CURRENT, VOLTAGE AND RESISTANCE MEASUREMENTS

28FR-3

NATIONAL RADIO INSTITUTE

ESTABLISHED 1914

WASHINGTON, D. C.

PIONEER HOME STUDY RADIO SCHOOL

NRI

STUDY SCHEDULE NO. 28

For each study step, read the assigned pages first at your usual speed. Reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind, then answer the Lesson Questions for that step. Study each other step in this same way.

☐ 1. Direct Current Meters .... Pages 1-10

The most widely used measuring device is the D'Arsonval d.c. meter. Learn its principles and all other meters are easy to understand. Here you learn how the meter range is extended and how meters are calibrated. This section is full of practical information on using current meters—information which may prevent your damaging your equipment. Answer Lesson Questions 1, 2, 3 and 4.

☐ 2. Alternating Current Meters .... Pages 10-19

There are many ways of measuring alternating current. These methods have advantages and disadvantages which you must keep in mind; otherwise, you can get misleading readings. Here the principles of these methods are fully developed. Pay particular attention to the information on the copper-oxide rectifier, as this is the most widely used a.c. rectifier. Answer Lesson Question 5

☐ 3. Voltmeters .... Pages 19-22

Voltages are measured by the same kind of meter used for current. The important difference is the arrangement of resistors used with the meter. A voltmeter will not always indicate the true operating voltage, depending on its sensitivity. The reason for this, as well as the practical means of allowing for this condition, is clearly brought out by practical examples. You won't be confused by your voltmeter readings after reading this section. Answer Lesson Questions 6 and 7.

☐ 4. Ohmmeters .... Pages 22-25

The ohmmeter is probably the most used service instrument. With it you determine resistor values, check condensers for shorts or leakage and check coils and circuits for continuity. Practical data on using and safeguarding this valuable device is given. Answer Lesson Questions 8 and 9.

☐ 5. Multimeters .... Pages 25-28

The multimeter is a combination current meter, voltmeter and ohmmeter, built into a single unit for convenience in using. The two basic types are covered, so you will know how to use either. Of course, there are many different scale ranges available, as each manufacturer has his own ideas as to the most desirable ones. Practically all the standard makes are good. however, once you learn to read their scales. This section closes with an important review of meter tolerances and their practical importance. Answer Question 10.

☐ 6. Mail your Answers for this Lesson to N.R.I. for Grading.

☐ 7. Start Studying the Next Lesson.

FM10M848 1948 Edition Printed in U.S.A.

CURRENT, VOLTAGE AND RESISTANCE MEASUREMENTS

Direct Current Meters

METERS are used constantly in radio work of all kinds. As a radio serviceman, you'll make at least a few meter measurements on practically every set you handle.

Early in your N.R.I. Course you learned the elementary facts about what these instruments are and how they are used to measure current, voltage and resistance. In this lesson you'll learn the practical details of actual commercial meters—how they're made, how they work, what to expect from them, and—most important of all—the correct ways to use them.

HOW IS CURRENT MEASURED?

We cannot see an electric current, but we can detect a number of effects produced by its flow. We might use any one of these effects to measure the amount of current flowing.

For example, we might use a thermometer to measure the heat produced by a current flowing through a wire. From this heat measurement, we could calculate the amount of current.

Or, we might send the current through a resistance wire that will become hot enough to give off light—a common light bulb, for example. By measuring the amount of light produced, we could determine the amount of current flow.

Again, we might make the current flow through a certain silver salt solution, causing a silver electroplating action. By weighing the amount of silver thus "plated," we would have another means of measuring current. (This last, under carefully controlled conditions, is an international standard method of determining exact current flow.)

But these methods are generally too slow and cumbersome for practical uses. We need a device which will react at once to changes in current and which can be used anywhere, not just under laboratory conditions.

One of the first electrical discoveries was that the magnetic field which always accompanies a current flow would make a compass needle move. Experiments soon proved that the distance the needle moves depends on the amount of current flowing. This was a highly important discovery, for it pointed out the basic principle used in most modern meters. Let's now see how these meters use this magnetic effect to measure current.

THE D'ARSONVAL METER

Early experimenters soon found that the compass needle method of measuring current was not accurate enough, since it depended on the amount of magnetism in the needle and the effect of the earth's magnetic field. A meter (known as the D'Arsonval type, after its inventor) was invented which overcame these objections.

Instead of placing a compass within

a coil, a small coil is suspended so it can move, and is placed in a strong magnetic field. When the current to be measured flows through the coil, a magnetic field is set up which interacts with the fixed field, causing the coil to move. The basic principle of this operation is shown in Fig. *1*. You remember that like magnetic poles will repel. If a small pivoted magnet is placed as shown in Fig. *1A*, it will move

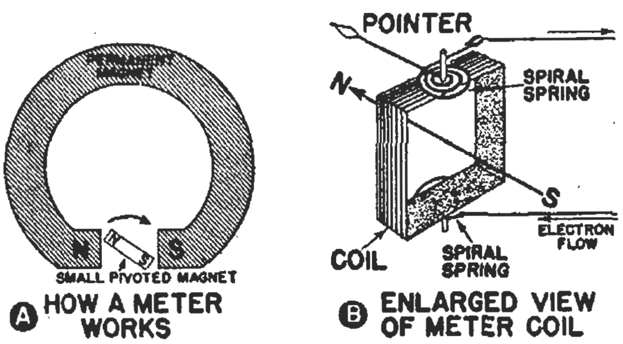


FIG. 1. The coil has a magnetic field and will move when placed in a fixed field.

in the direction of the arrow. A current-carrying coil, such as the one shown in Fig. *1B*, has a north and a south pole. If this coil were put in place of the small magnet in Fig. *1A*, it too would move.

Unless some means are taken to stop it, once the coil starts to rotate, it will continue to do so. That is why the two fine spiral springs are attached at the ends of the coil. When the coil moves, the springs are twisted so that they oppose the coil movement. The more the coil rotates, the more opposition the springs give. Thus, the coil moves only to the point where the magnetic force causing rotation is balanced by the retarding action of the springs. When the current stops, the magnetic field of the coil disappears, and the springs move the coil back to the starting position.

The magnetic force causing rotation of the coil is proportional to the amount of current flowing through the coil. Therefore, one particular value of current will make the coil rotate to one particular place. A larger current will rotate the coil farther; a smaller one will rotate it less. By attaching a pointer to the coil, the amount of movement can be indicated on a scale. This scale, when properly marked, will show us the amount of current flowing through the meter.

This is the basic principle of the D'Arsonval type meter movement. It has been developed into the modern, practical meter shown in Fig. *2*. Let's look at its features.

The small, powerful magnet is made from special steel or metal alloys, chosen for strong magnetic qualities and long magnetic life. The stronger the fixed field, the more the coil will move for a particular current, so the permanent magnetic strength is made as high as possible. The magnet is specially treated and aged until the field strength remains constant.

The pole pieces are soft iron, carefully shaped to give the desired magnetic field distribution. If the meter scale is to be linear (that is, so adjusted that equal increases in current will produce equal increases in meter movement), the magnetic field must be uniform through the gap in which the coil turns. A soft iron core is inside the coil form. The coil moves through a small gap between this core and the pole pieces. By making this gap small to reduce the reluctance of the magnetic path, we obtain a strong field.

To make the coil easy to move, it is wound on a very light, thin metal form, and the coil and form are suspended between almost frictionless pivots with jewel bearings. The number of turns and size of wire used to make the coil depend on the current range and sensitivity desired for the meter.

The coil must start to move from

the same position each time, in order for the pointer to come to rest at the proper point on the meter scale. This starting, or zero, position is determined by the springs. They are wound in a loose spiral so that they oppose any rotation which would either wind them tighter or unwind them. When the coil moves, one is wound while the other is

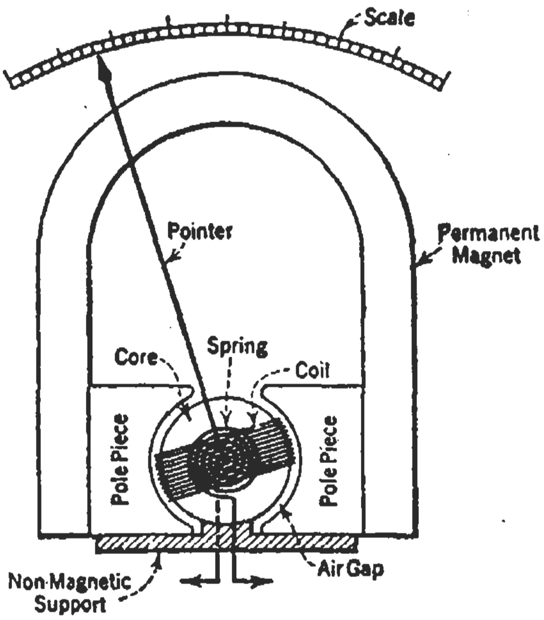


FIG. 2. The names of the meter parts.

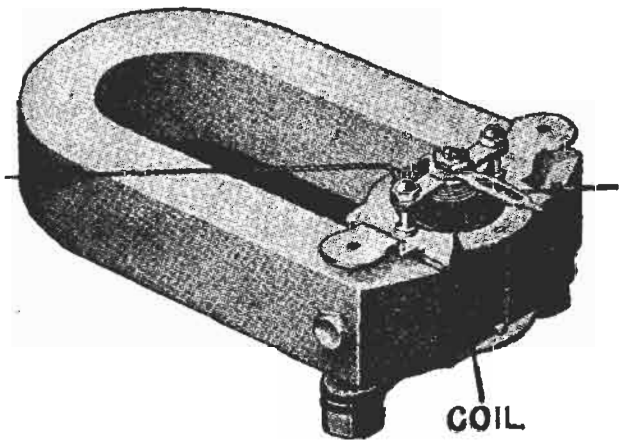
unwound. The springs thus oppose a coil movement in either direction away from the starting position, which is the position the pointer takes when no current is flowing in the coil.

Naturally, these springs won't always remain perfectly balanced. That is why practically all good meters have a zero adjustment. This is a small screw which usually protrudes through the case of the meter just below the meter coil. By turning this screw, the upper coil spring can be moved enough to balance the springs and bring the meter pointer back to the zero position.

The springs are also used to make the electrical connections to the coil, as shown in Fig. *1B*. The springs are metal, so they make ideal leads. Of course, this means they must be insulated from each other and from the meter frame.

Meter Damping. When a current flows through it, the coil (because of its inertia) tends to overshoot or move past the correct point a small distance. Then the springs pull the coil back on the other side of the correct point. In other words, there is a wavering back and forth for a time before the meter pointer settles down to the proper readings. To keep this wavering as small as possible, the meter coil frame is made of metal. When it moves through the permanent magnet field, eddy currents are induced in the frame. These eddy currents set up an opposing field which slows down the rate of coil movement, so that the coil comes to the correct point and stops. This steadying action is called damping.

Another common method of damping is to place a resistor between the meter terminals. A voltage is induced in the coil as it moves through the fixed field. This induced voltage causes a current flow through the resistor and coil, which sets up an opposing field with a result like that caused by the eddy currents induced in the coil form. In both cases, the damping action ceases as soon as the coil stops moving.



What the inside of a meter looks like.

The resistor value which will permit the most rapid coil movement, without noticeable wavering at full-scale meter reading, is called the *critical damping value*. This value varies widely with different meters—some may require

10,000 ohms, while others may need as low as 100 ohms. A resistor below the critical value causes overdamping and a slow meter movement, while too large a resistor does not damp enough.

The eddy current method of damping does not affect the meter range at all. The resistor method may or may not affect the current range of the meter, depending on the value of the resistance needed. You will learn more about this later on in this lesson.

CALIBRATION

The meter we have described will indicate when current is flowing. However, we are usually most interested in the actual amount of current flowing, so we want the meter to have a scale marked off in units of current flow.

By passing known currents through a meter, we can mark the scale according to the deflection obtained and thus calibrate the meter. "Calibrating" is the technical term for finding the accurate values of points on the scale of an instrument. For example, suppose you had a stick of wood with scratches on it that you wanted to use as a ruler. You'd "calibrate" it by finding how many inches each scratch was from one end of the stick. Meters are calibrated the same way—except, of course, each point on the scale is marked in terms of the current, voltage or other quantities needed to make the meter needle swing to that point.

