RADIO RESISTORS AND HOW THEY ARE USED

5FR-4

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

PIONEER HOME STUDY RADIO SCHOOL

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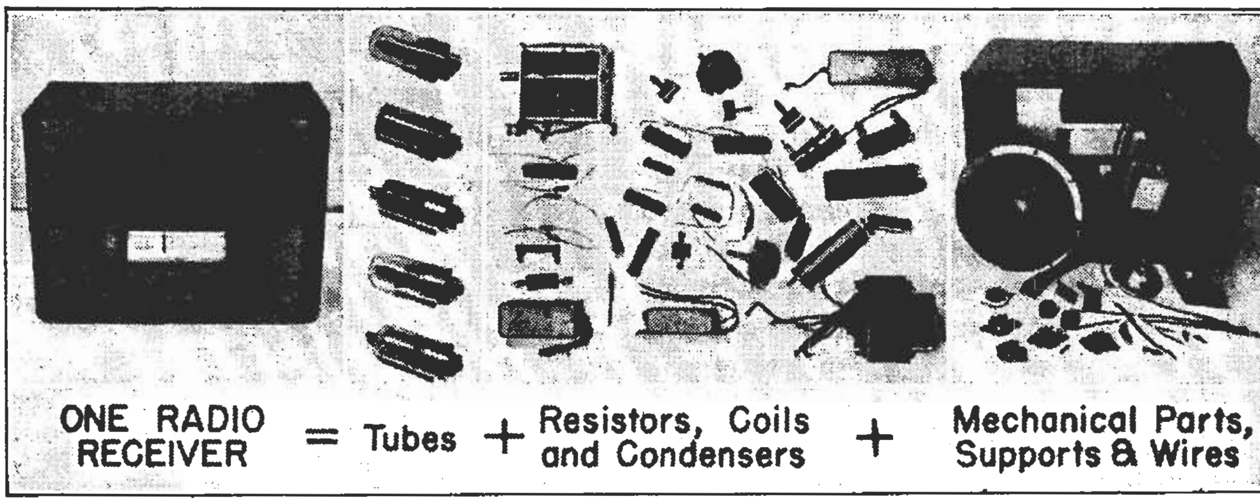
Why Resistors Are Important in Radio

IN addition to tubes, there are only three kinds of radio devices *which control voltages and currents in radio circuits,* and thereby make radio possible. These are *resistors, coils* and *condensers.* Terminals, wires, moving contacts or other mechanical parts merely provide connections or supports for these three basic radio parts.

You'll find resistors in power packs, reducing the high d.c. output voltage to the various lower voltage values required by the tubes in transmitters or receivers.

You'll often find resistors in tone control circuits, working with condensers to give you a choice of tone—mellow, brilliant or deep bass.



Thus, volume controls are combinations of *resistors* and mechanical parts. Audio, power and r.f. transformers are combinations of *coils.* I.F. transformers are combinations of *coils* and *condensers.* Loudspeakers are combinations of *coils* and mechanical parts.

Jobs for Resistors. You'll find resistors in practically every radio tube circuit. Sometimes they work alone or work with coils and condensers to keep radio signals in their correct paths. Sometimes they furnish the correct d.c. operating voltages for the tube electrodes. Sometimes they serve as loads for radio tube circuits.

In dozens and dozens of other places in radio equipment, you'll find resistors working silently and effectively to help make possible the magic of modern radio. Certainly, resistors deserve every bit of the attention we shall give them.

A Trio of Lessons. This lesson gives you practical information about resistors and the laws which govern their performance in radio circuits. The next two lessons give you the important basic facts about coils and condensers. Thus, in just three lessons you master the fundamental facts about three important radio parts.

Ohm's Law Tells "How Much"

Radio's Simplest Resistor Circuit. In Fig. *1* is the simplest complete circuit we can have in radio apparatus. The source provides exactly the correct voltage value for the resistance load, so the source and load are connected together directly by wires.

This simple circuit has only three values—the source voltage, the current, and the load resistance. In a previous lesson, you learned that these values are related to each other in a logical way. For instance, the current can be increased either by raising the source voltage or lowering the load resistance. Likewise, the current can be reduced by lowering the voltage or raising the resistance.

In most radio jobs, it is sufficient to know only in this general way how the current is going to change when either the voltage or resistance are changed. There will be times, however, when you want to know *exactly how much* the new current value will be.

The basic radio law which gives you this definite information is known to all radio men as Ohm's Law, because it was first discovered and proved to be true by the scientist George Simon Ohm, in 1826.

Ohm's Law expresses the exact relationship between voltage, current and resistance for any circuit containing only resistors. You'll find later that you can also make this law work for other radio parts, too.

Ohm's Law for Current. To find the current, *divide the voltage value by the resistance value.*

The voltage value should be in *volts* (as it usually is), and the resistance value should be *ohms*. The result will then be the current in *amperes*. For example, if the voltage is 50 volts and the resistance is 25 ohms, the current will be 2 amperes ($50 \div 25 = 2$).

Formula for Ohm's Law. Radio men usually prefer to work with a simplified version of Ohm's Law, in

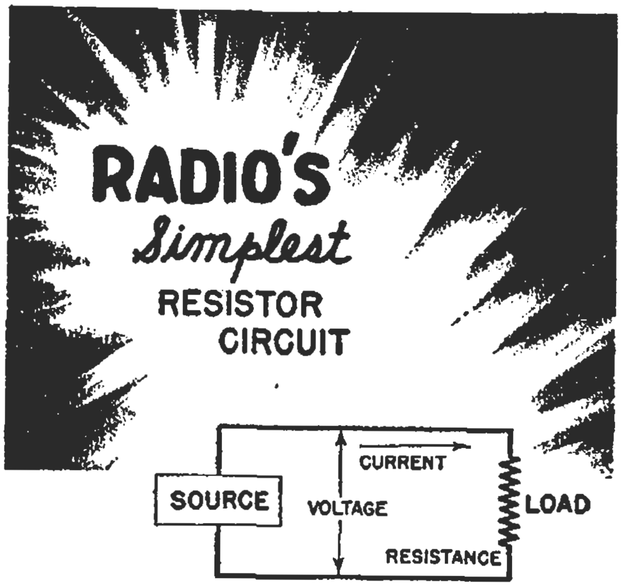


FIG. 1. Simplest basic circuit used in radio. The source voltage is exactly correct for the load, so these two parts are here connected together directly by wires. When the source voltage is too high for the load, however, the connection is made with a combination of wires and radio parts, chiefly resistors. The connecting system is sometimes known as a TRANSMISSION SYSTEM, because it serves to "transmit" power from the source to the load.

which letters and arithmetic signs replace words. These letters are an important part of the language of radio, so let us get acquainted with them now.

R is always used to represent **RESISTANCE.**

I is always used to represent **CURRENT.** (This may not seem logical, but is done to avoid confusion because the letter C is used for condensers. If you like, you can think of I as standing for *intensity of current.*)

E or V is used to represent VOLTAGE. (E comes from *electromotive force,* which is another name for a source voltage.)

By using these letters, we can condense Ohm's Law into a simple formula which is much easier to use.

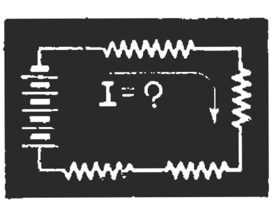
Instead of saying that current (I) is equal to voltage (E) divided by resistance (R), we can simply say: $I = E \div R$.

You will occasionally find Ohm's Law expressed in an even simpler manner. One letter is placed *under* the other to indicate division. The short line between the letters means that the *value above the line is to be divided by the value below the line.* This dividing line can either be slanting or horizontal. When we express Ohm's Law in this simplest possible form, here is what we get:

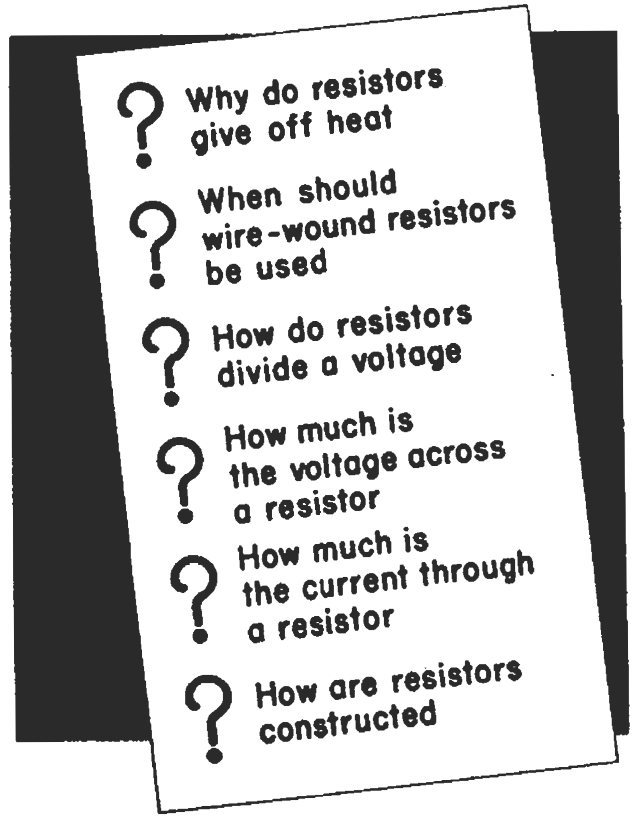
$$I = \frac{E}{R} \qquad I = E/R$$

Both formulas are pronounced *I equals E over R,* and both mean the same thing—that the amount of current is equal to the amount of voltage divided by the amount of resistance.

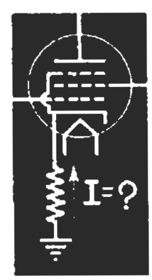
Ohm's Law can be used to find the exact current value flowing through a complete d.c. circuit or through any portion of the circuit. Of course, if you are figuring the current in *a complete circuit,* all your values should be total values for the entire circuit. Likewise, when figuring the current in *part of a circuit* or in a single resistor, all your values must be for just that part of the circuit. A few simple examples will illustrate these entirely logical rules for applying Ohm's Law.



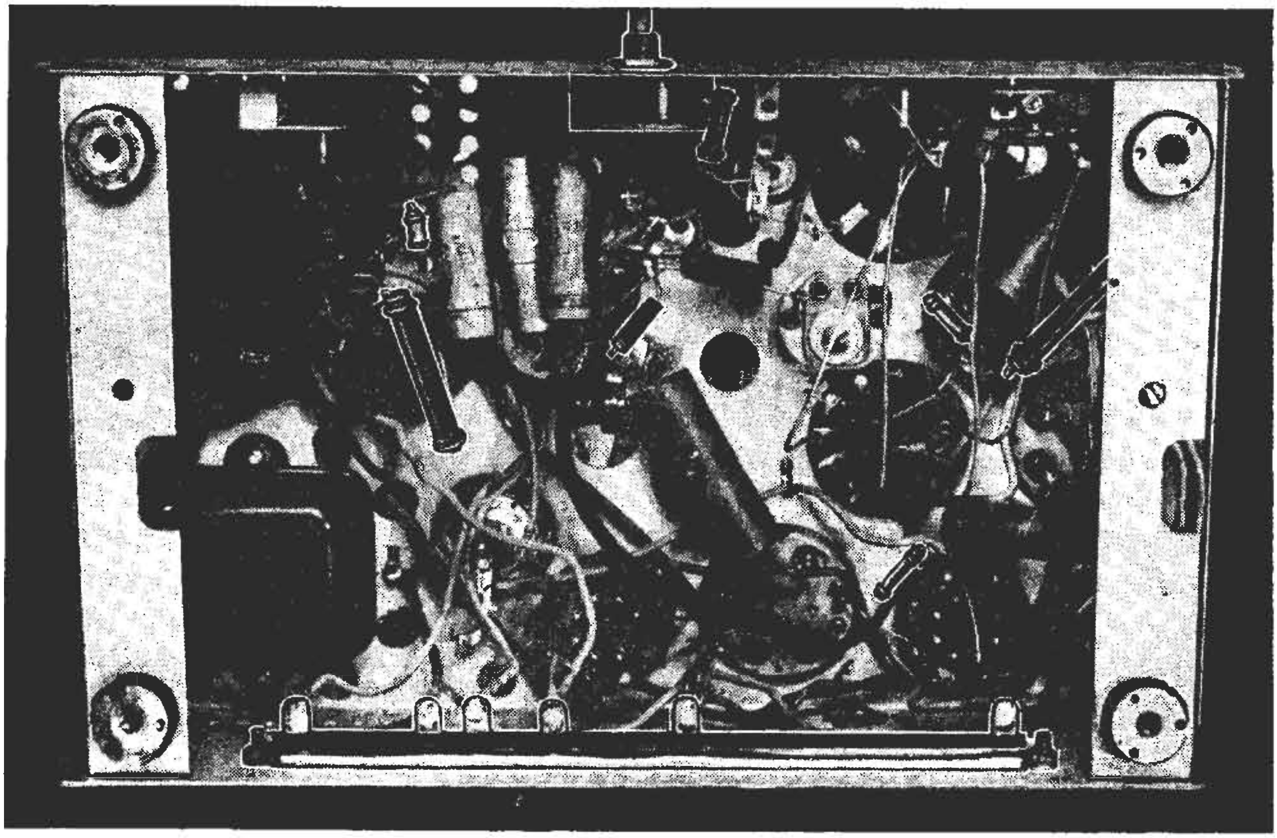
Suppose we want to find the current in this series circuit. The voltage which acts on the *complete* circuit is **the battery voltage: let's say it is 90** volts. The total circuit resistance is the sum of the individual resistor values since all four resistors are in series; let's say these values are known and add up to 30 ohms. The current value is equal to the voltage value divided by the resistance value, so we divide 90 by 30. This gives 3 amperes as the circuit current.



