulating forms.

sistors the following formula should be used.

$$Rt = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \text{etc.}}$$

The foregoing formula is very convenient where a parallel group of 3 or more resistors must be calculated for the effective value of Rt. This formula shows the arrangement for 4 resistors. For 5, 6 or 7, etc., the procedure is the same, and they are simply added as a fraction to the denominator, as $\frac{1}{R_5} + \frac{1}{R_6} + \frac{1}{R_7}$, etc. Note as each new resistor is added a + sign must also be added.

To illustrate this method of calculation (called the reciprocal method), in the foregoing formula, let R_1 equal 10, R_2 —20, R_3 —40 and R_4 —50 ohms respectively. The problem would be set up as follows:

$$Rt = \frac{1}{\frac{1}{10} + \frac{1}{20} + \frac{1}{40} + \frac{1}{50}}$$

This involves nothing more than the addition of fractions and common division. First find the least common denominator for 10, 20, 40, and 50. By inspection it can be seen that this will be 200—the lowest number divisible by all the other numbers. In terms of 200 as a denominator $\frac{1}{10} = \frac{20}{200}$. This is found by dividing 200 by 10 which equals 20, and 20 times 1 (the numerator) equals 20—thus the new fraction is $\frac{20}{200}$. In like manner

$$\frac{1}{20} = \frac{10}{200},\ \frac{1}{40} = \frac{5}{200}$$

$$\text{and } \frac{1}{50} = \frac{4}{200}.$$

The numerators are now added, to obtain 20+10+5+4=39. To complete the fraction, the denominator of 200 is next included, and you have $\frac{39}{200}$ for the sum of the four fractions.

Next note that the complete formula has the number 1 over all of it, making the entire formula a fraction. With this in mind, the foregoing problem may now be written as

$$\frac{1}{\frac{39}{200}}.$$

This means that 1 is to be divided $\frac{39}{200}$. You will remember the laws of fractions state to divide, invert the divisor and multiply. $\frac{39}{200}$ in this case is the divisor so it is inverted and multiplied by 1. Thus you have $1 \times \frac{200}{39} = 5.128$ ohms.

The effective value of 10, 20, 40 and 50 ohms in parallel is, therefore, 5.128 ohms. All other parallel resistor problems may be worked out on the same principle.

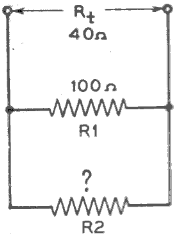


FIG. 10.

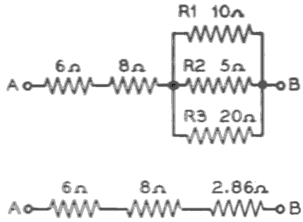
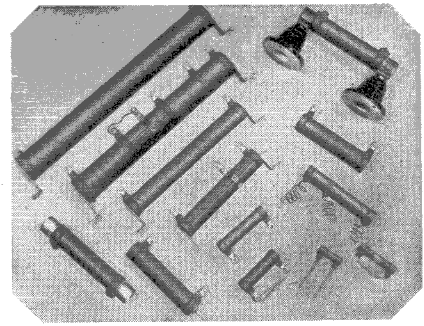


FIG. 11.



To the right is shown another view of "power wire wound" resistors. Several of these have tapped terminals and special leads at the ends for soldering.

(See your SAR math book for more details in working with fractions).

If you have to calculate the resistance for *only two* resistors connected in parallel, a somewhat simpler formula is as follows:

$$Rt = \frac{R_1 \times R_2}{R_1 + R_2}$$

Remember, however, that this formula is good for only two resistors in parallel.

Very often in radio work you will have a resistance problem where you have one resistor, R_1, and you wish to connect another, R_2, in parallel with it to give a certain total value Rt. In this case, you should use the following formula:

$$R_2 = \frac{R_1 \times R}{R_1 - R} \text{ or } R_1 = \frac{R_2 \times R}{R_2 - R}$$

Thus, if R_1 equals 100 ohms, and you want Rt (the effective value you want from the parallel combination) to equal 40 ohms (see Fig. 10), then arrange the problem as follows:

$$R_2 = \frac{100 \times 40}{100 - 40} = \frac{4000}{60} = 66 \text{ ohms.}$$

You can prove the correctness of this result by solving for the resistance of 100 ohms and 66 ohms in parallel. You will find that the result is 39.759 or very nearly 40 ohms (neglect the decimal value).

At this point, you should review the lesson thus far, making certain that you thoroughly understand the following points:

1—All conductors have *resistance,* a property which opposes the flow of current and which varies with the material of which the conductor is made.

2—The resistance of a wire is directly proportional to the specific resistance and the length and is inversely proportional to the cross section area.