Large laboratories, such as the Bureau of Standards, determine currents very accurately by chemical or other means and hand-calibrate a standard meter. Then the standard meter is placed in series with a meter to be calibrated, as shown in Fig. 3. The amount of current passing through the two meters is varied in steps, and the meter readings are noted for each step. Since the standard meter is indicating the exact current flowing through both meters, the other meter can be directly calibrated from the standard. This method is used in the manufacture of the more accurate and expensive meters.

Meters of reasonable accuracy and much lower in price can be made by duplicating the hand-calibrated meter as closely as possible in all parts. These production meters usually have about the same response as the meter on

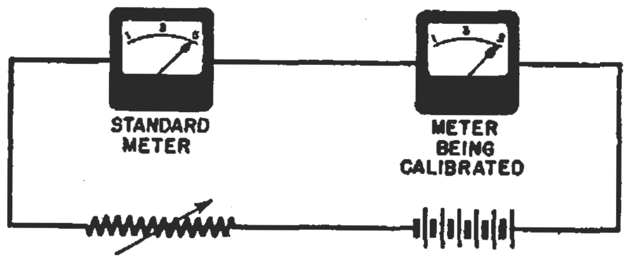


FIG. 3. Calibrating a meter by comparison.

which they were modeled, so the same scale can be used for all of them with fair accuracy. To improve the accuracy of their mass-produced meters, manufacturers adjust the spring tension and magnetic field so that the full-scale reading of each meter is correct.

Percentage Accuracy. Highly accurate, hand-calibrated meters are expensive, and not necessary for service work or ordinary testing. Servicemen generally use production meters with printed scales. The percentage of accuracy of such meters is expressed in terms of full-scale deflection. For example, suppose a milliammeter has a full-scale reading of 100 ma. If it is off 5 ma. when the needle gives a full-scale deflection, the meter is said to have a 5% accuracy. (5/100 = .05 or 5%). In other words, when the needle points to 100 ma., the actual current being measured may be 95 ma. or 105 ma., or any value in between.

Now this 5% accurate meter may have much poorer accuracy for readings at the low end of the scale. When the meter points to 10 ma., the meter may still be wrong by 5 ma., which would mean a 50% error. (5/10 = 0.5 or 50%). Of course, most of the better meters are held within 1% or 2% of full scale, and the inaccuracy at the low end of the scale is not as great as that given in our example. But here's a practical tip—if several meter ranges are available, use the one giving a deflection of more than half-scale. Then your reading will have the least error.

Parallax. Inaccurate readings may result from looking at a meter scale from an angle rather than from right above it. Figure *4* shows you why.

In order to swing freely, the pointer has to be at least a little distance above the scale. Now when you look right down on the pointer, you get one reading. Say it's 10. If you are off to one side, the pointer will seem to give a different reading. It might be 9 or 11, depending on which side you are. The farther you are to either side, the farther off the apparent reading will be from the true one. (You can prove this for yourself by trying to read your watch at an angle.) This shift in the apparent position of the pointer, due

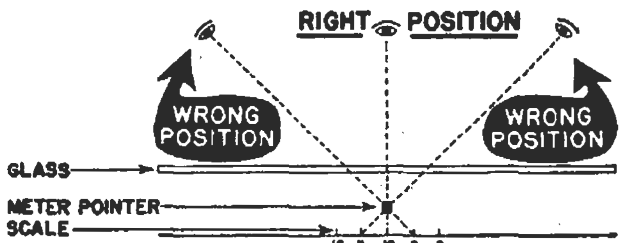


FIG. 4. Always look straight at a meter to avoid parallax.

to the position of the observer, is called parallax.

Most laboratory meters have a small mirror on the scale under the pointer, so unless your eye is directly above the pointer, you will see a reflection of the pointer in the mirror. With such meters, you can avoid parallax by always moving to where the reflection disappears behind the pointer before making the reading.

In service and communications work, highly accurate readings are usually unnecessary. Even so, good service meters have pointers shaped like knife blades. These pointers look thinnest when viewed from the correct position.

EXTENDING CURRENT RANGES

In practical service and laboratory work, both large and small currents have to be read. We could use a number of different meters having the required ranges, but meters are costly and bulky. It is far better to have one meter and a means of changing its current range.

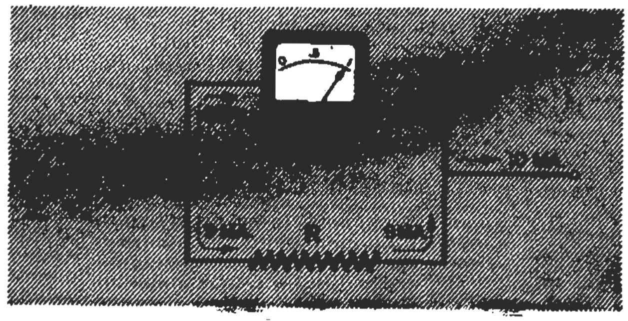


FIG. 5. The current flow divides between the meter and shunt.

Shunts. Suppose we have a 1-ma. meter and want to measure 10 ma. We can do so by putting a resistor across the terminals of the meter of such a value that 9/10 of the current coming into the resistor-meter combination will flow through the resistor and only 1/10 will flow through the meter. In other words, we use the resistor to "by-pass" 9/10 of the current. Figure *5* shows how this is done. When we read the meter, we simply remember that there is 10 times as much current flowing as the meter shows—so we multiply the meter reading by 10 to get the actual current flow. If our meter reads 0.5 ma., we know the real current is 5 ma. ($0.5 \times 10 = 5$); if it reads 1 ma., the actual current is 10 ma. ($1 \times 10 = 10$).

Since the "by-pass" resistor *R* makes

a parallel (or shunt) path around the meter, it is called a shunt. The ohmic value of *R* is calculated so that it will pass a current equal to the difference between the total current to be measured and the amount the meter needs for full-scale deflection. For example, suppose we want to measure currents up to 25 ma., but all we have is a 1-ma. meter. Then we'll have to find a shunt *R* which will pass 24 ma.

To do this, we use Ohm's Law, $R = E/I_S$. The voltage *E* is the voltage across the meter terminals. This voltage is called the meter millivolt rating and is equal to the basic meter current range multiplied by the meter resistance, so we can substitute for *E* in our Ohm's Law equation the quantity $I_M \times R_M$. (I_M is the basic meter current; R_M is the meter resistance.) The current I_S is the current which passes through the shunt. This current equals the total current minus the basic meter current, so we can substitute for I_S the quantity $I_T - I_M$ (I_T is the total current flowing; I_M, as before, is the basic meter current.)

Now our Ohm's Law equation reads:

$$R = \frac{R_M \times I_M}{I_T - I_M}$$

We can find *R* by substituting values for the other terms. (All currents must be figured in the same units—that is, all in milliamperes or all in amperes. Then *R* will come out in ohms.)

Suppose our 1-ma. meter has a resistance of 100 ohms. The current I_T we want to measure is 25 ma. Then,

$$R = \frac{100 \times .001}{.025 - .001} = \frac{.1}{.024} = 4.2 \text{ ohms,}$$

and we've found the size shunt we need.

To find the actual total current flowing, multiply the reading on a shunted meter by the ratio of the current range of the meter with shunt to the current range without shunt. In our example, a 1-ma. meter was made a 25-ma. meter by the use of a shunt, so meter readings must be multiplied by 25 to learn the actual current flow (25/1 = 25). *Remember—the meter itself is not passing 25 ma.* Only 1 ma. goes through the meter, and 24 ma. go through the shunt.

You remember that a shunt resistor helps damp a meter. Most shunts have a resistance less than the critical damping value, so the meter movement is slowed down somewhat. This overdamping is not usually objectionable, however.

MULTI-RANGE CURRENT METERS

Very likely the meter you'll use in your service work will have a number of ranges, with several built-in shunts and a switch arrangement. Figure *6* shows one way such a meter might be made. When the selector switch is in position *1*, the meter is not shunted. In other switch positions, different shunts are thrown in, giving various ranges. Typical ranges might be: 1 ma.; 10 ma.; 100 ma.; 10 amperes. Whatever

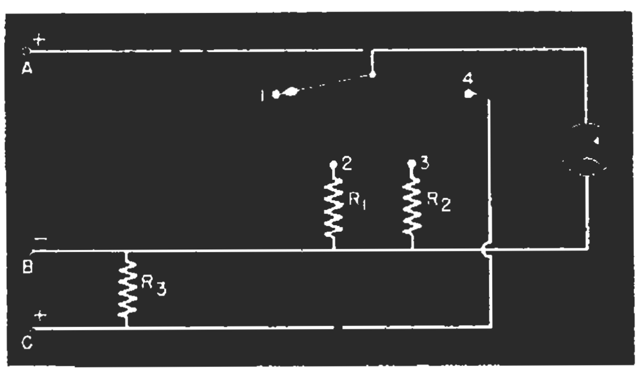


FIG. 6. Multi-range current meter.

the ranges, the manufacturer will mark the scale for each range so you won't have to do any figuring. The only usual exception is when one range is 10 times another, as when the ranges are 10 ma. and 100 ma. There, you may have to multiply by 10 when using the 100-ma. position, getting your readings from the 10-ma. scale. This is easy, however.

The greater the current range extension, the smaller the shunt resistor must be. With meters of low resistance, the shunt necessary to extend the range above 1 ampere is usually only a fraction of an ohm—so even a small amount of switch-contact resistance in series with the shunt might cause a large current to flow through the meter. To avoid this contact-resistance trouble on the high current range, many service instruments use the extra terminal *C* shown in Fig. *6*. Terminals *A* and *B* are used for the basic range and for the low extensions. For the high-current range, terminals *B* and *C* are used. Shunt R_3 is connected right between *B* and *C*. The selector switch is now in the meter circuit. In measuring high currents, switch-contact resistance will not matter greatly, as it adds to the meter resistance instead of to the shunt resistance. Also, the high current does not flow through the selector switch contacts. However, Fig. *6* does not represent the best arrangement, as it is possible to damage the meter if the switch develops too much contact resistance in position *2* or *3* or should open-circuit when switching.

This damage is avoided in the circuit shown in Fig. *7*, which is known as a "series or ring shunt." When the selector switch is in position *1*, the lowest range is obtained. Note that this is not the basic meter range, as the resistors R_1, R_2 and R_3 are acting as a shunt across the meter.

When the switch moves to position *2*, resistors R_2 and R_3 are the shunt, while R_1 is added to the meter resistance, since it is now in series with the meter. Similarly, in position *3*, R_3 is the shunt while R_1 and R_2 are in series with the meter.

There are two advantages to this arrangement; the meter is protected against damage at all times, and the resistors are relatively independent of the meter resistance, so they can be chosen to be any reasonable values.

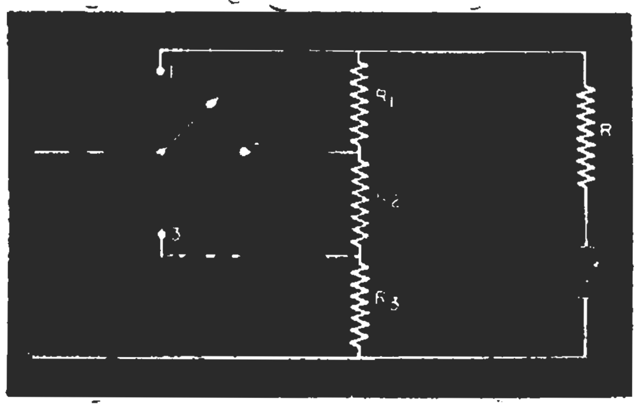


FIG. 7. The use of a ring shunt makes this a better multi-range current meter.

Switch-contact resistance causes no trouble, since it adds no resistance to either the meter or shunt circuit. Should the switch become defective, the entire meter circuit is opened and protected instead of damaged.

USING A DIRECT CURRENT METER

There are five things you must keep in mind when using a current meter. Let's see what they are and why they're important. Then we'll summarize our findings in five easy-to-remember rules.

