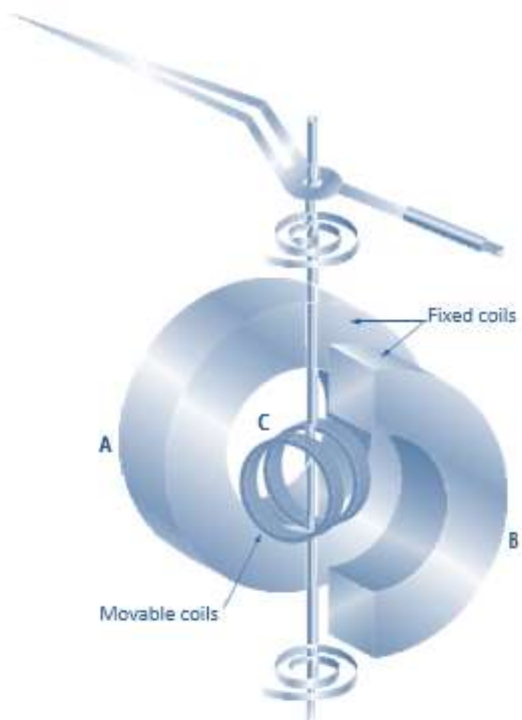
AC, DC Circuits, Voltmeter



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AC Circuits

Ohm's Law for AC Circuits

The rules and equations for DC circuits apply to AC circuits only when the circuits contain resistance alone, as in the case of lamps and heating elements. In order to use effective values of voltage and current in AC circuits, the effect of inductance and capacitance with resistance must be considered.

The combined effects of resistance, inductive reactance, and capacitive reactance make up the total opposition to current flow in an AC circuit. This total opposition is called impedance and is represented by the letter Z. The unit for the measurement of impedance is the ohm.

Series AC Circuits

If an AC circuit consists of resistance only, the value of the impedance is the same as the resistance, and Ohm's law for an AC circuit, I = E/ Z, is exactly the same as for a DC circuit. In Figure 10-126 a series circuit containing a lamp with 11 ohms resistance connected across a source is illustrated. To find how much current will flow if 110 volts DC is applied and how much current will flow if 110 volts AC are applied, the following examples are solved:

$$I = \frac{E}{R} \qquad I = \frac{E}{Z} \text{ (where Z = R)}$$

$$I = \frac{110V}{11W} \qquad I = \frac{110V}{11W}$$

$$I = 10 \text{ amperes DC} \qquad I = 10 \text{ amperes AC}$$

When AC circuits contain resistance and either inductance or capacitance, the impedance, Z, is not the same as the resistance, R. The impedance of a circuit is the circuit's total opposition to the flow of current. In an AC circuit, this opposition consists of resistance and reactance, either inductive or capacitive or elements of both.

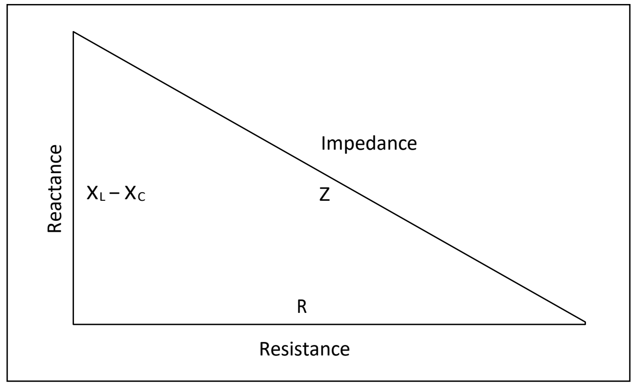

Figure 10-127. Impedance triangle.

Resistance and reactance cannot be added directly, but they can be considered as two forces acting at right angles to each other. Thus, the relation between resistance, reactance, and impedance may be illustrated by a right triangle. [Figure 10-127]

Since these quantities may be related to the sides of a right triangle, the formula for finding the impedance, or total opposition to current flow in an AC circuit, can be found by using the law of right triangles. This theorem, called the Pythagorean theorem, applies to any right triangle. It states that the square of the hypotenuse is equal to the sum of the squares of the other two sides. Thus, the value of any side of a right triangle can be found if the other two sides are known. If an AC circuit contains resistance and inductance, as shown in Figure 10-128, the relation between the sides can be stated as:

$$Z^2 = R^2 + X_L^2$$

The square root of both sides of the equation gives

$$Z = \sqrt{R^2 + X_L^2}$$

This formula can be used to determine the impedance when the values of inductive reactance and resistance are known. It can be modified to solve for impedance in

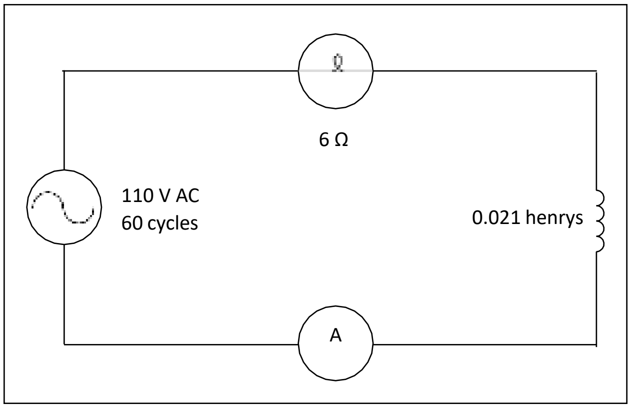

Figure 10-128. A circuit containing resistance and inductance.

circuits containing capacitive reactance and resistance by substituting X_C in the formula in place of X_L. In circuits containing resistance with both inductive and capacitive reactance, the reactances can be combined, but because their effects in the circuit are exactly opposite, they are combined by subtraction:

$X = X_L - X_C$ or $X = X_C - X_L$ (the smaller number is always subtracted from the larger).

In Figure 10-128, a series circuit consisting of resistance and inductance connected in series is connected to a source of 110 volts at 60 cycles per second. The resistive element is a lamp with 6 ohms resistance, and the inductive element is a coil with an inductance of 0.021 henry. What is the value of the impedance and the current through the lamp and the coil?

Solution:
First, the inductive reactance of the coil is computed:

$X_L = 2\pi \times f \times L$
$X_L = 6.28 \times 60 \times 0.021$
$X_L = 8$ ohms inductive reactance

Next, the total impedance is computed:

$Z = \sqrt{R^2 + X_L^2}$
$Z = \sqrt{6^2 + 8^2}$
$Z = \sqrt{36 + 64}$
$Z = \sqrt{100}$
$Z = 10$ ohms impedance

Then the current flow,

$I = \dfrac{E}{Z}$
$I = \dfrac{110}{10}$
$I = 11$ amperes current

The voltage drop across the resistance (E^R) is

$E^R = I \times R$
$E^R = 11 \times 6 = 66$ volts

The voltage drop across the inductance (E_{XL}) is

$E_{XL} = I \times X_L$
$E_{XL} = 11 \times 8 = 88$ volts

The sum of the two voltages is greater than the impressed voltage. This results from the fact that the two voltages are out of phase and, as such, represent the maximum voltage. If the voltage in the circuit is measured by a voltmeter, it will be approximately 110 volts, the impressed voltage. This can be proved by the equation,

$E = \sqrt{(E_R)^2 + (E_{XL})^2}$
$E = \sqrt{66^2 + 88^2}$
$E = \sqrt{4356 + 7744}$
$E = \sqrt{12100}$
$E = 110$ volts

In Figure 10-129, a series circuit is illustrated in which a capacitor of 200 μf is connected in series with a 10 ohm lamp. What is the value of the impedance, the current flow, and the voltage drop across the lamp?

