CURRENT, VOLTAGE, AND POWER METERS

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STUDY SCHEDULE NO. 37

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

CURRENT, VOLTAGE, AND POWER METERS

Direct Current Meters

METERS are a means of knowing what is happening in a radio or electronic circuit. They are used constantly in radio work of all kinds. As a radio operator, you will use meters daily in checking and adjusting the performance of the transmitter and other equipment in your charge. When trouble occurs, your main reliance will be on meter readings and test meters to locate its cause. You will use meters that are a part of the radio apparatus you are operating, and portable meters that you can use for temporary or emergency measuring.

Early in your NRI 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 CURRENT IS 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 pro-duced, 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 that will react at once to changes in current and that can be used anywhere.

One of the first electrical discoveries was that the magnetic field that always accompanies a current flow will 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 work.

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, for its inventor) has been developed that overcomes these objections.

Instead of placing a compass within a coil, a small coil suspended on bearings so it can rotate is placed in a

strong magnetic field. When the current to be measured flows through the coil, a magnetic field is set up that interacts with the fixed field, causing the coil to move. The basic operation can be shown with Fig. 1. You remember that like magnetic poles will repel. If a small pivoted magnet is placed as

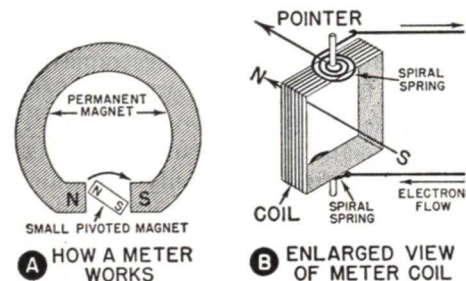A HOW A METER WORKS   B ENLARGED VIEW OF METER COIL

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

shown in Fig. 1A, it will move 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.

Once the coil starts to rotate, it will continue to do so, unless some means is taken to stop it. That is why the two fine spiral springs are attached to 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. The amount of movement, and therefore the amount of current flowing, can be indicated on a scale by attaching a pointer to the coil.

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
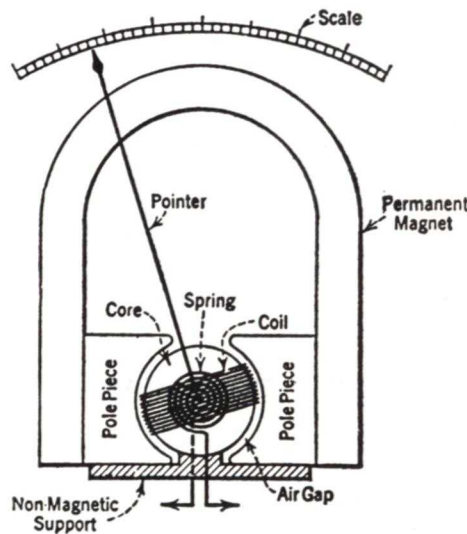

FIG. 2. The names of the meter parts.

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

*In most modern panel meters, the magnet and the pole pieces are one, cast complete or made up of layers of stamped pieces.

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.

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 used in the coil depend on the 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 that would either wind them tighter or unwind them. When the coil moves, one is wound while the other is unwound. The springs thus oppose a coil movement in either direction away from the starting position (the position the pointer takes when no current flows in the coil).

Naturally, these springs won't always remain perfectly balanced. That is why most meters have a zero adjustment. This is a small screw that usually protrudes through the case of the meter just below the meter coil. Turning this screw moves the upper coil spring 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. Of course, this means they must be insulated from each other and from the meter frame.

D.C. Meter Scales. All d.c. meters, current meters and voltmeters, have linear scales. That is, the spacing between scale divisions over all of the

scale is exactly the same. Let us see why this is so.

The air gap in which the moving coil rotates is designed to give a uniform magnetic field in all of the space through which the coil may move. The torque or turning force exerted by the coil against the springs will be directly proportional to the current flowing in
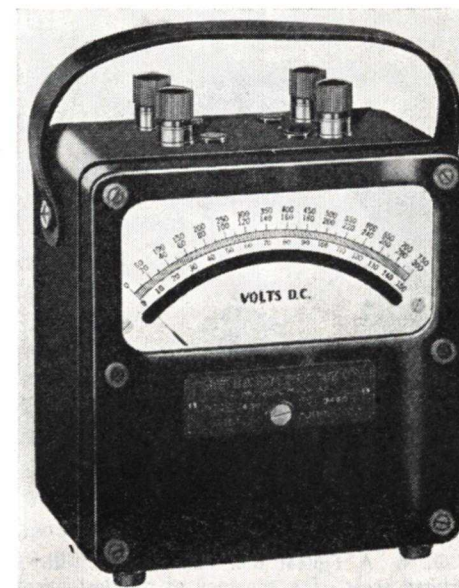
Courtesy Weston Electrical Instrument Corp.

FIG. 3. A portable d.c. voltmeter that has an accuracy of better than ±1/2% over the entire scale. This is an example of an accurate hand calibrated instrument.

the coil. Since the springs allow the coil to turn by an amount proportional to the torque, the movement of the pointer will be proportional to the current and therefore the scale will be linear. Note the linearity of the scale of the meters shown in Figs. 3 and 4.

Most of the meters in radio transmitting equipment are d.c. meters with D'Arsonval movements and linear scales because most of the measurements are made in the d.c. circuits supplying current to tube elements.

The uniform spacing of markings on a d.c. meter scale readily distinguishes

it from a.c. meters, which, as we shall see, generally have non-linear scales.

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 before the meter pointer

Courtesy Weston Electrical Instrument Corp.

FIG. 4. A typical d.c. milliammeter with a printed scale. The accuracy of this instrument is ±2%.

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 magnetic field that 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 creating 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 oppos-

ing 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.

The resistor value that 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—some meters require 10,000 ohms, others need 100 ohms. A resistor below the critical value causes over-damping and a slow meter movement, whereas 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 scales of the meters we have studied were "calibrated" — that is, they were marked to indicate the amount of current flowing. Let us see how this is done.

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 current meter to be calibrated, as shown in Fig. 5. The amount of current passing through the two meters is varied in steps, and the meter readings are noted for each step. The current through both is the same regardless of their resistance. Since the standard meter is indicating the exact current flowing through both meters, the other meter can be directly calibrated from the standard and a hand-drawn scale prepared. This method is used in the manufacture of the more accurate and expensive meters.

Fig. 3 shows an example of a hand-

calibrated meter. Meters of reasonable accuracy that are much lower in price can be made by duplicating the hand-calibrated meter as closely as possible in all parts. These mass-produced meters usually have about the same response as the meter on which they were modeled. The same scale can
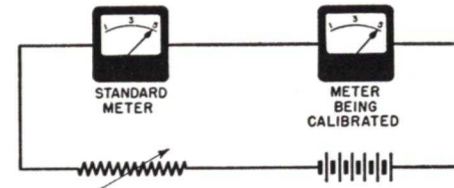

FIG. 5. Calibrating a current meter by comparison.

therefore be used for all of them with fair accuracy, so the scales are printed. To improve the accuracy of such meters, manufacturers adjust the spring tension, magnetic field, and internal resistance so that the full-scale reading of each meter is reasonably correct. Fig. 4 shows a typical meter of this type.

Percentage Accuracy. Highly accurate hand-calibrated meters are large in size and very expensive. Their accuracy is in the neighborhood of $\frac{1}{4}$ of one per cent or better. For transmitters, meters having an accuracy of 2% are satisfactory. These meters have printed scales and are adjusted internally at the time of manufacture to the required accuracy.

The accuracy of meter movements is generally expressed as a percentage of the full-scale reading. If a meter with 50 scale divisions has 2% accuracy, it is in error by one scale division at a full-scale reading. This fact, however, does not indicate how accurate the meter is at other readings, because it may also be wrong by as much as one scale division at any other part of the scale. For example, when the meter pointer is at 10 (1/5 of full scale), the

reading may still be in error by 1 division; this would mean that the meter error has increased to 10%. For this reason the FCC requires that on a linear scale meter the minimum normal reading be at least 1/5 of the full-scale reading.

The majority of instruments used in radio transmitters have 2% accuracy, and the error at the low end of the scale is generally much less than the 10% given in the above example.

Parallax. Inaccurate readings may result from looking at a meter scale from an angle rather than from right above it. Fig. 6 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,
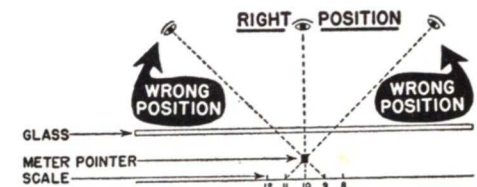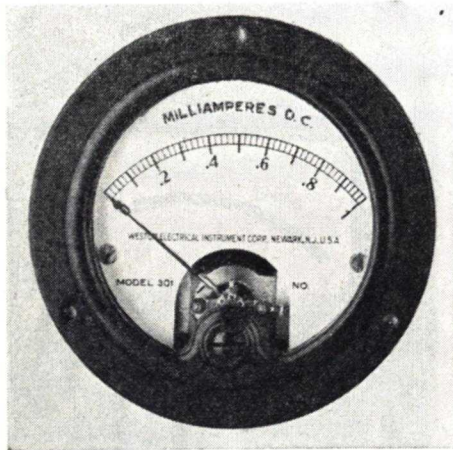

FIG. 6. Always look straight at a meter to avoid parallax.

caused by the position of the observer, is called parallax.

Most laboratory meters have knife blade pointers and a small mirror on the scale under the pointer. Unless your eye is directly above the pointer, you will see an image of the pointer in the mirror. With such meters, you can avoid parallax by always moving your

eye to where the image disappears behind the pointer before making the reading. In Fig. 3, the mirror appears as a black band below the scale.

In radio operation and maintenance work, highly accurate readings are usually unnecessary. Some multimeters have knife-blade pointers, but not for the same reason that such pointers are used in laboratory meters; they are made this way because these pointers must generally cover several meter scales, and the knife-blade shape permits readings to be made with equal ease on all scales. Meters for radio transmitters and all "standard" meters, such as the one shown in Fig. 4, usually have an arrow-tipped pointer.

EXTENDING CURRENT RANGES

In communication circuits and in laboratory work, both large and small currents have to be measured. Meters are made with a wide variety of full-scale ranges, from 30 microamperes up
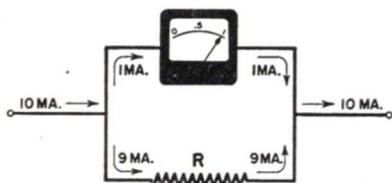

FIG. 7. The current flow divides between the meter and shunt.

to thousands of amperes. Of course, it would be possible to design and build a separate meter movement for each current range, but this is not done in practice. Instead, meter movements are made in a few basic ranges, and any additional ranges desired are secured by connecting elements called current shunts in parallel with the meter movements. For example, a 10-milliampere basic meter movement (one that gives a full-scale reading when a current of 10 milliamperes

flows through it) is commonly used for transmitter panel meters with ranges from 10 ma. up to several amperes. A basic meter movement of 1 ma. or less is used in portable meters.