1. Series Connection. The most important thing to remember is that the current meter must be *in series* with the circuit. If necessary, unsolder a lead or cut a wire so the meter can be placed in the circuit. *Remember, the circuit current you want to measure must pass through the meter itself. If a milliammeter is ever connected across a circuit part (in parallel), it is almost certain to be burned out.*

2. Correct Point. In the simple circuit shown in Fig. *8*, the meter may be placed anywhere in the circuit. The meter readings at *A*, *B* and *C* will be the same, because the same current flows through the entire circuit. However, when checking screen-grid or pentode tubes another problem arises. The screen-grid current also flows in the cathode lead in returning to the B supply. Hence, the plate current alone can be measured only at positions *B* or *C*. Position *A* will give both screen and plate currents together.

When more than one tube is used, as shown in Fig. *9,* notice there are now two paths for current, one for each tube. If you want to measure the plate current for tube VT_1 only, be careful to locate a point where *only* the plate current of this tube is flowing. The cathode lead of tube VT_2 may connect

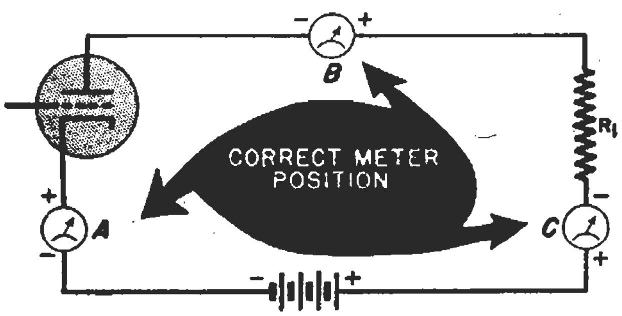


FIG. 8. Be sure to place a current meter in series and use the proper polarity.

directly to the cathode of VT_1 and the B+ ends of resistors R_1 and R_3 may be directly connected together, so positions such as *A* and *C* of Fig. *8* may not be usable. The shaded areas of Fig. *9* show the proper places to measure the plate current of VT_1. You must be sure to insert your meter where only the *desired* current is flowing. Otherwise, false readings will result. The meter may even be damaged if the sum of the currents exceeds the meter range you have chosen.

3. Current Range. The current range of the meter must be higher than the expected current; otherwise, the meter may be badly damaged or even ruined. The circuit current is determined by Ohm's Law, $I = E/R$, where *R* is the total of all the resistance in the circuit. In a circuit like Fig. *8*, with a fixed supply voltage, the tube plate resistance plus resistor R_1 determines the current flow. The current will be about 5 to 10 ma. if this is an ordinary amplifier tube. However, if the tube or resistor R_1 is short-circuited in some way, the resistance of that part is removed and the current will be many times higher—perhaps enough to burn out the meter.

This danger is the reason that current measurements are not made very often in service work, except where voltage and resistance measurements indicate that it is safe to do so. When using a multi-range current meter, *always start with the highest current range* and switch to lower ranges if the readings permit. Voltage and resistance measurements properly made will usually make it possible to calculate the current, saving you the trouble of opening the circuit except in rare instances. (In transmitters it is necessary to know certain current values at all times for adjustment and maintenance purposes, so current meters are permanently connected in the proper plate and grid circuits.)

4. Meter Resistance. In the usual plate circuit, the tube and other parts

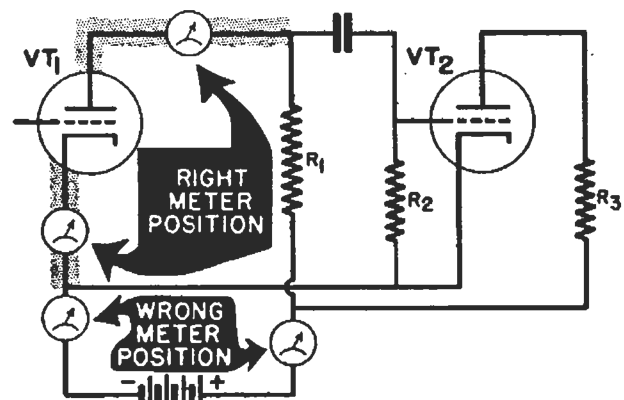


FIG. 9. The right meter position is important.

have resistances many times the meter resistance, so inserting the meter does not affect the amount of current flow much. For example, a meter of 100 ohms added into a circuit of 10,000 ohms obviously will not greatly change the circuit resistance. Suppose we were to apply 200 volts to a 10,000-ohm resistor. From Ohm's Law ($I = V \div R$), the current would be .02 ampere or 20 ma. Now if the circuit resistance is increased 100 ohms by the insertion of a 100-ohm meter, the total resistance will be 10,100 ohms. The current then will be .0198 ampere or 19.8 ma. You would not be able to read the average meter close enough to tell the difference between 19.8 ma. and 20 ma., so for all practical purposes, the meter has not changed the current flowing in the circuit.

However, if the meter is inserted in a low-resistance circuit, it will frequently change the current or may even determine the amount of current flow. For example, a tube filament may have a resistance of 40 ohms. If a 100-ohm meter is connected in series, the original current will be cut considerably. If the voltage is 2 volts, the original filament current for a 40-ohm filament resistance would be 50 ma. With the meter resistance added in series, the total is now 140 ohms; so the current would be cut to about 14 ma., which is about ¼ of the original value. Here you would have to depend on voltage and resistance measurements. In laboratory work particularly, the effect of the meter must be carefully considered, and the lowest resistance meter available, with the required range, must be used. If a suitable meter is not available, other types of measurements must be made.

5. Polarity. The direction of movement of the meter coil and the attached needle depends on the direction of the magnetic force, which in turn depends on the direction of current flow through the coil. If the meter is connected backwards, it will indicate backwards or down-scale.

The meter terminals are marked so that proper connections can be made. Just remember to connect the positive terminal of the meter toward the positive terminal of the source, so electrons *enter* the *negative* meter terminal.

To help fix this in your mind, refer back to Fig. *8* where the correct meter polarity is indicated. When a tube is in the circuit, it acts as a signpost, showing the direction of electron flow through the entire circuit. Electrons, of course, flow only from the cathode of a tube to its plate and continue to flow in the same direction through the rest of the circuit. To make the meter needle read up-scale, the electrons must *enter* the *negative* meter terminal. Should the meter connections be reversed so the electrons enter the meter terminal marked +, the meter needle will read down-scale.

If the circuit does not contain a tube, you have to determine the polarity of the source and follow the rule of connecting the positive meter terminal toward the positive of the source.

Now let's summarize what we've learned about using current meters.

1. Always connect the meter *in series* with the circuit.

2. In multiple circuits, connect the meter where *only* the desired current flows.

3. Always use a meter range *higher* than the expected current.

4. The meter (and shunt, if used) resistance must be *much smaller* than the circuit resistance.

5. Connect the meter so electrons enter the *negative* terminal.

PULSATING CURRENT

Suppose we tried to measure a.c. with our d.c. meter. What would happen?

If it were very slowly changing a.c., the coil would turn first in one direction and then in the other, as indicated by the fact that we must watch polarity. This means that half of the time the meter needle would be off-scale. This would not happen with 60-cycle a.c., however, because the meter movement is too slow to follow a.c. variations occurring more than 5 or 10 times per second. For alternating currents of higher frequency than 5 cycles, the inertia of the meter movement makes the D'Arsonval meter indicate the *average* current over a period of time.

When you analyze an a.c. wave, you will notice that in each cycle the current is alternately positive and negative, so the *average* current is zero. That is, the positive swings are equal to the negative swings, so their effect on a slow-moving object is zero. This is important; it means that a D'Arsonval meter alone will not read on a.c.—it can only indicate the a.c. average (zero), regardless of the amount of a.c. current passing through it.

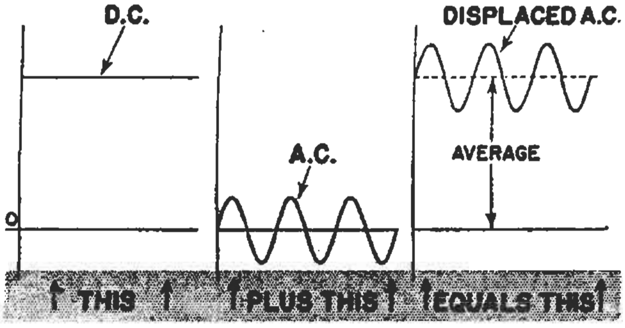


FIG. 10. The average value of a pulsating d.c. wave is equal to the d.c. component.

Now a pulsating current has both a d.c. and an a.c. component, as shown in Fig. *10*. Our meter won't read the a.c., but it will read the d.c. So, on pulsating d.c., a meter reading shows only the amount of d.c. present.

In the case shown in Fig. *11A*, an a.c. cycle has been rectified by a half-wave rectifier. Now the pulses exist in the same direction all the time, so this is another form of pulsating current. Even though there are gaps when no current flows, there is still an average value. (Naturally, this average is low; it's only about .3 of the peak value.) The D'Arsonval meter will indicate this average value. When a full-wave rectifier is used, the average value is higher, as shown in Fig. *11B*. The average is now about .64 of the peak value.

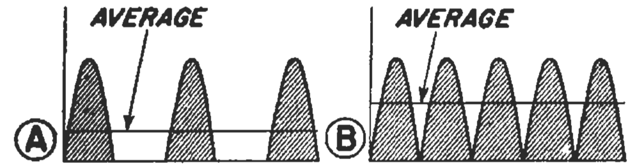


FIG. 11. Notice that full-wave rectification (B) produces a d.c. average twice that of half-wave rectification.

Just remember this—any pulsating current has a d.c. average which can be read on a D'Arsonval meter.

Alternating Current Meters

In discussing alternating current meters, we will consider power line, a.f. and r.f. currents all as a.c. The only difference is one of frequency; however, this is important because some a.c. meters cannot measure the higher audio or r.f. frequencies accurately.

In the preceding section, you saw that a D'Arsonval meter could not by itself measure a.c., because the average value of a sine wave current over a period of time is zero. But our meter can be used to measure a.c. if we find some way to make this average value different from zero. Actually, there are three general classes of a.c. measuring devices, and D'Arsonval meters are used in two of them. The three classes are:

1. The D'Arsonval d.c. meter with a vacuum tube or copper-oxide rectifier.

2. The d.c. meter with a conversion device, such as the thermocouple or photoelectric cell.

3. True a.c. meters, such as the hot-wire, magnetic-vane and the electrodynamometer types.

Let's examine each type to see how it works.

ALTERNATING CURRENT RECTIFIERS

Vacuum Tubes. Any diode tube will rectify a.c., as current can pass through the tube only when the plate is positive with respect to the cathode of the tube. In the circuit shown in Fig. *12,* the diode tube *VT* passes current only when terminal *1* is positive with respect to terminal *2.* The resulting half-wave pulses have an average value which is about .3 of the a.c. peak. This average value will produce a deflection on a D'Arsonval meter.

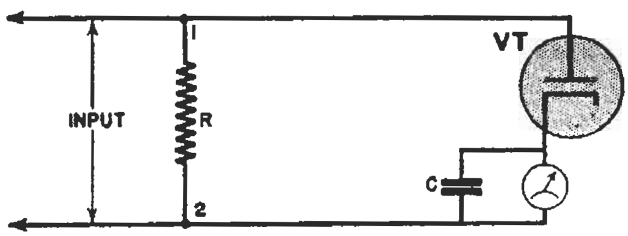


FIG. 12. A diode can be used to rectify a.c.

The condenser *C* in Fig. *12* is used to by-pass the high-frequency pulsations around the meter. The meter movement is a coil and so has inductance. If not by-passed, the inductive reactance would be added to the meter resistance and might both upset the circuit and make it non-linear with respect to frequency. The condenser also serves to smooth out the pulsating current, bringing the peak value down and raising the d.c. average. This not only gives a greater sensitivity, but also reduces the danger of high peak values damaging the meter.

The rectifier tube and meter can't be placed in series with the circuit whose current we wish to measure, because the tube will change the a.c. in the circuit to a pulsating current. We want rectification for the meter, not for the complete circuit. We get it by inserting resistor *R* in series with the circuit. The a.c. voltage developed across the resistor then is applied to the tube-meter combination. Thus, we are actually measuring the current indirectly by the voltage drop produced in this resistor. The meter is calibrated so all these conditions can be accounted for. Usually, it indicates the effective or r.m.s. value of the a.c.