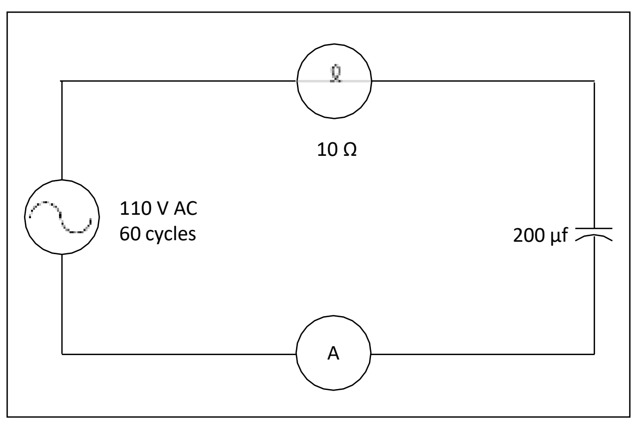

Figure 10-129. A circuit containing resistance and capacitance.

Solution:

First the capacitance is changed from microfarads to farads. Since 1 million microfarads equal 1 farad, then

$$200\ \mu f. = \frac{200}{1{,}000{,}000} = 0.000200 \text{ farads}$$

$$X_C = \frac{1}{2\pi f C}$$

$$X_C = \frac{1}{6.28 \times 60 \times 0.00200 \text{ farads}}$$

$$X_C = \frac{1}{0.07536}$$

X_C = 13 ohms capacitive reactance

To find the impedance,

$$Z = \sqrt{R^2 + X_C{}^2}$$
$$Z = \sqrt{10^2 + 13^2}$$
$$Z = \sqrt{100 + 169}$$
$$Z = \sqrt{269}$$

Z = 16.4 ohms capacitive reactance

To find the current,

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

$$I = \frac{110}{16.4}$$

I = 6.7 amperes

The voltage drop across the lamp (E^R) is

$$E^R = 6.7 \times 10$$
$$E^R = 67 \text{ volts}$$

The voltage drop across the capacitor (E_{XC}) is

$$E_{XC} = I \times X_C$$
$$E_{XC} = 6.7 \times 13$$
$$E_{XC} = 86.1 \text{ volts}$$

The sum of these two voltages does not equal the applied voltage, since the current leads the voltage. To find the applied voltage,

the formula $E_T = \sqrt{(E_R)^2 + (E_{XC})^2}$ is used.

$$E_T = \sqrt{67^2 + 86.1^2}$$
$$E_T = \sqrt{4489 + 7413}$$
$$E_T = \sqrt{11902}$$
$$E_T = 110 \text{ volts}$$

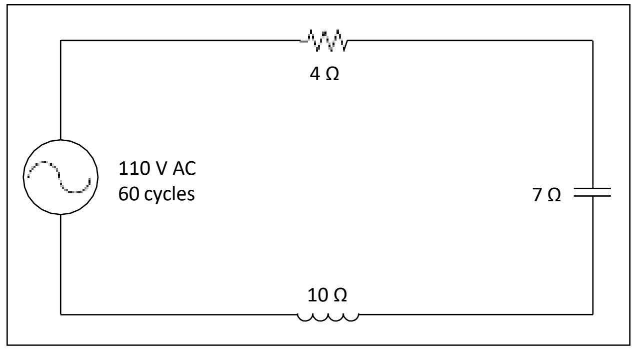

Figure 10-130. A circuit containing resistance, inductance, and capacitance.

When the circuit contains resistance, inductance, and capacitance, the equation

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

is used to find the impedance.

Example: What is the impedance of a series circuit, consisting of a capacitor with a reactance of 7 ohms, an inductor with a reactance of 10 ohms, and a resistor with a resistance of 4 ohms? [Figure 10-130]

Solution:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$Z = \sqrt{4^2 + (10 - 7)^2}$$
$$Z = \sqrt{4^2 + 3^2}$$
$$Z = \sqrt{25}$$

Z = 5 ohms

Assuming that the reactance of the capacitor is 10 ohms and the reactance of the inductor is 7 ohms, then X_C is greater than X_L. Thus,

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$Z = \sqrt{4^2 + (7 - 10)^2}$$
$$Z = \sqrt{4^2 + (-3)^2}$$
$$Z = \sqrt{16 + 9}$$
$$Z = \sqrt{25}$$

Z = 5 ohms

Parallel AC Circuits

The methods used in solving parallel AC circuit problems are basically the same as those used for series AC circuits. Out of phase voltages and currents can be added by using the law of right triangles. However, in solving circuit problems, the currents through the branches are added since the voltage drops across the various branches are the same and are equal to

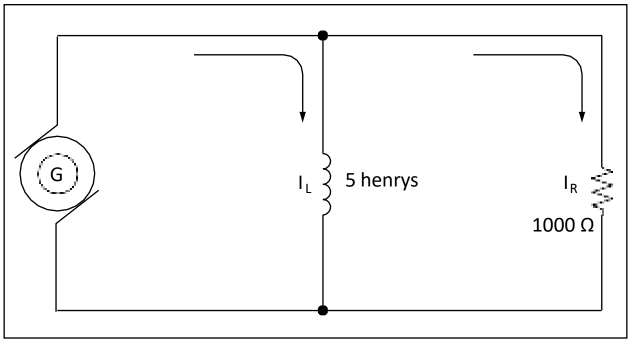

Figure 10-131. AC parallel circuit containing inductance and resistance.

the applied voltage. In Figure 10-131, a parallel AC circuit containing an inductance and a resistance is shown schematically. The current flowing through the inductance, I_L, is 0.0584 ampere, and the current flowing through the resistance is 0.11 ampere. What is the total current in the circuit?

Solution:

$$I_T = \sqrt{I_L{}^2 + I_R{}^2}$$
$$= \sqrt{(0.0584)^2 + (0.11)^2}$$
$$= \sqrt{0.0155}$$
$$= 0.1245 \text{ ampere}$$

Since inductive reactance causes voltage to lead the current, the total current, which contains a component of inductive current, lags the applied voltage. If the current and voltages are plotted, the angle between the two, called the phase angle, illustrates the amount the current lags the voltage.

In Figure 10-132, a 110-volt generator is connected to a load consisting of a 2 µf capacitance and a 10,000-ohm resistance in parallel. What is the value of the impedance and total current flow?

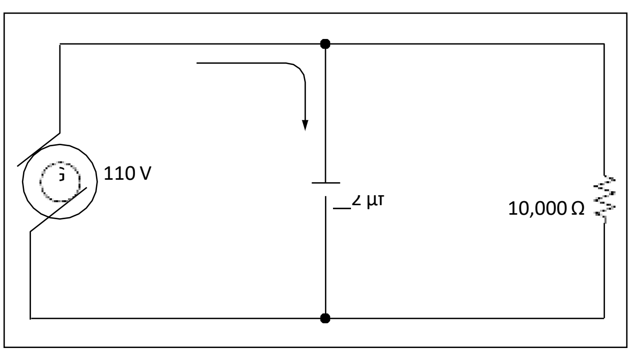

Figure 10-132. A parallel AC circuit containing capacitance and resistance.