How Shunts Are Used and Calculated. Suppose we have a 1-ma. meter and want to measure 10 ma. We can do so by putting a resistor across the meter terminals 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 through the meter. In other words, we use the resistor to "by-pass" 9/10 of the current. Fig. 7 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. 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. ($1 \times 10 = 10$). Of course, if the meter is to be connected permanently to read 10 ma. we will mark the scale 0-10 ma., so that the total current can be read directly.

Since the "current 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 that is the difference between the total current to be measured and the amount the meter needs for full-scale deflection. For example, if we want to measure currents up to 25 ma. with a 1-ma. meter, we must find a shunt R that 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 cur-

rent; R_M is the meter resistance.) The current I_S is the current that 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 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 find 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 of the meter, so some resistance must be added to the meter movement to adjust the damping to a satisfactory amount. This is done by connecting a small resistance (usually a small coil of high resistance wire) in series with the meter movement.

In small panel instruments having current ranges of around 20 amperes or less, like those frequently used in communications work, the shunt is

contained within the instrument itself. In portable instruments of high accuracy and in panel instruments having current ranges of over 50 amperes, the meter is generally used with an external shunt. Portable instruments generally have a movement sensitivity of 50 millivolts full scale so that interchangeable shunts may be used.

MULTI-RANGE CURRENT METERS

Portable meters used for maintenance and trouble-shooting work have a number of ranges, with several built-
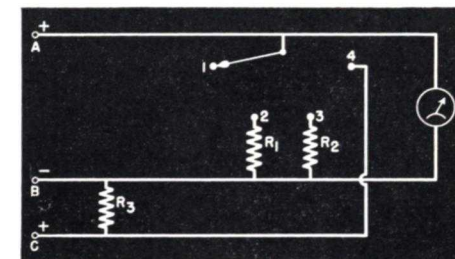

FIG. 8. Multi-range current meter.

in shunts and a switch arrangement for selecting the range. Fig. 8 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 the ranges, the manufacturer will mark the scale for each range so you won't have to do any figuring. The only usual exception occurs when one range is 10 times another. For example, when the ranges are 10 ma. and 100 ma., you may have to get readings on the 100-ma. scale by multiplying the 10-ma. scale readings by 10.

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 possible contact-resistance trouble, many multi-range ammeters use a separate shunting system on the high-current range.
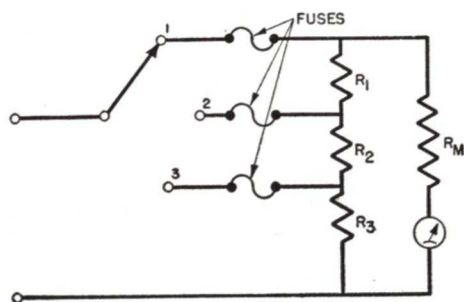

FIG. 9. The use of a ring shunt makes this a better multi-range current meter. Notice the proper position for fuses in a meter of this type.

Fig. 8 shows one form of high-current shunting. When medium or low-current readings are to be made, the test leads are connected to terminals A and B; terminals B and C are used for high currents. Shunt R_3 for the high-current range is connected between B and C. When these terminals are used, the selector switch is in the meter circuit, and switch-contact resistance does not matter greatly, because it adds to the meter resistance instead of to the shunt resistance. This arrangement also has the advantage that the high current does not flow through the selector switch contacts.

However, Fig. 8 does not represent the best arrangement, because it is possible to damage the meter if the switch develops too much contact resistance in position 2 or 3 or open-circuits during the switching operation. This possibility of damage is not present in the circuit shown in Fig. 9, which is known as a "series or ring shunt." When the selector switch is in

position 1, the instrument is set to its lowest range. Note that this is not the basic meter range, because the resistors R_1, R_2, and R_3 act as a shunt across the meter.

With the switch in position 2, resistors R_2 and R_3 are the shunt; R_1 is added to the meter resistance. Similarly, in position 3, R_3 is the shunt and 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.
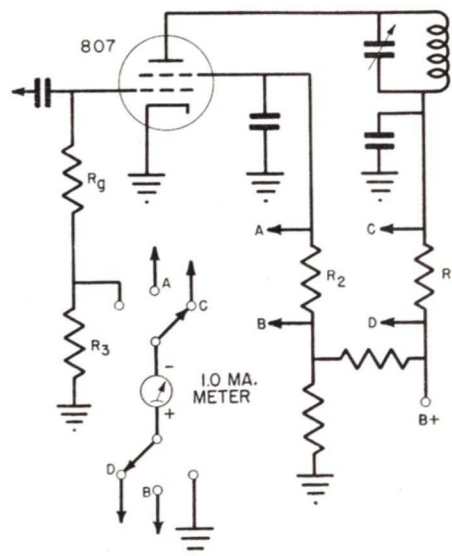

FIG. 10. How one meter can be used to measure current at several points in a transmitter by using permanent meter shunts R_1, R_2, and R_3 and a selector switch to connect the meter across any of these shunts. Throwing either meter switch to any position connects it to a similarly marked point elsewhere in the circuit.

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

In transmitters, it is sometimes de-

sirable to use a single meter to measure the plate currents, grid currents, and cathode currents of several stages. This saves panel space required for meters and also some expense in the meters themselves. One practical system of accomplishing this is to connect separate current shunts permanently in each circuit where a current measurement is to be made, then connect the meter movement to the shunt with a tap switch when a reading is to be made in the circuit. In this case, the contact resistance of the switch is not in the current path—only in the meter branch—so that its effect on accuracy is negligible. Meters used in this manner are sometimes called "test meters."

Fig. 10 shows such a meter and individual shunts (R_1, R_2, and R_3) arranged to measure plate, grid, and screen current in an r.f. amplifier stage. This same meter can be used to measure currents in all stages of the transmitter by adding more taps to the switch and using shunts in other stages.

Each shunt for the test meter is of the right resistance to give a suitable full-scale range to the meter when connected to it. For instance, in the low-power transmitter stage shown in Fig. 10, the shunt for measuring plate current is adjusted to give 200-ma. full-scale deflection, and those for measuring grid and screen currents are adjusted to give 10-ma. full-scale deflection.

USING A DIRECT CURRENT METER

There are four things you must keep in mind when using a direct current meter. Let's see what they are and why they're important. Then we'll summarize our findings in four 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 current meter is ever connected across a circuit component such as a resistor or a condenser, it is almost certain to be burned out.*

2. Correct Point. In the simple circuit shown in Fig. 11, the meter readings at A and C are the same, because the same current flows through
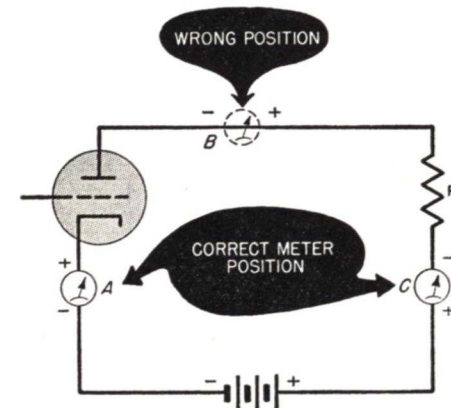

FIG. 11. Be sure to place a current meter in series and use the proper polarity.

the entire circuit. However, this would not be true if a screen-grid or pentode tube were substituted for the triode in this circuit, because, in such tubes, the screen current also flows in the cathode lead. The plate current alone could be measured only at C. Position A would give both screen and plate currents together.

We hasten to point out with reference to Fig. 11 that in transmitters meters are *never* placed between the load and the plate of a tube—for example, in position B in Fig. 11. In that position the meter would be subjected to audio or radio frequency currents that are damaging to the delicate meter mechanism.

When more than one tube is used,

as shown in Fig. 12, notice there are 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 directly to the cathode of VT_1 and the B+ ends of resistors R_1 and R_3 may be connected together directly, so positions such as A and C of Fig. 11 may not be usable. Fig. 12 shows the proper places to measure the plate current of VT_1. Remember, insert your meter where only the *desired* current is flowing.
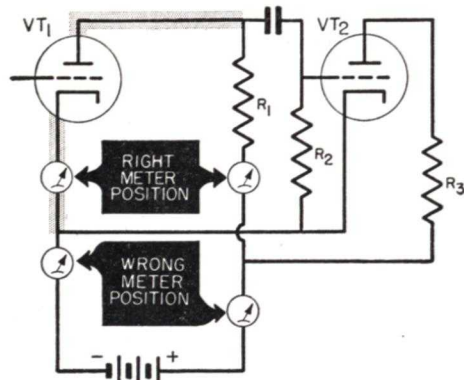

FIG. 12. The right meter position is important.

In communications circuits, special care is taken in locating the meters so that they will not be subject to strong r.f. fields. A strong field will induce r.f. currents in the meter wiring and thereby affect the accuracy of the meter. High r.f. voltage may also cause insulation breakdown. To avoid this, the d.c. meters are (a) connected in a circuit so that they are at ground potential with respect to r.f., or (b) shunted by r.f. by-pass condensers, or (c) placed in series with r.f. chokes. The first method is illustrated in Fig. 13.

When a meter must be placed where it might be damaged by r.f. fields or in a lead that carries r.f. or a.f. currents,

a by-pass condenser having a low impedance compared to the meter impedance is connected across the meter terminals as shown in Fig. 14A. The r.f. or a.f. current then follows the low impedance path through the condenser rather than the high impedance path through the meter. (In Fig. 13, condensers C_o are already in the circuit and are not introduced to protect the meter.) This protection is sometimes increased by adding a resistor (Fig. 14B) or r.f. choke (Fig. 14C) in series with the meter and within the circuit shunted by the by-pass condenser. The resistor, besides increasing the meter impedance, acts to damp out and prevent any resonance effects that might result from the parallel combination of the inductance of the meter coil and the capacitance of the by-pass condenser.

The by-pass condenser for r.f. circuits may be any value between .001 mfd. and .01 mfd. For a.f. circuits, the by-pass condenser should be .01 mfd. to 1 mfd., depending upon the circuit. The size of the series resistor depends upon the current flowing in the circuit, but a value approximately equal to the meter resistance is generally used. More protection to the meter will result from using a resistor with as high a value as the circuit will allow without reducing the required d.c. current too much.

When a current meter is used in high voltage circuits of over 250 volts, the meter unit must be insulated from ground and installed so that operating personnel cannot touch it. This is necessary because the meter case is not normally constructed to withstand high voltages.

This matter of protection of meters and personnel has been made the subject of Federal Communications Commission and National Electrical Code rules. All meters in equipment that

comes under the jurisdiction of the FCC must conform to its rules.