Here are just a few of the resistor questions which are answered in this lesson.



Now suppose we need to find the current through the single cathode resistor in this tube circuit, and haven't time to unsolder the cathode connection and insert an ammeter. We measure the voltage across the resistor with a d.c. voltmeter—let's say we find it's 12 volts. *Next,* we read the resistance value marked on the resistor—and let's say this is 300 ohms. Remembering $I = E \div R$, we divide 12 by 300, and get .04 ampere as the current through the resistor. Notice that we didn't have to pay any attention to the rest of the



No matter whether it's the voltage, current or resistance value you want to know for any one of the resistors underneath the chassis of this receiver, Ohm's Law can tell you how much the value will be.

circuit; we wanted to know the resistor current, so we used only the voltage and resistance values of the resistor itself.

One thing you must realize when using Ohm's Law is that you are dealing with *numbers*. You are not dividing volts by ohms. You can't do that any more than you can divide dollars by people. However, you can divide a *number* of dollars by a *number* of people, to get something entirely different—the *number* of dollars each person gets. That's what we do in radio—we divide the *number* of volts by the *number* of ohms, and get something entirely different—the *number* of amperes flowing. Keep this in mind, and you will never be asking, *"How many volts are there in an ohm?"* This question would be just like asking how many people there are in a dollar!

Finding Voltage or Resistance. So far, we have used Ohm's Law only to find the current when we know the voltage and resistance values. But sometimes we know what the current is, and want to find one of the other values instead. This can still be done with Ohm's Law—in fact, whenever *any two* of the three values (voltage, current and resistance) are known, Ohm's Law will help you find the third value.

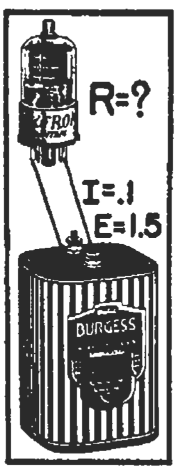
It is perfectly possible to use our already-familiar current formula to find voltage or resistance, even though this might be a bit inconvenient. For example, if I was 2 amperes and E was 10 volts, but R was unknown, we could start with $I = E/R$. Putting our two known values in place of the letters, we would get $2 = 10/R$. This tells us that 10 divided by the value of R gives 2. There is only one value of R which will work here—5. Thus, we find that the resistance is 5 ohms.

In much the same way, the current formula could be used to find the

value of E. It works out all right, but in many cases it is easier and quicker to use Ohm's Law in two other forms, one for finding voltage and the other for finding resistance. While you are reading about these, keep in mind that the three versions of Ohm's Law are just convenient different ways of expressing *the same basic principle.*

Ohm's Law for RESISTANCE. To find the resistance, *divide the voltage value by the current value.* Thus, if the voltage is 10 volts and the current is 2 amperes, the resistance will be 5 ohms ($10 \div 2 = 5$).

This version of Ohm's Law can likewise be expressed in simpler forms, as $R = E \div I$ or $R = E/I$.



The filament circuit in a portable radio receiver makes an interesting example for this resistance-finding formula. The voltage is 1.5 volts, and let's say the rated filament current is .1 ampere for the tube shown here. First we write: $R = E \div I$. Next, we substitute the two known values: $R = 1.5 \div .1$, and divide, thus getting 15 ohms as the resistance of the filament when hot.

Ohm's Law for VOLTAGE. To find the voltage, *multiply the current value by the resistance value.* Thus, if the current is 2 amperes and the resistance is 5 ohms, the voltage will be 10 volts ($2 \times 5 = 10$).

This version of Ohm's Law can be written as $E = I \times R$. Sometimes the multiplication sign is omitted, giving $E = IR$. (In formulas, letters are often placed side by side like this to indicate multiplication.)

To illustrate a practical example of this voltage-finding formula, we can take the plate circuit of almost any vacuum tube and draw this one complete circuit by itself as shown in Fig. 2. We want to find out how much d.c. voltage to expect across plate load resistor R. All we do know is that this is a 50,000-ohm resistor with a

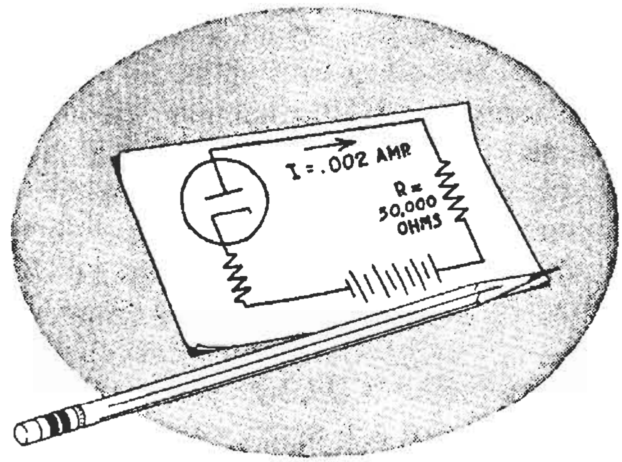


FIG. 2. Drawing the plate circuit of a tube by itself in this way simplifies any Ohm's Law figuring you might want to do for the resistors in the circuit.

current of .002 ampere flowing through it. These two values are all we need to use the formula $E = I \times R$. We get $E = .002 \times 50,000$. Multiplying this out gives 100 volts as the voltage drop which would normally exist across R.*

What About A.C. Circuits? Ohm's Law holds true for all simple d.c. circuits and for all a.c. circuits which contain only resistors, provided that voltage values are in *volts,* current values are in *amperes,* and resistance values are in *ohms.*

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* As a special feature of the NRI Consultation Service, a Data Sheet on resistors will be sent to you with your graded answers for this Lesson. This Data Sheet contains a number of additional examples of applying Ohm's Law to practical resistor circuits, as well as a reference listing of all the formulas taken up in this Lesson.

You are not *required* to study this supplementary material; it is provided only as additional information for those who want to learn more about this subject. Remember, you won't have to do any involved calculating when you do radio servicing—these examples are given to help you understand what happens when parts of different resistances are used.

Useful Data for Ohm's Law

In radio, current values are often in milliamperes, and resistance values are occasionally in megohms. Once in a while, you will even encounter millivolts and microvolts instead of volts. Before you can use these values with Ohm's Law, you must change them to amperes, ohms and volts.

Changing Milliamperes to Amperes. You will recall from a previous lesson that a milliampere is a thousandth of an ampere. Therefore, a value in milliamperes *must be divided by 1000* to change it to amperes. This is easily done *by moving the decimal point THREE places to the LEFT*. Here are a few examples:

.3	*milliampere*	=	*.0003*	*ampere*
1	*milliampere*	=	*.001*	*ampere*
25	*milliamperes*	=	*.025*	*ampere*
600	*milliamperes*	=	*.6*	*ampere*
1000	*milliamperes*	=	*1.*	*ampere*

Changing Megohms to Ohms. In radio work, we often deal with resistance values running up into millions of ohms. To avoid having to write large numbers a larger unit of resistance called the *megohm* is used. One megohm is equal to one million ohms.

To change a resistance value in megohms into ohms, all you need to do is multiply by 1,000,000. The easiest way to do this is *by moving the decimal point SIX places to the RIGHT*. Here are some examples:

.1	*megohm*	=	*100,000*	*ohms*
.75	*megohm*	=	*750,000*	*ohms*
1	*megohm*	=	*1,000,000*	*ohms*
2.5	*megohms*	=	*2,500,000*	*ohms*
10	*megohms*	=	*10,000,000*	*ohms*

Changing to Volts. A millivolt is one thousandth of a volt, so a value in millivolts must be divided by 1000 to change it to volts. This can be done by moving the decimal point THREE places to the LEFT.

A microvolt is a millionth of a volt. A value in microvolts must be divided by 1,000,000 to change it to volts. This can be done by moving the decimal point SIX places to the LEFT.

Symbols for Ohms. Resistance values appear so many times in radio diagrams that a single Greek letter is, for convenience, used instead of the word *ohm*. The two ways of writing this letter, or rather symbol, are shown in Fig. *3*. You will find that some diagrams use one way, some the other. On your own diagrams, you can choose whichever symbol is easier for you to make, because both are perfectly correct.

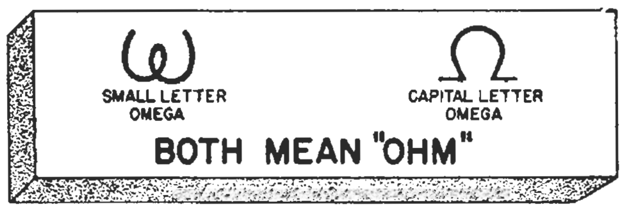


FIG. 3. Symbols used in radio for ohm. (The letter is omega, pronounced oh-MEE-gah. It is the last letter of the Greek alphabet.)

In rare cases, you may find both symbols appearing on the same diagram. The small letter ω then represents *ohms*, and the capital letter Ω represents megohms. Remember—this applies only when both symbols appear on the same diagram.

Abbreviations. On circuit diagrams the abbreviation *MEG.* is often used for megohms. Thus, a 10-megohm (ten million ohm) resistor would be marked 10 MEG. on a diagram.

You will sometimes find either the letter *M* or the letter *K* used to represent *thousands of ohms.* Whenever you see an *M* or *K*, just read it as thousand ohms. Thus, 250M and 250K would both be read as two hundred and fifty thousand ohms.

Figure *4* shows some of the most commonly used ways of specifying a typical resistance value on diagrams.

Using Resistors to Reduce Voltage

A Common Radio Problem. When the source voltage in a d.c. circuit is *higher* than is required by the load, the source cannot be connected directly to the load with wires, because the excessively high source voltage would send too much current through the load and possibly damage it.

"Why not change the d.c. source voltage, or get a different load which can handle this higher voltage?", you ask. Either is a perfect solution, but unfortunately they are not always possible. The high source voltage may be needed for other circuits, and the particular load may be essential for satisfactory operation of the radio set. In many cases, the only practical solution is to place between the source and load some part which will take part of the source voltage, thus lowering the load voltage to the required value.

A Resistor Will Do It. If we place a resistor between source and load in the manner shown in Fig. 5, the current flowing through the resistor will produce a voltage drop across it. This voltage drop cannot act on the load, so less voltage is available for the load. By choosing the proper resistance value for this series resistor, we can reduce the load voltage to any desired value.

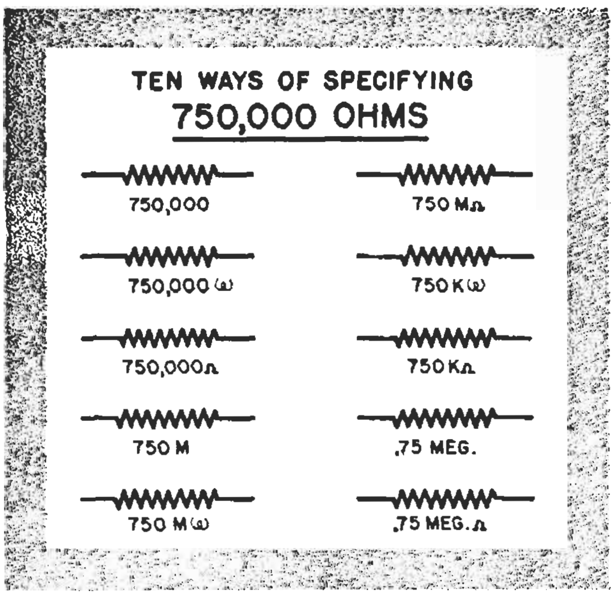


FIG. 4. You may find resistor values specified in any of these ways on circuit diagrams used in radio work. Don't try to memorize these ways now, because you can easily figure them out when necessary, and need refer to this diagram only when in doubt.

A series resistor is often called a *voltage-dropping resistor*, because it uses up, wastes or "drops" the undesired portion of the source voltage.