Solution:

First, find the capacitive reactance of the circuit:

$$X_C = \frac{1}{2\pi f C}$$

Changing 2 µf to farads and entering the values into the formula given:

$$= \frac{1}{2 \times 3.14 \times 60 \times 0.000002}$$
$$= \frac{1}{0.00075360} \text{ or } \frac{10,000}{7.536}$$
$$= 1,327\ X_C \text{ capacitive reactance.}$$

To find the impedance, the impedance formula used in a series AC circuit must be modified to fit the parallel circuit:

$$Z = \frac{RX_C}{\sqrt{R^2 + X_C{}^2}}$$
$$= \frac{10,000 \times 1327}{\sqrt{(10,000)^2 + (1327)^2}}$$
$$= 0.1315 \text{ W (approx.)}$$

To find the current through the capacitance:

$$I_C = \frac{E}{X_C}$$
$$I_C = \frac{110}{1327}$$
$$= 0.0829 \text{ ampere}$$

To find the current flowing through the resistance:

$$I_R = \frac{E}{R}$$
$$= \frac{110}{10,000}$$
$$= 0.0829 \text{ ampere}$$

To find the current flowing through the resistance:

$$I_R = \frac{E}{R}$$
$$= \frac{110}{10,000}$$
$$= 0.011 \text{ ampere}$$

To find the total current in the circuit:

$$I_T^2 = \sqrt{I_R^2 + I_C^2}$$
$$I_T = \sqrt{I_L^2 + I_R^2}$$
$$= 0.0836 \text{ ampere (approx.)}$$

Resonance

It has been shown that both inductive reactance ($X_L = 2\pi f L$) and capacitive reactance:

$$X_C = \frac{1}{2\pi f C}$$

…are functions of an alternating current frequency. Decreasing the frequency decreases the ohmic value of the inductive reactance, but a decrease in frequency increases the capacitive reactance. At some particular frequency, known as the resonant frequency, the reactive effects of a capacitor and an inductor will be equal. Since these effects are the opposite of one another, they will cancel, leaving only the ohmic value of the resistance to oppose current flow in a circuit. If the value of resistance is small or consists only of the resistance in the conductors, the value of current flow can become very high.

In a circuit where the inductor and capacitor are in series, and the frequency is the resonant frequency, or frequency of resonance, the circuit is said to be "in resonance" and is referred to as a series resonant circuit. The symbol for resonant frequency is Fn.

If, at the frequency of resonance, the inductive reactance is equal to the capacitive reactance, then:

$$X_L = Xc, \text{ or}$$

$$2\pi f L = \frac{1}{2\pi f C}$$

Dividing both sides by 2 fL,

$$Fn2 = \frac{1}{(2\pi)\, 2\, LC}$$

Extracting the square root of both sides gives:

$$Fn = \frac{1}{2\pi\sqrt{LC}}$$

Where Fn is the resonant frequency in cycles per second, C is the capacitance in farads, and L is the inductance in henries. With this formula, the frequency at which a capacitor and inductor will be resonant can be determined.

To find the inductive reactance of a circuit use:

$$X_L = 2\,(\pi)\, f\, l$$

The impedance formula used in a series AC circuit must be modified to fit a parallel circuit.

$$Z = \frac{X_L}{\sqrt{R^2 - X_L^2}}$$

To find the parallel networks of inductance and capacitive reactors, use:

$$X = \frac{X_L + X_C}{\sqrt{X_L + X_C}}$$

To find the parallel networks with resistance capacitive and inductance, use:

$$Z = \frac{R\, X_L\, X_C}{\sqrt{X_L^2\, X_C^2 + (RX_L - RX_C)^2}}$$

Since at the resonant frequency X_L cancels X_C, the current can become very large, depending on the amount of resistance. In such cases, the voltage drop across the inductor or capacitor will often be higher than the applied voltage.

In a parallel resonant circuit, the reactances are equal and equal currents will flow through the coil and the capacitor. [Figure 10-133]

Since the inductive reactance causes the current through the coil to lag the voltage by 90°, and the capacitive reactance causes the current through the capacitor to lead the voltage by 90°, the two currents are 180° out of phase. The canceling effect of such currents would mean that no current would flow from the generator and the parallel combination of the inductor, and the capacitor would appear as infinite impedance. In practice, no such circuit is possible, since some value of resistance is always present, and the parallel circuit, sometimes called a tank circuit, acts as very high impedance. It is also called an antiresonant circuit, since its effect in a circuit is opposite to that of a series resonant circuit, in which the impedance is very low.

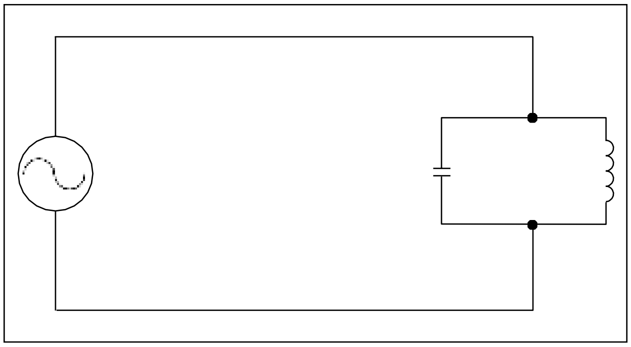

Figure 10-133. A parallel resonant circuit.

Power in AC Circuits

In a DC circuit, power is obtained by the equation, P = EI, (watts equal volts times amperes). Thus, if 1 ampere of current flows in a circuit at a pressure of 200 volts, the power is 200 watts. The product of the volts and the amperes is the true power in the circuit.

True Power Defined

The power dissipated in the resistance of a circuit, or the power actually used in the circuit.

In an AC circuit, a voltmeter indicates the effective voltage and an ammeter indicates the effective current. The product of these two readings is called the apparent power.

Apparent Power Defined

That power apparently available for use in an AC circuit containing a reactive component. It is the product of effective voltage times the effective current, expressed in volt-amperes. It must be multiplied by the power factor to obtain true power available.

Only when the AC circuit is made up of pure resistance is the apparent power equal to the true power. [Figure 10-134] When there is capacitance or inductance in the circuit, the current and voltage are not exactly in phase, and the true power is less than the apparent power. The true power is obtained by a wattmeter reading. The ratio of the true power to the apparent power is called the power factor and is usually expressed in percent. In equation form, the relationship is:

$$\text{Power Factor (PF)} = \frac{100 \times \text{Watts (True Power)}}{\text{Volts} \times \text{Amperes (Apparent Power)}}$$

Example: A 220-volt AC motor takes 50 amperes from the line, but a wattmeter in the line shows that only 9,350 watts are taken by the motor. What are the apparent power and the power factor?

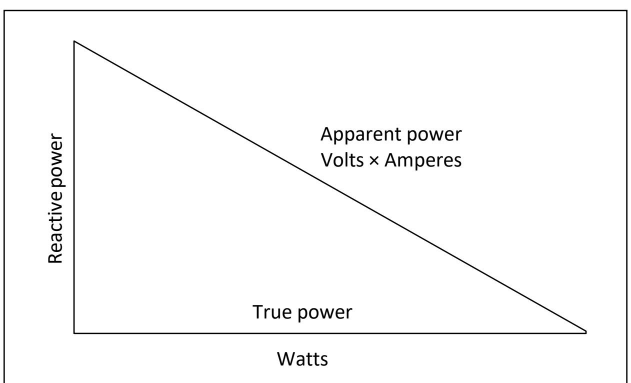

Figure 10-134. Power relations in AC circuit.

Solution:

Apparent power = Volts × Amperes

Apparent power = 220 × 50 = 11,000 watts or volt-amperes.

$$\text{(PF)} = \frac{\text{Watts (True Power)} \times 100}{\text{VA (Apparent Power)}}$$

$$\text{(PF)} = \frac{9{,}350 \times 100}{11{,}000}$$

$$\text{(PF)} = 85\text{, or } 85\%$$

Transformers

A transformer changes electrical energy of a given voltage into electrical energy at a different voltage level. It consists of two coils that are not electrically connected, but are arranged so that the magnetic field surrounding one coil cuts through the other coil. When an alternating voltage is applied to (across) one coil, the varying magnetic field set up around that coil creates an alternating voltage in the other coil by mutual induction. A transformer can also be used with pulsating DC, but a pure DC voltage cannot be used, since only a varying voltage creates the varying magnetic field that is the basis of the mutual induction process.