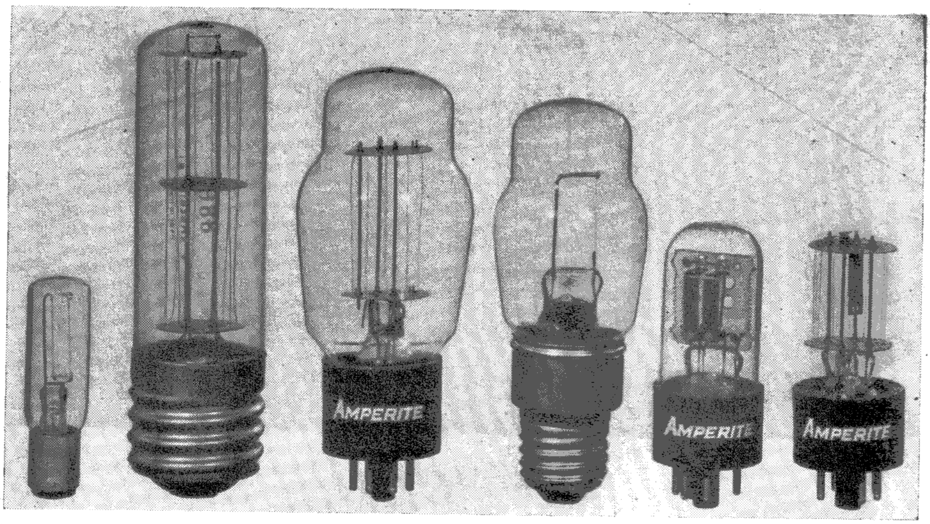
3—Ohm's law: The resistance of a conductor is equal to the voltage across the conductor divided by the current flowing through it.

4—The three algebraic forms of Ohm's law.

5—The use of the formulas for computing the total resistance of series and parallel combinations of resistors.

Often in radio circuits you will encounter more complex combinations of resistance than simple series and parallel arrangements.

In Figs. 11 and 12 are shown what are called series-parallel circuits, because they consist of a combination of series and parallel connections. In circuits of this type, first find the resistance of the parallel group, then add this



Courtesy of Amperite

The above photo shows several types of "ballast" resistors sealed in a vacuum. Note the several types of bases. Such resistors "take up" line voltage and current surges and maintain an even input into the receiver. They find their most common application in small AC-DC sets.

equivalent value to the other series values. For example, in Fig. 11 first find the effective resistance of 5, 10 and 20 ohm resistances, which are connected in parallel. In this case, the problem would be set up as follows:

$$R = \frac{1}{\frac{1}{5} + \frac{1}{10} + \frac{1}{20}}$$

$$= \frac{1}{\frac{4}{20} + \frac{2}{20} + \frac{1}{20}} = \frac{1}{\frac{7}{20}}$$

$$= 1 \times \frac{20}{7} = \frac{20}{7} = 2.86 \text{ ohms.}$$

To find the total resistance of the circuit, merely add the effective resistance value of the parallel group to the other resistances which are in series. This would simply be:

$R=6+8+2.86$ or 16.86 ohms.

Remember, this is the *total value* of the resistance between A and B of Fig 11. In Fig. 12 there is a circuit which is slightly more complex. However, the total resistance of the circuit may easily be found by using formulas which have already been mentioned.

First, find the equivalent resistances of branches A and B in parallel. Branch A, being in series, is obviously 15 ohms; the total resistance formed by adding 30 ohms in parallel to 15 ohms is

$$R = \frac{15 \times 30}{15+30} = \frac{450}{45} = 10 \text{ ohms.}$$

In series with this combination, add branch D of 15 ohms, giving a total of 25 ohms. Now branch C is connected in parallel with the entire combination thus far. The total equivalent resistance is then equal to:

$$Rt = \frac{25 \times 20}{25+20} = \frac{500}{45} = 11.1 \text{ ohms.}$$

This value is the equivalent resistance between terminals M and N.

You can solve for the resistance value of all ordinary circuits, no matter how complicated, by first solving for the small parallel

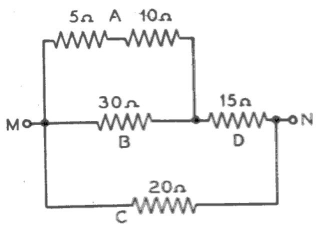


FIG.12.

groups and then solving for the value of the main circuit branches.

As you may have guessed, Ohm's law holds true just as well for alternating current circuits as for DC circuits where resistance only is concerned. That is, the relations between voltage, current and resistance are the same as for direct current, and the caluculations are done in exactly the same way as in the previous examples.

Next examine the circuit shown in Fig. 13. Resistor arrangements similar to this are sometimes used as *volume controls* in radio receivers. This circuit consists of a *fixed* resistor of 250 ohms in series with a *variable* resistor whose resistance may be varied from zero to 500 ohms. Across this combination assume that a constant voltage of 10 volts is maintained by a voltage source. The problem in this case is to determine how the different resistor voltage drops and the current varies when the variable resistor is changed in value.