Figure *13* shows how a triode tube may be used for rectification. The C bias is adjusted so that the plate current is nearly zero. When an alternating current flows through resistor *R,* an a.c. voltage is developed across it. Negative alternations make the grid even more negative and so have practically no effect on plate current. However, the positive alternations swing the grid in the other direction so that plate current pulses flow. The meter then responds to the average plate current.

This plate current is proportional to the a.c. grid voltage, which is determined by the alternating current in the circuit and the value of resistor *R.* Thus, the plate current is an indirect measure of the circuit current.

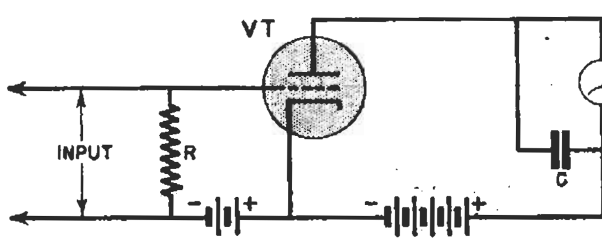


FIG. 13. How a triode rectifier is connected.

Resistor *R* acts just like a shunt in this circuit. For example, we may need 1 volt on the grid to produce a full-scale meter deflection. By using a 1000-ohm resistor, a circuit current of 1 ma. would give 1 volt. If we use a 100-ohm resistor, 10 ma. would be needed to produce 1 volt.

Copper - Oxide Rectifiers. The D'Arsonval meter and copper-oxide rectifier* combination is the most

---

*Selenium on iron is also used in place of copper oxide, and the same rectifier circuits are used.

widely used a.c. measuring device, and is found in the equipment used by most servicemen. The copper-oxide rectifier is stable, relatively reasonable in cost, and can be designed to work on small currents.

Each rectifier element consists of a copper disc or washer, which has one surface oxidized by a special heat treatment. A contacting washer, usually made of lead, is pressed on the oxide layer. This oxide layer rectifies because it permits electron flow through the layer in one direction much more readily than in the other. In other words, electrons can move easily from the copper through the oxide to the lead contacting disc but they encounter a fairly high opposition when trying to move in the other direction.

There are several different ways of connecting these elements, but the most common is the full-wave bridge circuit shown in Fig. *14*. Four separate elements are used in the bridge. In practice, these elements would be mounted on an insulated single bolt, with insulating washers between the elements.

The arrows alongside the elements in Fig. *14* indicate the directions in which electron movement most easily occurs for each half cycle. When terminal *1* is negative (*2* is positive), the electrons move in the direction shown by the solid arrows. At point *A* the electrons choose the path toward point *B*, because rectifier *W* conducts better than rectifier *X* for this half of the a.c. cycle. At point *B*, the electrons go through the meter instead of rectifier *Z*, since *Z* offers a high impedance to electrons moving in this direction. Reaching *C*, the electrons pass through rectifier *Y* to point *D*, and from there go to terminal *2*.

When the cycle reverses, terminal *2* becomes the negative terminal. Now electrons follow the dotted arrows from terminal *2* to *D*, then through rectifier *Z* to *B*. From here, the path is through the meter to *C*, then through rectifier *X* to *A* and so to terminal *1*. Note that regardless of the polarity at *1* and *2*, electrons *always* pass through the meter in the same direction, which is exactly the action of a direct current. Hence, a direct current meter can be used at *M*.

We use full-wave rectification in this circuit because it gives a higher

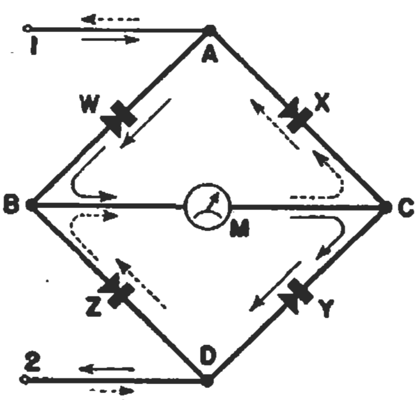


FIG. 14. The copper-oxide rectifier in a bridge is the most common rectifier for service work

average current, about twice that for half-wave rectification. This practically doubles the meter sensitivity by giving a higher meter deflection for the same amount of alternating current, so that our meter has an a.c. sensitivity almost as good as that on d.c.

If one element of the bridge burns out, half-wave rectification will be obtained instead of full-wave. Then, since the average current is only about half that for full-wave, the meter will only read about half as much as it should. You can easily spot a damaged rectifier element in a meter of this type —check a known a.c. current; if the reading is half what it should be, one of the elements is damaged.

The back-to-back circuit is another form of full-wave bridge, with the advantage of using only two rectifier elements instead of four. The circuit gets its name from the rectifier connections, where the "backs" are connected together as shown in Fig. *15*. The resistors R_1 and R_2 replace two of the rectifier elements of the usual bridge circuit, and are chosen to have a resistance about halfway between the conductive and non-conductive values of a copper-oxide element. (An element may have only 100 ohms opposition to electron flow one way and several thousand ohms opposition to electron flow in the other direction.)

There is a continuous a.c. path through the resistors, but this current does not pass through the meter. When electrons move from source terminal *1*, rectifier *W* becomes conductive, so there will be an electron flow through this rectifier to point *B*. Rectifier *Z* opposes current flow by having more resistance than the path through meter *M* and resistor R_2, so the major electron movement is from *1* to *A*, through *W* to *B*, through *M* to *C*, through R_2 to *D* and thus to *2*. On the next half cycle, the major electron movement is from terminal *2*, through rectifier *Z*, then through the meter and resistor R_1 back to terminal *1*. Thus, when the rectifier is conducting, it offers less opposition than the resistor directly across from it, but when the cycle reverses the resistor is more conductive than the rectifier.

To extend the a.c. range with either form of bridge, shunts are connected between terminals *1* and *2* instead of across the meter. If shunts were used across the meter, higher currents would have to flow through the rectifier elements and would burn them out.

Copper-oxide rectifiers have two faults: *1*, they are easily damaged; and *2*, they have a high shunting capacitance between terminals.

Reasonable care to prevent overloading will protect them from burnout. They must not be exposed to high temperatures for very long. Heat tends to change the chemical characteristics of the oxide layer, causing a change in the rectifying ability of the unit. Too much heat, such as from a soldering iron, can ruin a rectifier.

The high self-capacitance generally limits the copper-oxide rectifier to power line and the lower audio frequencies. By reducing the size of the rectifier elements the capacity is reduced, so the frequency range can be extended somewhat.

Of course, the capacitance does not prevent the use of these rectifier-meter units as r.f. current indicators; it just changes the calibration. With increases in frequency, the capacity acts as a decreasing shunt reactance, so the current range changes rapidly. However, reasonably accurate readings on the original meter scales of some types of meters can be made up to 80 kc. without special calibration charts. Since you, as a serviceman, will be primarily interested in measuring operating volt-

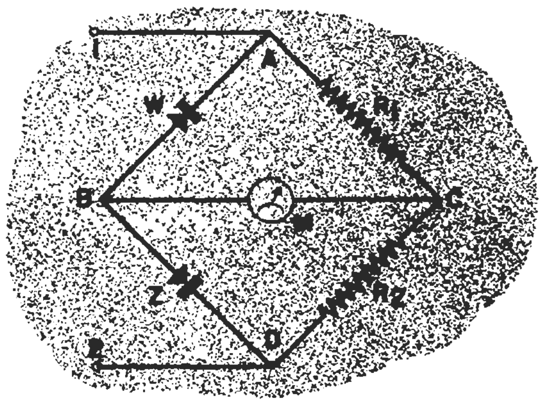


FIG. 15. The back-to-back bridge saves two rectifier elements.

ages and currents which are d.c., power line a.c. or low audio frequency a.c., you can usually ignore the frequency characteristics.

CONVERSION DEVICES

Thermocouple. The need for a sensitive indicator for r.f. currents led to the development of the thermocouple, commonly found in transmitter installations and research laboratories.

This device works on an interesting principle—the fact that when a juncbulb. The bulb can then be connected in the circuit carrying the current, and the photocell-meter used to indicate the current. This method is not very accurate—it's more useful to indicate when changes occur or when maximum current flows than it is to indicate the exact amount of current.

TRUE A.C. METER MOVEMENTS

You recall the D'Arsonval meter cannot be used directly on a.c. because it cannot follow the rapid reversals of current. Even if it could, it would reverse its direction when the a.c. reverses. This is because the coil field reverses with the a.c. flowing through it, but the fixed magnetic field continues to have the same polarity. If we can arrange the meter so both magnetic fields reverse at the same time the a.c. reverses, the magnetic turning force will always be in the same direction and the meter will indicate just as if d.c. were applied. There are two meters that do this, the magnetic-vane and the electrodynamometer types.

Magnetic-Vane Meters. This meter works in a different manner from the D'Arsonval movement. Instead of using a fixed magnet and a moving coil, the coil is fixed and a soft iron vane is the moving element, as shown in Fig. *19A*. When current flows through the coil, the vane is magnetized by the coil's magnetic field, with a magnetic polarity opposite to that of the coil. Since opposite poles attract, the vane will be attracted into the coil until the magnetic force is balanced by the spring. The vane is soft iron, so it does not become a permanent magnet. Hence, when the current flow through the coil reverses, the reversal of the coil magnetic field also reverses the polarity of the magnetic vane and the attraction is maintained.

Figure *19B* shows another type of magnetic-vane meter. Two pieces of soft iron are used in this type, with the coil wound around both. The triangular piece *AB* is bent in a cylindrical shape and is mounted on the inside of the coil form. The rectangular piece *CD* is also bent in a cylindrical shape. This piece is connected to the spindle *XY*, to which is attached the meter pointer and restoring spring.

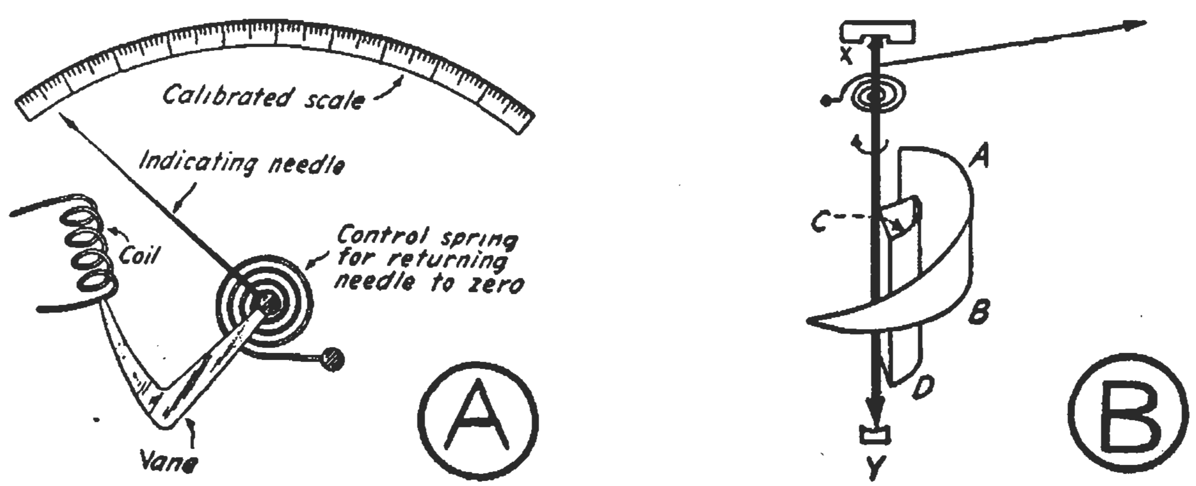


FIG. 19. Here are two common types of magnetic vane movements.

When current flows through the coil, both pieces of iron are magnetized. As the coil field is along the axis of *XY*, the top and bottom edges of vanes *AB* and *CD* will become the magnetic poles. The edges *C* and *D* will have the same polarity as *A* and *B* respectively. Thus, *C* and *A* may be north poles, while *D* and *B* may be south poles. This means like poles are near each other and will repel. The soft iron pieces are so placed and shaped that *CD* rotates to the right (clockwise). Again, the movement will be to the point where the spring balances the magnetic force.