A transformer consists of three basic parts. [Figure 10-135] These are an iron core which provides a circuit of low reluctance for magnetic lines of force, a primary winding which receives the electrical energy from the source of applied voltage, and a secondary winding which receives electrical energy by induction from the primary coil.

The primary and secondary of this closed core transformer are wound on a closed core to obtain maximum inductive effect between the two coils.

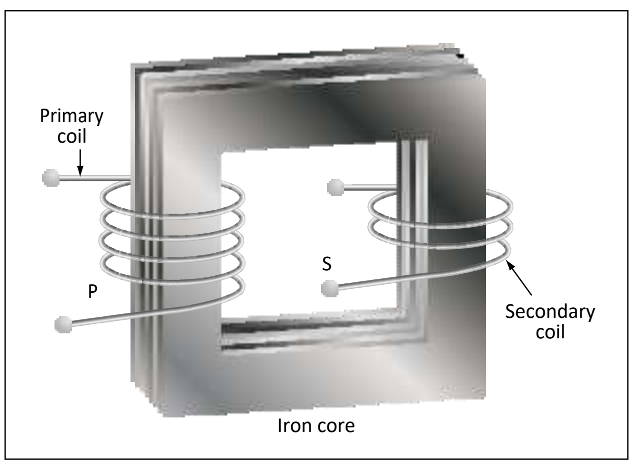

Figure 10-135. An iron-core transformer.

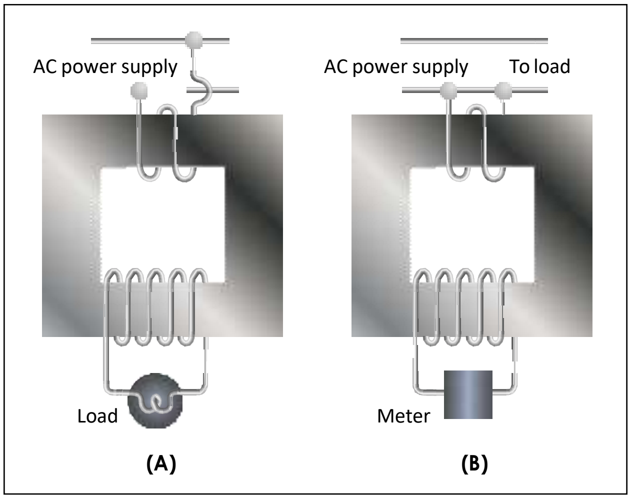

Figure 10-136. Voltage and current transformers.

There are two classes of transformers: (1) voltage transformers used for stepping up or stepping down voltages, and (2) current transformers used in instrument circuits.

In voltage transformers, the primary coils are connected in parallel across the supply voltage as shown in Figure 10-136A. The primary windings of current transformers are connected in series in the primary circuit [Figure 10-136B]. Of the two types, the voltage transformer is the more common.

There are many types of voltage transformers. Most of these are either step-up or step-down transformers. The factor that determines whether a transformer is a step-up, or step-down type is the "turns" ratio. The turns ratio is the ratio of the number of turns in the primary winding to the number of turns in the secondary winding. For example, the turns ratio of the step-down transformer shown in Figure 10-137A is 5 to 1, since there are five times as many turns in the primary as in the secondary. The step-up transformer shown in Figure 10-137B has a 1 to 4 turns ratio.

The ratio of the transformer input voltage to the output voltage is the same as the turns ratio if the transformer is 100 percent efficient. Thus, when 10 volts are applied to the primary of the transformer shown in Figure 10-137A, two volts are induced in the secondary. If 10 volts are applied to the primary of the transformer in Figure 10-137B, the output voltage across the terminals of the secondary will be 40 volts.

No transformer can be constructed that is 100 percent efficient, although iron core transformers can approach this figure. This is because all the magnetic lines of force set up in the primary do not cut across the turns

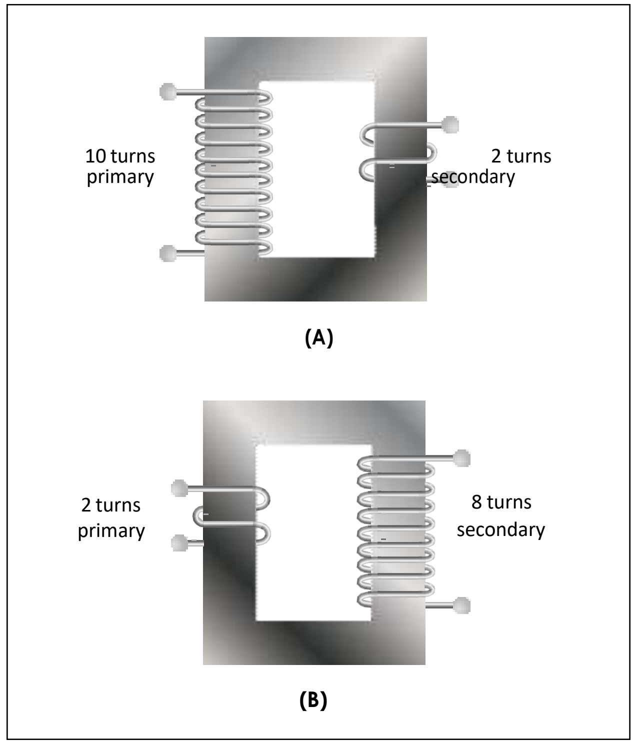

Figure 10-137. A step-down and a step-up transformer.

of the secondary coil. A certain amount of the magnetic flux, called leakage flux, leaks out of the magnetic circuit. The measure of how well the flux of the primary is coupled into the secondary is called the "coefficient of coupling." For example, if it is assumed that the primary of a transformer develops 10,000 lines of force and only 9,000 cut across the secondary, the coefficient of coupling would be 0.9 or, stated another way, the transformer would be 90 percent efficient.

When an AC voltage is connected across the primary terminals of a transformer, an alternating current will flow and self induce a voltage in the primary coil that is opposite and nearly equal to the applied voltage. The difference between these two voltages allows just enough current in the primary to magnetize its core. This is called the exciting, or magnetizing, current. The magnetic field caused by this exciting current cuts across the secondary coil and induces a voltage by mutual induction.

If a load is connected across the secondary coil, the load current flowing through the secondary coil will produce a magnetic field which will tend to neutralize the magnetic field produced by the primary current. This will reduce the self-induced (opposition) voltage in the primary coil and allow more primary current to flow. The primary current increases as the secondary load current increases, and decreases as the secondary load current decreases. When the secondary load is removed, the primary current is again reduced to the small exciting current sufficient only to magnetize the iron core of the transformer.

If a transformer steps up the voltage, it will step down the current by the same ratio. This should be evident if the power formula is considered, for the power (I × E) of the output (secondary) electrical energy is the same as the input (primary) power minus that energy loss in the transforming process. Thus, if 10 volts and 4 amps (40 watts of power) are used in the primary to produce a magnetic field, there will be 40 watts of power developed in the secondary (disregarding any loss). If the transformer has a step-up ratio of 4 to 1, the voltage across the secondary will be 40 volts and the current will be 1 amp. The voltage is 4 times greater and the current is one-fourth the primary circuit value, but the power (I × E value) is the same.

When the turns ratio and the input voltage are known, the output voltage can be determined as follows:

$$\frac{E_2}{E_1} = \frac{N_2}{N_1}$$

Where E is the voltage of the primary, E_2 is the output voltage of the secondary, and N_1 and N_2 are the number of turns of the primary and secondary, respectively.