Remember that this is a *series* circuit, and that the same current flows through both resistors. Using Ohm's law, you can write the following equations:

$$I = \frac{E_1}{R_1} \text{ and } I = \frac{E_2}{R_2} \text{ therefore,}$$

$$\frac{E_1}{R_1} = \frac{E_2}{R_2} \text{ and } \frac{E_1}{E_2} = R_1 \times R_2$$

This emphasizes a very important fact which you should have concluded from the problem of Fig. 2; that where the current is constant the voltage is directly proportional to the resistance. Now, in addition,

$$I = \frac{10}{R_1+R_2}$$

and since $\frac{E_1}{R_1} = I$, the following relation will be true.

$$\frac{E_1}{R_1} = \frac{10}{R_1+R_2} \text{ and } E_1 = \frac{10R_1}{R_1+R_2}$$

In exactly the same way,

$$E_2 = \frac{10R_2}{R_1+R_2}$$

Thus, the voltage drop across either one of the resistors is equal to the applied voltage times the value of that resistor divided by the sum of the two. Suppose that the variable resistor is set at 250 ohms. Then, of course,

$$E_1 = \frac{10 \times 250}{250+250} = 5 \text{ volts.}$$

and E_2 has the same value. Now suppose that R_2 is set at 500 ohms. Then,

$$E_1 = \frac{10 \times 250}{250+500} = 3.33 \text{ volts.}$$

A quick way of finding E_2 is to notice that

$E_2 = 10 - E_1$ so that

$E_2 = 10 - 3.33 = 6.67$ volts.

If R_2 is set at zero, then E_2 is zero.

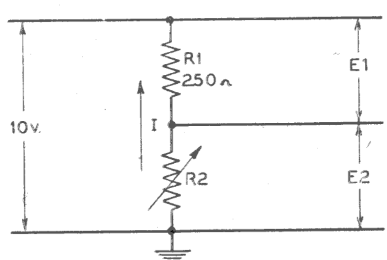


FIG. 13

and E_1 has the full value of 10 volts.

The current for any setting of R_2 is simply found from the formula which has already been given in that

$$I = \frac{10}{R_1 + R_2}$$

If R_2 is zero, the current is

$$I = \frac{10}{250} = .04 \text{ ampere}$$

and if R_2 is set at its full value, the current is

$$I = \frac{10}{750} = .0133 \text{ ampere.}$$

The foregoing two values give the maximum *variation* of the current for all of the possible settings of the variable resistor. This same type of circuit is very common in radio, and you should be sure that you understand the calculation processes involved and can duplicate them for any setting of the variable resistance.

A circuit which you will encounter frequently is the *voltage divider* which will be explained in greater detail in later lessons. When you come to study the lessons on vacuum tubes, you will learn that it is often necessary in a radio receiver to obtain voltages of various values from one common supply. A resistance network called a voltage divider is often used to obtain these voltages. In Fig. 14, such a combination is shown. The common supply in this case furnishes 300 volts with which to start. A *positive* voltage of 200 volts between terminal B and the chassis (indicated by the *ground* symbol) is needed. The circuit connected to this terminal requires a current of 2 ma. The circuit connected to terminal C operates at a positive voltage of 290 volts and requires a 10 ma. current. In addition, it is required that the *negative* lead of the two circuits at terminal A shall operate with a negative voltage of 10 volts between A and the chassis. The current drawn from the 300 volt supply is to be 22 ma. The problem is to find the proper resistance values for resistors R_1, R_2 and R_3 in order that the voltage and current requirements will be properly filled.

Before proceeding with the solution, you should be familiar with one electrical principle which has not been mentioned before. *Kirchhoff's law* for currents simply states that the sum of the currents entering an electrical junction

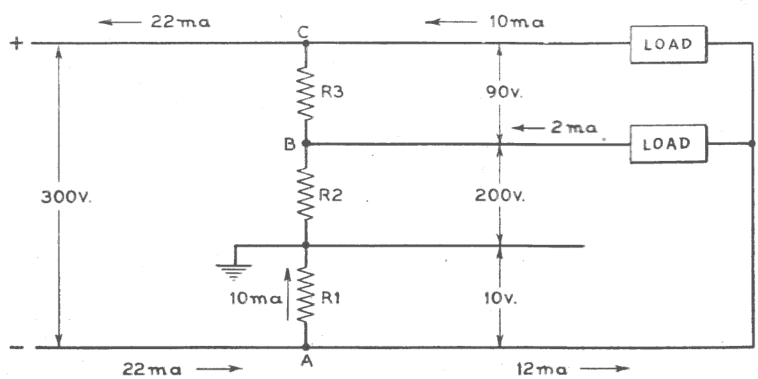


FIG. 14

point is equal to the sum of the currents leaving the junction point. This fact hardly needs mentioning, since it is exactly what you would expect, but you will need to use it in the voltage divider problem.

To begin, you should always draw a diagram of such a circuit and label the various leads and terminals with the proper current and voltages, as shown in Fig. 14. At terminal A, the supply furnishes a current of 22 ma. Since the negative lead carries the current of both of the load circuits, the current in this lead is 10 plus 2, or 12 ma. From Kirchhoff's law, then, the current flowing in resistor R_1 must be the difference of 22 and 12, or 10 ma. The voltage drop across this resistor is 10 volts, and, therefore,

$$R_1 = \frac{10}{.01} = 1000 \text{ ohms.}$$

The same current of 10 ma. flows through R_2. Since the voltage drop across this resistor is 200 volts,

$$R_2 = \frac{200}{.01} = 20{,}000 \text{ ohms.}$$

At terminal B, the 10 ma. current from R_2 and the 2 ma. current from one of the load circuits add to give a current of 12 ma. flowing through R_3. The voltage drop across R_3 is 90 volts, and, therefore,

$$R_3 = \frac{90}{.012} = 7500 \text{ ohms.}$$

As a final check, you will notice that the 12 ma. current from R_3 and the 10 ma. current from the other load circuit combine to give the supply current of 22 ma. Thus the three resistance values are determined.