When the coil field reverses, both magnetic poles reverse, so the magnetic opposition remains the same as before.

Although several other types of magnetic-vane movements have been developed, they all have similar characteristics. To produce the strong magnetic field required, the coil must have a large number of turns. The coil thus has considerable inductance, which will upset the calibration if high-frequency currents are measured. Also, there is a limit to the frequency with which the vane magnetism can be changed, so these meters are used only for d.c. and low-frequency a.c. measurements.

The inductance of the meter coil makes it hard to use shunts for extending the range, because the coil reactance changes with frequency — so these meters usually have only one range. In spite of all its shortcomings, low cost and rugged construction have made the magnetic-vane meter very popular for use where great accuracy is not required.

Electrodynamometer. This meter is a moving-coil type, but is quite different from the D'Arsonval meter. No fixed magnet is used; instead, the field is produced by an electromagnet, and the moving coil has an air core. Figure *20* shows a typical electrodynamometer. Coil *A* is the field coil, which may be wound on any suitable coil form. The inner coil *B* is the moving coil, made so it can rotate within coil *A*. The two coils are connected in series. When current flows through the coils, both develop magnetic fields proportional to the current strength and the number of turns on each coil. This causes coil *B* to rotate until the magnetic force is balanced by the spring, as in other meters.

When alternating current is measured, the reversal of the direction of current reverses both magnetic fields, so the repulsion remains the same as before. Hence, the meter can be used either for a.c. or d.c.

The moving coil has a tendency to waver back and forth a while before

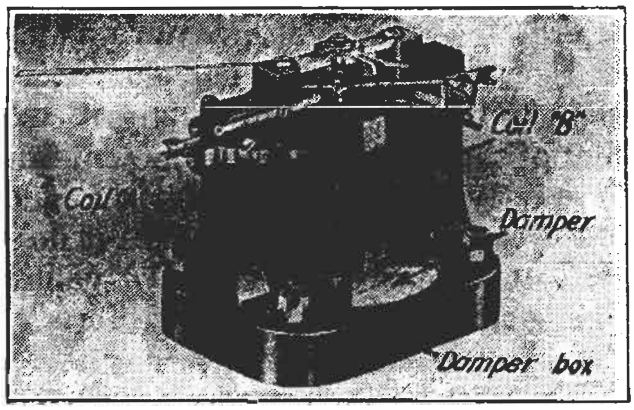


FIG 20. This electrodynamometer does not use a permanent magnet.

settling down to the correct reading, just as with other meter movements. This wavering is damped by a vane attached to the moving coil and fixed to rotate through a closed chamber known as a damper box. When the coil moves, the damper vane also moves, compressing the air ahead of it in the damper box. The compressed air acts as a cushion, so that the pointer comes slowly up to the correct reading and then stops.

Because of the inductive effects of the coil windings, the frequency range of such meters is limited. The usual types hold their calibration for frequencies up to 130 cycles; special meters can have ranges up to 1000 cycles or more, but will be accurate only for frequencies very close to the frequency for which they were built.

The original electrodynamometers were used as standard instruments, as they could be calibrated directly from their dimensions. Modern commercial tion of two *dissimilar* metals is heated, a d.c. voltage is produced. Thus if a junction between a copper rod and an iron rod is heated in a flame, a d.c. voltage is produced; the two unjoined ends of the rods are now the d.c. terminals. This method of getting a voltage suggests a means of converting a.c. power through its heating effects.

We know that current flow through a resistance produces heat, so if we can bring a junction of dissimilar metals up to a resistor acting as the source of heat, the d.c. voltage so developed can be used to operate a d.c. meter. Figure *16* is a typical arrangement.

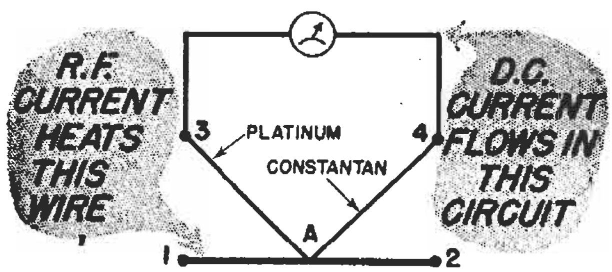


FIG. 16. The thermocouple is widely used for r.f. measurements.

The wire between terminals *1* and *2* is a resistance wire, called the heater. The wires between *A* and *3* and *A* and *4* are the thermocouple elements.

The heater wire is made short, and the ends are connected to large terminals so that heat developed near the ends will be rapidly conducted away. Hence, the heat is concentrated at point *A*, the center of the heater. The dissimilar metal junction, called the thermocouple, is placed at *A*. In some cases, the thermocouple is just near the heater, while in others it is welded to it. Since the voltage produced for a particular temperature depends on the metals used in the thermocouple, these metals are carefully chosen to give the greatest d.c. voltage. The wire between *3* and *A* may be platinum, while the wire between *4* and *A* may be constantan.

The current to be measured is permitted to flow through the heater wire, between terminals *1* and *2*. The resulting heat is proportional to the power dissipated in the resistance of the heater, which in turn makes the heat proportional to the square of the current. ($P = I^2R$) The temperature rise heats the thermocouple junction at *A*, producing a d.c. voltage which will cause a d.c. current flow through the meter. Notice this is a *produced* d.c. and is not the current being measured, which is usually a.c.

The heating effect of a current flow through a resistance will occur regardless of frequency or wave form, so any a.f. or r.f. current can be measured by this device. In fact, the thermocouple is practically a standard r.f. current meter. To eliminate skin effect*, the resistance wire is made in the form of a hollow tube in models intended for ultra-high frequencies.

These instruments are made in many ranges, from a few milliamperes up to practically any value wanted. An instrument sensitive to low currents is made by sealing the thermocouple and heater in a glass tube from which the air has been pumped. This is known as a vacuum thermocouple.

The use of a thermocouple has another advantage—the meter and thermocouple do not have to be mounted together. This is important, as currents frequently must be measured in hard-to-reach places, such as in a transmission line, transmitter tank circuit or antenna installation. It is impossible to run r.f. currents over long leads to a more convenient meter location without upsetting the circuit. Therefore, the thermocouple and heater unit is

---

* Skin effect is the tendency of high-frequency currents to flow on the surface instead of through the center of the wire. This produces the effect of a change in resistance. By eliminating the center of the wire, all current must flow along the surface, so there is no change.

placed right in the circuit containing the current to be measured. Then the d.c. produced is fed over a feeder line to the meter, as shown in Fig. *17*. Choke coils L_1 and L_2, together with condensers C_1 and C_2, filter r.f. currents out of the line to the meter. Should the thermocouple be connected in a circuit where one terminal of the heater is grounded, the filter probably would not be required. If the line to the

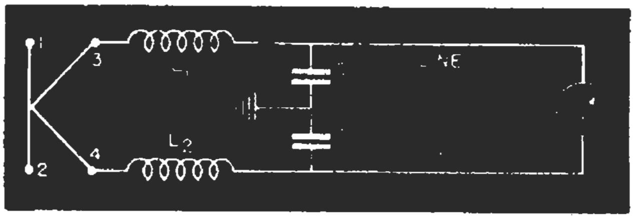


FIG. 17. The thermocouple permits remote meter readings.

meter passes through any r.f. fields, it may pick up some r.f. energy which could cause an undesired current through the meter. Another condenser (or a pair connected like C_1 and C_2) may be connected across the meter terminals to by-pass this r.f.

The meter is calibrated by passing known currents through the heater element. These currents are usually d.c. or low-frequency a.c., which can be more accurately determined than r.f.

As the deflection is proportional to the square of the a.c. being measured, the meter scale will be crowded at the lower end if a standard meter is used. That is, the deflection is smaller than normal for small currents, and is greater than normal for high currents. By using a meter with specially shaped pole pieces, it is possible to obtain a progressively decreasing d.c. sensitivity as the meter moves up-scale, so that the scale is more uniform.

Such a meter is shown in Fig. *18*. The pole faces have a shape which creates a non-uniform field between them with the maximum lines between the closest points (*1* and *2*). When the meter coil is in the position shown in Fig. *18*, the twisting force caused by the reaction of its field with the meter field is a maximum, so the coil will give a large deflection as the current through it increases. The more the coil rotates to the right or clockwise, the smaller this twisting force becomes, so larger coil currents are needed to give the same amount of deflection. Thus we have the decreasing sensitivity at the upper end of the scale that we were looking for, and our scale becomes practically uniform over its whole length.

This special method of cutting the meter pole pieces increases the meter cost, but it is a means of getting an extended current range without sacrificing the ability to read small values accurately.

Photoelectric Types. This method is used only in experimental work, but you may meet it, so we'll go into it briefly.

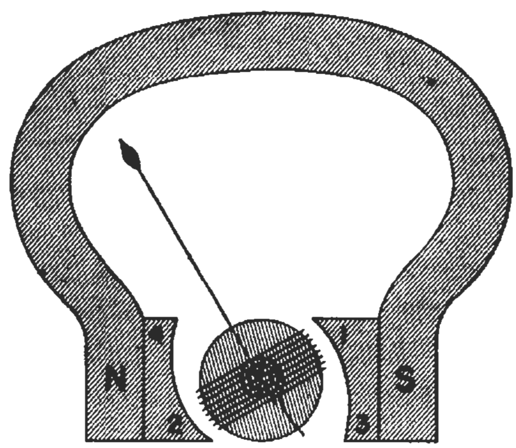


FIG. 18. Using pole pieces having a special shape produces a non-uniform magnetic field.

The amount of light obtained from an electric light bulb varies according to the amount of current flow through the bulb. By connecting a photovoltaic cell to a meter and exposing the cell to a light bulb, the light will produce currents through the cell and meter proportional to that through the bulb. Then we can calibrate the meter in terms of the current flow through the electrodynamometers are calibrated by comparison with a standard, however, just like other meters.

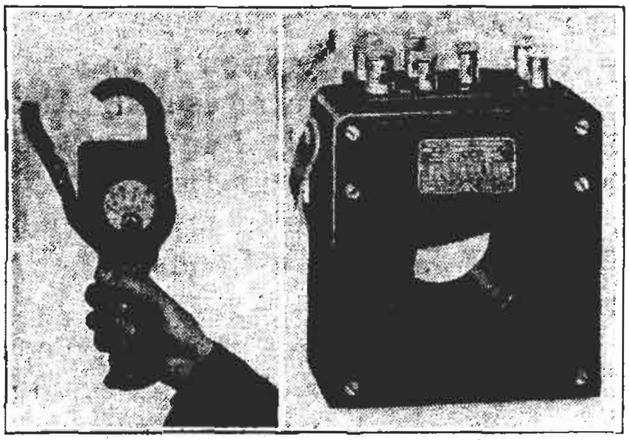
As the same current flows through both of the series-connected coils and as the deflection depends on the strength of both magnetic fields, the deflection is proportional to the square of the current for direct current. For an alternating current, the meter deflection is proportional to the square of the effective or r.m.s. value. Since an alternating current of any r.m.s. value will produce a magnetic field equivalent to that produced by a direct current of the same value, the meter scale is exactly the same both for d.c. and low-frequency a.c. This makes it possible to compare the effective values of currents regardless of wave form.

Large currents cannot be measured easily with an electrodynamometer, because the moving coil cannot be made of exceedingly large wire or have heavy leads going to it. Although shunts can be used to a certain extent, a current transformer is the most common way of extending the range of this meter.

Current Transformers. As you will recall, a transformer will step up or down an a.c. voltage according to the ratio of turns on the primary and secondary windings. Also, neglecting losses in the windings and core, the primary power will equal the secondary power. This means that if the secondary voltage is stepped up, the secondary current will be reduced in the same ratio so that the power (I × E) will be the same. Hence, a transformer which steps up voltage by a ratio of 1 to 3 also steps down current by a ratio of 3 to 1. For example, if the primary voltage and current are 110 volts and 4 amperes, the primary wattage is 440 watts. If the secondary voltage is stepped up three times, to 330 volts, the secondary current must be one-third the primary current (1-1/3 amps.), so that the secondary power will also equal 440 watts.