Transposing the equation to find the output voltage gives:

$$E_2 = \frac{E_1 N_2}{N_1}$$

The most commonly used types of voltage transformers are as follows:

1. Power transformers are used to step up or step down voltages and current in many types of power supplies. They range in size from the small power transformer shown in Figure 10-138 used in a radio receiver to the large transformers used to step down high power line voltage to the 110 – 120 volt level used in homes.
   Figure 10-139 shows the schematic symbol for an iron core transformer. In this case, the secondary is made up of three separate windings. Each winding supplies a different circuit with a specific voltage, which saves the weight, space, and expense of three separate transformers. Each secondary has a midpoint connection, called a "center tap," which provides a selection of half the voltage across the whole winding. The leads from the various windings are color coded by the manufacturer, as labeled in Figure 10-139. This is a standard color code, but other codes or numbers may be used.

Figure 10-138. Power supply transformer.

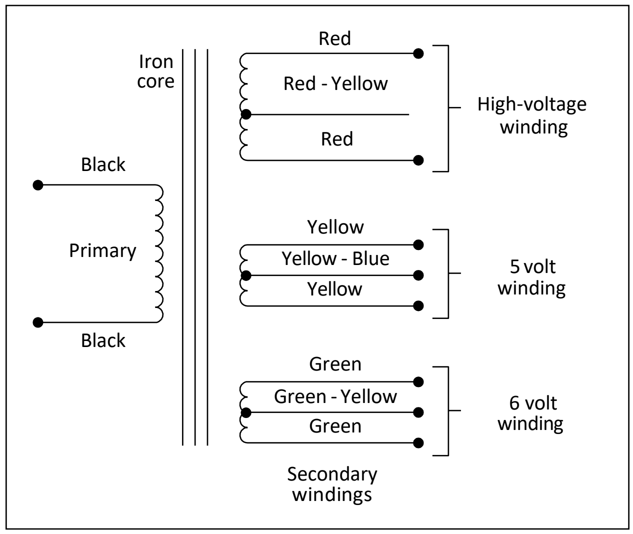

Figure 10-139. Schematic symbol for an iron-core power transformer.

2. Audio transformers resemble power transformers. They have only one secondary and are designed to operate over the range of audio frequencies (20 to 20,000 cps).
3. RF transformers are designed to operate in equipment that functions in the radio range of frequencies. The symbol for the RF transformer is the same as for an RF choke coil. It has an air core as shown in Figure 10-140.
4. Autotransformers are normally used in power circuits; however, they may be designed for other uses. Two different symbols for autotransformers used in power or audio circuits are shown in Figure 10-141. If used in an RF communication or navigation circuit (Figure 10-141B), it is the

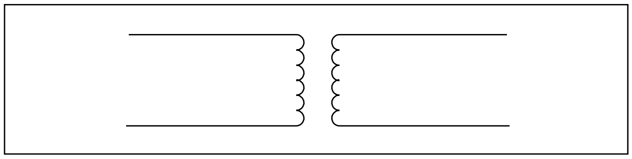

Figure 10-140. An air-core transformer.

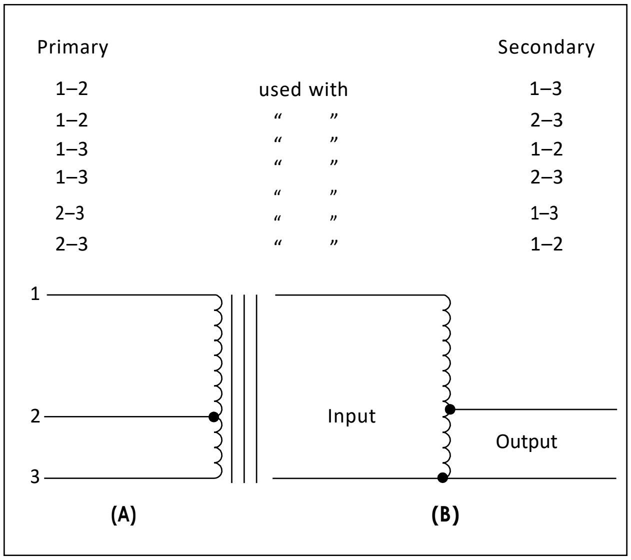

Figure 10-141. Autotransformers.

same, except there is no symbol for an iron core. The autotransformer uses part of a winding as a primary; and, depending on whether it is step up or step down, it uses all or part of the same winding as the secondary. For example, the autotransformer shown in Figure 10-141A could use the following possible choices for primary and secondary terminals.

Current Transformers

Current transformers are used in AC power supply systems to sense generator line current and to provide a current, proportional to the line current, for circuit protection and control devices.

The current transformer is a ring-type transformer using a current carrying power lead as a primary (either the power lead or the ground lead of the AC generator). The current in the primary induces a current in the secondary by magnetic induction.

The sides of all current transformers are marked "H1" and "H2" on the unit base. The transformers must be installed with the "H1" side toward the generator in the circuit in order to have proper polarity. The secondary of the transformer should never be left open while the system is being operated; to do so could cause dangerously high voltages, and could overheat the transformer. Therefore, the transformer output connections should always be connected with a jumper when the transformer is not being used but is left in the system.

Transformer Losses

In addition to the power loss caused by imperfect coupling, transformers are subject to "copper" and "iron" losses. The resistance of the conductor comprising the turns of the coil causes copper loss. The iron losses are of two types called hysteresis loss and eddy current loss. Hysteresis loss is the electrical energy required to magnetize the transformer core, first in one direction and then in the other, in step with the applied alternating voltage. Eddy current loss is caused by electric currents (eddy currents) induced in the transformer core by the varying magnetic fields. To reduce eddy current losses, cores are made of laminations coated with an insulation, which reduces the circulation of induced currents.

Power in Transformers

Since a transformer does not add any electricity to the circuit but merely changes or transforms the electricity that already exists in the circuit from one voltage to another, the total amount of energy in a circuit must remain the same. If it were possible to construct a perfect transformer, there would be no loss of power in it; power would be transferred undiminished from one voltage to another.

Since power is the product of volts times amperes, an increase in voltage by the transformer must result in a decrease in current and vice versa. There cannot be more power in the secondary side of a transformer than there is in the primary. The product of amperes times volts remains the same.

The transmission of power over long distances is accomplished by using transformers. At the power source, the voltage is stepped up in order to reduce the line loss during transmission. At the point of utilization, the voltage is stepped down, since it is not feasible to use high voltage to operate motors, lights, or other electrical appliances.

DC Measuring Instruments

Understanding the functional design and operation of electrical measuring instruments is very important, since they are used in repairing, maintaining, and troubleshooting electrical circuits. The best and most expensive measuring instrument is of no use unless the technician knows what is being measured and what each reading indicates. The purpose of the meter is to measure quantities existing in a circuit. For this reason, when a meter is connected to a circuit, it must not change the characteristics of that circuit.

Meters are either self-excited or externally excited. Those that are self-excited operate from a power source within the meter. Externally excited meters get their power source from the circuit that they are connected to. The most common analog meters in use today are the voltmeter, ammeter, and ohmmeter. All of which operate on the principles of electromagnetism. The fundamental principle behind the operation of the meter is the interaction between magnetic fields created by a current gathered from the circuit in some manner. This interaction is between the magnetic fields of a permanent magnet and the coils of a rotating magnet. The greater the current through the coils of the rotating magnet, the stronger the magnetic field produced. A stronger field produces greater rotation of the coil. While some meters can be used for both DC and AC circuit measurement, only those used as DC instruments are discussed in this section. The meters used for AC, or for both AC and DC, are discussed in the study of AC theory and circuitry.