A series voltage-dropping resistor can be anywhere in the circuit—next to the source, next to the load, on the

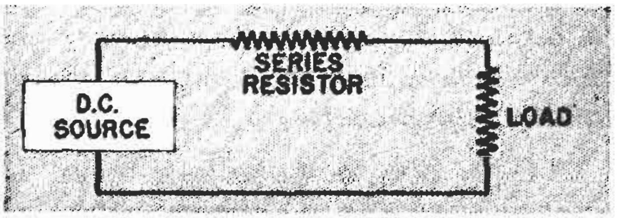


FIG. 5. Basic radio circuit in which the source voltage is too high for the load.

other side of the source, on the other side of the load, or anywhere in between source and load—*because the same current flows through all parts of a series circuit.*

There are two ways to look at this series resistor. First, we can think of it as increasing the total circuit resistance. (When resistors are in series, their ohmic values add together.) Increasing the circuit resistance reduces the current to the correct value for the load. When a load gets its correct current, it is also getting its correct voltage.

Here is the second way to think of this series resistor. Whenever current flows through a resistor, the voltage drop produced across this resistor is equal to the current value multiplied by the resistance value ($E = I \times R$). The load voltage is then equal to the source voltage minus the voltage drop across the resistor.

The important thing to remember is that a series resistor of the correct value will reduce the load voltage in a simple series circuit to its correct value.

Can Voltage Vanish? In the circuit of Fig. *5*, we have three different voltages: 1. The source voltage; 2. The voltage drop across the series resistor; 3. The load voltage, which is also a voltage drop.

The relationship between these voltages is highly important because it tells you how much voltage to expect in actual radio circuits. Before we take up these voltage relationships, however, study the circuit in Fig. *5* a bit and see if you can answer the following questions from reasoning and what you already know:

- *Can the load voltage ever be higher than the d.c. source voltage?*
- *Can the sum of the two voltage drops ever be HIGHER than the source voltage?*
- *Can the sum of the two voltage drops ever be LOWER than the source voltage?*
- *Can any of the source voltage just vanish?*

Kirchhoff's Voltage Law. If you answered "no" to all four questions you were entirely correct, and already have a clear understanding of the highly important voltage law now to be taken up. This fundamental law is known as *Kirchhoff's Voltage Law,* in honor of the scientist who first proved that it always holds true.

KIRCHHOFF'S VOLTAGE LAW

In a complete circuit, the sum of the voltage drops is always equal to the source voltage.

Examples. Like Ohm's Law, Kirchhoff's Law has a great number of practical applications in radio circuits. Examples involving real radio problems always help in remembering important ideas, so let us consider now a few of the ways in which this law is used by radio men. These examples will demonstrate even more clearly that the law is *"just what you would naturally expect."*

Filament Circuit. In the simple filament circuit shown in Fig. *6*, the storage battery sends current through the tube filament and series resistor *R*. If you measured each voltage in the circuit with voltmeters connected

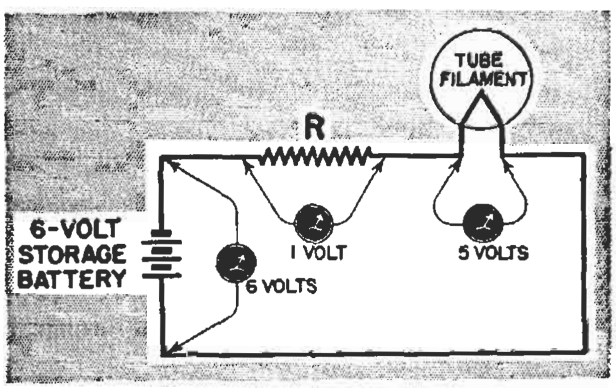


FIG. 6. Example of a circuit in which the source has too high a voltage for the load. Series resistor R cuts the load voltage down to the required value of 5 volts.

as indicated in the diagram, you would find that adding the filament voltage drop of 5 volts to the resistor voltage drop of 1 volt gives the source voltage value of 6 volts, just as predicted by Kirchhoff's Voltage Law.

Nearly every universal a.c.-d.c. radio receiver has a series resistor in its filament circuit, to use up that portion of the power line voltage which is not needed by the filaments in series. Later in this lesson, you will get acquainted with the line cord resistors and resistance tubes which are used for this purpose in a.c.-d.c. receivers.

Plate Circuit. Kirchhoff's Voltage Law holds true for any *complete* circuit no matter how many other cir-

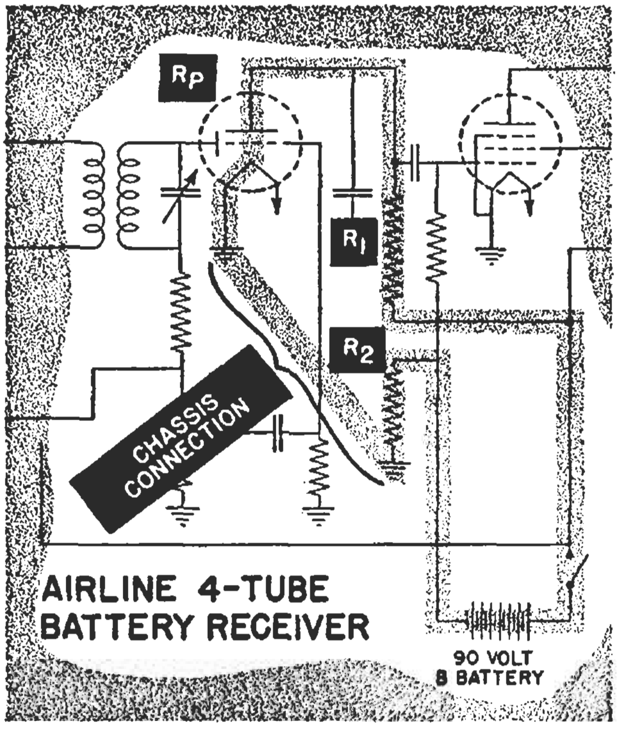


FIG. 7. This portion of an actual receiver circuit diagram is given here only to illustrate how voltages can be checked in one complete circuit regardless of nearby circuits. Note: No dots at cross-overs mean no connections.

cuits or radio parts are connected to various points in the circuit. For example, if a radio man were to pick up the service manual of an Airline Model 93BR-462A portable receiver and trace along the plate supply circuit of one tube in the manner shown by the shading in Fig. 7, he would ignore all the other circuits, and apply the voltage law just to that one circuit.

Thus, if he took a d.c. voltmeter and measured in turn the voltage across resistor R_1, resistor R_2 and plate-cathode resistance R_P while the receiver was in operation, then added these three voltage drops together, the result would be equal to 90 volts, the voltage of the B battery which is the source in this circuit.

The plate-cathode path through the tube in Fig. 7 is marked R_P and considered as a resistance because it acts exactly like a resistor in this circuit. In other words, it obeys Ohm's Law. To find the value of this resistance, you would divide the plate-cathode voltage by the plate current ($R = E \div I$). You'll learn more about this when you study the lesson on tubes.

Note that numbers and letters are used after the letter *R* to distinguish between the three resistors in this plate circuit. This is always done whenever more than one resistor is shown on a diagram. You can pronounce these notations as *R sub one* and *R sub pee*, or simply as *R one* and *RP*.

Variable Series Resistors. In some circuits, we use a *variable resistor* or *rheostat* in series with the load, and adjust its resistance value until the load is getting its correct voltage and current.

The construction of one type of variable resistor is shown in Fig. 8. The position of the contact arm can be changed by rotating the shaft of the unit. Since the movable arm is connected to one terminal, the position of the arm determines how much resistance there is between the terminals.

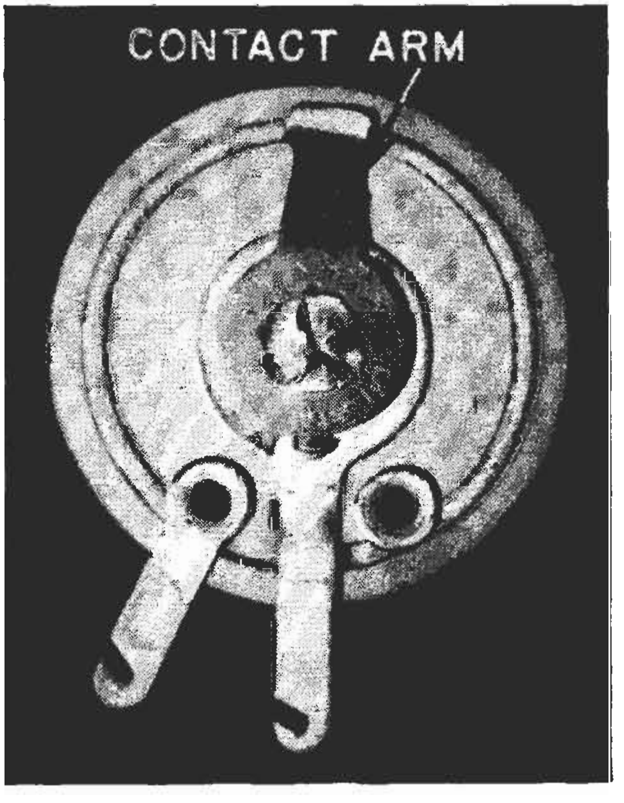


FIG. 8. Adjustable resistor or rheostat.

Resistors in Parallel

When two resistors are connected in parallel to a voltage source, as they are in Fig. *9A*, both resistors are acted on by the same voltage. This means that each of the parallel resistors gets the same current as if it were connected all by itself to the battery (Figs. *9B* and *9C*).

The current through each parallel resistor will be determined by Ohm's Law: $I = E \div R$. Thus, the current I_1 through resistor R_1 in Fig. *10* will depend upon the source voltage and the ohmic value of R_1. Likewise, the current I_2 through R_2 will depend upon the source voltage and the ohmic value of R_2.

Since the source in Fig. *10* must supply current to two resistors in parallel, it is logical to expect that the source current I will be the *sum* of currents I_1 and I_2 flowing through the parallel resistors. This is quite correct, and we express it as a fundamental radio rule known as Kirchhoff's Current Law. Here it is:

KIRCHHOFF'S CURRENT LAW

The currents flowing *toward* a terminal in a radio circuit must equal the currents flowing *away from* that terminal.

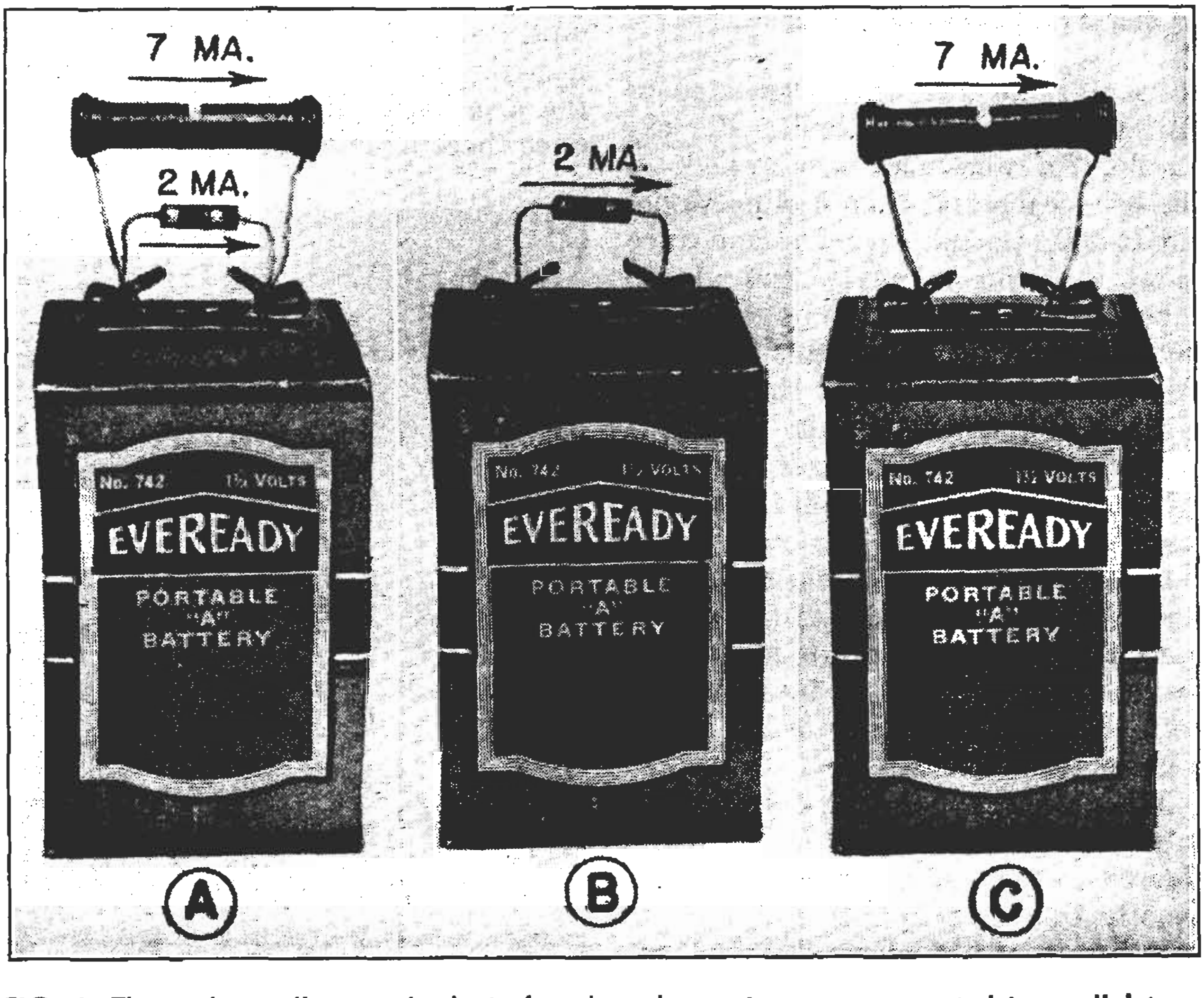


FIG. 9. These photos illustrate the basic fact that when resistors are connected in parallel to a voltage source, each draws the same current it would get if connected by itself to the source.