ELECTRICAL POWER

Whenever current flows in a conductor, the resistance opposes the flow of electrons. Thus the electrons encounter a kind of *frictional* force, and, in overcoming this force, *heat is generated.* This heat energy is wasted to the surrounding air, and an *energy loss* occurs.

It takes *power* to sustain any kind of energy flow, and, in the case of the heat loss from a resistor, the power comes from the same current whose action generates the heat. The common mechanical unit of power is the *watt,* which is $\frac{1}{746}$ of a horsepower.

The power in a resistive electrical circuit is very easily calculated from the following formula:

$$P = EI$$

where P is the power in watts, E is the voltage across the circuit, and I is the current in amperes flowing through it. From Ohm's law, the value for either the voltage or the current may be substituted in the power formula to give the power in terms of the resistance, as follows:

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

Or, $P = EI = I \times I \times R = I^2R$

Thus, if any two of the factors involved in Ohm's law are known, the power can be calculated.

For example, calculate the power dissipation of resistors R_1 and R_2 in Fig. 14. For R_1, $P = I^2R_1 = .01 \times .01 \times 1000 = 0.1$ watt. For R_2

$$P = \frac{E^2}{R_2} = \frac{200 \times 200}{20{,}000}$$

$$= \frac{40{,}000}{20{,}000} = 2 \text{ watts.}$$

The power or *watt rating* of a resistor has no connection with its resistance value. Do not make the mistake of assuming that a certain resistance limits the current to a definite value because the current is determined by the applied voltage. A 10,000 ohm resistor with a voltage drop of 100 volts need have a power rating of only one watt, but if the voltage were raised to 1000 volts, a 100 watt resistor would be needed.

Whereas a 1 watt resistor may be only as large as a pencil, a 10,000 watt resistor having the same number of ohms would be as large as a railroad cross-tie or of an entirely different form. It either must be large enough so that the free air about it may carry away the heat or it must be artificially cooled by a fan blast or water jacket and radiator. This shows clearly that the resistance value of a resistor does not determine its current carrying capacity except for a definite voltage and that neither individually has anything to do with its size.

If a resistor has a surface area of 2 square inches per watt of power, it will operate safely without an abnormal increase in temperature because the free air around it can carry off the heat at the rate of 1 watt easily. The smaller it is made, the less will be its surface area and hence the higher will be its operating temperature. As mentioned before temperature has very little effect on the resistance value, but heat may cause a chemical change, oxidization, etc., causing the unit to become defective. The larger the unit, the less will be its operating temperature, as compared to normal or room temperature. Certain types of resistors—ceramic enameled types—are made to operate quite hot, while this heat value may destroy other types. Such resistors may dissipate as high as 10 watts per square inch of surface area and yet be safely operated.

The power rating is that specified by the maker of the unit for normal operation. In practice, resistors often have a power rating from 50% to 100% in excess of the actual power they are required to dissipate. This is done to provide for an ample safety factor, and as a protection against overload.

Some of the more common uses of resistors in radio circuits are shown in Fig. 15. At A there is a plate resistor R_1 (250,000 ohms), which must carry a current of 1 ma. maximum. Converting 1 ma. into amperes, this value of current is equal to .001 ampere. From $P=I^2R$ the power rating of the resistor is equal to:

$$P=.001^2\times 250{,}000$$
$$=.000001\times 250{,}000$$
$$=.25$$ watt which is the actual power rating.

At B in Fig. 15 there is a screen grid resistor, R_1 (75,000 ohms) which must carry 2 ma. (.002 ampere) with 150 volts impressed across it. If you did not know the

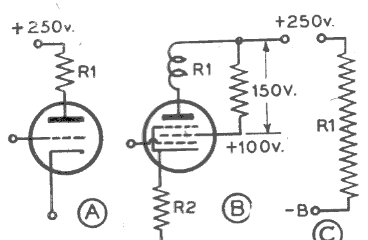


FIG. 15

current value the power value could be obtained as follows:

$$P = \frac{E^2}{R} = \frac{150^2}{75,000} = \frac{22,500}{75,000}$$
$= .3$ watt.

For R_2 of this same circuit there must be impressed 3 volts with a current of 10 ma. flowing—thus $\frac{3}{.01} = 300$ ohms and the power rating is equal to $3 \times .01 = .03$ watt.

For the voltage divider at C in Fig. 15 there is a current of 20 ma. (.02 ampere) with a voltage of 250 volts. Without finding what value of resistance is needed, you know that P equals $E \times I$ and therefore $250 \times .02 = 5$ watts for R_1.

You should now go over the material covered since the first review, being sure that you understand thoroughly the following points:

1—The calculation procedure in solving series-parallel combinations.

2—Kirchhoff's law of currents.

3—The solution of the voltage divider type of problem.