D'Arsonval Meter Movement

This basic DC type of meter movement — first employed by the French scientist, d'Arsonval in making electrical measurement — is a current measuring device, which is used in the ammeter, voltmeter, and ohmmeter. The pointer is deflected in proportion to the amount of current through the coil. Basically, both the ammeter and the voltmeter are current measuring instruments, the principal difference being the method in which they are connected in a circuit. While an ohmmeter is also basically a current measuring instrument, it differs from the ammeter and voltmeter in that it provides its own source (self-excited) of power and contains other auxiliary circuits.

Current Sensitivity and Resistance

The current sensitivity of a meter movement is the amount of current required to drive the meter movement to a full-scale deflection. A simple example would be a meter movement that has 1mA sensitivity. What this indicates is that meter movement will require 1mA of current to move the needle to a full-scale indication. Likewise a half scale deflection will require only 0.5mA of current. Additionally, what is called movement resistance is the actual DC resistance of the wire used to construct the meter coil.

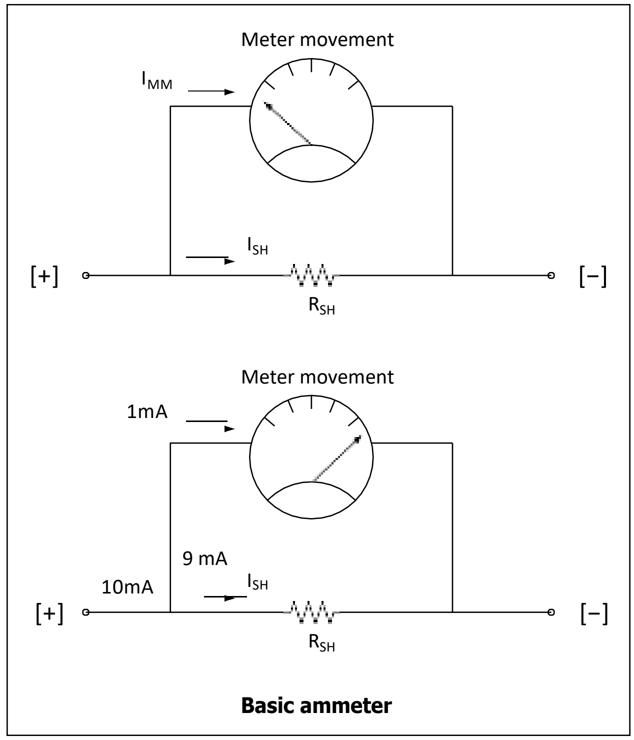

Figure 10-142. Basic meter drawing.

In a standard d'Arsonval meter movement may have a current sensitivity of 1mA and a resistance of 50Ω. If the meter is going to be used to measure more than 1mA then additional circuitry will be required to accomplish the task. This additional circuitry is a simple shunt resistor. The purpose of the shunt resistor is to bypass current that exceeds the 1mA limitation of the meter movement. To illustrate this, assume that the 1mA meter in question is needed to measure 10mA. The shunt resistor used should carry 9mA while the remaining 1mA is allowed to pass through the meter. [Figure 10-142]

To determine the proper shunt resistance for this situation:

R_{SH} = Shunt resistance
R_M = Meter resistance = 50Ω

Because the shunt resistance and the 50Ω meter resistance are in parallel, the voltage drop across both of them is the same.

$E_{SH} = E_M$

Using Ohm's law, this relationship can be rewritten as:

$E_{SH} = I_{SH} \times R_{SH}$
$E_M = I_M \times R_M$

$I_{SH} \times R_{SH} = I_M \times R_M$

Simply solve for R_{SH}

$$R_{SH} = \frac{I_M \times R_M}{I_{SH}}$$

Substituting the values

$$R_{SH} = \frac{\text{ImA} \times 50\Omega}{9\text{mA}} = 5.56\Omega$$

Damping

To make meter readings quickly and accurately, it is desirable that the moving pointer overshoot its proper position only a small amount and come to rest after not more than one or two small oscillations. The term "damping" is applied to methods used to bring the pointer of an electrical meter to rest after it has been set in motion. Damping may be accomplished by electrical means, by mechanical means, or by a combination of both.

Electrical Damping

A common method of damping by electrical means is to wind the moving coil on an aluminum frame. As the coil moves in the field of the permanent magnet, eddy currents are set up in the aluminum frame. The magnetic field produced by the eddy currents opposes the motion of the coil. The pointer will therefore swing more slowly to its proper position and come to rest quickly with very little oscillation.

Mechanical Damping

Air damping is a common method of damping by mechanical means. As shown in Figure 10-143, a vane is attached to the shaft of the moving element and enclosed in an air chamber. The movement of the shaft is retarded because of the resistance that the air offers to the vane. Effective damping is achieved if the vane nearly touches the walls of the chamber.

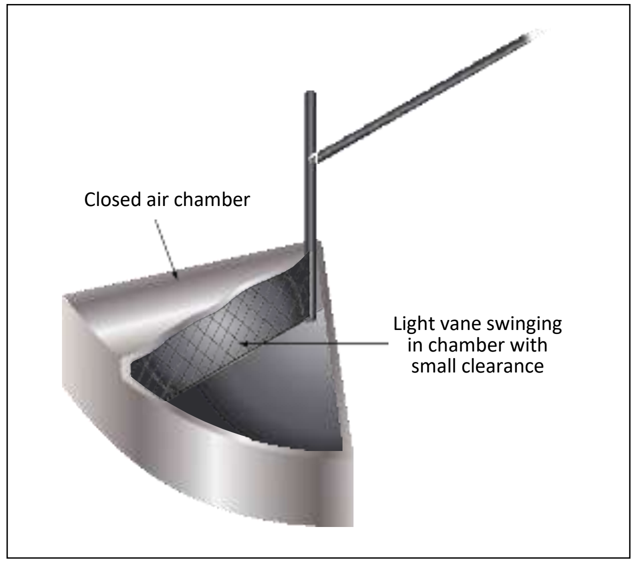

Figure 10-143. Air damping.

A Basic Multirange Ammeter

Building upon the basic meter previously discussed is the more complex and useful multirange meter, which is more practical. The basic idea of a multirange ammeter is to make the meter usable over a wide range of voltages. In order to accomplish this, each range must utilize a different shunt resistance. The example give in this text is that of a two-range meter. However, once the basics of a two range multirange ammeter are understood, the concepts can easily be transferred to the design of meters with many selectable ranges.

Figure 10-144 shows the schematic of an ammeter with two selectable ranges. This example builds upon the previous 10mA range meter by adding a 100mA range. With the switch selected to the 10mA range, the meter will indicate 10mA when the needle is deflected to full scale and will likewise indicate 100mA at full scale when selected to 100mA.

The value of the 100mA shunt resistor is determined the same way the 10mA shunt resistor was determined. Recall that the meter movement can only carry 1mA.

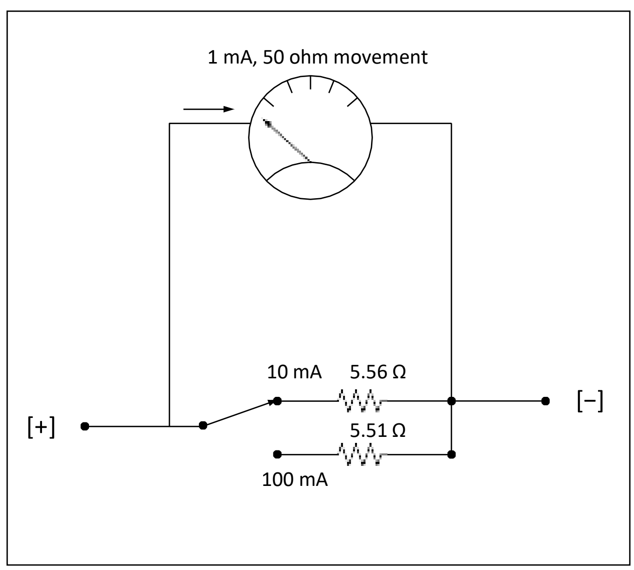

Figure 10-144. Ammeter with two ranges.