In the circuit of Fig. *10,* this means that current I flowing *toward* terminal a must be equal to the sum of currents I_1 and I_2 flowing *away from* terminal a. Likewise, $I_1 + I_2$ flowing *toward* b must equal I flowing away from b.

Combined Resistance. Since the sum of two values is larger than either one alone, total current I in the circuit of Fig. *10* is larger than either of the resistor currents. There is only one thing which can make it possible for the source to deliver this larger current—the combined resistance of R_1 and R_2 must be lower than that of either resistor alone. (Remember that lowering the total resistance in a circuit is one way to make the current increase.) Our conclusion is, then, that the combined resistance of two resistors in parallel is *less* than that of either resistor alone.

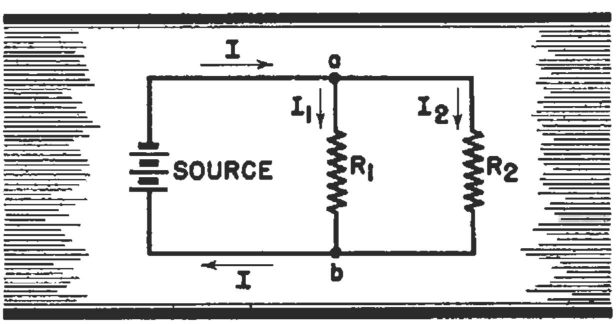


FIG. 10. Two resistors in parallel.

Different Resistors in Parallel. When two parallel resistors have different values, the combined resistance will always be *less than that of the smaller resistor.* This is true because the smaller resistor gets the most current. Any resistor placed in parallel with it will make the total circuit current go up, and this means that *the combined resistance of two parallel resistors is less than that of the smaller resistor.* See Fig. *11* for two illustrations of this fact.

Identical Resistors in Parallel. When two parallel resistors are alike in ohmic value, the same current must flow through each. The total current is then twice the current through one resistor. For any given voltage value, the current can be doubled only by cutting the resistance value in half. The combined or equivalent resistance of two equal resistors in parallel is thus *exactly half* that of one resistor.

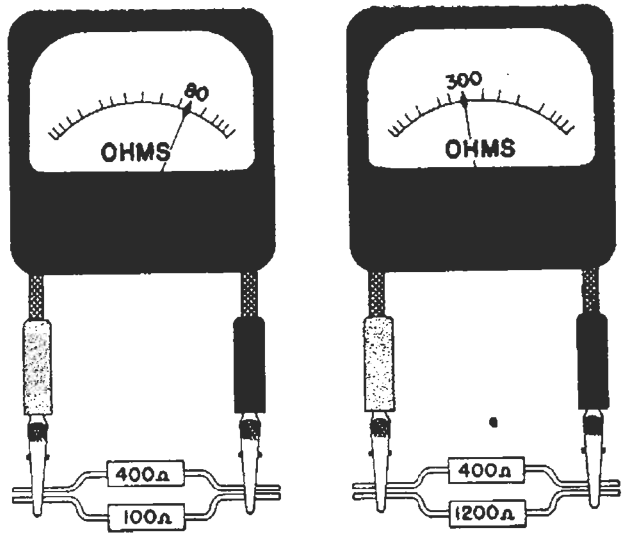


FIG. 11. When two different resistors are in parallel, the combined resistance is LESS than that of the smaller resistor. Note: Zero is at the extreme right on the scale.

Likewise, the combined resistance of three equal resistors in parallel is exactly one-third that of one resistor. Actual hook-ups of two and three equal resistors in parallel are shown in Fig. *12.*

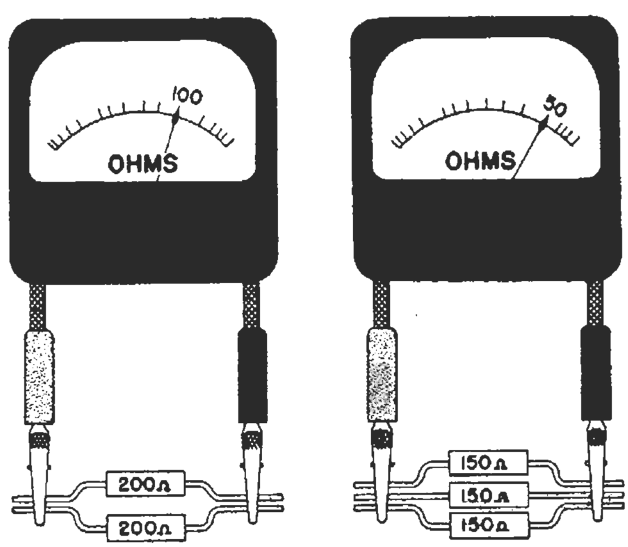


FIG. 12. When two equal resistors are in parallel, the combined resistance is exactly half that of one resistor. When three equal resistors are in parallel, the combined resistance is one-third that of one resistor.

The general rule is: To find the combined resistance of *equal* resistors in parallel, divide the resistance of one resistor by the number of resistors. *Example:* Four 40,000-ohm resistors in parallel have a combined resistance of 40,000 ÷ 4, which is 10,000 ohms.

Parallel Resistance Formula. The foregoing general information is usually sufficient for a radio man when making resistance measurements in a receiver. There is, however, a fairly simple way of figuring out exactly the combined resistance of two resistors in parallel. Just multiply the two resistance values together, then divide by the sum of the resistance values, and you have the combined resistance. Of course, all values must be in ohms.

As a formula, this method of figuring parallel resistance values appears even simpler. Let R_1 and R_2 represent the values in ohms of the two resistors. The combined resistance R of the two resistors in parallel then is:

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

In this kind of formula, the horizontal line means that everything above the line is to be divided by everything below the line, after the indicated multiplication and addition have been carried out. A few examples will illustrate this.

Example 1. Find the combined resistance of two 10-ohm resistors in parallel.

SOLUTION: Write the parallel resistance formula, then repeat it with the two known values in place of R_1 and R_2, as follows:

$$R = \frac{R_1 \times R_2}{R_1 + R_2} \qquad R = \frac{10 \times 10}{10 + 10}$$

Now multiply the two top numbers, add together the two bottom numbers, then divide the results as follows, to get 5 ohms as the combined resistance (exactly half the value of one resistor):

$$R = \frac{100}{20} \qquad R = 5 \text{ ohms}$$

Example 2. Find the combined resistance of 3 ohms and 6 ohms in parallel.

$$R = \frac{3 \times 6}{3 + 6} \qquad R = \frac{18}{9} \qquad R = 2$$

The combined resistance is thus 2 ohms. As we expected, this is less than the value of the smaller resistor.

Combining Large and Small Resistors. When two unequal resistors are in parallel and one is more than about 25 times larger than the other, the combined resistance will be very close to the smaller resistance value. In practical work, a radio man wouldn't even bother to figure out the value; he'd say the combined resistance was about the same as the value of the smaller resistor.

Example 1. Find the combined resistance of 1 ohm and 25 ohms.

$$R = \frac{25 \times 1}{25 + 1} \qquad R = \frac{25}{26}$$

R = .96 ohm, which for practical purposes is *1 ohm.*

Example 2. Find the combined resistance of 300 ohms and 10,000 ohms.

$$R = \frac{300 \times 10{,}000}{10{,}300} \qquad R = \frac{3{,}000{,}000}{10{,}300}$$

R = 291.2 ohms, which for practical purposes is *300 ohms.*

Three or More In Parallel. When more than two different resistors are in parallel, disregard all resistors which are more than 25 times larger than the smallest. If three resistors are left, combine two of them by means of the formula, then combine the result with the third resistor. By taking resistance values two at a time in this way, you can figure out the combined resistance of any number of resistors in parallel. The combined

resistance will always be *less* than that of the smallest resistor in the group.

Example: Find the combined resistance of 2 ohms, 5 ohms, 10 ohms, 250 ohms and 1 megohm in parallel.

First, we cross out 250 ohms and 1 megohm, since they are more than 25 times larger than 2 ohms. Now we combine 2 ohms with 5 ohms by means of our formula, and get 1.43 ohms. Next, we combine 1.43 ohms with 10 ohms, and get 1.26 ohms as the combined resistance of these five resistors in parallel. Note that this is less than the value of the smallest resistor in the group.

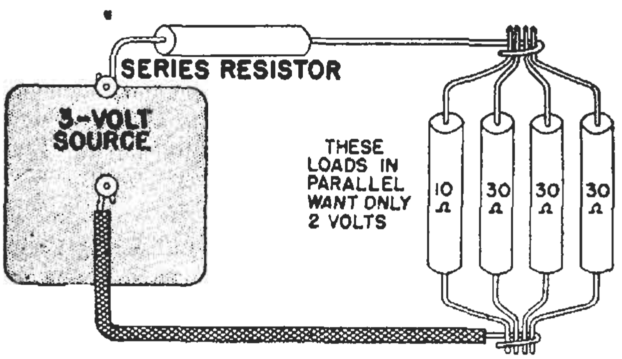


FIG. 13. A series resistor is often used to reduce the voltage for loads in parallel.

Parallel Loads With Series Resistor. In radio, we quite often have a number of loads in parallel, all requiring the same voltage, and a source which has too high a voltage for the loads. A series resistor will reduce the load voltage here, the same as it did for a single load resistor. All you have to do is figure out the combined resistance of all the loads in parallel, then use this value as if it were for a single load resistor.

An arrangement of parallel loads with a series resistor is shown in Fig. *13*. The parallel loads require 2 volts, but the source furnishes 3 volts. As a review of the formulas you've already learned, let's figure out what the series resistor value should be.

First, we find the combined resistance of the load. The three 30-ohm resistors have a combined resistance of 10 ohms, and combining this with the 10-ohm resistor gives 5 ohms as the combined resistance of the group. (We chose easy values purposely here, but you could do this for *any* values by using the parallel resistance formula.)

Next, we find the current which this combined load resistance will draw through the series resistor. We have a 5-ohm load and it requires 2 volts; $I = E \div R$, so I is $2 \div 5$, which is .4 ampere.

We want to find R for the series resistor, so we bring out another Ohm's Law formula: $R = E \div I$. We've already found that I is .4 ampere. Kirchhoff's Voltage Law tells us that E (the voltage drop across the series resistor) plus 2 volts (the load voltage) must be equal to 3 volts, so E must be 1 volt ($3 - 2 = 1$). Substituting these values, we find that R is $1 \div .4$, which is 2.5 ohms, the value of the series resistor.

Example. The filament circuit arrangement in Fig. *14* is an excellent example of how a series resistor reduces the voltage for parallel loads in a receiver. The filaments of the five tubes are connected in parallel between terminals *a* and *b*, with the connections between ground symbols be-

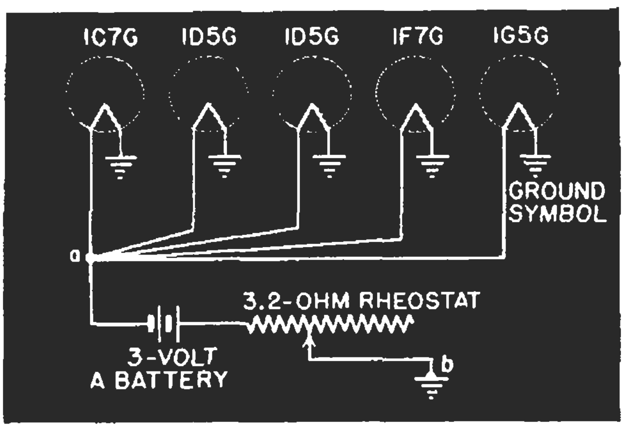


FIG. 14. Filament circuit arrangement of a 5-tube battery-operated radio set.

ing completed by the metal chassis of the receiver.

Each tube filament requires 2 volts, so the voltage between *a* and *b* must be 2 volts at all times. The battery delivers 3 volts when new, but this voltage drops gradually as the battery runs down. This is why a rheostat (variable resistor) is used as a series resistor for reducing the load voltage to 2 volts.