Therefore, by designing a step-up voltage transformer with low losses and a small primary, we have a step-down current transformer in which a large primary current flow will result in a small secondary current which can be indicated on a meter. This secondary current is proportional to the primary current, so the meter can be calibrated in terms of primary current.

Current transformers are usually found where very large currents are measured. Where the current is several thousand amperes, the current transformer may be just clamped around the conductor carrying the current, allowing this conductor to act as a single-turn primary winding. Typical current transformers are shown in Fig. 21.



Courtesy Weston

FIG. 21. Current transformers. The core of the one at the left is snapped around the current-carrying wire. The one at the right is installed permanently, passing the power line through the center. These transformers are usually used on high-current power lines, where currents of 25 amperes to thousands of amperes are to be measured.

Although commonly used with electrodynamometers, current transformers can be used with any other a.c. meter having the required characteristics, such as the proper range and proper impedance. However, since the type of meter used may have an effect on the calibration, the current transformer and meter combination have to be calibrated as a unit.

Hot-Wire Meter. Another method which has been used to measure current depends on the fact that metals expand when heated. Any kind of current (a.c. r.f. a.f. or d.c.) with any wave form will heat and expand a resistance wire through which it passes; the amount of expansion will be a measure of the heat produced, and therefore of the current flowing. We can use this principle in a meter by making the expansion cause movement of a needle.

Figure *22* shows a method of doing this. The wire which is heated is shown between *A* and *B*. This wire is held under tension by an adjustable spring (not shown). Attached to this wire at *C* is a metallic cord *D* which passes around the pulley *P*, continuing to the spring *S* which is fastened at *E*. The pulley and support *E* are made of insulating materials to prevent grounding the supply circuit through the meter frame or case. When a current flows through the wire *A-B*, it heats and stretches, sagging downward. This allows the spring *S* to pull the cord *D* around the pulley *P*, thus rotating the pulley to the right. The meter pointer *X* is attached to the pulley and is thus moved over a calibrated scale.

This meter measures only high currents and is easily burned out. Elaborate means of compensating for surrounding temperature changes must be used. Also the amount the wire stretches when a given current passes through it changes with repeated use, so such meters are no longer very popular.

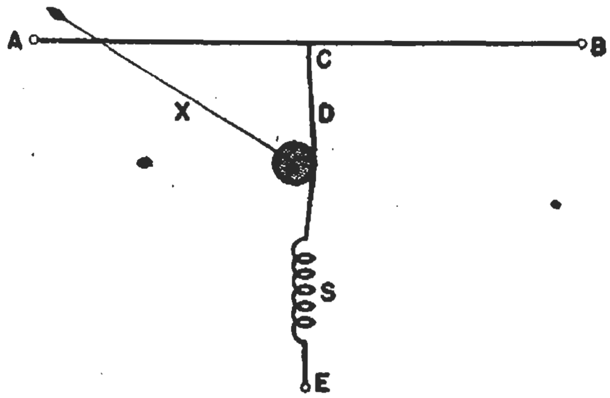


FIG. 22. The mechanism of a hot-wire ammeter.

Voltmeters

Voltages, like currents, are measured by meters. In fact, a current meter can be used for voltage measurements if properly calibrated. You will recall that a certain voltage is necessary to force the required current through the resistance of the current meter. We'd be justified in saying that meter deflection is proportional to the applied voltage, and in calibrating our meter accordingly.

As an example, a 1-milliampere meter may have a resistance of 200 ohms. The voltage required for full-scale deflection is $E = I \times R$, or $.001 \times 200 = .2$ volt. Hence, we can use this meter as a 0-.2 voltmeter. This range is too low for ordinary service purposes, but we can increase it by increasing the meter resistance.

Since increasing the resistance of the meter movement itself is not practical, resistance is added in *series* with the movement, so that a higher applied voltage is needed to drive full-scale current through the meter. If 800 ohms external resistance were added to the 1-ma. meter in the example above, 1 volt would be needed to give a full-scale reading.

By adding sufficient resistance, any desired voltage range can be obtained.

As with current meters, a single meter having several ranges is desirable, so a low basic range is usually chosen and then additional resistors are connected in series to extend the range further. A typical switching arrangement is shown in Fig. *23*. Resistor R_1, together with the meter resistance, sets the basic voltage range. Then other resistors are added by the switch to obtain the desired extensions.

Notice that a current flow through the meter is being interpreted as voltage because of the known resistance of the meter. This current must come from the source being measured, in addition to that taken by the load, because the voltmeter is connected *across*

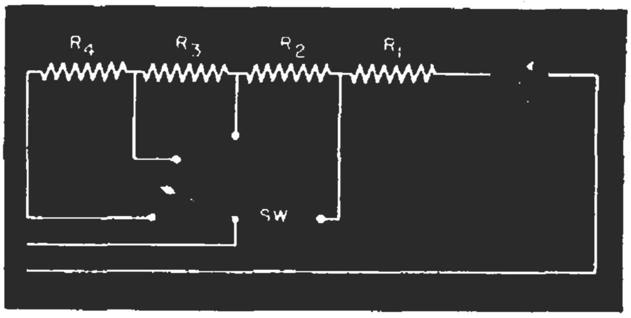


FIG. 23. Voltmeter ranges are extended by using multiplying resistors in series.

the terminals where the electrical pressure (voltage) is to be measured.

When the source has a low internal resistance (as is the case with a good battery) and the source is not supplying appreciable current to a load, the current taken by the voltmeter scarcely matters. However, *if there is appreciable resistance in the source or between the point of voltmeter connection and the source, the readings will vary with the sensitivity of the voltmeter.* Let's learn more about this now.

VOLTMETER SENSITIVITY

As a practical example of a typical radio circuit, consider Fig. *24*. Suppose that resistor R_1 has a value of 50,000 ohms and the tube plate-cathode resistance is 25,000 ohms. The total resistance is then 75,000 ohms, so 4 ma. flows from the 300-volt source ($300 \div 75{,}000 = .004$ ampere). The tube plate-to-cathode voltage will be 100 volts, and the drop in resistor R will be 200 volts.

Now suppose we connect a voltmeter as shown. Will it indicate 100 volts? This depends on the current taken by the meter, which must flow through resistor R_1, in addition to the plate current of the tube. In other words, the meter is in parallel with the tube resistance, so our circuit is really that shown in Fig. *25*. A few practical cases will help you see what happens.

Case I. If the voltmeter in Fig. *24* has a 100-volt range which requires 10 ma. for full-scale deflection, its resistance $R_M = E \div I$, or 10,000 ohms. This resistance is in parallel with the tube resistance R_P of 25,000 ohms, as shown in Fig. *25*, so the resulting parallel combination of meter and tube is

$$R = \frac{R_P \times R_M}{R_P + R_M} = \frac{25{,}000 \times 10{,}000}{25{,}000 + 10{,}000} =$$

7100 ohms, approximately. This value is in series with the 50,000-ohm resistor R_1, so the total circuit resistance has changed from 75,000 ohms to about 57,100 ohms. The new total current from the 300-volt source is about 5.25 ma. ($300 \div 57{,}100 = .00525$ ampere). This current through R_1 gives a voltage drop of 262.5 volts, leaving only 37.5 volts for the tube and meter parallel combination. In other words, the tube plate voltage is now only about 7/57 of the total, instead of 1/3. (The ratio is 7100 to 57,100 instead of 25,000 to 75,000.) This means that the voltage measured by the meter is about 38 volts, instead of 100 volts. The connection of the voltmeter has upset the voltages so that more drop exists across R_1 (now about 262 volts) and less across the tube, giving a false indication of the conditions existing without the meter.

Case 2. Suppose we now use a voltmeter having a 100-volt range which only requires 1 ma. for full-scale deflection. The meter resistance is now 100,000 ohms. Figuring current and voltages as we did in Case *1*, we find that the plate voltage now measures 85 volts, much closer to the original 100 volts.

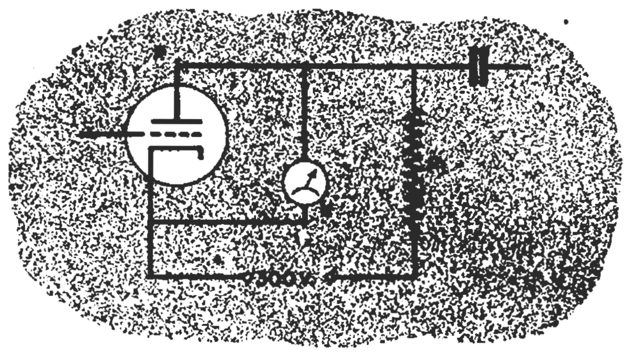


FIG. 24. A typical voltage-measuring problem. The accuracy depends on the ohms-per-volt sensitivity of the meter.

Case 3. A 100-volt meter requiring only 0.1 ma. has a resistance of 1,000,000 ohms. Such a meter will indicate about 98 volts if placed in the circuit of Fig. *24*. The error now is only about 2%, well within the normal tolerances allowed for this kind of circuit.

Obviously, in any circuit having appreciable series resistance, the lower the current needed to give deflection, the more nearly correct the results.

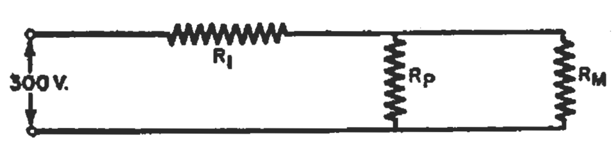


FIG. 25. Notice how the voltmeter resistance is in parallel with the tube plate-cathode resistance.

For this reason, voltmeters used in radio service work require 1 ma. or less for full-scale deflection.

Ohms-Per-Volt. The term "ohms-per-volt" is used to express voltmeter sensitivity. The smaller the current needed for full-scale deflection, the greater the sensitivity of the meter. Also, the smaller the current for a given voltage, the greater the meter resistance must be. ($R = E \div I$) By dividing the total meter resistance by the basic full-scale voltage range, the ohms-per-volt rating will be obtained. Thus a 2-volt meter having 2000 ohms resistance is a 1000 ohms-per-volt meter. Ohm's Law will let you figure ohms-per-volt ratings easily. Notice that this rating increases as meter sensitivity increases.

Now here's something you should remember. Service manuals usually give you radio circuit voltages (plate-to-cathode voltages, etc.) which are taken with 1000 ohms-per-volt voltmeters. But if you are using a more sensitive meter — say 20,000 ohms-per-volt — the readings you get when you measure these circuit voltages *will be higher than the manual says for any high-resistance circuits, but will be more nearly correct for the actual circuit operating conditions.* (You just learned why this happens.) Just remember this —set voltages will be *higher* than their service manual ratings in resistance coupled circuits, if you measure them with a voltmeter having a sensitivity greater than 1000 ohms-per-volt. How much higher, of course, depends upon the sensitivity of the meter, and the resistance in the circuit where it is connected.

Knowing the ohms-per-volt rating of the meter makes it easy to extend the range. Just multiply the ohms-per-volt rating by the number of volts the range is to be extended. For example, if a 1000 ohms-per-volt meter is to be extended from 100 volts to 500 volts, the extension is 400 volts. Multiplying 400 by 1000 gives 400,000 ohms as the needed extra series resistance.

A.C. VOLTMETERS

Any of the standard alternating current meters can be used as an a.c. voltmeter in exactly the same manner just described. For service work. the copper-oxide rectifier and D'Arsonval meter combination is generally used. This type has better sensitivity characteristics than any except the vacuum tube voltmeter, which will be taken up in another lesson.

The copper-oxide rectifier type a.c. voltmeter usually has a sensitivity of 1000 ohms-per-volt, requiring 1 ma. for full-scale deflection. Even lower sensitivities are permissible in service work, where the usual a.c. meter readings are filament voltage, power line voltage, rectifier plate voltage and output voltages during alignment. The sources for these first three measurements have low series resistance, so the current drawn by the meter does not greatly matter. For output readings, only an indication of the maximum voltage, not the exact amount, is usually desired.