This means that in a 100mA range the remaining current of 99mA must pass through the shunt resistor.

$$R_{SH} = \frac{I_M \times R_M}{I_{SH}}$$

Substituting the values

$$R_{SH} = \frac{ImA \times 50\Omega}{99mA} = 0.51\Omega$$

Precautions

The precautions to observe when using an ammeter are summarized as follows:

1. Always connect an ammeter in series with the element through which the current flow is to be measured.
2. Never connect an ammeter across a source of voltage, such as a battery or generator. Remember that the resistance of an ammeter, particularly on the higher ranges, is extremely low and that any voltage, even a volt or so, can cause very high current to flow through the meter, causing damage to it.
3. Use a range large enough to keep the deflection less than full scale. Before measuring a current, form some idea of its magnitude. Then switch to a large enough scale or start with the highest range and work down until the appropriate scale is reached. The most accurate readings are obtained at approximately half-scale deflection. Many milliammeters have been ruined by attempts to measure amperes. Therefore, be sure to read the lettering either on the dial or on the switch positions and choose proper scale before connecting the meter in the circuit.
4. Observe proper polarity in connecting the meter in the circuit. Current must flow through the coil in a definite direction in order to move the indicator needle up scale. Current reversal because of incorrect connection in the circuit results in a reversed meter deflection and frequently causes bending of the meter needle. Avoid improper meter connections by observing the polarity markings on the meter.

The Voltmeter

The voltmeter uses the same type of meter movement as the ammeter but employs a different circuit external to the meter movement.

As shown before, the voltage drop across the meter coil is a function of current and the coil resistance. In another example, $50\mu A \times 1000\Omega = 50mV$. In order for the meter to be used to measure voltages greater than 50mV, there must be added a series resistance to drop any excess voltage greater than that which the meter movement requires for a full scale deflection. The case of the voltmeter, this resistance is called multiplier resistance and will be designated as R_M. Figure 10-145 illustrates a basic voltmeter. This voltmeter only has one multiplier resistor for use in one range. In this example, the full scale reading will be 1 volt. R_M is determined in the follow way:

The meter movement drops 50mV at a full scale deflection of 50µA. The multiplying resistor RM must drop the remaining voltage of $1V - 50mV = 950$ mV. Since RM is in series with the movement, it also carries 50µA at full scale.

$$RM = \frac{950 \text{ mV}}{50\mu A} = 19k\ \Omega$$

Therefore, for 1 volt full scale deflection, the total resistance of the voltmeter is 20 k Ω. That is, the multiplier resistance and the coil resistance.

Voltmeter Sensitivity

Voltmeter sensitivity is defined in terms of resistance per volt (Ω/ V). The meter used in the previous example has a sensitivity of 20 k Ω and a full scale deflection of 1 volt.

Multiple Range Voltmeters

The simplified voltmeter in Figure 10-145 has only one range (1 volt), which means that it can measure voltages from 0 volts to 1 volt. In order for the meter to be more useful, additional multiplier resistors must be used. One resistor must be used for each desired range.

For a 50µA movement, the total resistance required is 20 k Ω for each volt of full scale reading. In other words, the sensitivity for a 50µA movement is always 20 k Ω regardless of the selected range. The full-scale meter current is 50µA at any range selection. To find the total meter resistance, multiply the sensitivity by the full scale voltage for that particular range. For

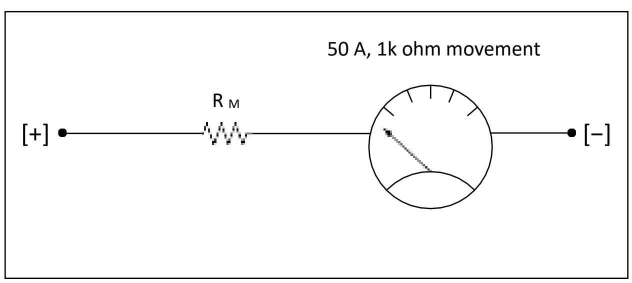

Figure 10-145. Basic voltmeter.

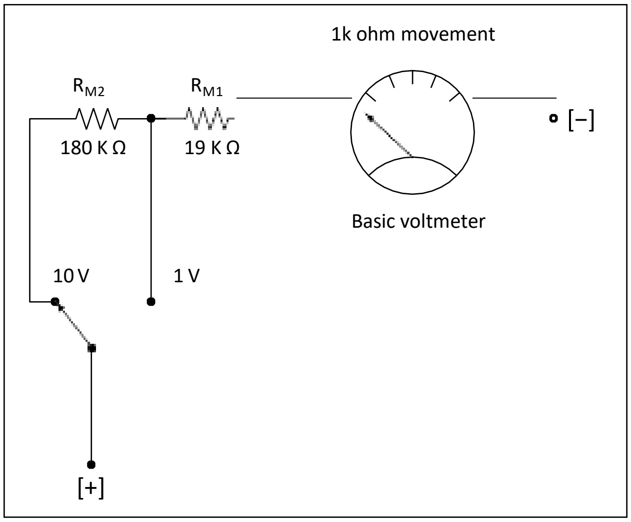

Figure 10-146. Two range voltmeter.

example for a 10 volt range, RT = (20k Ω/ V)/(10 V) = 200k Ω. The total resistance for the 1 volt range is 20k Ω, so RM for a 10 V range will be 200k Ω − 20k Ω = 180k Ω. This two-range voltmeter is illustrated in Figure 10-146.

Voltmeter Circuit Connections

When voltmeters are used, they are connected in parallel with a circuit. If unsure about the voltage to be measured, take the first reading at the high value on the meter and then progressively move down through the range until a suitable read is obtained. Observe that the polarity is correct before connecting the meter to the circuit or damage will occur by driving the movement backwards.

Influence of the Voltmeter in the Circuit

When a voltmeter is connected across two points in a circuit, current will be shunted. If the voltmeter has low resistance, it will draw off a significant amount of current. This will lower the effective resistance of the circuit and change the voltage readings. When making a voltage measurement, use a high resistance voltmeter to prevent shunting of the circuit.

The Ohmmeter

The meter movement used for the ammeter and the voltmeter can also be used for the ohmmeter. The function of the ohmmeter is to measure resistance. A simplified one-stage ohmmeter is illustrated in Figure 10-147, which shows that the basic ohmmeter contains a battery and a variable resistor in series with the meter movement. To measure resistance, the leads of the meter are connected across an external resistance,