During normal use of this receiver, the owner adjusts the rheostat about once a week by means of a knob at the back of the receiver, in the position shown in Fig. *15*. He *reduces* the ohmic value of the rheostat, so

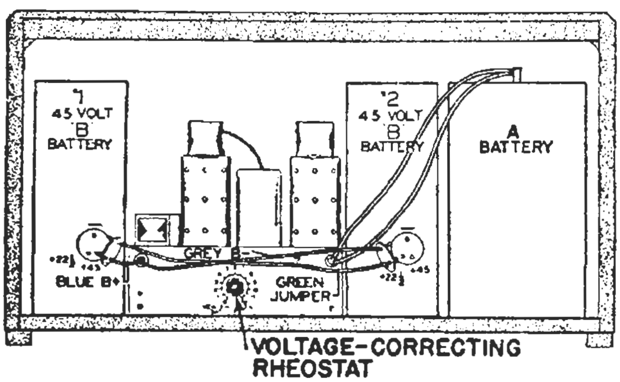


FIG. 15. Rear view of Belmont Model 524 radio receiver, showing the location of the control knob for the series rheostat which adjusts the filament voltage. The set owner is instructed to turn the rheostat one marked division further each week, which gives approximate correction of filament voltage during normal use.

that the voltage drop across it becomes less and less as the battery runs down. When the battery is down to 2 volts, the rheostat is down to zero resistance, and further drops in voltage can no longer be corrected. The receiver eventually stops working, and a new A battery must then be installed.

Problem: Load Voltage Varies Too Much. When the load is a resistor, a series resistor does a perfect job of reducing the load voltage to the correct value. When the load is a vacuum tube which acts like a resistance, however, we find that the load voltage just won't stay where it should.

A typical situation of this kind is presented in Fig. *16*. The vacuum tube load in this particular example requires 40 volts at all times, and the series resistor is chosen to provide this

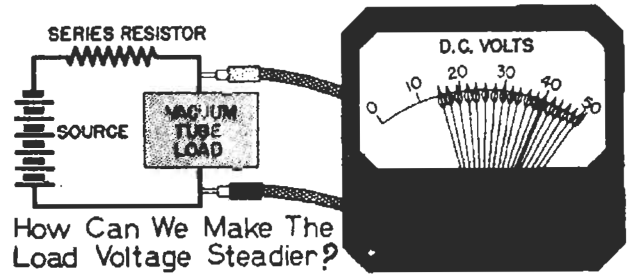
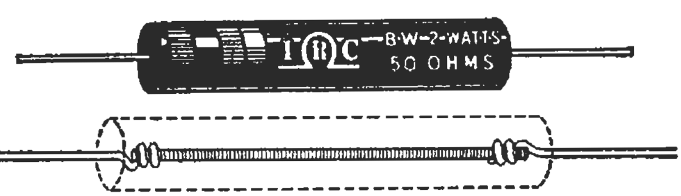


FIG. 16. Here's an interesting practical radio problem: The load is a vacuum tube whose resistance varies so much that a voltmeter across the load may read any value between 15 volts and 49 volts when the voltage is supposed to be 40 volts at all times. This lesson shows you how just one extra resistor of the proper value, properly connected into the circuit, will "save the day."

voltage when the tube resistance is at its normal value of 4000 ohms. During normal operation, the tube resistance can drop all the way down to 1000 ohms or go up to 6000 ohms, and this explains why the d.c. voltmeter in Fig. *16* is showing dozens of different readings ranging from 15 volts to 49 volts.



This low-wattage, low-value wire-wound resistor appears exactly like a carbon or metallized resistor. The resistance wire is wound on a core of insulating fiber, wire terminal leads are crimped over each end, and an insulating material similar to bakelite is molded over the entire assembly.

Each change in load resistance changes the total circuit resistance and the circuit current flowing through the series resistor, thus changing the amount of voltage which the series

resistor leaves for the load. What's to be done about it?

Clearly, our problem is to make the load voltage independent of the load resistance. We can do this by placing across the load a resistor having considerably lower resistance than the load, as shown in Fig. *17*. (This resistor is usually called a *shunt resistor*, because *shunt* and *parallel* have the same meaning in radio.)

After the shunt resistor is connected, we must change the series resistor value so the load still gets 40 volts initially. Now the voltmeter just barely flickers around 40 volts when the tube resistance varies as it did before. For all practical radio purposes, we have a perfect solution to our problem. Let's see now why this single extra resistor has such an effect on the behavior of the circuit.

It is the combined resistance of shunt and load which determines how much voltage drop there is across the load. If we use a shunt resistor having much lower resistance than the load, the combined resistance will be just a little smaller than the shunt resistance. Furthermore, variations in load resistance will have little effect on the combined resistance because even the lowest load resistance value is still many times larger than the shunt value.

With the combined resistance staying essentially constant, the circuit current and all the circuit voltages likewise stay about the same. Thus, the shunt resistor does a fine job of steadying the load voltage.

A shunt resistor is sometimes called a *bleeder* resistor, because it draws or "bleeds" from the source a certain amount of current which flows through the series resistor but never gets a chance to do useful work in the load.

Voltage Regulation. When the load voltage varies excessively with load resistance, radio men say that the circuit has *POOR voltage regulation.* When the load voltage stays essentially the same despite variations in load resistance, the circuit has *GOOD voltage regulation.* A shunt or bleeder resistor across a load thus *improves* the voltage regulation of the circuit.

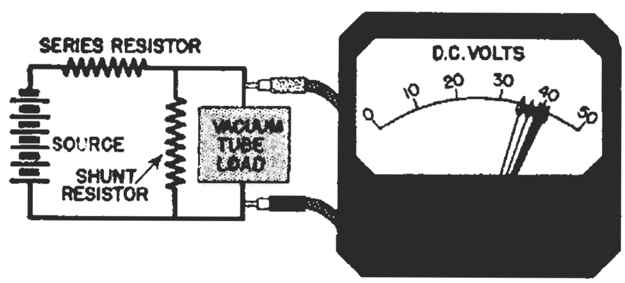


FIG. 17. With a suitable shunt resistor value in our circuit, the load voltage can vary only over the limited range of 35 volts to 41 volts, which is hardly enough variation to worry a practical radio man.

Review Example

The circuit in Fig. *18*, representing the plate supply circuits of three radio tubes in a simple public address amplifier, is an excellent illustration of how a serviceman can use Kirchhoff's Laws to speed up trouble-shooting in radio circuits.

All trouble-shooting is based upon a knowledge of *what should exist* when everything is working properly. Thus, a Radiotrician working on this circuit knows from Kirchhoff's Voltage Law that the d.c. voltage drops in

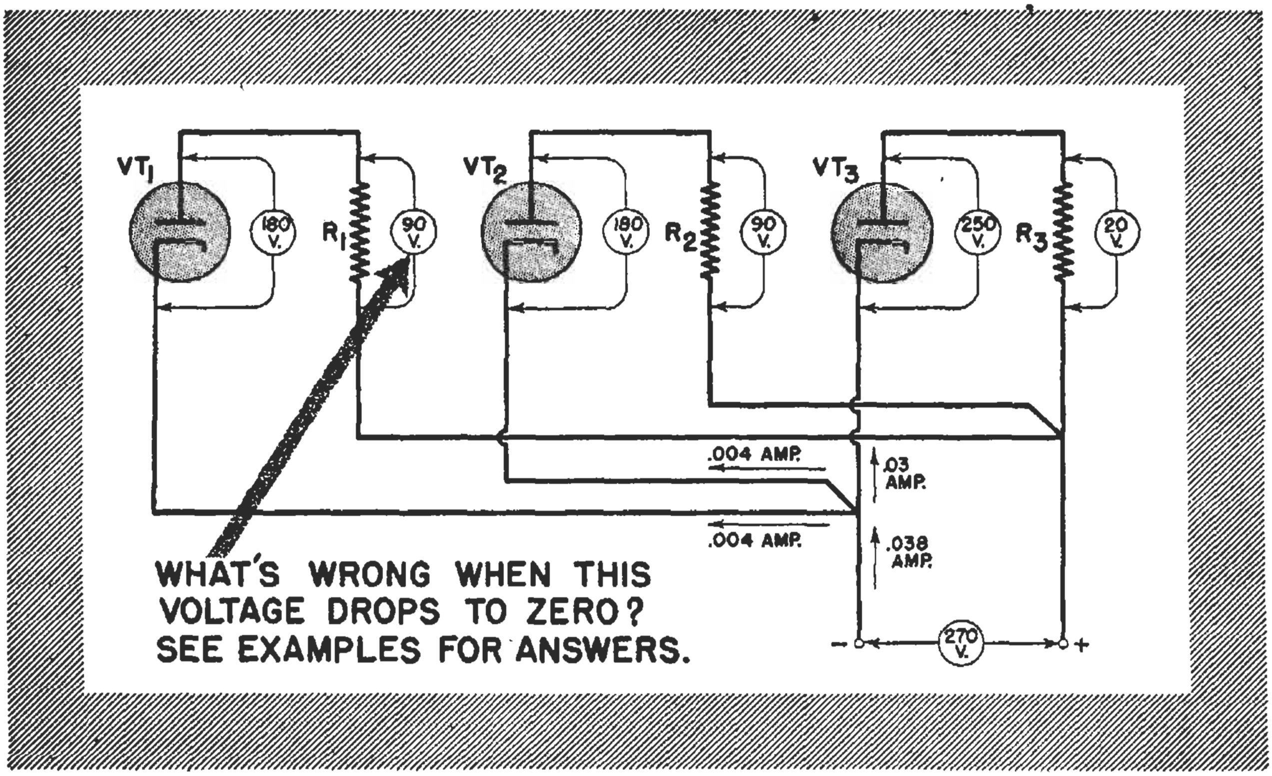


FIG. 18. Simplified plate supply circuits of a public address amplifier, showing voltage and current values a Radiotrician would measure if these circuits were free of trouble.

each *complete* plate circuit should add up to the source voltage of 270 volts. Voltage values which he might measure during normal operation are indicated in the diagram in Fig. *18,* so let's check them.

In tube circuit VT_1, we add the tube drop of 180 volts to the 90 volts across R_1, and get just what the law says we should—270 volts. Tube circuit VT_2 gives exactly the same result. In tube circuit VT_3, we add the tube drop of 250 volts to the 20 volts across R_3, and again get exactly 270 volts.

Normal circuit current measurements are also indicated in Fig. *18,* and can be checked quickly against Kirchhoff's Current Law. Thus, adding .004 amp., .004 amp., and .03 amp. gives .038 amp., which is the source current.

Here are two examples of how a Radiotrician would use his knowledge of radio laws to help locate trouble in this circuit.

Example 1. Instead of the voltage and current values shown in Fig. 18, suppose there is no voltage across resistor R_1, and tube VT_1 has the full source voltage of 270 volts. In addition, the plate current for tube VT_1 is much higher than the expected value of .004 ampere. What is wrong?

No voltage across R_1 can mean that R_1 is shorted and current is flowing around it through the shorting path, or can mean that no current is flowing through the entire circuit which includes R_1. We know that plate current is flowing through the circuit, so R_1 must be shorted. Full source voltage across tube VT_1 confirms the fact that there is no series resistance in the circuit, so the Radiotrician investigates R_1 to see if it is defective or if its leads are touching each other.

Example 2. Measurements indicate the same voltage situation as for Example 1, but this time there is no plate current.

Absence of current means that either R_1 or the tube is open. (When a tube does not pass current, it acts just like an open resistance.) Full

voltage across the tube proves that continuous paths exist from the tube terminals to the voltage source, so R cannot be open. This means that the tube is guilty this time. Whenever a break occurs in a complete circuit such as at the tube here, full source voltage appears *across the break,* just as if your meter were connected directly to the source terminals.

Controlling Load Voltage with Potentiometers

In radio, it is often necessary to have a circuit arrangement which makes it possible to change the voltage of a load by turning a knob. You have already seen one way of doing this, by means of a rheostat in series with the load. A rheostat can reduce the load voltage only a certain amount, however—never all the way down to zero.

When complete control of load voltage from the maximum value to zero is required, we use a special type of variable resistor known as a potentiometer (pronounced *poe-TEN-shi-om-eh-ter*). The basic circuit is shown in Fig. *19*.

As you can see, a potentiometer is simply a rheostat having three terminals instead of two. The entire resistance element of the potentiometer is connected across the source. The load is connected between the movable contact (P) and one of the end terminals of the resistance element, and hence the load can be connected across any desired portion of the resistance element by changing the position of the movable contact.

When P is set at X, the load gets the full source voltage (lower left in Fig. *19*).

When P is moved downwards, such as to the position shown at the top in Fig. *19,* the upper potentiometer section (R_1) is a series resistance, and the lower potentiometer section (R_2) is a shunt resistance connected directly across the load. The voltage drop across R_1 now cuts down the amount of voltage available to the load. Note that both the load current and the current drawn by R_2 flow through series resistance section R_1 and produce this voltage drop.

Moving P farther downward reduces the load voltage still more. When P is moved all the way down to Y, as at the lower right in Fig. *19,* the load voltage is zero.