Of course, the copper-oxide unit has the same faults described before; it is easily overloaded and has shunting capacity. When overloaded, one element usually burns out so readings fall to half-normal. The effect of the capacity of the copper-oxide rectifier is more pronounced with a voltmeter than with a milliammeter, because of the series resistances. However, the copper-oxide types are reliable up to 1000 cycles or so, which is sufficient for output purposes, as most signal generators are modulated at about 400 cycles.

Ohmmeters

Since we can now measure voltages and currents, we can use Ohm's Law and calculate the resistance in a circuit or device. However, this is a cumbersome method; a more speedy way of finding the resistance is desirable.

Suppose we make up a circuit consisting of a known fixed voltage source in series with a current meter. When we connect a resistor into this circuit, the amount of current flow will be inversely proportional to the value of the resistor. Then we can calibrate the meter in terms of resistance, and we will have a resistance indicator or ohmmeter.

Figure *26* shows how such a meter is designed. The resistance R_2 is adjusted so that its resistance plus that of R_1 and the meter is just sufficient to permit a full-scale deflection on the current meter (using a known battery voltage) when the test prods are touched together. Then when the circuit is opened and the unknown resistance R_X is inserted, the meter will indicate some lower value, depending on the added resistance.

As the battery voltage will decrease with age and use, and also since the meter and resistance values may be off somewhat, resistor R_2 is adjustable. Actually, R_1 and R_2 could be a single resistor, but if adjustments are not correctly made, the meter could be damaged. Hence, R_1 is fixed and has a value sufficient to prevent meter damage.

This adjustable resistor is set for a full-scale meter deflection, which adjusts for zero ohms on the scale.

As the battery ages, its voltage drops, so R_2 is decreased to restore zero. This change in voltage and resistance upsets the calibration, however; the ohmmeter accuracy will vary directly with the percentage change of battery voltage. Thus, a 10% drop in battery voltage will cause a 10% error in the ohmmeter reading. Fortunately, battery voltages are relatively stable over long periods of time, so replacements are not too frequently required.

By designing the ohmmeter for the rated battery voltage, advantage can be taken of the fact that battery voltages are somewhat higher when new. Then the ohmmeter will read a few per cent high with fresh batteries, and will then drop to exact readings and gradually read lower as battery voltage decreases. This has the effect of halving the error, as a 10% battery voltage change now produces a 5% variation each way from the correct reading. The sizes of R_1 and R_2 are usually chosen so that when R_2 can no longer be adjusted for zero ohms, the percentage of error has exceeded that set by the manufacturer, so a new battery must be obtained.

The ohmmeter is definitely a service instrument—it does not have sufficient accuracy for laboratory work. However, in service work, parts may normally vary as much as 20% anyway,

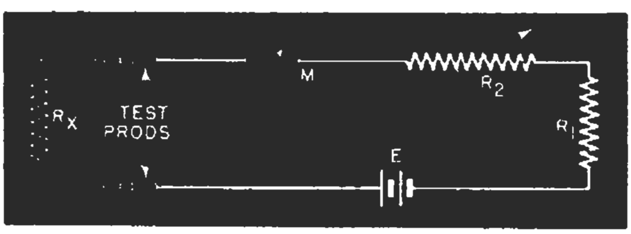


FIG. 26. This series ohmmeter is best for medium and high-resistance values.

so an error of a few per cent in measurement is not of great importance.

The fact that voltage variations will upset the ohmmeter is one of the reasons that power packs are not more widely used with ohmmeters. Only a well-regulated power pack will have a sufficiently stable output voltage.

The type of ohmmeter we have been considering is known as the series type, as the battery, meter and resistances are in series. This type can easily be recognized, as the "zero-ohms" position is at the right of the meter scale, with increasing resistance values to the left. This is just the reverse of the ordinary meter scale.

As with other instruments, the range is of importance. In service work, the wide range of resistances met (from .05 ohm for r.f. transformers to several thousand megohms for leakage measurements) presents quite a problem. Let's investigate this further.

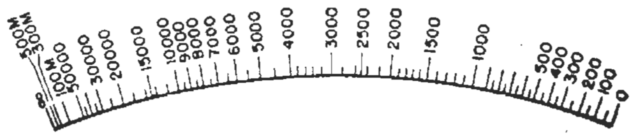


FIG. 27. A typical series ohmmeter scale having a 3000-ohm center-scale value.

Useful Range. Having made an ohmmeter using some particular meter and total resistance, just what range of values will it indicate? Let us suppose we are using a 1-ma. meter and a 3-volt battery. This means the meter $+ R_1 + R_2$ resistance is adjusted to 3000 ohms so 1 ma. can flow. You will see that the meter will read mid-scale (half the current) when a resistance of 3000 ohms is being measured, as we then have doubled the circuit resistance and still have the same voltage. Now, the most useful portion of the meter scale will be between values about 100 times the mid-scale value and 1/100 the mid-scale value. Thus, if the mid-scale value is 3000 ohms, the ohmmeter will be best calibrated and easiest read between 300,000 ohms and about 50 ohms. Higher and lower values can be read on this scale, but the readings become hard to make. Actually, this range is probably readable up to about 500,000 ohms, and values of 10 ohms or so may be estimated.

Figure 27 shows a typical ohmmeter scale based on these values. The crowding at the low end is caused by the fact that the meter resistance is becoming much larger than the resistance being measured, so that changes in the latter have less and less effect on the current flow.

At the other end of the scale, the current is primarily determined by the external resistance. When the external resistance gets large, adding more resistance doesn't change the current much. Thus, at the low-resistance end, a scale division may represent only 50 ohms, while at the other end, several thousand ohms may be indicated by the same space on the scale.

The series ohmmeter is excellent for medium and high ranges, but is not the best type for low ohmic values. For measuring low resistances, we can lower the series resistance, but the lowest normal battery voltage is 1.5 volts, so there must be enough resistance to limit the current at the full-scale value. By reducing the meter resistance through the use of high current meters or shunts, or by using voltage dividing circuits to get lower voltages, somewhat better results can be obtained. However, this requires complex circuits and means a high current flow, which in turn means short battery life and possible damage to the device being tested.

Low-Range Ohmmeter. A shunt-type ohmmeter circuit, shown in Fig. *28*, is used to measure low values of resistance. The resistor R is adjusted until the meter reads full-scale with the test leads separated. When the test leads are connected to the resistance being measured, a lower meter reading results, as the unknown resistance R_X is connected in parallel with the meter and acts as a shunt across the meter. Notice these two important facts: (*1*) zero ohms on the shunt meter is at the *left*, exactly opposite to a series ohmmeter; (*2*) if the test probes are held together, the meter is short-circuited and cannot read. You will see that the "zero adjustment" on a shunt meter is actually the full-scale adjustment.

This circuit is excellent for low resistances. By using a low-resistance meter, the battery current flow will be primarily determined by resistance R, which can be fairly high. For example, if a 27-ohm, 1-ma. meter were used with a 1.5-volt battery, resistor R would have to be adjusted to about 1473 ohms to limit the current to 1 ma.

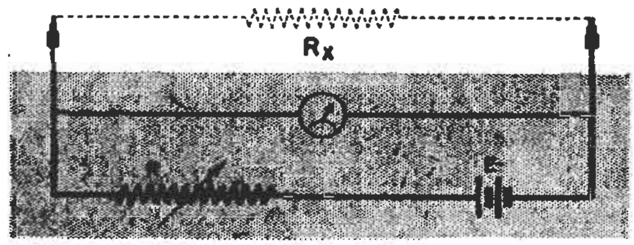


FIG. 28. This shunt ohmmeter is excellent for low-resistance values.

Since the resistance of R is so high compared to that of the meter, shunting the latter with even a very low-resistance device will have very little effect on the current drawn from the battery. We can assume the current flow is a constant amount and just divides between the meter and the unknown R_X.

A resistance equal to the meter resistance gives mid-scale deflection (since the current then divides equally between the meter and the unknown resistor). The best scale range is again from about 100 times to 1/100 the center scale value.

High-Range Ohmmeters. As mentioned before, the series ohmmeter is a medium and high-resistance indicator. However, there is a practical limit to the range, which is determined by the current required for the meter. Until recent years, service instruments were usually 1-ma. meters—and such meters require very large power supplies to measure very high resistances. For example, using a 1-ma. meter to obtain a useful scale above 50 megohms requires 500 volts or so.

Servicemen were thus limited to ranges readable up to 1 or 2 megohms. However, when more sensitive meters became generally available, one of the first results was an extension of the upper ohmmeter range. Meters with 50 to 200-microampere ranges (.05 to .2 ma.) permit the construction of ohmmeters of 20 to 50-megohm ranges, using no more than 45 volts.

Even these meters aren't sensitive enough to measure small amounts of leakage in condensers or in shielded cables. Laboratories formerly used "meggers" for this purpose. These megohmmeters were high-voltage devices with a hand-operated 500-volt generator and a special meter movement.

In recent years, vacuum tube circuits have been developed which measure values up to 1000 megohms and higher. These have replaced "meggers" generally; they will be taken up elsewhere in your Course.

Using Ohmmeters. Since the ohmmeter depends on its own battery for operating power, it is not used like a voltmeter or current meter. The latter two measure operating conditions, so the radio circuit being checked must be connected to its normal source of power and must be turned on. On the other hand, the circuit *must be turned off* when an ohmmeter is being used. This is an advantage at times, as the circuit need not be in operating condition when an ohmmeter is being used.

When making tests for circuit continuity, the ohmmeter is connected between selected points, as you will learn in other lessons. Then, when the defective circuit has been located, the various parts are individually checked. When a certain part is to be checked, remember that any parallel path in the set can give false readings. Hence, the part being checked should be disconnected from other parts if the results appear unusual.

The shunt-type meter draws current continuously from its battery as long as it is connected. Therefore, it always has a switch or other means for disconnecting the battery when readings are not being made. Remember to turn off this meter when not in use; otherwise, the battery will run down quickly.

Multimeters

As you have probably noticed, the same kind of meter can be used for voltage, current and resistance measurements. The only differences are the ways in which resistances are arranged as shunts and multipliers, the use of rectifiers for a.c., and the variable resistances and battery used on ohmmeters. Naturally, it would be very handy to have all these functions combined in a circuit using a single meter. That's exactly what the modern service multimeter is.

There are many types of multimeters, having the same basic functions but differing in appearance, method of switching ranges, meter sensitivity and sometimes in the number and extent of the ranges available. These can be separated into two types, those using rotating switches for selecting ranges and functions, and those using plug-in or pin jacks for this purpose. Let's consider the latter type first.

PIN-JACK TYPE

Figure *29* shows a typical circuit. There are five controls on this instrument—two switches and three ohmmeter adjustments. Switch SW_1 is used to set the meter for a.c. or d.c. measurements.

There are eighteen jacks on the tester into which the test leads can be plugged. By choosing the proper pair of jacks, the proper range is obtained automatically. When a different range is needed, another pair of jacks is used.

Resistors R_1, R_2 and R_3 serve as a series shunt across the meter for d.c. current measurements. The jack marked *"DC —"* is used for all d.c. ranges so is called the "common terminal"; one test lead is plugged here while the other is placed in the current jack marked for the desired range.

Resistors R_4 to R_7 are voltage multipliers. The current shunt resistors R_1, R_2, R_3 remain in the circuit to give a basic 1-ma. meter movement (sensitivity is 1000 ohms-per-volt). Again the *"DC —"* jack is the common terminal; one test lead goes here while the other is plugged into the desired d.c. voltage jack.

For a.c. voltage measurements, switch SW_1 is thrown to the AC position, thus inserting a copper-oxide rectifier in the circuit. The jack marked *"AC±"* is the common a.c. voltage jack so one test lead is plugged in here for a.c. readings. However, at times you have to make a measurement in a circuit containing both a.c. and d.c. As the d.c. would cause false a.c. readings, it is blocked out by a condenser *C*, connected to a jack marked *"output."* This jack is used as the common jack whenever the a.c. only is to be read. The other test lead is plugged into the "A.C. VOLTS" jack corresponding to the proper range. Resistors R_8 to R_{11} are the necessary voltage multipliers. Resistor R_{12} is a correction resistor, used to adjust the a.c. range according to the meter and copper-oxide rectifier characteristics.