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. A meter range that will put the current reading in the upper half
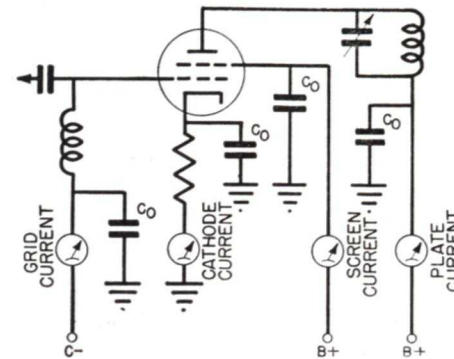

FIG. 13. As shown in this example, meters are connected in a transmitter at points that are at ground potential with respect to r.f. voltages and in circuits that do not carry r.f. currents.

or third of the meter scale should be selected if possible. The circuit current is determined by Ohm's Laws, $I = E/R$, where R is the total of all the resistance in the circuit. In a circuit like that in Fig. 12, 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 a voltage amplifier stage using a receiving tube.

When you are using a multi-range current meter to measure an unknown current, *always start with the highest current range* and switch to lower ranges if the readings permit.

Properly made voltage and resistance measurements will usually make it possible to calculate the current, saving you the trouble of opening the circuit except in rare instances. In radio transmitters, radio frequency generators, and other high-powered electronic apparatus, the necessary

current meters are permanently connected to the circuit and the correct meter range is selected at the time the apparatus is developed.

4. 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.

Meter terminals are marked to show the proper connections. The positive terminal is marked with a "+" sign on the end of the meter stud or on the meter case adjacent to it.

The *positive* meter stud must always be connected in the circuit so that it is toward the *positive* terminal of the power supply. This is illustrated in Fig. 11. The positive terminal of the
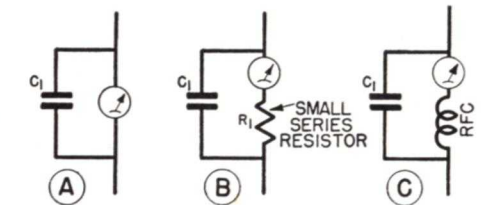

FIG. 14. An ammeter, subject to strong electrical fields, may be protected from damage by suitable by-pass condensers C_1. Adding a series resistor R_1 makes this protection more effective.

meter at C is connected directly to the positive terminal of the battery.

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. Connect the meter so that the positive terminal is toward the positive terminal of the power supply.

PULSATING CURRENT MEASUREMENTS

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 the other; half the time the meter needle would deflect in the wrong direction. This would not happen with 60-cycle a.c., 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 can see that in each cycle the current is alternately positive and negative, and the positive swings are equal to the negative swings; therefore, the *average* current is zero. This means that a D'Arsonval meter alone will not read on a.c.—it can only indicate the a.c. average (which is zero), regard-
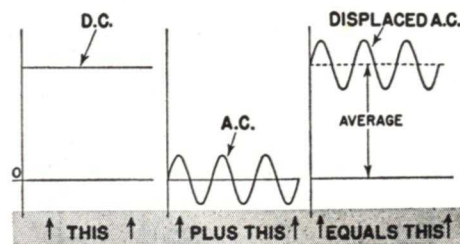

FIG. 15. The average value of a pulsating d.c. wave is equal to the d.c. component.

less of the amount of a.c. flowing through it.

Now a pulsating current has both a d.c. and an a.c. component, as shown in Fig. 15. 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.

Measuring D. C. Voltages

Voltages, like currents, are measured by meters. In fact, a voltmeter is made up of a sensitive current meter and a series resistance of a suitable value to limit the current flowing through the meter. Current meters themselves are voltmeters in a sense, because it takes a certain voltage to force the current through the resistance of the coil windings.

For instance, a 0-1 ma. meter with a resistance of 100 ohms is in reality a voltmeter with a full-scale range of one-tenth of a volt or 100 millivolts ($E = IR = .001 \times 100 = 0.1$ volt).

D.C. voltmeters use 0-100-microampere meters, 0-200-microampere meters, 0-500-microampere meters, 0-1-milliampere meters, or 0-10-milliampere meters as their basic elements.

The sensitivity chosen for a particular use depends upon the circuit in which measurements are to be made.

If the circuit can "spare" several milliamperes for the voltmeter without affecting the circuit operation or the accuracy of the voltage measurement, then a 0-10 ma. movement may be satisfactory. On the other hand, if a drain of 1 ma. will affect the circuit and cause an error in the voltage measurement, then a 0-100-microampere movement should be used. More will be said about this later under the heading "Voltmeter Sensitivity."

The basic voltmeter circuit in use is shown in Fig. 16. The resistor and meter are connected in series and the combination is connected across the voltage supply to be measured. The

resistance and wattage rating of the resistor can be determined from Ohm's Law; they depend upon the sensitivity of the current meter (milliamperes full-scale range) and the full-scale voltage the voltmeter is to measure.

For example, suppose the full-scale sensitivity of the current meter is 1 ma. and a voltmeter having a full-scale range of 100 volts is desired. From Ohm's Law, the resistance that will limit the current to 1 ma. with 100 volts impressed is

$$R = \frac{E}{I} = \frac{100}{.001} = 100,000 \text{ ohms.}$$

This is the value of the series resistor required.

The wattage rating of this resistor should be

$$P = \frac{E^2}{R} = \frac{100 \times 100}{100,000} = \frac{10,000}{100,000}$$
$$= .1 \text{ watt.}$$

Actually a resistor of at least a 1-watt rating would be used here to provide ruggedness, stability, and ample overhead capacity.

If the resistance of the meter movement is an appreciable portion of the series resistance required, say ½% or greater, it must be subtracted from the series resistance calculated by the above formula to arrive at the true value of the series resistor to be added. In our example above, however, if the meter resistance were 100 ohms, it would be negligible compared to the 100,000-ohm series resistor, and no compensation would be made.

In voltmeters having accuracies of ½% or better, the series resistors, or "voltmeter multipliers" as they are sometimes called, are precision wire-wound units in order to assure the accuracy of the meters under varying temperature conditions. If carbon resistors were used, the accuracy of the meters would vary with a change in temperature because of the variation of resistance values of carbon resistors

with temperature. The wire used in the wire-wound series resistors is of a special composition to reduce temperature effects to a minimum. One frequently used wire is called "constantan."

In panel-type voltmeters having an accuracy of 2%, carefully selected carbon or composition resistors are generally used. Properly aged under heat treatment, such resistors retain their accuracies fairly well under reasonable changes in temperature.
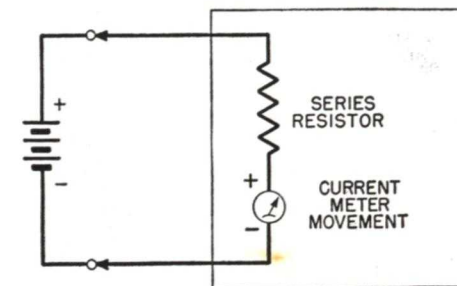
The voltmeter resistor is mounted

FIG. 16. This is how a voltmeter consisting of a current meter movement and a series resistor, is connected across a battery or power supply source to measure the voltage.

inside the meter unit when the meter has a full-scale range of up to approximately 300 volts. A higher-range meter usually has an external multiplier that must be connected to the meter when it is installed in the apparatus.

Fig. 17 shows several types of series resistors. One type is mounted in a cage with binding posts as terminals. Another is manufactured in the form of a long tube and is mounted in fuse clips for support and electrical connections. The others look like ordinary resistors.

To protect the voltmeter and personnel using it, the meter and the multiplier should be connected, as shown in Fig. 18, so that the meter is at the lowest or ground potential and only the end of the multiplier is connected to the high voltage. This is necessary
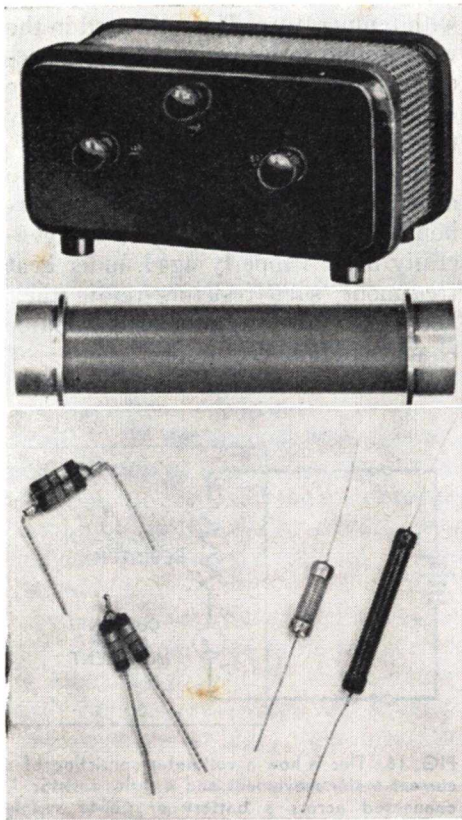
FIG. 17. Voltmeter multiplier resistors. At top is an enclosed resistor, in the center a tubular resistor; these are usually mounted externally. Matched resistor pairs (bottom left) and precision-ground Wilkor resistors (bottom right) are usually mounted inside the meter case. (Top and center photographs courtesy Weston Electrical Instrument Corp.)

because meters are not ordinarily well enough insulated to withstand high voltages; if a meter were connected in the wrong position shown in Fig. 18, an operator standing on a good ground might get a severe shock if he touched the meter.

Incidentally, if two or more voltmeters are connected in parallel, they should each indicate the same voltage, even though their resistances may not be the same. When voltmeters are connected in series, the voltage across them is the sum of the voltages indicated on the individual meters.

MULTI-RANGE VOLTMETERS

Just as there are multi-range current meters for applications requiring an instrument with several current ranges, there are also multi-range voltmeters for similar uses. Generally a multi-range current meter and a multi-range voltmeter are combined in a single instrument called a "multimeter."

In a multi-range voltmeter, a single current meter is used in conjunction with several series resistors. The different series resistors are connected to the measuring circuit with a tap switch. Fig. 19 shows a simple arrangement of series resistors for a multi-range voltmeter. In this circuit, the low range is 5 volts; extra series resistors give additional ranges of 10 volts, 50 volts, 100 volts, and 500 volts. The basic meter is a 0-1-ma. current meter with an internal resistance of 100 ohms.

Ohms-Per-Volt Rating. This basic meter will deflect full-scale if the total resistance in series with the meter movement is 1000 times the applied voltage in numerical value. You can see this from Ohm's Law, $I = \dfrac{E}{R}$; as long as the ratio of E to R is 1 to 1000, the current flowing through the meter will be 1 ma. For this reason, the meter is said to have a rating of 1000 ohms-per-volt.