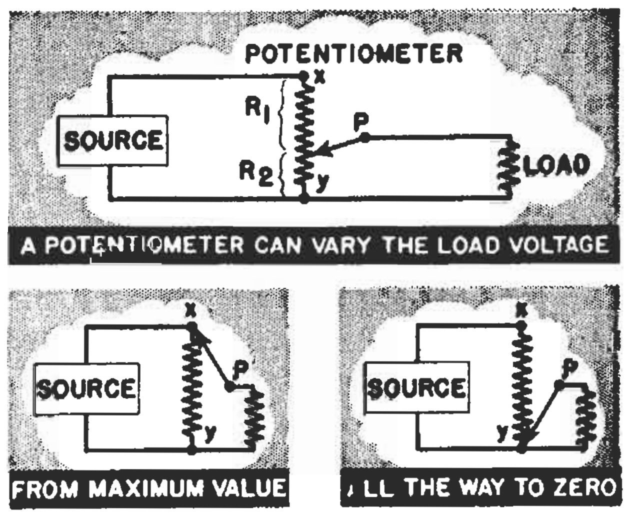


FIG. 19. Basic circuit using a potentiometer.

A potentiometer is often thought of as a voltage divider, because it divides the source voltage in the desired proportion between two parts of a circuit (in this case, it divides the voltage between R_1 and the load-R_2 parallel combination).

When the total resistance of the potentiometer is much lower than the load resistance, the current drawn from the source depends chiefly on the resistance value of the potentiometer. The source current then stays essentially the same regardless of the position of the movable contact; this is a highly desirable condition in some radio circuits.

Wattage Ratings of Resistors

If you glance through any catalog or listing of resistors, you will see that in addition to the ohmic value, each resistor has a *wattage rating.* This rating tells a radio man whether or not a resistor can "take it" in a particular circuit without getting too hot or burning out.

The rate at which a resistor produces heat is its *power* in *watts.* This value must for safety be lower than the wattage rating, because the wattage rating represents the maximum rate at which the resistor can safely produce heat. Since practical radio men work with resistors just about every day, the subjects of power, wattage ratings and watts are an important part of our study of resistors.

What is POWER? Let us suppose that we have two quart pans full of water, which we want to boil. If we set one pan on a small electric hot plate and the other on the large super-speed burner of an electric range, it may take the small burner three times as long to boil the water. Both burners accomplish the same result, however, for both have to supply the same total amount of heat to the quart of water.

The large burner accomplishes its work at three times the *rate* of the small burner. *The rate of doing work*—in this case, of producing heat—*is called power.*

This definition of power holds true for radio, too, because a resistor produces heat at a definite rate when current flows through it. Before we consider power problems in resistors, however, let us first get acquainted with the practical *units* used by radio men for specifying amounts of power.

Units of Power. In radio and electricity, power is measured in *watts* or in *kilowatts.* One kilowatt is equal to 1000 watts, hence one watt is one-thousandth of a kilowatt. Small radio sets draw about 40 watts, which is the same as the power drawn by a 40-watt soldering iron or a 40-watt electric lamp bulb. Large sets draw as much as 150 watts.

In radio, we occasionally encounter a smaller unit of power called the *milliwatt.* This is equal to one-thousandth of a watt, and is used chiefly in designating the strength of audio signals.

Figuring Power. To find the amount of power which a voltage source is delivering to a circuit, all you need to do is *multiply the amount of voltage by the amount of current.* The voltage should be in volts and the current in amperes; the result will then be the electrical power in watts which is being delivered to the circuit by the voltage source. Thus, if a 6-volt battery is furnishing 2 amperes, the power being delivered is 12 watts ($6 \times 2 = 12$).

This wire-wound resistor looks much like a carbon or metallized resistor. It is made with various ohmic values, ranging from 5 ohms to 70,000 ohms, and in two different wattage ratings—5 watts or 10 watts. A red dot on the resistor changes to brown when the resistor is overloaded (when the wattage rating is exceeded). The dot changes back to red when the overload is corrected.

To find the amount of power which is producing heat in a resistance, simply *multiply the current* flowing through the resistance *by the voltage drop* across the resistance. Voltage must be in *volts* and current in *amperes.* The result will then be the power in *watts* which is producing heat. Thus, if a current of 4 amperes

produces a voltage drop of 5 volts across a resistor, the power in the resistor is 20 watts ($5 \times 4 = 20$).

Power Formula. In radio, we let the capital letter *P* stand for power. The simple formula which expresses what has just been said about figuring power is:

$$P = E \times I$$

Remember that *P* stands for the power *in watts, E* stands for the voltage *in volts,* and *I* stands for the current *in amperes.*

This power formula applies to all direct current circuits, and to all a.c. circuits containing only resistance.

Radio men use the power formula chiefly to figure how much power a resistor is handling. A given resistor can handle only a certain amount of power without getting too hot and destroying itself, because all of the power supplied to a resistor is used to produce heat. This is the reason why resistors have *wattage ratings* in addition to their resistance values.

Wattage Ratings of Resistors. The wattage rating of a resistor is the *maximum* amount of power in watts which the resistor can handle without becoming excessively hot. Naturally, a resistor can safely handle any power value which is *less* than its wattage rating.

The wattage rating depends essentially on the physical size of a resistor (length, thickness and surface area), and is entirely independent of the ohmic value. In plain language, the wattage rating depends upon how fast the resistor can get rid of the heat produced by its resistance element.

The larger the physical size of a resistor, the more heat it can withstand and the higher will be its wattage rating. A 10-watt resistor will thus be larger in dimensions than a 1-watt resistor.

As a matter of fact, in a radio store you could get a resistor with a suitable wattage rating by holding up the old resistor and saying, *"I want a 500-ohm resistor which is this big or bigger."* When ordering a resistor from a mail order radio supply firm, however, you would have to specify the wattage rating as well as the ohmic value.

Most of the resistors which you will encounter in radio circuits have low wattage ratings, such as ¼, ½, 1 or 2 watts. A ¼-watt resistor is less than an inch long, and is scarcely any thicker than a piece of insulated hookup wire. Figure *20* shows how the physical dimensions of resistors vary with the wattage rating.

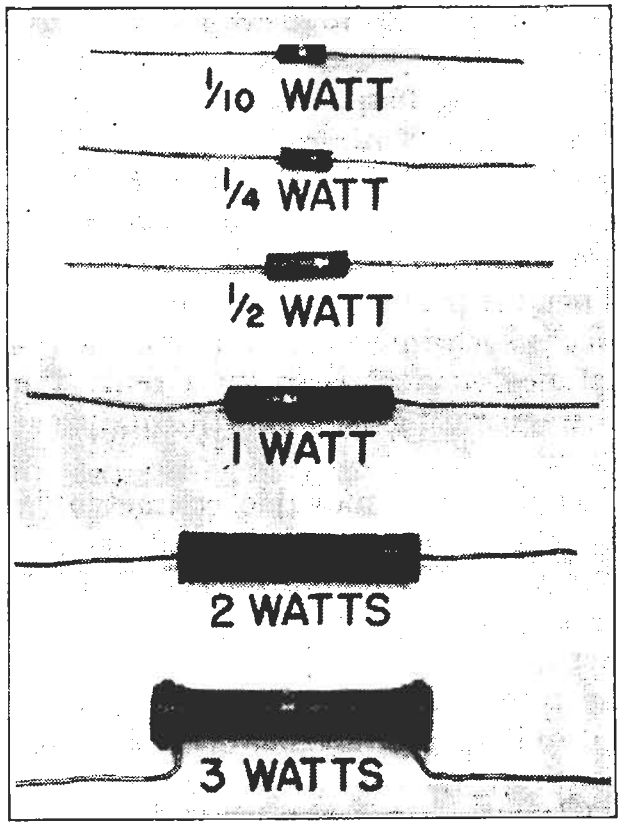


FIG. 20. Examples of carbon resistors having different wattage ratings.

Margin of Safety. It is good practice to provide a margin of safety by using a resistor having a wattage rating which is about twice the actual power it must handle. This prevents resistor failure even though the power should for some reason get considerably higher than the normal value.

Another reason for providing a margin of safety is that wattage ratings are for resistors mounted in free air. When resistors are mounted in enclosed places, such as under a shallow chassis where there is little circulation of air, the heat-dissipating ability is greatly reduced.

Examples. If a resistor is to handle 4 watts, choose a 10-watt resistor for safety. If it is to handle .4 or .6 watt, use a 1-watt resistor. If it is to handle 1 watt, use a 2-watt resistor. As a general rule, try to use a wattage rating which is about twice the actual power being handled.

Rheostat Wattage Ratings. Wattage ratings of variable resistance units, such as rheostats and potentiometers, apply to the *entire resistance element.* When the position of the movable contact is such that only a part of the resistance element is in the circuit, the wattage rating is *proportionately reduced.*

Thus, if the movable contact of a rheostat is at the mid position, the unit can safely handle only half of the wattage rating. If the movable contact is set so only about one-eighth of the total resistance is in the circuit, the unit can safely handle only one-eighth of the wattage rating.

Potentiometers and rheostats invariably burn out near a terminal, because only a small portion of the resistance element is then in the circuit, and the useful wattage rating is correspondingly small.

A burned-out potentiometer is shown in Fig. *21*. When the contact arm was set near the right-hand terminal, the wire which forms the resistance element became so hot that it melted and the surrounding fiber of the unit became badly charred.

If you encounter a receiver in which a certain resistor, rheostat or potentiometer becomes too hot and perhaps even burns out frequently, yet no other parts in the receiver are defective and causing excessive current to flow, you should replace the overheated unit with another having the same ohmic value but a *higher* wattage rating.

Wattage Ratings of Parallel Resistors. When two or more resistors which have *the same ohmic values* and the same wattage ratings are connected in parallel, the wattage rating of the combination will be the *sum* of the ratings of the individual resistors.

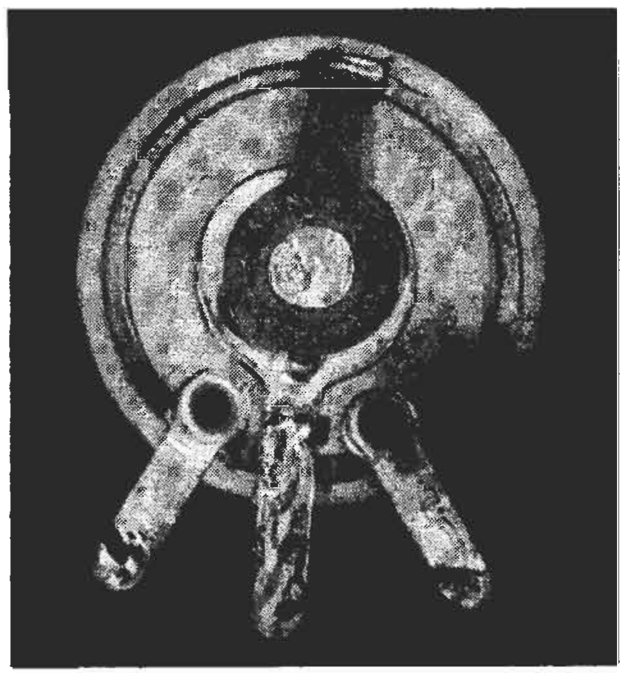


FIG. 21. Burned-out wire-wound potentiometer.

Thus, if two 100-ohm, 1-watt resistors are connected in parallel, the combined wattage rating is 1 + 1, or 2 watts. (The combined resistance is determined in the usual way by the parallel resistance formula, and is 50 ohms in this case.) If four 40,000-ohm, 3-watt resistors are connected in parallel, the combined wattage rating is 3 + 3 + 3 + 3, which is 12 watts.

When resistors having different wattage ratings and different ohmic values are connected in parallel or in series, the power must be figured for each resistor separately, to make sure that no resistor will be overloaded.

Other Power Formulas. Since the *resistance* value affects the amount of current which flows through a resistor, resistance also affects the amount of power being handled by a resistor. If we know the resistance value and either the voltage or current value, we can figure the power. Here are the formulas:

When the current and resistance are known, use this formula: $P = I \times I \times R$. This is usually written as $P = I^2 \times R$ or simply as $P = I^2R$ (*pronounced P equals I squared R*). The small numeral 2 at the upper right of a letter means that the value is to be multiplied by itself. Thus, if the current through a resistor is .5 ampere and the resistance is 40 ohms, the power will be $.5 \times .5 \times 40$, which is $.25 \times 40$, or 10 watts.

When the voltage and resistance are known, use this formula: $P = E \times E \div R$, which is usually written as $P = E^2/R$ (pronounced *P equals E squared over R*). If the voltage drop across a resistor is 20 volts and the resistance is 80 ohms, the power will be $20 \times 20 \div 80$, which is $400 \div 80$, or 5 watts.

Important: You are not expected to memorize any of the formulas in this lesson. You can always refer to this lesson when you have need for a particular formula. Eventually, after using a formula a few times, you'll find that you know it without ever having tried to remember it.