4—The calculation of power dissipation in resistors.

CONDUCTANCE

There is one more concept which is sometimes useful in studies of resistance, and that is the concept of *conductance*. In speaking of conductors, resistance measures their conductance ability in an *inverse* manner; that is, the poorer a conductor, the higher is its resistance. Conductance the symbol of which is G, however, is a direct measure of conducting ability; the better the conductor the larger is its conductance. Conductance is thus definned as the reciprocal of resistance.

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

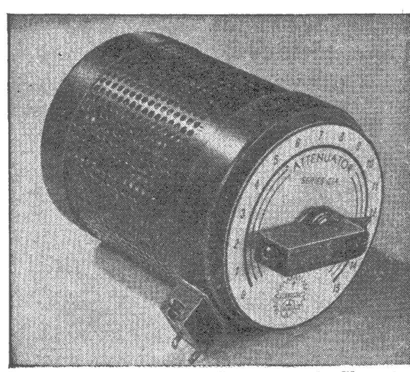
where R is the resistance in ohms, and G is the conductance in *mho* (ohm spelled in reverse). In Ohm's law, then.

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

$I = EG$ (meaning E times G).

Thus it is seen that Ohm's law holds true for conductance just as it does for resistance. When G is substituted for R, you again have the familiar arrangement for three letters, but, in this case, it shows the relation between voltage, current and *conductance.*

Now refer back to the parallel resistance formula. Mathematically speaking, this formula means that the effective resistance of a parallel group of resistors is equal to the reciprocal of the sum of the separate reciprocals. Reference to your SAR math book will show that the reciprocal of a number is nothing more than one divided by that number, that is, $\frac{1}{N}$. A still



Courtesy of Clarostat

This is a special "attenuator" which maintains a constant impedance. It is made of separate wire wound precision resistors. It is used in transmitter and Public Address systems.

more simple statement of this principle is that, if a reciprocal fraction is inverted so that the denominator becomes the numerator and the numerator becomes the denominator, the reciprocal value is automatically obtained. For instance, consider a resistor of 10 ohms. The reciprocal of this is the conductance of the resistor which is equal to $\frac{1}{10}$. If you want to reconvert this to a resistance value, merely turn the fraction over and it reads $\frac{10}{1}$ or, simply, 10.

Now it has been shown that conductance is equal to the reciprocal of the resistance. In a parallel group of resistors, to find the effective resistance value in terms of conductance, *add the conductances of the separate branches.* This gives the effective conductance of the combination. This will give you a fractional answer, and to find the effective resistance, merely invert the fraction and reduce it to its lowest terms and you automatically have the effective resistance value.

To give the conductance unit, mho, a definition as has been done with resistance, it may be stated that 1 mho is the conductance of a circuit through which 1 volt will force 1 ampere of current to flow. Later on you will learn that the unit mho is frequently too large, and thus is often divided into a unit called the micromho, which is equal to one-millionth of a mho.

Here are some rules which you might find convenient to remember about resistance and conductance. The effective resistance of a series circuit is the sum of the separate resistances. The effective conductance of a parallel circuit is the sum of the separate conductances. From this explanation, it should be clear that you are never to add resistances in parallel nor add conductances which are in series. It has already been pointed out that to find the resistance of a parallel circuit, all you have to do is take the reciprocal of the sum of the reciprocals of the individual resistors. In like manner, to obtain the conductance of a series combination of resistors, all you need to do is obtain the reciprocal of the sum of the reciprocals of the individual conductances.

SERIES CIRCUITS

Every type of electrical circuit has characteristics which are peculiar to it. For instance, in a series circuit, the following conditions apply. *The current is the same in every part of the circuit.* Both the resistance and voltage drops, however, may be of different values—in practical circuits, they usually are different. However, if it should happen that the separate resistors have the same value, then the voltage drops for the resistors will be the same for each resistor. In practical circuits, the separate resistors are not usually of the same value, and, therefore it follows that the voltage drop across the resistors will be of different value. And, as already demonstrated, the sum of the separate voltage drops across resistors in a series circuit must be equal to the total voltage applied to the series circuit.

PARALLEL CIRCUITS

Parallel circuits also have conditions which are peculiar to them. *In any parallel combination, the voltage drop is the same across each resistor in the parallel group.* The current, however, through each resistor will be of different value unless it happens that two or more resistors have the same value. The total current in the parallel circuit is, of course, the sum of the currents through the separate resistors. The effective resistance of a parallel circuit is always less in value than the smallest resistor in the group. It has already been pointed out that the effective resistance value may be found by the reciprocal method or by the conductance method, whichever is more convenient.

SERIES-PARALLEL CIRCUITS

In circuits of this type, the effective resistance may be found by a definite method just as for series or parallel circuits alone. The proper procedure is first to find the effective value of the series units by adding them to get a total value. This total value of the series part of the circuit will then be in parallel with one or more other parallel circuits. You then proceed just as for any other parallel circuit, letting the series part of the circuit remain equal to *one parallel value.* This principle is demonstrated in Fig. 12 where the 5 and 10 ohm resistors are added to give 15 ohms.