The ohms-per-volt rating of this or any other voltmeter shows you at once what the resistance values of the series resistors must be to produce the voltage ranges desired. For example, the low range of the voltmeter in this case is to be 5 volts; to produce such a range, there must be 5000 ohms in series with the meter movement. This is secured by connecting a 4900-ohm resistor to the meter (remember, the movement has an internal resistance

of 100 ohms that must be added to the series resistance). A total resistance of 10,000 ohms is needed to produce the 10-volt range; this is secured by adding a 5000-ohm resistor. Similarly, adding a 40,000-ohm resistor makes the total resistance 50,000 ohms, and extends the range to 50 volts; adding 50,000 ohms more makes the total 100,-000 ohms and extends the range to 100 volts; and, finally, adding 400,000 ohms makes the total 500,000 ohms and extends the range to 500 volts. In each case, multiplying the ohms-per-volt rating by the desired full-scale reading gives the numerical value of the series resistance that is necessary to produce the range wanted.

This fact makes it easy to calculate what series resistor is needed to extend the range of a voltmeter by any desired amount. All you need do is multiply the ohms-per-volt rating by the number of volts the range is to be ex-
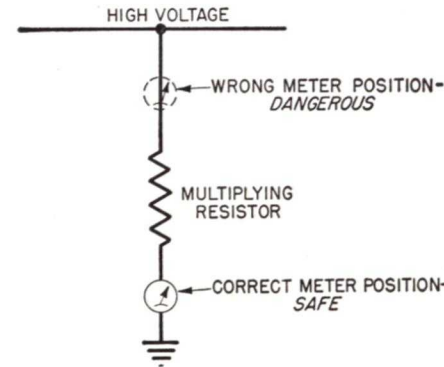

FIG. 18. The correct and incorrect methods of connecting a meter movement in series with a multiplying resistor in order to measure high voltages.

tended. For example, to extend the range of the 1000-ohms-per-volt meter by 500 volts, an extra series resistor of 500,000 ohms must be added.

From what we have said, you can see that the ohms-per-volt rating of a meter is an inverse indication of the

amount of current the meter requires. That is, a low-current meter has a high ohms-per-volt rating, and vice versa. For example, a 1-ma. meter has a rating of 1000 ohms per volt; a 10-ma. meter has a rating of only 100
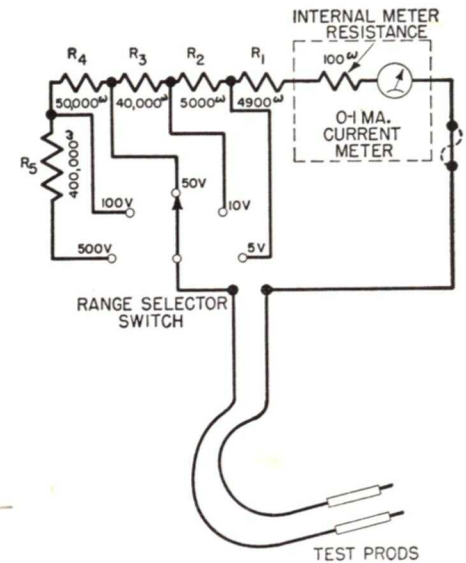

FIG. 19. Simple multi-range voltmeter circuit. This voltmeter has a sensitivity of 1000 ohms per volt on each range. The dotted line shows the proper location for a fuse in this kind of voltmeter circuit.

ohms per volt. (You can work out the ohms-per-volt rating of any meter from Ohm's Law, $I = \dfrac{E}{R}$, just as we did a few paragraphs earlier. The current rating of the meter is all you need to know.)

Since the sensitivity of a meter is determined by how little current is needed to make it read full-scale, the ohms-per-volt rating of a meter can be used as a direct measure of its sensitivity; the higher the ohms-per-volt rating, the more sensitive the meter. In fact, this rating is widely used for this purpose.

The sensitivity of a voltmeter must be considered every time the meter is

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used to measure voltages in a circuit. Let's see why.

VOLTMETER SENSITIVITY

The sensitivity of the current meter of a voltmeter must be determined by the use to which the voltmeter is to be put. If it is to be used in a circuit in which the voltage source can deliver considerable current to the voltmeter, the movement may be a less sensitive type. For example, in a radio transmitter where the filament supply provides 22 volts d.c. at 52 amperes, the volt-
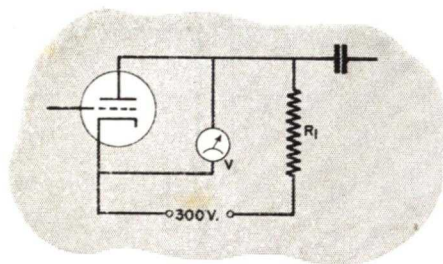

FIG. 20. A typical voltage-measuring problem. The accuracy depends on the ohms-per-volt sensitivity of the meter.

meter may take 10 or even 100 ma. without affecting the supply or producing an undesirably large power loss. On the other hand, if a voltmeter with a 10-ma. movement were used for measuring the 20,000-volt d.c. plate supply in the same transmitter, 200 watts would be taken from the power source to operate the meter; practically all this power would be dissipated in the voltmeter series resistor, which would, therefore, have to be extremely large. However, if a 0-1 ma. movement were used, only 20 watts would be taken from the source and dissipated in the series resistor; the resistor could then be more reasonable in size.

Voltmeters used in trouble-shooting and maintenance instruments require a sensitive movement because of the high resistances in some of the elec-

tronic circuits in which measurements are made. As a practical example of a typical electronic circuit, consider Fig. 20. Suppose that resistor R_1 has a value of 50,000 ohms and the tube's d.c. plate 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's plate-to-cathode voltage is 100 volts, and the drop in R_1 is 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 other words, the meter is in parallel with the tube resistance, so our circuit is really that shown in Fig. 21. A few practical cases will help you see what happens.

Case 1. If the voltmeter in Fig. 20 has a 100-volt range that requires 10 ma. for full-scale deflection, its resistance $R_M = E \div I$, or 10,000 ohms. (In other words, it is a 100-ohms-per-volt meter.) This resistance is in parallel with the tube's d.c. plate resistance R_P of 25,000 ohms, as shown in Fig. 22, so the resulting parallel combination of meter and tube is

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

approximately 7100 ohms in value. 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 parallel combination of the tube and meter. 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 when the meter is not present.

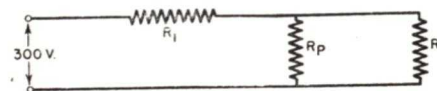**Case 2.** Suppose we now use a 1000-ohms-per-volt voltmeter having

FIG. 21. Notice how the voltmeter resistance is in parallel with the tube plate-cathode resistance.

a 100-volt range. The meter resistance is 100,000 ohms and the meter current 1 ma. 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.

Case 3. A 10,000-ohms-per-volt, 100-volt meter has a resistance of 1,000,000 ohms and a current demand of 0.1 ma. Such a meter will indicate about 98 volts if placed in the circuit of Fig. 20. This is an error of about 2%, well within the normal tolerance for such a circuit.

Obviously, in any circuit having appreciable series resistance, the lower the current drawn by the meter, the more nearly correct the results.

For the reasons illustrated in the above three cases, voltmeters designed for trouble-shooting and service work on electronic circuits use 1000- to 20,000-ohms-per-volt meters.

Protection from R.F. Voltmeters (like ammeters) are protected from r.f. fields and voltages by means of by-pass condensers around the meter movement. The internal multiplying resistor in a voltmeter aids considerably in reducing the amount of r.f. that reaches the meter movement.

Meter Fuses. Meters used for test

purposes can be equipped with a small fuse that will blow before the meter can be damaged by an overload. Fuse holders and fuses are not a part of the meter but must be attached to it.

Fuses are good protection against meter damage, but there is one disadvantage to using them: they have relatively high resistance. A fuse frequently used to protect 0-1 ma. movements has a resistance of about 110 ohms. This is about the same resistance as that of the meter itself, so, if the fuse were added to the meter circuit of a multimeter, the accuracy of all current ranges in which shunts are used would be destroyed. To prevent this from happening, the fuse must always be connected in series with the parallel combination of the meter movement and its shunt or shunts.

Fig. 22 shows the right and wrong locations of fuses in an ammeter or milliammeter. In Fig. 9 we saw the recommended location for fuses in a multi-range current meter. These fuses are in series with the measuring circuit, so all the current being measured flows through them. This arrange-
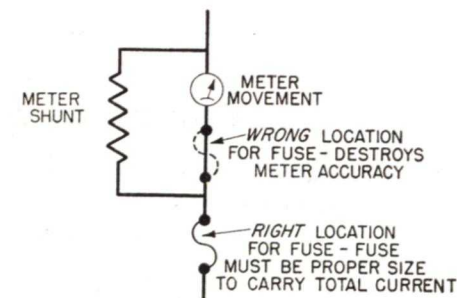

FIG. 22. Method of connecting a fuse in an ammeter or milliammeter circuit.

ment protects the shunts as well as the meter in case of overloads. In Fig. 19 we saw the recommended location for a fuse in a multi-range voltmeter. This fuse is in series with the meter, and only one fuse is needed regardless of the number of ranges. If the fuse

has a resistance of 100 ohms, the resistance of R_1 in this example should be reduced to 4800 ohms to compensate for it and keep the meter accurate on the 5-volt scale.

When fuses are inserted in voltmeter circuits, it is also advisable to protect the circuit by connecting a neon lamp (type 991) from the low-voltage end of the multiplying resistor to ground as shown in Fig. 23. This will prevent high voltage from appearing at this point should the fuse blow.

Let's see why this extra protection is necessary. Suppose the neon lamp were not in the circuit in Fig. 23. There would be no danger as long as the fuse was whole; current flow through the series resistor would cause so large a voltage drop across it that the low-voltage end of the resistor would be practically at ground potential. However, if the fuse should blow, there would be no current flow through the resistor, and thus no voltage drop across it. The high voltage of the power supply would then appear at what was previously the low-voltage end of the resistor. High voltage at this point

might well break down the insulation of the meter mount.

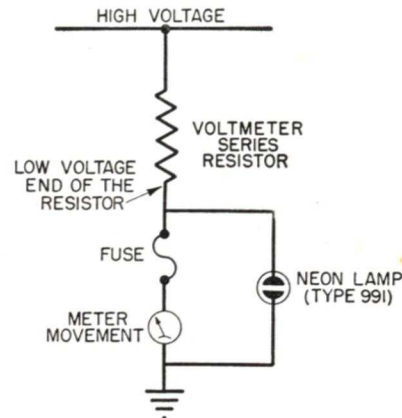The neon lamp prevents this from happening, because it will ionize if the

FIG. 23. How a fuse and neon lamp are used to protect a voltmeter.

voltage at the meter end of the resistor rises more than 90 volts above ground. Current will then flow through the lamp and the series resistor. The voltage-regulating action of the neon lamp will maintain the voltage across it at a safe value of about 70 volts.

Measuring Resistance

Since we can now measure voltages and currents, we could 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, as it is generally known.