How Resistors Are Made

Many Kinds of Construction. Resistors used in radio equipment not only have different ohmic values and different wattage ratings, but they also differ greatly in actual construction. Thus, fixed resistors can have wire-wound, carbon or metallized construction.

Some types of construction give greater accuracy than others; some are cheaper than others when mass production methods are used; some provide the high wattage ratings required for resistors which must withstand a lot of heat; some construction methods give extremely low or extremely high ohmic values.

We will first consider the materials from which resistors are made, then study the three types of construction methods used for resistors, and finally get acquainted with typical resistors used in radio.

What Resistors Are Made Of

If we took a piece of ordinary No. 18 lamp cord or bell wire long enough to reach all the way across the country from New York to San Francisco, and measured the total *resistance* of this wire, the result would be less than 100,000 ohms! To get 1 megohm of resistance, a value commonly used in radio circuits, we would have to run this copper wire all the way around the world and still add on about 5000 miles of wire.

You say, *"Use smaller wire, because it has much higher resistance per foot of length. Some copper wire is made as fine as human hair."*

All right, suppose we did use copper wire the size of a human hair. It would still take 190 miles of the wire to get a megohm of resistance, and that's a lot of wire to put into a radio part.

All this leads us to the conclusion that the resistance of copper is too low for use in resistors. This low-resistance characteristic of copper makes it ideal, however, for the hook-up wire used in connecting radio parts together, and for constructing radio parts

which *should* have low resistance, like coils and transformers.

What we need for practical radio *resistors* are materials having much higher resistance than copper. Two such materials are *nichrome* (used in wire-wound resistor construction) and *carbon* (used in carbon resistor construction). In addition, there is a *metallized* resistor construction which is often used in place of carbon but has slightly different characteristics.

Resistivity. The easiest way to compare the resistances of different materials is by considering pieces of wire which are all the same length and thickness, each made from a different material. The resistance in ohms of a specified length of wire is technically known as the *resistivity* of the material.

If, for convenience, we choose a length and thickness which will make the copper sample have a resistance of exactly 1 ohm, then similar samples of other common resistance materials will have approximately the ohmic values given in Table I. These values vary considerably in some cases, depending upon the purity of the metal and the manner in which it is made into wire.

Length. Increasing the *length* of a piece of resistance material without changing its thickness is just like placing resistors in series to get more resistance. Increasing the length *INCREASES* the amount of resistance.

Technically speaking, the resistance of a conductor is *directly proportional* to its length. In other words, 2 feet of wire will have two times the resistance of a 1-foot length; 7 feet will have seven times the resistance of a 1-foot length; one inch of wire will have one-twelfth the resistance of a 1-foot length.

Thickness. Increasing the thickness (cross-sectional area) of a piece of resistance material is just like placing resistors in parallel. As you will recall, resistors in parallel have less resistance than either resistor alone. Increasing the thickness thus *DECREASES* the resistance. Actually, doubling the cross-sectional area cuts the resistance exactly in half.

Reducing the thickness of a piece of resistance material *INCREASES* the amount of resistance, because this is like slicing a resistor lengthwise and using only part of it. Cutting the cross-sectional area in half doubles the resistance.

Silver	**.9 ohm**
Copper	**1 ohm**
Aluminum	**1.7 ohms**
Iron, soft	**6 ohms**
Manganin	**25 ohms**
Constantan	**29 ohms**
Nichrome	**60 ohms**
Carbon	**2000 ohms**

Table I. Resistances of wire samples which all have the same length and thickness but are made from different materials. The last five materials are used in resistors and are taken up later in this lesson. Note that carbon has 2000 times as much resistance as copper.

Resistor Construction

Wire-wound Construction. Resistors made from metal wire are known as *wire-wound resistors*. The metal wire used most often in resistor construction is an alloy called *nichrome*, made chiefly from nickel and chromium. As indicated in Table I, nichrome has about 60 times the resistance of copper. This means that the *resistivity* of nichrome is about 60 times that of copper.

The nichrome wire is wound on a flat strip of fiber, on a rod of porcelain, or on some other stiff insulating material. The turns may be spaced out so they do not touch each other, or the wire may have enamel insulation.

When higher-wattage wire-wound resistors are required, they are wound on large cement or baked clay forms. The wire used is made to have the largest possible cross-sectional area, so there is a large surface area to conduct the heat to the form and to the surrounding air.

If a resistor of low ohmic value is required, a few turns of fine wire wound on the form would give the desired resistance, but this short wire would not get rid of its heat quickly enough to give the desired wattage rating.

Thicker and longer wire having the same resistance value is better, because it will get rid of heat faster. Increasing length and thickness both increase the surface area which radiates heat, so the resistor can then radiate more heat safely. This makes possible a higher wattage rating.

As you know, heat is produced whenever current flows through a resistance. The larger the current, the more heat we get. Nichrome wire can get red hot without breaking or melting; in fact the material used for the heating elements of electric stoves, toasters, electric heaters and soldering irons is usually nichrome.

But nichrome is by no means the complete solution to our resistor-making problem. We would still need a little over three miles of the smallest size nichrome wire to get a million ohms of resistance, and the cost of that much wire would be too high for practical purposes.

Nichrome wire is ordinarily used only for fairly low resistance values (below about 50,000 ohms for both fixed resistors and rheostats or potentiometers). Even then, wire-wound resistors made from nichrome (or similar metal alloys sold under various other trade names) are used chiefly when the resistor must carry considerable current, when the ohmic value of the resistor must be highly accurate, or when the ohmic value must stay the same despite changes in temperature.

Carbon Construction. This is the construction method which makes possible the tiny high-value fixed resistors, rheostats and potentiometers found in modern radio sets.

By itself, carbon has a resistance ranging from 500 to 2500 times the resistance of copper. By mixing carbon particles with certain cements or clay products, however, we can increase the resistance to more than a million times that of a corresponding amount of copper. Cements or binders serve the added purposes of giving needed "backbone" or strength to carbon, and keeping the carbon particles in position so the resistance stays fairly constant. Carbon is really a good all-around resistance material for general use.

By varying the proportion of carbon to binder material and forming the mixture into rod-shaped pieces, fixed carbon resistors having the same physical size (length and thickness) can be made in any desired value from about 50 ohms to about 15 megohms.

A carbon resistor scarcely *half an inch* long can have a resistance of a million ohms. Compare this with the *miles* of metal wire which would be needed to get such a high resistance.

The ends of each carbon resistance element are copper-plated so terminal leads can be soldered to them. The completed unit is then painted with various colors of enamel so as to specify its ohmic value according to the standard resistor color code (explained elsewhere in the Course).

Sometimes carbon resistors are placed in tubes of insulating material or coated with an insulating material. More often, the insulating material is molded over the carbon resistance element. Color code markings are then applied over the insulation. Insula-

tion prevents short-circuits (accidental short-cut paths for current) when resistors touch each other or other parts in a crowded chassis.

The chief reason for making carbon resistors in larger physical sizes is to secure higher wattage ratings. A larger resistor has more surface area to radiate the heat which is generated in the resistor, and can therefore handle more electrical power without becoming too hot. Three watts is about the highest rating in which carbon resistors are ordinarily made, however, for carbon-cement mixtures cannot withstand much heat.

Carbon resistors are the lowest-priced of all resistors, and for this reason are widely used in ordinary radio equipment.

Carbon rheostats and potentiometers are commercially available in values from about 500 ohms to about 10 megohms. Thus, values below 500 ohms are ordinarily obtainable only as wire-wound units, and high ohmic values are available only as carbon units.

Metallized Construction. In this process of making resistance elements for resistors, a liquid solution of certain metals is produced by a secret chemical process. The backbone of the resistor, usually a glass or porcelain rod or tube, is coated with this liquid and heated. This evaporates the liquid, leaving on the glass a hard, thin metallic coating which serves as the resistance element. By varying the strength of the metallic solution and by varying the amount of solution sprayed on the backbone, any desired resistance value between about 250 ohms and 20,000,000 ohms can be obtained.

How Temperature Affects Resistance. Practically all metals *increase* in resistance a small amount when heated. For example, a piece of *nichrome* wire having a resistance of 1 ohm when in ice water would have a resistance of about 1.04 ohms when placed in boiling water (this is a temperature rise of 180° Fahrenheit). A piece of *copper* wire having a resistance of 1 ohm at freezing temperature would increase much more, to about 1.39 ohms, when placed in boiling water.

Constantan and Manganin are special metal alloys which are little affected by temperature. Thus, a 1-ohm piece of Manganin would increase only to 1.001 ohms when transferred from freezing water to boiling water. These and other similar alloys are used chiefly for making precision resistors used in meters and in laboratory equipment requiring highly accurate and stable resistance values.

Carbon actually drops in resistance when temperature is increased, and this drop can be quite large when carbon resistors heat up during use.

When a material having a resistance of one ohm is heated or cooled one degree, the resulting *CHANGE IN OHMIC VALUE* is known as the *temperature coefficient of resistance.*

Metals are said to have a *positive* temperature coefficient of resistance, because they *increase* in ohmic value when temperature is increased. Carbon, on the other hand, has a *negative* temperature coefficient of resistance, because it *decreases* in ohmic value when heated.

Pilot lamps and tube filaments are perhaps the most striking examples of how the resistance of a metal increases with temperature. In these parts, the change in temperature from a cold filament to a red or white-hot filament may be several thousand degrees.

The hot resistance of a tungsten filament may be as much as ten or fifteen times its cold resistance. Thus, a particular pilot lamp might have a resistance of 4 ohms if measured with an ohmmeter when cold, and a re-

sistance of 40 ohms when hot. (The hot resistance cannot be measured with an ohmmeter, but can be figured out with Ohm's Law if the pilot lamp voltage and current are known or are measured.)

Tube filaments do not increase quite as much when hot, because these filaments do not get as hot as those in pilot lamps. Just remember the general fact—that a tube or lamp filament has a higher resistance when hot than when cold. This will explain seemingly erroneous results which might be obtained when using lamps as resistances in experimental circuits. It also explains why tube filaments often burn out right after a receiver is turned on. The cold tube filaments have a low resistance, hence an excessively large initial current flows when the set is first turned on.

Lamps with carbon filaments are now quite rare, but it is nevertheless worth pointing out that these lamps have a *much lower* resistance when hot than when cold.

Iron or nickel are resistance materials which increase in resistance even more rapidly than nichrome when heated. This characteristic is utilized to advantage in the special resistance tubes which serve as filament voltage-dropping resistors in some universal a.c.-d.c. receivers. These resistance tubes are so designed that when normal current flows through the resistance wire and produces normal heat, all tube filaments in the receiver get correct voltages.

If the line voltage goes above normal, however, the increased current through the resistance tube makes its resistance increase, so the resistance tube takes most of the increase in line voltage. As a result, the tubes still receive normal voltage, and are thus protected from burn-outs.

In the same way, when the line voltage drops lower than normal, the resistance of this resistance tube drops, the voltage drop across the tube becomes lower, and the tube filaments still get essentially the same voltage even though the line voltage has dropped.

Tolerance of Resistors. In resistors, just as in other manufactured parts, there is no such thing as a perfectly accurate unit. Accuracy costs money, because it means additional testing and more careful adjustment of resistor values. A 100-ohm, 1 watt resistor which is accurate to within 20% may cost only four cents, whereas the same resistor with an accuracy of 1% may cost fifty cents, and with .1% accuracy may cost $2.

The per cent variation from the specified ohmic value is called the *tolerance* of a resistor. A tolerance of 20%, sometimes expressed as ±20% (*plus or minus twenty per cent*), means that any value in the range from 20% under to 20% over the specified resistor value is tolerated (passed) during manufacture.

Thus, a 100-ohm resistor with ±20% tolerance may actually be anywhere between 80 ohms and 120 ohms. (20% is .2; $.2 \times 100 = 20$; $100 - 20 = 80$; $100 + 20 = 120$). A 100-ohm resistor with 5% tolerance may be anywhere between 95 and 105 ohms.

A 500,000-ohm resistor with 20% tolerance can be anywhere between 400,000 and 600,000 ohms.

A resistor tolerance or accuracy of 10% or even 20% is entirely satisfactory for general use in radio circuits, because resistance values are not critical in most circuits. Only in measuring instruments and in certain special radio circuits is it necessary to use more accurate resistors.

Normally, carbon resistors are made only to an accuracy of 20%. For special applications, however, carbon resistors are available with a tolerance of 10% or 5%, depending upon circuit requirements.

Metallized resistors have a normal accuracy of 10%, but here again, more accurate units are available at increased cost. Even 2% accuracy is obtainable, because these resistors are more stable (less affected by temperature changes) than carbon resistors.

Wire-wound resistors can be made as accurate as .1%, but 5% is the normal tolerance for general-purpose wire-wound resistors. Greater permanent accuracy and greater power-handling ability are the two main features of wire-wound resistors.