THINGS TO REMEMBER ABOUT POWER RATINGS OF RESISTORS

All manufactured resistors are rated in both resistance and power values. Common radio resistors are rated at 1/3, 1/2, 1, 2, 5, 10, etc. watts. The more common watt rating for resistors ranges from 1/3 to 2 watts. Thus it is common practice on radio diagrams to see specified, for instance, a 1000 ohm resistor rated at various watt or power values. The only difference between a 1/2 and 2 watt 1000 ohm resistor is that the 2 watt resistor will dissipate four times as much electrical power as the 1/2 watt resistor. So do not confuse resistance and power ratings. They relate to entirely different things and should be so regarded.

Often in radio circuits, especially in replacement and repair work, it is necessary to use two or more resistors to replace one resistor. The reason for this is that the serviceman might not always have on hand or have readily obtainable a resistor of the correct value and power rating. Consider the example where the need is to replace an 8000 ohm, 2 watt resistor. The problem becomes what equivalent value may be used as a replacement? Either a series or parallel method of connection can be employed as long as the effective resistance is correct. For example, using the series method of connection, a 5000 and 3000 ohm resistor may be employed. In like manner, two 4000 ohm resistors may be used or a 6000 and a 2000 ohm resistor. Three or more resistors may also be used. For instance, 1000, 2000 and 5000 total 8000 ohms. Any other series group of resistors could be employed as long as the total was not more than 8000 ohms.

The next consideration is the power rating of the resistors. The original specification for the 8000 ohm resistor is 2 watts. Thus if

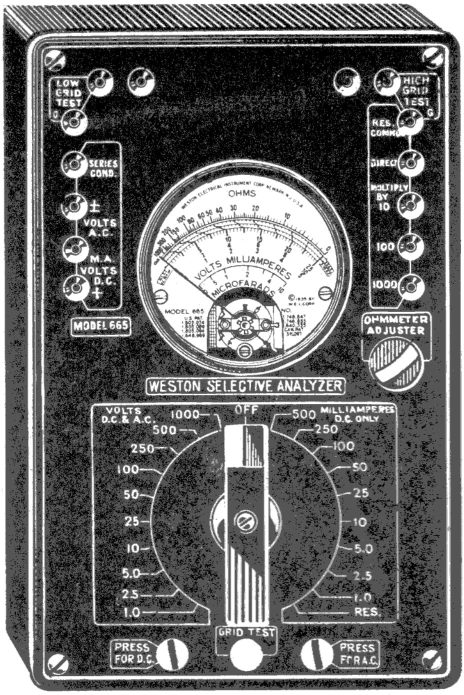


Photo Courtesy of Weston

This is a small unit analyzer often called a multimeter. It has several voltage and current ranges for both AC and DC. In addition, it includes 4 ohmmeter ranges enabling the serviceman to measure resistances up to several megohms.

two 4000 ohm resistors are used, they could be rated at 1 watt each, although they may be safely rated at more than 1 watt each. The additional, excess rating would do no harm, although the minimum requirement is 1 watt each. For another group of resistors that might be used to total 8000 ohms, the power rating of the separate resistors would be equal to I^2R (current squared, times resistance).

PRACTICAL POWER RATINGS FOR RESISTORS

Radio and electrical men rarely, if ever, use a resistor with a power rating which corresponds exactly to the calculated rating. If this were done, the resistor would be working under maximum load all the time and thus its life would be materially shortened. Then, too, there is the fact that calculated values are often in decimal parts of a watt, and such resistors are not available on the market. It is common practice in replacement work to use a resistor as a replacement from 50% to 100% in excess of calculated power requirements. For instance, in a circuit where calculations show that a 1-watt resistor should be used, it would be good practice to use as a minimum a 2-watt resistor. Most radio resistors are not required to dissipate more than one or two watts. There are some few cases in power units and in large public address installations and in transmitters, where the power requirements are up to 100 watts and more. Many such resistors are of special construction and may be quite lengthy or large so as to present the maximum surface area to the air in order to dissipate the required heat efficiently.

Ninety per cent of the replacement resistors for receivers will fall within the 1/2 to 2 watt rating. These units are standard by most manufacturers and are usually stock items carried by the radio parts jobber or wholesaler. Thus if you should have to guess as to the power rating of a resistor, a 2 watt unit and often a smaller rated resistor will be entirely sufficient. If you want to be sure, however, the exact power rating can be calculated according to formulas given in this lesson, and then you can select a unit for actual replacement, having at least a 50% excess rating.

TYPES OF RESISTORS

A resistor element is so common-place in radio and electrical work that little thought is given to the type of resistor that must be used. Most common resistors are wire wound, of the carbon stick type, or of the metallized type wherein a metallic mixture is sprayed, painted, or baked on a ceramic or other insulating form.

The type of construction selected for a given purpose is controlled by cost, power requirements, engineering preference, etc. Then, too, some forms of resistor elements will give the desired resistance in ohms in a small area, whereas a much larger area may be required for another type of element. In practical radio service work, you will find all types of resistors employed, so you ought to become familiar with them so that replacement work may be done quickly and efficiently. For instance, a certain manufacturer may employ carbon resistors for certain reasons of his own, but this does not mean that you would have to use carbon for replacement, provided, of course, the type you did use was of correct resistance and power rating. It might happen that you have available or can easily obtain a metallized resistor or a wire wound type. There is no reason why you could not use these resistors as replacements if it happens to be more convenient.