Fig. 24 shows the circuit of such a meter. The resistance R_2 is adjusted so that the sum of its resistance and those 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.

Since the battery voltage decreases with age and use, and also since the

meter and resistance values may be off somewhat, resistor R_2 is made adjustable. When you use such an ohmmeter, first touch the test prods together and adjust R_2 to produce a full-scale meter deflection. This gives an accurate zero ohms reading.

As the ohmmeter battery ages, its voltage drops, so R_2 must be readjusted from time to time to keep the zero setting accurate. 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 frequent.

By designing the ohmmeter for the rated battery voltage, manufacturers take advantage of the fact that new batteries have voltages somewhat higher than their ratings. Then the ohmmeter will read a few per cent high with fresh batteries, give exact readings when the batteries have aged a short time, and finally read increasingly lower as the battery voltage decreases. This keeps the ohmmeter reasonably accurate for a longer time than it would be if the circuit were designed for the voltage of fresh batteries.

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 and new batteries should be installed.

The ohmmeter is a very valuable instrument in maintenance and service work on electronic equipment in spite of the possibility of a small error in its readings. It is used extensively in laboratories as well as in servicing and maintenance work for making quick, though slightly inaccurate, measurements of resistance.

The ohmmeter we have been considering is known as the series type, so called because the battery, meter, and resistance are in series. This type can be easily recognized by the fact that 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 way ordinary meter scales run.

As it is in other instruments, the range of an ohmmeter is important. In electronic maintenance and 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.

Useful Range. Having made an ohmmeter using some particular meter and total resistance, what is its useful range? Suppose we are using a 1-ma. meter and a 3-volt battery. This means the sum of the resistances of the meter, R_1, and R_2 is 3000 ohms, permitting 1 ma. to flow. The meter will read mid-scale (half the current) when a resistance of 3000 ohms is being measured, for we will then have doubled the circuit resistance and still have the same voltage.
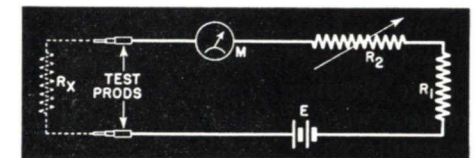

FIG. 24. This series ohmmeter is best for medium and high-resistance values.

In general, 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

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and lower values can be read on this scale, but only with difficulty. Actually, this range is probably readable up to about 500,000 ohms, and values of 10 ohms or so may be estimated.
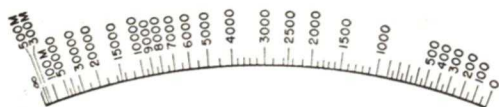
Fig. 25 shows a typical ohmmeter

FIG. 25. A typical series ohmmeter scale having a 3000-ohm center-scale value.

scale based on these values. At the high end of the scale, the current is primarily determined by the external resistance. When the external resistance gets large, adding more doesn't change the current much. Thus, a division that represents several thousand ohms at the high end of the scale may be no larger than one that represents only 50 ohms at the low end.

The series ohmmeter is excellent for medium and high ranges, but not for low ohmic values. For measuring low resistances, we can lower the series resistance, but, since the lowest normal battery voltage is 1.5 volts, this method is limited by the fact that there must be enough resistance in the circuit to prevent the current from exceeding the rating of the meter. By using high-current meters or shunts, or by using voltage dividing circuits to get lower voltages, we can obtain somewhat better results.

A ring-type shunt circuit, illustrated in Fig. 26, can be used to increase the ability of an ohmmeter to indicate low ohm values. Notice that the battery, the meter and its shunt R_D, and resistor R_C form an ordinary series ohmmeter when an unknown resistance is connected between the RES and R × 1000 terminals. One milliampere will flow through R_C when the leads are shorted and R_D, the zero or battery

adjustment, is varied until the meter reads full scale. R_A and R_B, though connected across the meter, will not shunt it because their resistance (4520 ohms) is much higher than the combined meter and shunt resistance (25 ohms). The center scale marking on this range is 4500 ohms.

However, when the unknown resistor is connected between RES and R × 10, the current limiting resistor is R_A; this makes the center scale reading about 45 ohms, which is 1/100 of the reading on the other scale. Resistor R_B is in series with the meter-shunt combination and serves to limit the current to the meter to a safe value.

As the battery voltage decreases, the value of the shunt resistance R_D must be increased to compensate. Notice, however, that even large variations in the value of this shunt resistor can
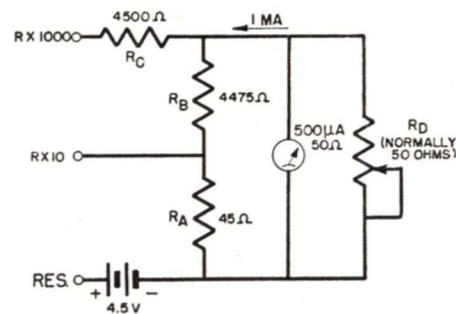

FIG. 26. How the ring-type shunt circuit can be used to increase the low-ohms sensitivity of an ohmmeter.

have very little effect on the total resistance in the circuit. Thus, the ohmmeter accuracy is relatively unaffected by large variations in battery voltage. This is a definite advantage.

One disadvantage of this circuit is the large current drain on the R × 10 scale. When the R × 10 and RES terminals are shorted, the current drain is 100 ma. This means shorter battery life. Also, since the current-limiting resistor in this section of the ohmmeter

is relatively small, a fairly large current will flow through any low-resistance device tested; occasionally this may damage the device.

Low-Range Ohmmeter. A shunt-type ohmmeter circuit, shown in Fig. 27, is also 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, because the unknown resistance R_X is connected in parallel with the meter and acts as a shunt across the meter. When the test leads are touched together (zero ohms), the meter will read zero at the extreme left of the scale.

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. To adjust a shunt meter to compensate for changes in battery voltage, keep the test leads apart and vary the knob controlling R until the meter indicates infinite resistance at the right-hand end of the scale.

This circuit is excellent for low resistances. If a low-resistance meter is used, 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 about 1473 ohms to limit the current to 1 ma. 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 re-

sistance 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, or from about .027 to 270 ohms.

High-Range Ohmmeters. As we said 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 recently, most instruments used 1-ma. meters, which require high-voltage 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.

Ordinary equipment therefore had ranges readable only up to 1 or 2 megohms. More sensitive meters have since become available, however, and recent instruments have a considerably extended upper range. Meters with 50- to 200-microampere ranges (.05 to .2 ma.) permit the construction of ohmmeters
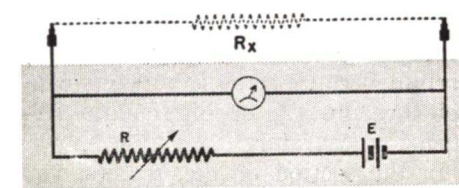
FIG. 27. This shunt ohmmeter is excellent for low-resistance values.

of 20- to 50-megohm ranges, using no more than 45 volts.

Even these meters aren't sensitive enough to measure small leakages in condensers or shielded cables. Meggers are used for this purpose. These are high-voltage devices with a hand-operated 500-volt generator and a special meter movement. Cranking the generator supplies the voltage for the resistance - measuring circuit. Resist-

ances up to thousands of megohms can be measured with this device.

In recent years, vacuum tube circuits have been developed that measure values over 1000 megohms. These have largely replaced meggers for measuring all but the very highest resistances.

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

When it is used to check circuit continuity, the ohmmeter is connected across the ends of the circuit in question. If the meter indicates the circuit is open, the various parts are individually checked. If a parallel path exists across any part that is to be checked, the part must be disconnected from the circuit before its resistance is measured; otherwise, the reading will be inaccurate.

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. This meter should always be turned off when it is not in use; otherwise, the battery will run down quickly.

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 generally is one of frequency; however, this difference is important because some a.c. meters cannot measure r.f. or high audio frequencies accurately.

In the section on d.c. meters, you learned 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.

Before we study the various types of a.c. meters, let us briefly review the relationships between the average, effective, and peak values of a sine-wave a.c., a half-wave rectified a.c., and a full-wave rectified a.c. These are shown in Fig. 28.

Notice that the *average* value of a sine-wave a.c. (Fig. 28A) is zero. However, when a.c. is connected across a resistor, heat will be produced; therefore, a.c. has an *effective* value even though its *average* value is zero. The value of a.c. voltage that will produce the same average heat effect as a given d.c. voltage is called the *effective* a.c. voltage (also called root-mean-square or r.m.s. value, because heat is proportional to the square of the instantaneous voltage or current). This *effective* value is .707 of the peak a.c. value, and, conversely, the *peak* is 1.41 of the *effective*. Thus, if the current in a circuit is 20 ma. r.m.s., the *peak* current is 28.2 ma.

Half-wave rectified a.c. (Fig. 28B) contains half-cycles that are all of the same polarity, so the *average* value differs from zero. This *average* value is about .32 of the *peak* value. Full-wave rectification (Fig. 28C) doubles the average value.

There are three classes of a.c. meters:

① The D'Arsonval d.c. meter with a vacuum-tube, selenium, 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 magnetic-vane and the electrodynamometer types.
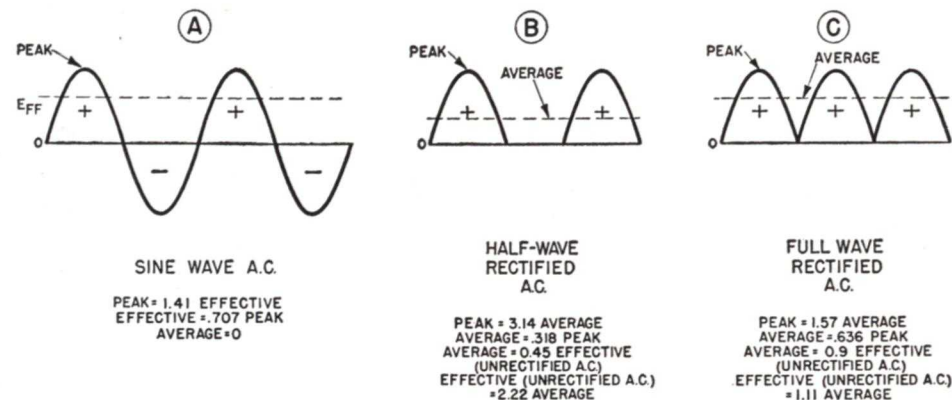

FIG. 28. The relationship between the average, effective and peak values of a sine wave, a half-wave rectified sine wave and a full-wave rectified sine wave.

Let's see how each kind of a.c. meter works, and where and why it is used.

CONVERSION DEVICES

Thermocouple. The need for a sensitive indicator for r.f. currents led to the development of the thermocouple. This device works on an interesting principle—the fact that when a junction 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. to d.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. Fig. 29 shows a typical arrangement. 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, 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 chosen to give the greatest d.c. voltage. The wire between 3 and A is often platinum; constantan is frequently used between 4 and A.