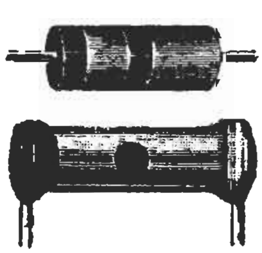
The tolerance encountered in actual resistors makes it unnecessary to figure resistance values with extreme accuracy. This is why practical radio men think nothing of using a 1000-ohm resistor when their figuring indicates that 900 ohms is needed.

Types of Resistors Used in Radio Work

FIXED RESISTOR. A radio part having an essentially constant ohmic value, used to introduce a definite resistance value permanently into a circuit. Fixed resistors have two terminals, leads or lugs, one at each end of the resistance element.

Three types of fixed resistor construction are found in radio: 1. Carbon Resistors; 2. Metallized Resistors; 3. Wire-wound Resistors.

◆ **1. Carbon Resistor.** A fixed resistor having as its resistance element



a mixture of carbon and a clay-like material which has been formed into a rod and baked until hard. Carbon resistors are made in various wattage ratings from $\frac{1}{10}$ watt up to 3 watts. They are the lowest-priced of all resistors. Standard tolerance is 20%, but resistors with 10%, 5% or 2% tolerance are available at higher cost. Carbon resistors always decrease in ohmic value when heated. Both insulated and non-insulated types are in common use. The wire leads come out either from the ends or sides.

◆ **2. Metallized Resistor.** A fixed resistor having wire leads attached to the ends of a metallized resistance element, with the entire

unit encased in cement, bakelite or other insulating material. They have essentially the same appearance, wattage ratings and ohmic values as carbon resistors, and can ordinarily be used interchangeably in radio circuits.

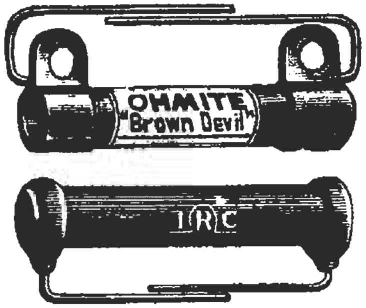
◆ **3. Wire-Wound Resistor.** A fixed resistor made of nichrome wire wound on a strip or rod of insulating material. The two ends of the resistance wire are soldered, welded, riveted or clamped to terminal lugs or leads.

Flat wire-wound resistors with exposed wire usually have ohmic values

ranging from 1 ohm to 1000 ohms, and a wattage rating of only ½ watt. These resistors are therefore suitable only for circuits where both resistance and power-handling requirements are low.

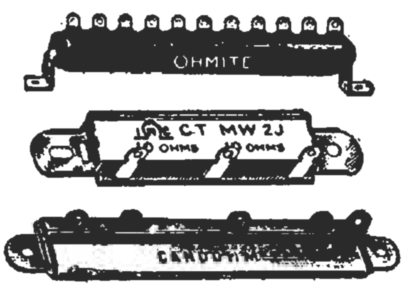
Flat wire-wound resistors wrapped in heavy fiber paper, then encased in a piece of sheet steel, are sold under the trade name

"Candohm." The metal shield protects the resistance wire from damage and helps to get rid of heat.



In wire-wound resistors which must handle a great deal of power, the resistance wire is wound on a porcelain tube and is covered with a baked-on layer of vitreous (glass-like) porcelain enamel or a special heat-resisting cement.

TAPPED RESISTOR. A fixed wire-wound resistor having one or more extra permanent terminals or taps along the length of the resistance element, and used chiefly as a voltage divider in the power pack of a radio set. Some tapped resistors have the



SYMBOL FOR TAPPED RESISTOR

resistance wire completely exposed, but more often the wire is protected with a vitreous enamel coating, a combination bakelite and steel housing, or a fiber and steel wrapping. Carbon and metallized resistors are not made with taps, but two or more of these resistors can be used in series to get taps.

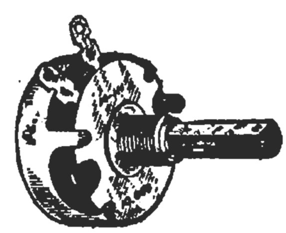
ADJUSTABLE RESISTOR. A fixed wire-wound resistor having one or more semi-movable extra terminals or taps which can be clamped in position at desired points along the length of the resistor. A semi-adjustable rheostat is obtained by using one sliding terminal and one end terminal. A potentiometer is obtained by using one sliding terminal and both end terminals. A screwdriver or wrench is required to change the resistance value. Adjustable resistors are used chiefly as voltage dividers in power packs.

SYMBOL FOR ADJUSTABLE RESISTOR OR POTENTIOMETER

RHEOSTAT. A resistor which can be changed in ohmic value by rotating a knob. In wire-wound rheostats, bare nichrome resistance wire is wound around a strip of flexible insulating material. The strip is then bent into a ring and mounted so a contact arm can be rotated over the edges of the turns of wire. One terminal of the rheostat goes to one end of the resistance wire, and the other terminal goes to the movable contact.

When the contact arm is at the fixed terminal, the resistance between the two terminals is zero. When the contact arm is moved *away from* the fixed terminal, the resistance between the terminals increases. When the contact

WIRE-WOUND



CARBON

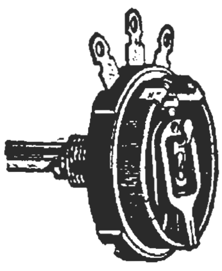
SYMBOLS FOR A RHEOSTAT

arm is farthest away from the fixed terminal, the resistance is a maximum.

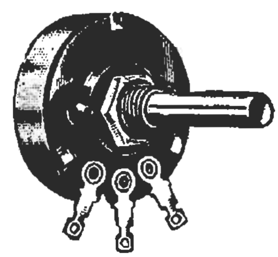
In one type of carbon rheostat, a shallow groove in a round disc of bakelite is filled with a mixture of carbon and cement. In another type, a washer-shaped disc of paper or the

inside of a paper ring is sprayed with a solution containing carbon. This circle of resistance material is broken at one point to form the resistance element over which the contact slides.

POTENTIOMETER. A rheostat having terminals at both ends of the resistance element, making three terminals in all. Construction is exactly the same as for rheostats; in fact, a potentiometer can be used as a rheostat by leaving one end terminal unconnected. Carbon units have a maxi-



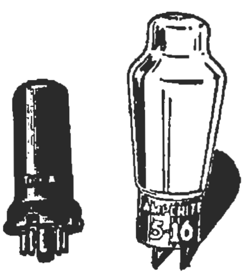
WIRE-WOUND

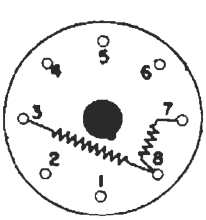


CARBON

mum wattage rating of one watt or less, hence are used chiefly in low-current signal circuits. Wire-wound units ordinarily have 5-watt ratings in radio work, but larger units are available.

RESISTANCE TUBE. A length of iron, nickel or nichrome wire mounted in either a glass or metal radio tube housing, and used in series with the filaments of tubes in universal a.c.-d.c. receivers for voltage-dropping purposes. A resistance tube is plugged into the standard tube socket provided for it on top of the receiver chassis. In this open-air position, the heat produced by the tube is dissipated much faster than by an equivalent under-chassis resistor.



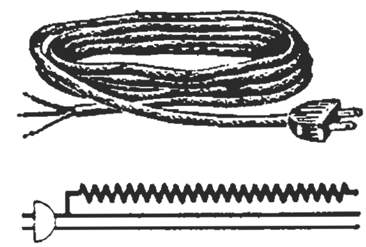


SYMBOL FOR RESISTANCE TUBE

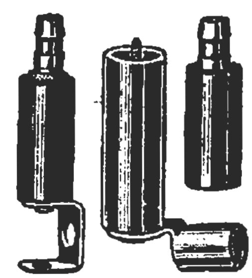
Resistance tubes using iron or nickel wire are sometimes known as ballast tubes, because they offset variations in line voltage by changing in resistance when the line voltage changes.

Resistance tubes usually have one or more taps, so pilot lamps can be connected across part of the resistance. The schematic symbol for a resistance tube shows the internal connections between the resistance wire and the base prongs or socket terminals.

LINE CORD RESISTOR. A spirally wound resistance wire covered with asbestos, running alongside the two regular stranded copper wires of the power cord in a universal a.c.-d.c. receiver. The cord gets warm when in use, since it must get rid of the same amount of heat as a resistance tube.



SUPPRESSORS. Fixed carbon or wire-wound resistors used in series with spark plug and distributor cables of automobile ignition systems to suppress interference which might affect auto radio reception. They have special terminals to permit easy mounting on spark plugs and distributor.



Looking Ahead

In the next lesson, you will learn about coils in much the same way that you have just learned about resistors. You will find that coils act like resistors in some ways, but coils act entirely different from resistors in alternating current circuits. The manner in which a coil can change the amount of its opposition instantly when the frequency of the current changes is one of the truly fascinating actions in radio.

Lesson Questions

Be sure to number your Answer Sheet 5FR-4.

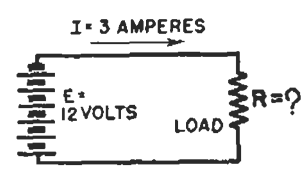
Place your Student Number on *every* Answer Sheet.

***Send in your answers for this lesson immediately after you finish them,* as instructed in the Study Schedule. Do this, and get the greatest possible benefit from our speedy personal grading service.**

1. What does each of the following represent:
   (a) E
   (b) I
   (c) R
   (d) ω
   (e) MEG.

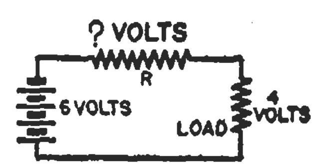
2. Give the formula you should use to find the amount of current flowing in a circuit, if you know the source voltage and the total resistance of the circuit.

3. In the circuit at the right, the load voltage E is 12 volts, and the load current I is 3 amperes. The formula to use is R = E ÷ I. Is the load resistance value: *4 ohms; 36 ohms;* or *¼ ohm?*



4. How much voltage would be measured across a 5 ohm resistor if the current flowing through it is 4 amperes?

5. In the circuit at the right, the source voltage is 6 volts, and the load voltage is 4 volts. How much is the voltage drop across series resistor R?



6. Currents of 3 amperes, 7 amperes, and 2 amperes are flowing *toward* a terminal. How many amperes of current are flowing *away* from that terminal?

7. If a 5 ohm, 10 ohm, and another 10 ohm resistor are connected in parallel will the total resistance be: *25 ohms; 20 ohms;* or *less than 5 ohms?*

8. Write one of the formulas for finding the power dissipated in a resistor.

9. About how much higher than the actual power should the wattage rating of a resistor be to give a margin of safety?

10. When the filament of a vacuum tube is heated does the filament resistance: *increase; decrease;* or *remain the same?*

STUDY SCHEDULE NO. 5

Use this schedule to help you master the fifth part of your N.R.I. Course. Unless other instructions are given, study one step at a time, as follows: Read the specified pages first at your usual reading speed, then reread slowly one or more times until you understand the entire section. Finish with one quick reading to tie the ideas together in your mind, then figure out your answers to the Lesson Questions specified for that step.

☐ 1. **Why Resistors Are Important in Radio..............Page 1 of this lesson**
One careful reading of this introductory section is enough to show you the importance of learning about resistors.

☐ 2. **Quickly review pages 3 to 13 of Lesson 3FR-2.**
These pages contain three sections: What Radio Men Measure; How Voltage and Resistance Affect Current in Simple Circuits; Load Connections for Radio Circuits. It is highly essential for you to review this material, so do it now. One quick reading should be enough.

☐ 3. **Ohm's Law Tells "How Much" for Resistors....Pages 2 to 6 of this lesson**
Ohm's Law, the radio man's most important rule for figuring out what *has* happened, *is* happening or *will* happen in a circuit containing resistance, is presented here in a complete, easy-to-understand manner. After you master this section, answer Lesson Questions 1, 2, 3, and 4.

☐ 4. **Using Resistors to Reduce Voltage........................Pages 7 to 9**
In this short section, you learn what to do when the source voltage is too high for the load, and master Kirchhoff's famous Voltage Law. Answer Lesson Question 5.

☐ 5. **Resistors in Parallel..................................Pages 10 to 17**
Another short section, giving useful information on resistors in parallel and showing how Kirchhoff's Current Law applies to radio circuits. Answer Lesson Questions 6 and 7.

☐ 6. **Wattage Ratings of Resistors..........................Pages 18 to 21**
Resistors give off heat when in use. If a resistor cannot withstand this heat, it burns out. The wattage rating is your guide as to whether a particular resistor will stand up in a particular circuit without becoming overheated. That's why this section is so important for practical radio work. Answer Lesson Questions 8 and 9.

☐ 7. **How Resistors Are Made..............................Pages 21 to 28**
The characteristics, advantages and disadvantages of various types of resistor construction are taken up. Answer Lesson Question 10, then read "Looking Ahead" on page 28.

☐ 8. **Mail Your Answers for Lesson 5FR-4 to N.R.I. for Grading.**

☐ 9. **Start Studying the Next Lesson on Coils.**

JD20M448 1948 Edition Printed in U.S.A.