WIRE WOUND RESISTORS

Resistor units may be made by hand, by winding wire on a suitable insulating form although this would be a crude way of making a resistor. For instance, if copper wire is used, it would take a large amount of it to make a very large resistor. As a consequence, special wire alloys have been made and where wire wound resistors are required, a special alloy type of wire is used. Nichrome wire is usually used for this purpose as well as Manganin and Constantan. For power units and large installations, the wire wound resistor is used in nearly all cases, especially where values of power above 5 watts are to be dissipated. These are known to practical radio men as *power wire wound resistors,* and that is what you would call for if you were buying a resistor of this type. When you purchase the resistor, however, you probably could not see the wire winding, because it would be covered with a cement or enamel coating.

CARBON RESISTORS

The carbon stick type of resistor is nothing more than a length of carbon rod or stick, cut to specified length with wire leads attached to the ends. These are made from powdered carbon combined with other ingredients in various sizes and lengths, depending upon resistance and power requirements. There are many millions of resistors of this type in use, and many service men do not use anything but carbon resistors for replacement work. They are entirely satisfactory as long as an adequate choice of power rating is made.

METALLIZED RESISTORS

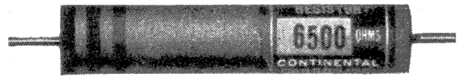
The metallized resistor is similar in shape and size to the carbon type and both types of resistors will often be found in a single radio set. In manufacturing the metallized type of resistor, a *mix* is sprayed, painted or otherwise applied to a small ceramic form. The length and thickness of the applied *mix* determines the resistance value. The *mix* itself is, of course, a trade secret. It consists of powdered ingredients mixed in various proportions, depending upon the resistance value wanted. As applied to the ceramic form, the *mix* is liquid which makes for efficient manufacturing in large quantities. After the *mix* is put on its form, it is allowed to dry and then leads are attached to the ends. The whole unit is then completely sealed with a Phenolic compound which completely insulates it. Thus, as a finished resistor, all you can see is the insulating compound which surrounds the resistor element and the two wire leads to the ends.

RHEOSTATS AND POTENTIOMETERS

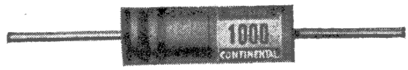
Resistors are also made in a variable form wherein the ohmic resistance can be varied by turning a control knob. Such units as these are used for volume controls, tone controls, etc. The two terminal type is called a rheostat and the three terminal type is called a potentiometer. They are made in wire wound, metallic and various carbonized forms. The wire wound type is usually required to dissipate considerable power—from 2 watts on up to 100 watts or more. The other type, wherein carbon or metallized manufacturing is employed, consists of a circular insulating form over which a moving contact travels, and in this way a variation in the degree of resistance is obtained.

TEMPERATURE COEFFICIENT

All known resistor elements will either decrease or increase in resistance value as heat is dissipated.



C2-2 Watt 11/32 x 1 13/16



C1-1 Watt 9/32 x 7/8

C½-½ Watt 7/32 x 5/8

C⅓-⅓ Watt 13/32 x 7/64

Courtesy of Continental

These are common replacement type resistors for radio sets. Sizes are shown for 1/3, ½, 1 and 2 watts. They may be of either the carbon or metalized types.

Practically all of the wire wound and metallized resistor units will increase slightly in resistance with an increase in temperature. This is particularly true of incandescent light bulbs, pilot light bulbs and filaments of vacuum tubes. Their cold or non-operating resistance value may be very low, but when they are heated to operating temperature, their resistance value may increase up to 100% or more. There is not this much variation in the usual type of replacement resistor for it will only increase a slight amount and is not a factor that you ordinarily need to consider. Resistor elements which show an increase in resistance with an increase in temperature are said to have a *positive temperature coefficient.*

The carbon resistor acts differently from the wire wound and metallized types. Its resistance will decrease slightly with an increase in temperature, and for this reason it is said to have a *negative temperature coefficient.*

TOLERANCE

When you buy from your radio parts jobber a resistor rated at 100 ohms, it does not mean that you are getting a resistor with an exact value of 100 ohms. Resistors are made commercially with a tolerance value, *plus or minus* a certain per cent of the rated value. Most replacement resistors for ordinary radio work have a tolerance of plus or minus 20%. Thus, in this case, the resistor you buy can have a value as low as 80 ohms or as high as 120 ohms. Practically, it will usually have a value somewhere between 80 and 120 ohms.

Resistors are available in tolerance of from .1% to 20% of the rated value. The less the tolerance value, the more expensive the resistor because it takes much more testing and adjusting to make a resistor of an exact value than it does to make one of approximate value. That is the reason, for example, that a 20% tolerance resistor costs only a few cents whereas a wire wound type with a tolerance of .1% may cost two or three dollars.

R. M. A. COLOR CODE FOR RESISTORS

The Radio Manufacturers Association has adopted a standard color code which indicates the resistor value for a given resistor. Thus, colors are placed on practically every resistor manufactured in this country which indicates the ohmic value of the resistor.