The current to be measured flows through the heater wire between terminals 1 and 2. The resulting heat is proportional to the power dissipated in the resistance of the heater, and

therefore proportional to the square of the current ($P = I^2R$). The temperature rise heats the thermocouple junction at A, producing a d.c. voltage that causes a d.c. current flow through the meter. Notice that this is a *produced* d.c. and is not the current being measured, which is usually a.c.

Since the heating of the junction is proportional to the square of the current, and the generated d.c. is proportional to the heating of the junction, the meter scale will also be proportional to the square of the current. This causes the scale to be crowded at the zero end and expanded at the full-scale end, a characteristic of the thermocouple instrument. The scale is called a "square law" scale. An example is shown in Fig. 30.

Because of the crowding at the zero end of the meter, a small error in the meter pointer position near this end produces a large error in current reading. For this reason, the FCC requires that the minimum normal indication of such a meter when used in a broadcast transmitter be on the upper two-thirds of the scale.

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
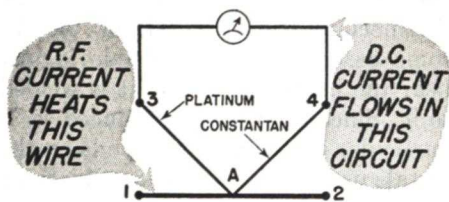

FIG. 29. The thermocouple is widely used for r.f. measurements.

this device. In each case, the effective, or root-mean-square, value of the wave form is indicated. In fact, the thermocouple is practically a standard r.f. current meter. The resistance wire is made in the form of a hollow tube to

eliminate skin effect* 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
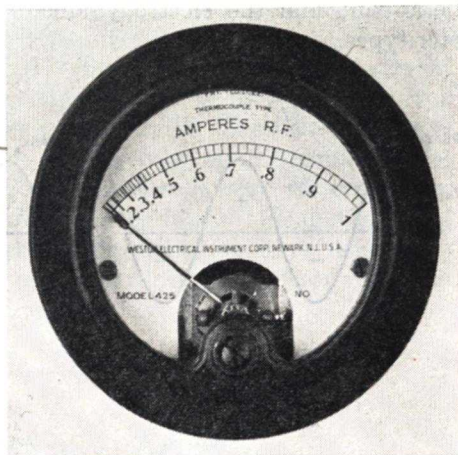
Courtesy Weston Electrical Instrument Corp.
FIG. 30. A typical "square law" scale of a thermocouple meter.

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, because currents must frequently be measured in hard-to-reach places, such as in a transmission line, a transmitter tank circuit, or an antenna installation. It is impossible to run r.f. currents over long leads to a more convenient meter location without upsetting the circuit.

*Skin effect is the tendency of high-frequency currents to flow on the surface instead of through the center of the wire. This appears to make the resistance of the wire depend on the frequency of the current flowing through it. Eliminating the center of the wire makes any current flow along the surface, regardless of its frequency, so the resistance of the wire remains constant.

Therefore, the thermocouple and heater unit is 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. 31. These feeder lines may be several hundred feet long or longer if the thermocouple and meter are initially calibrated with a resistance simulating the feeder line in the circuit.

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 to a circuit where one terminal of the heater is grounded, the filter probably would not be required. If the line to the meter passes through any r.f. fields, it may pick up some r.f. energy that could cause an undesired current through the meter. To avoid such pick-up, the lines are generally made of shielded wire or are placed in metal conduit. Another condenser (or a pair connected like C_1 and C_2) may be connected directly across the meter terminals to by-pass any r.f. picked up in the lines.

Thermocouple meters are calibrated by passing known currents through the heater element. These currents are usually d.c. or low-frequency a.c. when
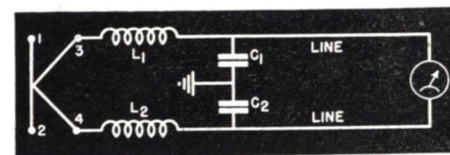

FIG. 31. The thermocouple permits remote meter readings.

the meter is to be used in r.f. circuits not requiring a high degree of accuracy. In antenna and transmission line circuits, where a high degree of accuracy is required, the meters are calibrated at the frequency at which they are to be used.

A D'Arsonval movement for ther-

mocouple instruments has been developed that has a decreasing sensitivity with increasing reading. This is known as an "expanded scale" r.f. meter; its purpose is to reduce the crowding of the scale near the zero end
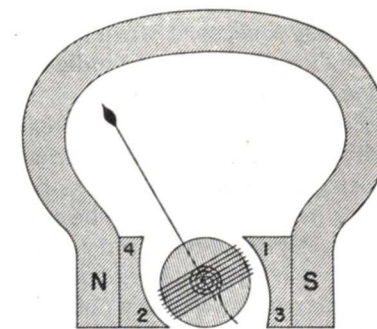

FIG. 32. Using pole pieces having a special shape produces a non-uniform magnetic field for an "expanded scale" meter.

and increase the usable range of the meter.

The principle of the construction of the expanded scale meter is shown in Fig. 32. The pole faces have a shape that creates a non-uniform field between them. The effect of this construction is to make the meter coil deflect relatively more for small currents than for large ones; thus, the scale of the meter becomes more nearly 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. The amount of light obtained from an electric light bulb varies according to the amount of current flow through the bulb. If we connect a photovoltaic cell to a meter and expose 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 cali-

brate the meter in terms of the current flow through the bulb. The bulb can then be connected in the circuit carrying the current, and the photocell-meter used to indicate the current. This method, which is seldom used except in experimental work, is not very accurate—it is more useful to indicate when changes occur or when maximum current flows than it is to indicate the exact amount of current.

A simple meter of this type can be rigged up using a suitable lamp and a photoelectric exposure meter as the indicating instrument. It will be surprisingly effective as a temporary or emergency device for adjusting transmitter circuits to resonance. It is not suitable for use as a neutralizing indicator, however, because the lamp will be insensitive through the minimum current region.

TRUE A.C. METER MOVEMENTS

As you know, 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 retains the same polarity. If we can arrange the meter so both magnetic fields reverse simultaneously when the a.c. reverses, 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 differs basically from the D'Arsonval movement. Instead of using a fixed magnet and a moving coil, the magnetic-vane meter contains a fixed coil and a movable iron vane.

One type is shown in Fig. 33A. 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.
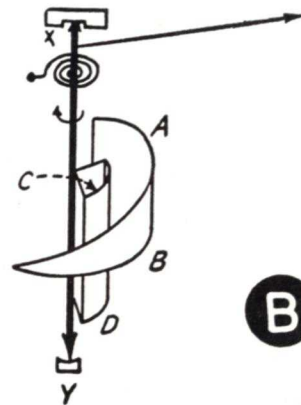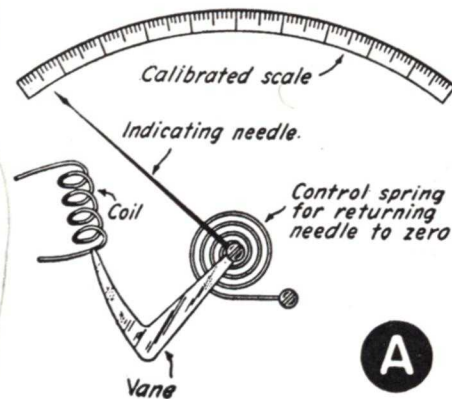
FIG. 33. Here are two common types of magnetic-vane movements.

net 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.

Fig. 33B 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.

When current flows through the coil, both pieces of iron are magnetized. Since 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 polarities 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.

Several other types of magnetic-vane movements have been developed. 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 impractical 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. Fig. 34 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 propor-
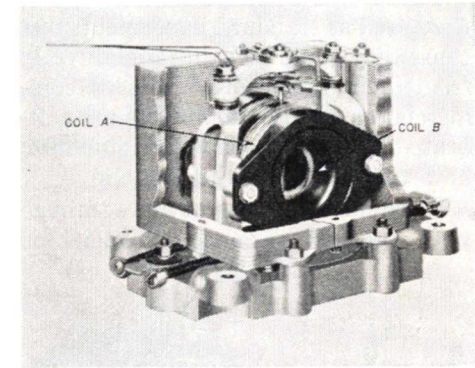
Courtesy Weston Electrical Instrument Corp.
FIG. 34. This electrodynamometer does not use a permanent magnet.

tional 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 a spring.

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 for either a.c. or d.c.

The moving coil tends to waver back and forth before settling down to the correct reading, just as it does in other meter movements. This wavering is damped mechanically by a vane attached to the moving coil that rotates in a closed chamber known as a damper box. When the coil moves, the vane also moves, compressing the air ahead of it in the box. The compressed air

26

27

acts as a cushion, so the pointer comes slowly to the correct reading and stops.

Because of the inductive effects of the coil windings, the frequency ranges of such meters are limited unless special constructions are used. The usual types hold their calibration for frequencies up to 130 cycles. However, precision meters of this type have been developed that have an accuracy of ±½% over a range of frequencies from 25 to 2500 cycles.

The original electrodynamometers were used as standard instruments, because they could be calibrated directly from their dimensions. Modern commercial electrodynamometers are calibrated by comparison with a standard, however, just like other meters.

Since the same current flows through both the series-connected coils, and
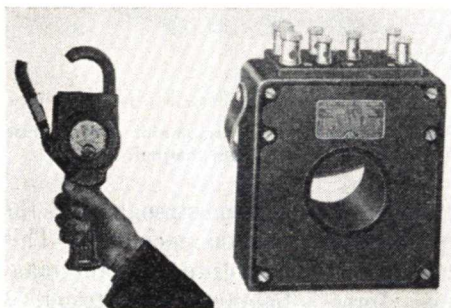
Courtesy Weston Electrical Instrument Corp.
FIG. 35. Current transformers. The core of the one at the left is snapped around the current-carrying wire. The one at the right is installed permanently, passing the power line through the center. These transformers are usually used on high-current power lines, where currents of 25 amperes to thousands of amperes are to be measured.

since 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 (r.m.s.) value. The alternating current need not be a sine wave; an electrodynamometer can be used to measure the effective value of a current of any wave shape. 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 for both d.c. and a.c.

Large currents cannot be measured easily with an electrodynamometer, because the moving coil cannot be made of very large wire or have heavy leads. 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. current according to the ratio of turns on the primary and secondary windings. Therefore, a practical way of measuring a large current is to step it down with a current transformer in which a large primary current flow will result in a small secondary current that 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 used in power generating stations, sub-stations, electric locomotives, and similar equipment to measure large currents of power-line frequencies. Currents up to thousands of amperes are measured in this way. Typical transformers are shown in Fig. 35.

In Fig. 35 the instrument at the left contains both the transformer and meter and is used by maintenance men and inspectors to check the current in lines. The U-shaped piece at the top that snaps around the wire is the core of the current transformer.