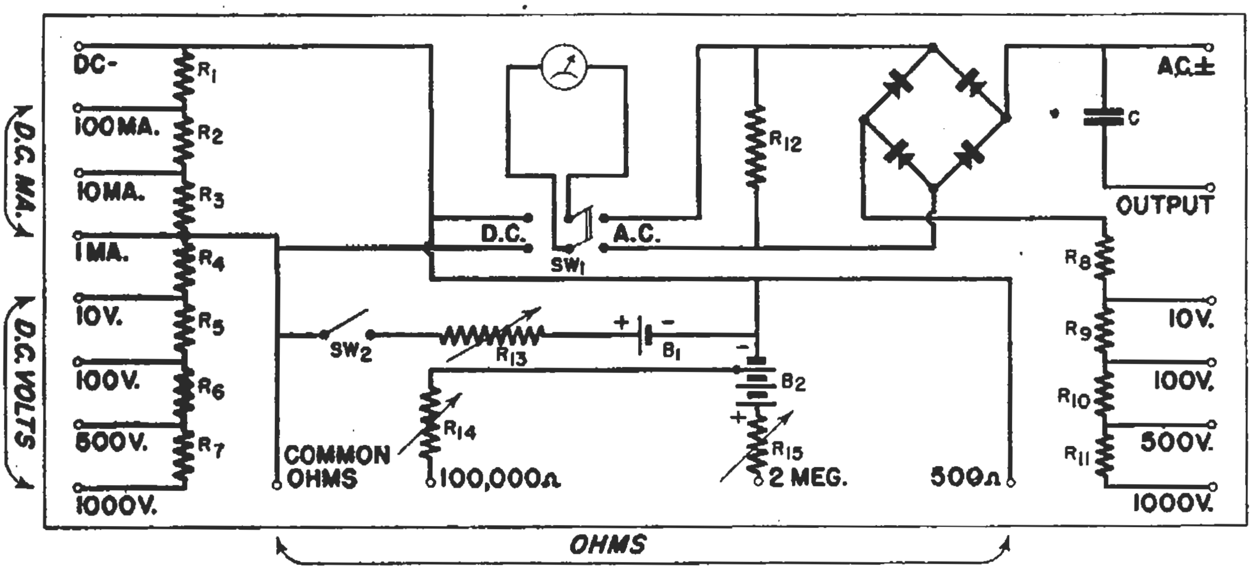


FIG. 29. A multimeter of the pin-jack type.

Although the ranges of the d.c. and a.c. voltages are the same, they do not usually use the same meter scale, because the rectifier characteristics change somewhat with the amount of current flowing through it. This usually means that the a.c. scale will be crowded near zero. Separate scales are therefore on the meter face for each purpose, direct current and voltage, a.c. voltage, and resistance. A typical scale is shown in Fig. *30*.

Both series and shunt ohmmeter ranges are provided. The *"Common*

Ohms" jack is one terminal for all ohmmeter ranges. Switch SW_2 is closed for shunt ohmmeter measurements. (*This switch must be open for all other measurements.*) This places R_{13} and battery B_1 in the circuit. The *"500ω"* jack is used for this shunt ohmmeter.

There are two series ohmmeter ranges, using a tapped battery B_2 and separate zero adjustments. *The a.c.-d.c. switch must be in the d.c. position for all ohmmeter measurements.*

Practical multimeters of this type may have fewer or different ranges, but the circuits will be essentially like the one just described.

SELECTOR SWITCH TYPE

This multimeter eliminates most of the jacks by using a multiple selector switch to select the desired range and function. A typical one is shown in Fig. *31*. Switches SW_1 and SW_2 are ganged together. In position *1*, the highest voltage range is obtained, through multipliers R_1, R_2, R_3 and R_4. Notice that only switch SW_2 is in the circuit at this setting, while at other settings SW_1 is in alone or in combination with SW_2.

In positions *2*, *3* and *4* of the selector switches we have the remaining voltage ranges; positions *5*, *6* and *7* are the current ranges; position *8* is a shunt ohmmeter and position *9* is a series ohmmeter. Other ranges can be provided by adding other switch contacts.

Note that the same multiplying resistors are used both for a.c. and d.c. voltages. This is possible where similar ranges and sensitivities are provided. Of course, the a.c. ranges will be marked on different scales.

Where the d.c. voltage ranges are at sensitivities greater than 1000 ohms-per-volt, it is standard practice to shunt the a.c. ranges so they remain 1000 ohms-per-volt. This requires separate multipliers for d.c. and a.c. and usually requires more switch sections.

The test leads are plugged into the jacks marked "DC —" and "+" for d.c. voltage, d.c. current and ohmmeter measurements. The jacks "+" and "AC ±" are used for a.c. voltages, while the jacks "+" and "output" are used for a.c. readings when d.c. must be blocked out. This jack is marked "output" because it is usually used for making output voltage measurements in the plate circuit of the power tube.

Tolerance. How accurate do our measuring devices have to be? The answer depends on the type of work being done.

In a research or design laboratory, highly accurate measurements may be desired. Here, expense usually does not matter; it is worth the price of hand-calibration and extreme care to make sure of success in the particular work being done. Further, precision parts

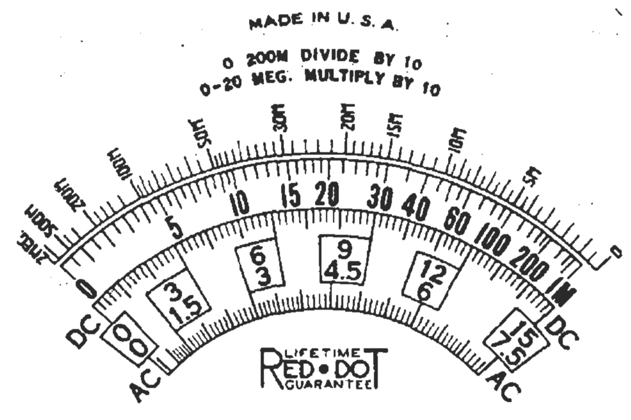


FIG. 30. Typical multimeter scales. Don't worry about reading this one—you will get instructions with any meter you buy. From the top down, the scales are: series ohmmeter; shunt ohmmeter; d.c. voltage and current; and last, a.c. voltage.

are usually used in research, so the observed results can be checked closely by calculations.

If this research is being carried on for a radio set manufacturer, some particular circuit design may be developed. Then, parts will be varied over wide limits to see just what variations can be permitted and still obtain rea-

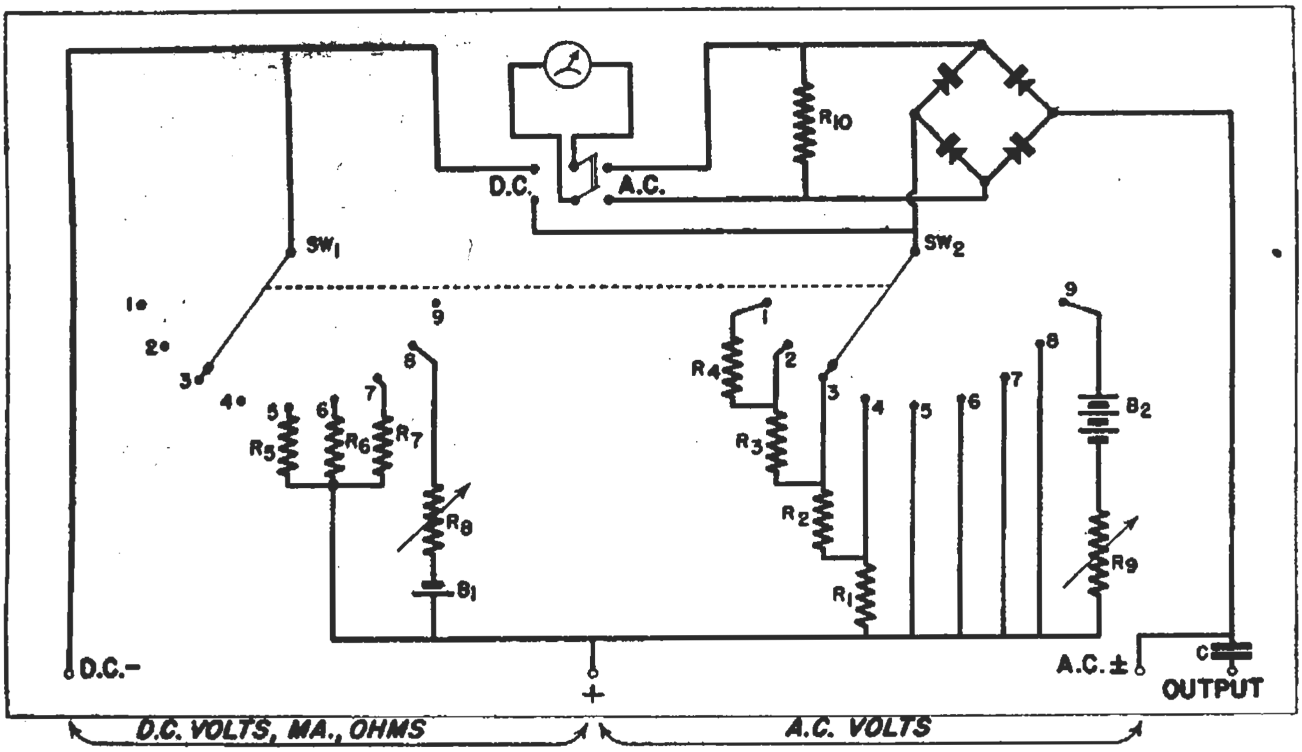


FIG. 31. A multimeter of the selector switch type.

sonably good results. There is a very important reason for this—the question of cost. Precision parts are practically hand-made, and therefore quite expensive. But if wider tolerances are permissable, it will be possible to use cheaper mass-production parts, thus lowering the cost of the set.

When a radio set is made from parts having tolerances of 10% to 20%, the manufacturer is interested in over-all results, not the exact happenings in each stage. Thus, it is possible for readings to be off 30% to 40% from the expected value in many instances, yet the receiver may give average results for its type. Therefore, there is little reason for the serviceman to use meters having an accuracy better than 2%. Far wider variations will arise in the radio circuit itself.

One of the things you must learn in service work is to interpret the readings obtained, considering the circuits where measurements are being made. In one circuit, variations of 50 volts or so may be expected, while in another a few volts variation may indicate trouble. After gaining a little experience, your growing knowledge of circuits and their operation will soon help you determine just what to expect. Just remember that a meter cannot point out the trouble; it can only tell you what circuit conditions are, from which you in turn figure out the cause.

Lesson Questions

Be sure to number your Answer Sheet 28FR-3.

Place your Student Number on *every* Answer Sheet.

***Send in your set of answers for this lesson immediately after you finish them,* as instructed in the Study Schedule. This will give you the greatest possible benefit from our speedy personal grading service.**

1. Is the resistance of a shunt used to extend a 1-ma. meter to 100 ma. *more, less, or the same* as the shunt used to extend the range to 10 ma.?

   less

2. Will the current indicated by a milliammeter in the cathode circuit of a screen grid tube be an accurate measurement of the plate current?

   No

3. Give the five rules for connecting a current meter.

   P 9

4. What will happen if you attempt to measure 60-cycle a.c. with a D'Arsonval meter alone?

   the meter will read 0

5. Which types of meters can be used to measure high audio frequency currents accurately, regardless of wave form?

   P 10

6. Suppose a copper-oxide rectifier voltmeter reads about 55 volts when you are checking a 110-volt power line. What is the probable trouble?

   One of the rectifier elements is shorted out

7. In measuring voltage in high-resistance circuits, will a 20,000 ohms-per-volt meter or a 1000 ohms-per-volt meter give more accurate circuit voltage measurements?

   20 000 ohms per volt meter

8. Which type of ohmmeter, when turned on, draws current from its battery even though the test leads are not touching each other?

   a shunt type

9. Is the "zero" adjustment for a shunt type ohmmeter made when the test leads are held together or when they are separated?

   separated

10. Suppose you are measuring in a circuit where both a.c. and d.c. exist together and you wish to measure only the a.c. Would you use: 1, the "AC±" multimeter jack; or 2, the "OUTPUT" jack, to exclude the d.c.?

    [illegible]