There are two standard systems in use although the same color code is employed. Figure 16 shows one system wherein the body of the resistor is colored, and a band or dot of color in about the center is used for the third color. Figure 17 shows the second system in use where three colors at one end of the resistor are used. Sometimes a fourth color is used in both systems, and it indicates the *tolerance* of the resistor.

In Fig. 16, the body color represents the first significant figure of the resistor value. The end color represents the second significant figure of the resistor value, and the band in the center (or a single dot of color, in some cases) denotes the number of ciphers after the first two significant figures.

In Fig. 17 the first band of color indicates the first significant figure of the resistor value, the second band indicates the second significant figure, and the third band represents the number of ciphers following the two significant figures.

In cases where a fourth band or dot of color is employed, it will be either gold or silver. The gold color is for a tolerance of plus or minus 5%, and the silver color is for a

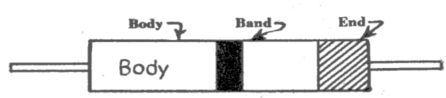


FIG. 16

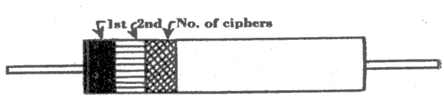


FIG. 17

tolerance of plus or minus 10%. No gold or silver color indicates that the resistor has a tolerance of plus or minus 20%. Thus, most resistors will not have this fourth color. To the right is a box of typical resistor color code examples and below you will find an explanation of the color code for resistors.

RESISTANCE	BODY A	END B	DOT C
200 ohms	Red	Black	Brown
300 ohms	Orange	Black	Brown
500 ohms	Green	Black	Brown
1,000 ohms	Brown	Black	Red
1,500 ohms	Brown	Green	Red
2,000 ohms	Red	Black	Red
3,500 ohms	Orange	Green	Red
5,000 ohms	Green	Black	Red
9,000 ohms	White	Black	Red
10,000 ohms	Brown	Black	Orange
15,000 ohms	Brown	Green	Orange
25,000 ohms	Red	Green	Orange
75,000 ohms	Violet	Green	Orange
200,000 ohms	Red	Black	Yellow

COLOR	SIGNIFICANT FIGURE	MULTIPLY BY
Black	0	0
Brown	1	10
Red	2	100
Orange	3	1,000
Yellow	4	10,000
Green	5	100,000
Blue	6	1,000,000
Violet	7	10,000,000
Gray	8	100,000,000
White	9	1,000,000,000

How table is used:
A resistor is colored Brown-Green-Yellow. What is its value? Referring to the table, brown is the body color and corresponds to the first significant figure of 1. Green is the end color and shows the second significant figure to be 5. Yellow is the dot or band color and according to the table has a multiplying value of 10,000. The first two significant figures are 15, and this multiplied by 10,000 gives a value of 150,000. Other examples follow:

(7) Violet	(5) Green	(100) Red	Value=7,500
(4) Yellow	(0) Black	(1000) Orange	Value=40,000
(4) Yellow	(0) Black	(10,000) Yellow	Value=400,000
(3) Orange	(0) Black	(100,000) Green	Value=3,000,000
(3) Orange	(3) Orange	(.1) Gold	Value=3.3

Odd values of resistors are color coded in the following manner. Gold denotes a multiplying value of .1 and Silver denotes a multiplying value of .01. Thus, orange-orange denotes 33 and with a gold band or dot the multiplying value is .1. Thus $33 \times .1 = 3.3$ ohms.

In cases where gold or silver is used with *three other colors,* gold or silver represents the *tolerance value.* In the case where gold or silver is used with *two other colors* they represent .1 and .01 multiplying values respectively.

These questions are designed to test your knowledge of this lesson. Read them over first to see if you can answer them. If you feel confident that you can, then write out your answers, numbering them to correspond to the questions. If you are not confident that you can answer the questions, re-study the lesson one or more times before writing out your answers. Be sure to answer every question, for if you fail to answer a question, it will reduce your grade on this lesson. When all questions have been answered, mail them to us for grading.

QUESTIONS

No. 1. When two resistors are wired in series, will the total resistance be greater or less than either resistor?

No. 2. Where two resistors are wired in parallel, will the total resistance which they form be equal to, greater, or less than either resistor?

No. 3. If you have a 1000 ohm circuit and place a 500 ohm resistor in series with it, will the current through the circuit increase or decrease if the same voltage is maintained?

No. 4. If you know the resistance of a circuit and the current flowing through it, how can you find the voltage impressed across it?

No. 5. What is the total effective resistance of two 500 ohm resistors connected in parallel?

No. 6. If you have a 200 ohm circuit and place a 25 ohm resistor in parallel with it will the current increase or decrease?

No. 7. In a series circuit such as that of Fig. 4, can one tube filament carry more or less current than the other?

No. 8. Does the resistance of a wire depend entirely on its length and diameter or partly on the material of which it is made?

No. 9. Does the resistance value of a resistor have anything to do with its size?

No. 10. What is the color code of a 400,000 ohm resistor having a tolerance of 5%?