The current transformer at the right is used with portable ammeters designed for it. This type is used in temporary and experimental applications where power line currents are being

measured. Another type of current transformer not shown looks just like a commercial power transformer; it is installed in conjunction with an ammeter for permanent installations such as power switchboards.

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.

Current transformers with iron cores are not used in r.f. circuits or in circuits having frequencies of over 30 kc. or so.

In r.f. circuits a current transformer is sometimes made by loosely coupling a single turn of wire to a tank circuit and connecting a thermocouple in the single turn loop. This kind of current meter cannot be permanently and accurately calibrated in terms of current, but it gives a useful indication of maximum, minimum, or ratio of current. This current meter in its simplest form is used by amateurs and experimenters with a small incandescent lamp replacing the meter; in this form, it is called a pickup loop or resonance indicator. When coupled to a transmitter tank circuit, the bulb lights, and resonance of the circuit can be judged by the relative brilliance of the lamp as the circuit is tuned.

Measuring A. C. Voltages

All the different types of alternating current movements can be, and are, used as the basic movements of alternating current and direct current voltmeters. Thermocouple, moving vane, and electrodynamometer movements are commonly used. In addition, copper-oxide rectifiers in conjunction with D'Arsonval movements are commonly used in portable maintenance and service instruments and in small panel instruments. Vacuum tube voltmeters are also used for a.c. voltage measurements; these will be studied elsewhere in your Course.

Thermocouple Voltmeters. These are constructed by connecting a non-inductive resistance in series with a very sensitive vacuum thermocouple. The operation of the combination is similar to that of a d.c. voltmeter using a sensitive D'Arsonval movement. The sensitive thermocouple voltmeters are used extensively in laboratories and by telephone companies in measuring a.f. and r.f. voltages in the medium-fre-

quency range—to about 3 mc.

Thermocouple voltmeters require a sensitive instrument that will give full-scale deflection at very low currents, just as d.c. voltmeters do. However, thermocouples that will operate on very low current are difficult to manufacture. The most sensitive thermocouple meters commercially available require at least 5 ma. to 10 ma. for full-scale deflection; since these would impose a severe load on high-impedance a.f. and r.f. circuits, the instrument cannot be used in such circuits.

Moving Vane Voltmeters. These voltmeters are constructed on the same principles as the moving vane current meters, except that the field coils are wound with many turns of resistance wire to make up the resistance the voltmeter must have. These voltmeters have the same accuracy characteristics as the current meters and are found only in inexpensive meters.

Electrodynamometer Voltmeters.

The electrodynamometer voltmeter is the type most commonly used to measure alternating voltages of power line frequencies. The a.c. voltmeters on radio transmitters and other electronic apparatus of good quality are of this type. The instrument is capable of great accuracy and stability of calibration, an attribute not shared by any
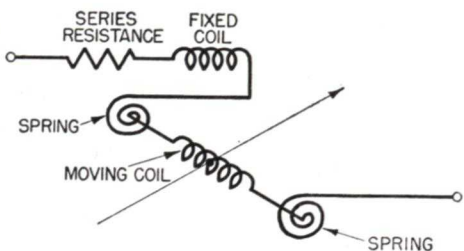

FIG. 36. Schematic diagram of an electrodynamometer voltmeter.

of the other types. The electrodynamometer voltmeter is constructed exactly like the current meter, except that the coils are of many turns of fine wire, and a noninductive resistor is connected in series with the fixed and moving coils as in other voltmeters. Fig. 36 shows a schematic diagram of the voltmeter.

Fig. 37 shows a portable voltmeter of the electrodynamometer type. This voltmeter has an accuracy of ±¼% and may be used to measure a.c. up to 2500 cycles. Notice that it has two scales, 0-150 volts and 0-300 volts, and can measure d.c. as well as a.c.

A.C. VOLTMETERS USING COPPER-OXIDE RECTIFIERS

The D'Arsonval meter and copper-oxide rectifier combination is the most widely used a.c. measuring device. It is found in some of the panel type a.c. voltmeters and in most multimeters and volt-ohmmeters capable of measuring a.c. voltages. The copper-oxide rectifier is stable, relatively reason-

able in cost, and can be designed to work on small currents.

Each rectifier element consists of a copper disc or washer that has one surface oxidized by a special heat treatment. A contact is pressed against the oxide layer.

Rectification takes place at the interface between the copper and copper-oxide layers of the washer. This interface rectifies because it permits current flow from the oxide to the copper much more readily than from the copper to the oxide. In other words, electrons can move easily from the copper through the oxide to the 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; the most

Courtesy Weston Electrical Instrument Corp.
FIG. 37. A Weston Model 341 electrodynamometer voltmeter suitable for precise measurements.

common is the full-wave bridge circuit shown in Fig. 38. Four separate elements are used in the bridge.

The arrows alongside the elements in Fig. 38 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
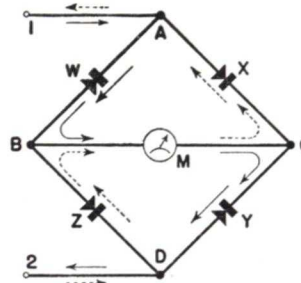

FIG. 38. The copper-oxide rectifier in a bridge is the most common rectifier for a.c. instruments.

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. Notice 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 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 a.c., so that our meter has an a.c. sensitivity almost as good as that on d.c.

If one element 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 read only 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. voltage; if the reading is half what it should be, one element 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, in which the "backs" are connected together as shown in Fig. 39. 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.)
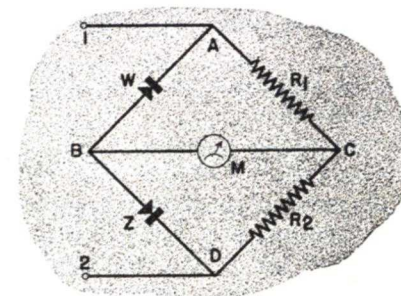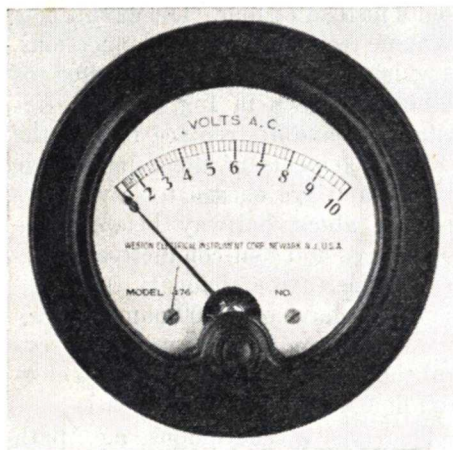
There is a continuous a.c. path

FIG. 39. The back-to-back bridge saves two rectifier elements.

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 is an electron flow through this rectifier to point B. Rectifier Z opposes current flow by having more re-

sistance 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.

Because of the non-linearity of the rectifying action of copper-oxide rectifiers, the scales of these meters are non-linear. An example is shown in Fig. 40.

To extend the a.c. voltage range of rectifier type meters, series resistances are added just as with d.c. voltmeters. Increasing the series resistance of a copper-oxide rectifier voltmeter improves its linearity.

Shunts are not used across the meter terminals of copper-oxide rectifier type meters to increase current ranges as they are with d.c. meters. If they were, the rectifier elements would have to be overloaded in order to bring the

Courtesy Weston Electrical Instrument Corp.
FIG. 40. The meter scale of a 0-10 volt a.c. meter using copper-oxide rectifiers.

D'Arsonval meter movement up to a full-scale reading, and would probably be damaged. The current range can be extended by connecting shunts across the input terminals to the rectifier.

Copper-oxide rectifier instruments are not commonly used in a.c. current measurements because of temperature effects on their accuracy.

Copper-oxide rectifiers have two chief faults: (1) they have a high shunting capacitance between terminals; and (2) their accuracy is affected by high temperatures.

Copper-oxide rectifiers are designed to withstand an overload considerably greater than the full-scale capacity of their meter movement, so it is seldom that they are damaged before the meter unit is damaged. They may, however, be damaged by overheating by the soldering iron during installation if care is not exercised.

The high self-capacitance limits the copper-oxide rectifier meter to power line and audio-frequency voltage measurements. With increase in frequency, the capacity acts as a decreasing shunt reactance around the rectifier so that a greater and greater portion of the current is by-passed around the rectifier. The result is the same as if the meter were shunted. Meter manufacturers make copper-oxide rectifiers small to minimize frequency effects.

The capacitance between the elements of normal copper-oxide rectifiers is such that the meters read low by approximately ½ of 1% for each 1000 cycles of frequency. Thus at 10,000 cycles the meter readings will be about 5% low, which is reasonably accurate. Above that frequency, allowance should be made for the frequency error. For example, at 50 kc., the meter readings will be 25% low (½ × 50). Thus any reading at that frequency indicates 75% of the actual voltage present—for example, a 131-volt reading

obtained at 50 kc. means that the voltage is actually 175 volts.

The capacitance does not *prevent* the use of the meter at much higher frequencies, it just causes the meter to be inaccurate.

For special purposes, copper-oxide voltmeters have been manufactured that have no frequency error up to 100 kilocycles. These are special instruments and are not practical for the ordinary applications of power line voltmeters, VU meters, and multimeters with which we are concerned.

A very important application of the copper-oxide rectifier type meter in broadcasting stations and other places where power levels of audio-frequency voltages are being measured is in the VU (Volume Unit) meter. The copper-oxide units in these meters are carefully selected for thermal, frequency, and sensitivity characteristics to insure accuracy and stability.

The effect of temperature on the accuracy of copper-oxide meters is very great. If the meter is located in a position where it is warmed by other apparatus such as resistors or vacuum tubes to a temperature of 140° F., the meter may read low by as much as 30 volts out of 150 volts; this is an error of 20%. For this reason, care should be exercised to place these meters in cool positions and to allow for the effects of temperature if they are in a warm location.

► It is possible to use vacuum tube rectifiers in place of copper-oxide rectifiers in an a.c. voltmeter. Such meters will be discussed in a later Lesson.

POTENTIAL TRANSFORMER

To measure very high a.c. voltages, such as are used on power transmission lines, the voltage is reduced with a step-down transformer called a "potential transformer" to a suitably low value, generally between 100 and 500 volts. The primary of the potential transformer is connected to the power line and the secondary is connected to a low-voltage a.c. voltmeter of any type. The voltage can be found by multiplying the voltmeter reading by the step-down ratio of the transformer.

The advantage of this system is that the voltage applied to the meter is low, and one terminal of the meter can be grounded for the protection of personnel. If the phase voltages of polyphase systems were measured directly without the use of potential transformers, it would be impossible to ground one terminal of the voltmeter being used. As you can see, this method of measuring high-voltage a.c. is similar in principle to the method previously described for measuring high-current a.c. with current transformers.

Measuring Power

The amount of power being taken at any *instant* of time is the product of the *instantaneous* voltage and the *instantaneous* current. Of course, meters don't measure the instantaneous values—they are too slow-acting. Therefore, the simple formula $P = I \times E$ holds true only on dc, where the instantaneous value doesn't change and

is the meter reading, or in ac circuits containing a resistive load, where the phase and rms values permit the determination of power this way. When the load is reactive, we cannot obtain the *true* power by multiplying the I and E meter readings, because of the phase shift.

Therefore, the product $I \times E$ is

called the *apparent* power, and it must be multiplied by a term called the "power factor" to determine the true power. (The *true* power = I × E × pf.) When the source is dc, or in an ac circuit that is resistive, the power factor is 1, so the apparent and true powers are equal. When the circuit contains a reactance, the phase shift causes the power factor to be less than 1, so the *apparent* power (I × E) is greater than the *true* power.

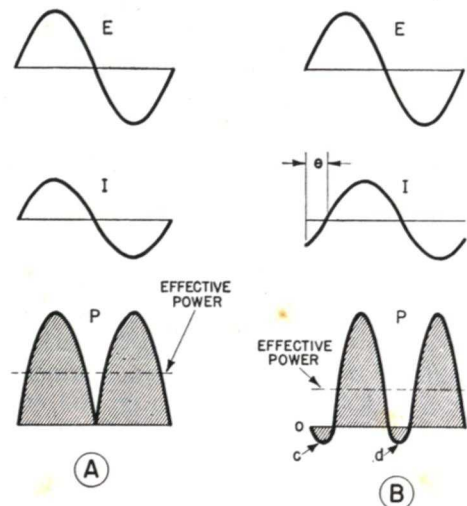Let us see why this is so. In Fig. 41A are shown the voltage (E), current

FIG. 41. These curves show the relationship between E, I, and effective, or true, power in a resistive circuit A, and a reactive circuit B. Notice that the effective power in the reactive circuit is less than that in the resistive circuit.

(I), and power (P) of a resistive load when an a.c. is applied. Notice that the power at any instant equals the product of E and I at that time. The average area under curve P during the entire cycle represents the power dissipated, which, in this case, equals the product of E and I.

However, consider Fig. 41B. Notice that the amplitude of E and I is the same as before but that there is now a phase difference (φ) of 45° between them. Again, the power P at any in-

stant is equal to E × I at that time; notice, however, that the *effective* power over a cycle is much less than before. (This is true because all the power is not dissipated in the load; during the intervals marked c and d, in fact, the load is actually returning power to the source.) Clearly, then, the effective a.c. power in a reactive load is not equal to E × I but also depends on the power factor as well. Special power meters that take power factor into account are needed to measure true a.c. power.

The electrodynamometer is generally used as a wattmeter to indicate the amount of power in a load. As shown in Fig. 42, the line current passes through the stationary, or current coil, which is a few turns of heavy wire. The rotating, or voltage, coil, made of many turns of fine wire, is connected across the line. The deflection of the pointer at any time is proportional to the product of the magnetic fields of these two coils; therefore, it indicates the true power at all times.

When the instrument is used to measure a.c. power, the pointer will not be able to follow the variations in the power curves of Figs. 41A and 41B, but it will indicate the effective power for the entire cycle. When the load is reactive, the pointer will still indicate the true power in the circuit. Notice that an electrodynamometer can also be used to measure the power in a d.c. circuit.

There are some precautions that must be observed in using wattmeters. The most important is not to overload the current and voltage coils. Since a wattmeter measures the *product* of current and voltage, it is possible, if the line voltage is very low, to overload the current coil without making the meter read off-scale. For instance, suppose a wattmeter is designed to be used with line voltages of up to 150

volts and line currents of up to 10 amperes maximum and has a 0-1000 watt scale. If we connect it to a 110-volt line in which 9 amperes are flowing, the wattmeter will read 990 watts and neither the voltage nor the current coil will be overloaded.

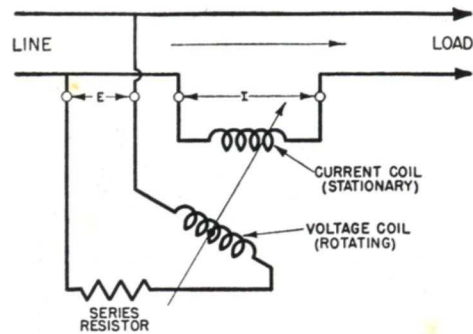If, instead, we connect the meter to a

FIG. 42. Diagram of an electrodynamometer wattmeter. Notice that the current coil is connected in series with one line like an ammeter and the voltage coil is connected across the line like a voltmeter.

32-volt power line in which 20 amperes are flowing, the meter will read only 640 watts—well within the meter range—but the current coil will be 100% overloaded and probably damaged. The voltage and current coils of all wattmeters are given maximum ratings. These must be observed or the instrument may be damaged.

In connecting a wattmeter, care must be taken not to connect the voltage to the current terminals and vice versa. Most instruments provide different types of terminals for the voltage and current connections to make it easy to avoid wrong connections. If the wrong connections are made, the instrument will be ruined and the line fuses will be blown the instant the power is turned on.

There are special wattmeters for measuring polyphase power. They consist essentially of two wattmeters connected to a common shaft so that

the readings will add. These meters are expensive and used only when the application justifies the expense.

In laboratories and other places where an occasional measurement of three-phase power is required, the two-wattmeter method of measuring power is generally used. Three-phase power can be readily measured by properly connecting two single-phase wattmeters in the lines as shown in Fig. 43 and adding their readings. Strict observance of connections must be practiced for dependable measurements. Under conditions of unbalanced loads and reactive loads, one of the three-phase circuits may be absorbing power and sending it back to the generating station, causing the wattmeter to read backwards in that circuit. This constitutes a negative power reading. If the meter is properly connected, its direction of reading is changed by means of a switch on the instrument, and then its reading is subtracted from the other meter reading.

MULTIMETERS

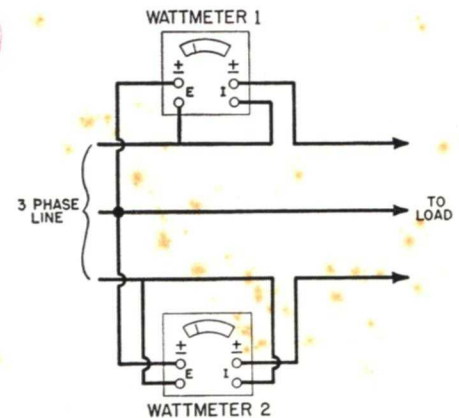As you have noticed, the same meter

FIG. 43. Method of connecting two wattmeters to measure three-phase power.

unit can be used to make d.c. voltage and current measurements, a.c. volt-

age measurements, and resistance measurements. All that is required in addition to the meter unit are resistors for shunts and multipliers and switches to connect the combinations in the right way for the voltage, current, or resistance to be measured. Since the resistors and other apparatus are small in size, and switching circuits are simple, it is possible to construct an instrument called a multimeter that uses one meter and will measure most electrical quantities. These instruments are also called volt-ohm meters, volt-ohm-milliammeters, testers, and multi-testers.

Multimeters are available in many different shapes, sizes, and combinations of measuring ranges. Some contain an extra-sensitive meter that requires only 50 or 100 microamperes for full-scale deflection. These instruments thus have voltmeters with resistances of 20,000 or 10,000 ohms-per-volt, and cause a minimum disturbance when measurements are made on an operating circuit. These instruments are also capable of measuring very high resistances, up to 30 megohms, because of their high sensitivities. These high-sensitivity multimeters are particularly useful in servicing and laboratory work where measurements must be made on high-resistance and high-impedance circuits in which the resistance of a less sensitive voltmeter would disrupt the operation of the circuit.

Typically, a multimeter is completely contained in a small case designed for portability. It has two flexible leads about three feet long, with sharp-pointed prods on the end, to connect the meter to the circuit under test. The other ends of the test leads terminate in small plugs that are plugged into the multimeter. Switching meter ranges and functions is accomplished by plugging the test leads into different sets of pin jacks, by using a selector switch, or by operating push buttons.

For general maintenance and trouble-shooting work on transmitters, such as you will be concerned with, an instrument like the Weston Model 697 Volt-Ohm-Milliammeter (Fig. 44) is

Courtesy Weston Electrical Instrument Corp.
FIG. 44. Weston Model 697 Volt-Ohm-Milliammeter.

satisfactory. It has all the essential voltage, current, and resistance scales, yet it is light enough to be held in one hand while using the other to manipulate the test probes, and small enough to be slipped in a pocket for easy carrying. The meter movement, which is about 0-1 milliampere, is accurate enough for the measurements you will make and is more rugged than the more sensitive types.

Lesson Questions

1. In calibrating a d.c. ammeter against a standard d.c. ammeter, will the fact that the two meters have a different value of d.c. resistance affect the calibration?

2. In what three ways may the meters in a transmitter be protected against damage caused by stray r.f. energy?

3. How much current is required to produce full scale deflection of the meter in a "1000 ohms-per-volt" d.c. voltmeter?

4. If a series ohmmeter consists of a 4.5-volt battery, a 50-ma. d.c. meter, and the meter and the current-limiting resistor total 90 ohms, what value of external resistance will cause a mid-scale deflection?

5. If the effective value of a sine-wave current is 12 ma., what is its average value; its peak value?

6. Which of the following types of meters may be used to measure r.f. currents: (a) moving coil, (b) moving vane, or (c) thermocouple?

7. In measuring the effective value of an a.c. voltage known not to be a sine wave, would you use (a) an electrodynamometer, (b) a copper-oxide rectifier type a.c. meter, or (c) a D'Arsonval meter?

8. What is the probable trouble if a bridge type copper-oxide rectifier voltmeter reads about 60 volts when measuring a 110-115 volt a.c. line?

9. Will multiplying the a.c. voltage across a load by the a.c. current flowing through the load give you (a) power factor, (b) apparent power, or (c) true power?

10. Draw a three-phase circuit using the least number of single-phase wattmeters needed to indicate the power that is being taken from the source.

DIG A LITTLE DEEPER

A poor Boer farmer struggled for years to gain a living out of his rocky South African soil, then finally gave up in despair and sought his fortune elsewhere. Years later, coming back to his old farm, he found it swarming with machinery and people. More wealth was being dug out of his rocky old farm every day than he had ever dreamed existed. His farm had become the great Kimberley diamond mine.

Many of us struggle along just like that poor Boer farmer, never dreaming that success could be ours if we dug a little deeper right where we are. Millions of men are just barely getting along today, when they have the ability to do much better things, simply because they lack confidence in themselves. They are victims of mental defeat; they don't believe they can do anything better.

If *you* lack self-confidence—if you lack a sense of mastership, a consciousness of power, and a victorious mental attitude, begin now to cultivate self-confidence. How? Make your decisions with confidence and speed, and stick to them. Dig into your work a little harder, keep going a little longer, and soon you'll have the self-confidence which carries you speedily to success.

                                        J. E. SMITH