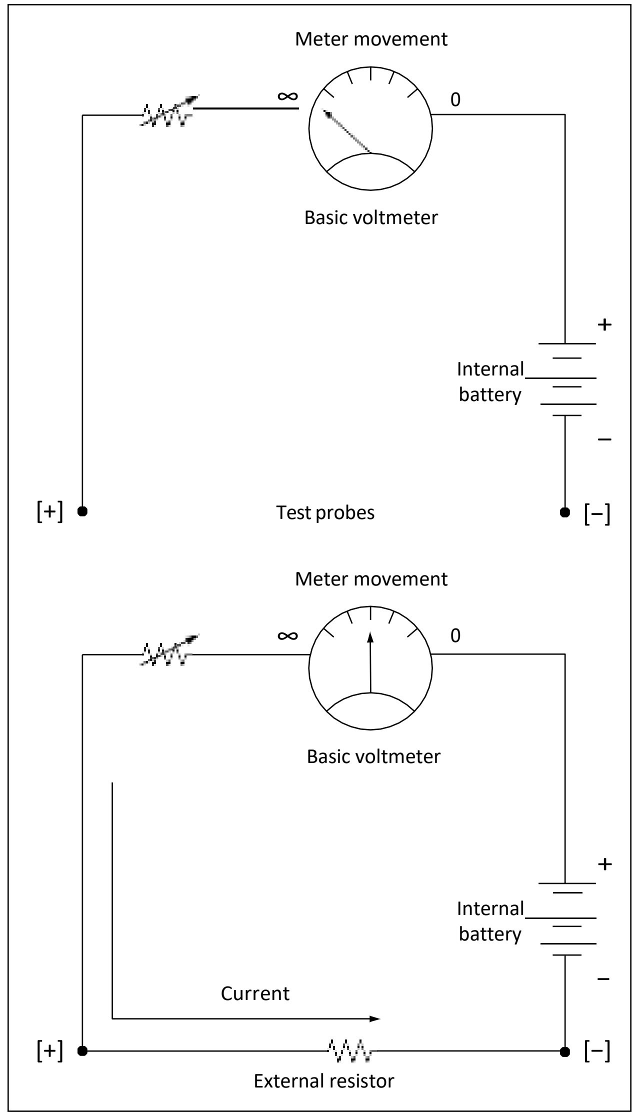

Figure 10-147. Basic ohmmeter.

which is to be measured. By doing this the ohmmeter circuit is completed. This connection allows the internal battery to produce a current through the movement coil, causing a deflection of the pointer proportional to the value of the external resistance being measured.

Zero Adjustment

When the ohmmeter leads are open as shown in Figure 10-148, the meter is at a full scale deflection, indicating an infinite (∞) resistance or an open circuit. When the leads are shorted as shown in figure “zero adjust,” the pointer will be at the full right hand position, indicating a short circuit or zero resistance. The purpose of the variable resistor in this figure is to adjust the current so that the pointer is at exactly zero when the leads are shorted. This is used to compensate for changes in the internal battery voltage due to aging.

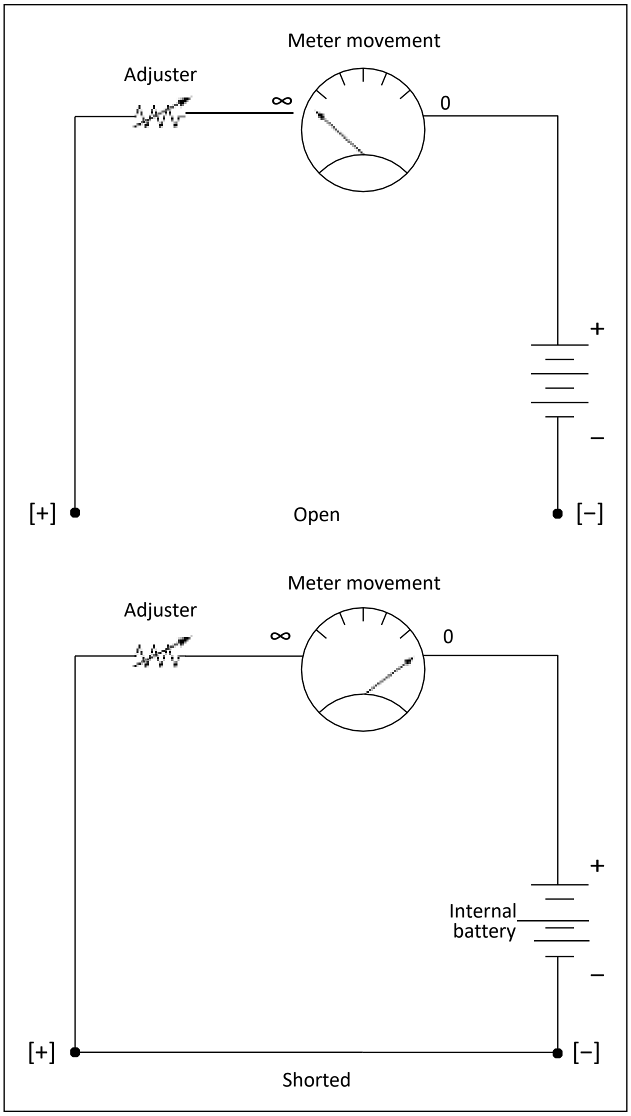

Figure 10-148. Zero adjustment.

Ohmmeter Scale

Figure 10-149 shows a typical analog ohmmeter scale. Between zero and infinity (∞), the scale is marked to indicate various resistor values. Because the values decrease from left to right, this scale is often called a back-off scale.

In the case of the example given, assume that a certain ohmmeter uses a 50μA, 1000Ω meter movement and has an internal 1.5 volt battery. A current of 50μA produces a full-scale deflection when the test leads are shorted. To have 50μA, the total ohmmeter resistance is 1.5 V/50μA = 30kΩ. Therefore, since the coil resistance is 1kΩ, the variable zero adjustment resistor must be set to 30kΩ – 1kΩ = 29kΩ.

Now consider that a 120kΩ resistor is connected to the ohmmeter leads. Combined with the 30kΩ inter-

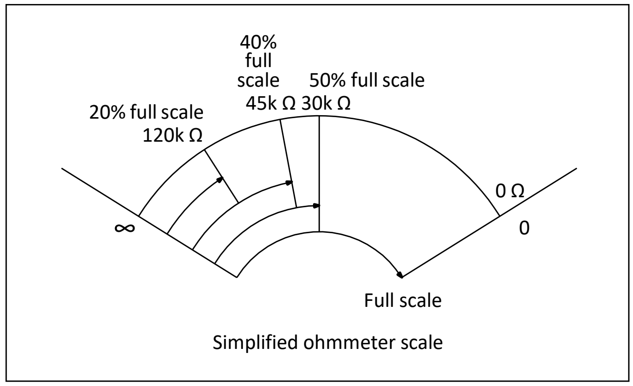

Figure 10-149. Ohm scale.

nal resistance, the total R is 150kΩ. The current is 1.5 V/150kΩ = 10μA, which is 20% of the full scale current and which appears on the scale as shown in Figure 10-149.

Now consider further that a 120kΩ resistor is connected to the ohmmeter leads. This will result in a current of 1.5V/75kΩ = 10μA, which is 40% of the full scale current and which is marked on the scale as shown. Additional calculations of this type show that the scale is nonlinear. It is more compressed toward the left side than the right side. The center scale point corresponds to the internal meter resistance of 30kΩ. The reason is as follows:

With 30kΩ connected to the leads, the current is 1.5V/60kΩ = 25μA, which is half of the full scale current of 50μA.

The Multirange Ohmmeter

A practical ohmmeter usually has several operational ranges. These typically are indicated by R × 1, R × 10, R × 100, R × 1k, R × 100k and R × 1M. These range selections are interpreted in a different manner than that of an ammeter or voltmeter. The reading on the ohmmeter scale is multiplied by the factor indicated by the range setting. For example, if the pointer is set on the scale and the range switch is set at R × 100, the actual resistance measurement is 20 × 100 or 2kΩ.

To measure small resistance values, the technician must use a higher ohmmeter current than is needed for measuring large resistance values. Shunt resistors are needed to provide multiple ranges on the ohmmeter to measure a range of resistance values from the very small to very large. For each range, a different value of shunt resistance is switched in. The shunt resistance increases for higher ohm ranges and is always equal to the center scale reading on any selected range. In some meters, a higher battery voltage is used for the

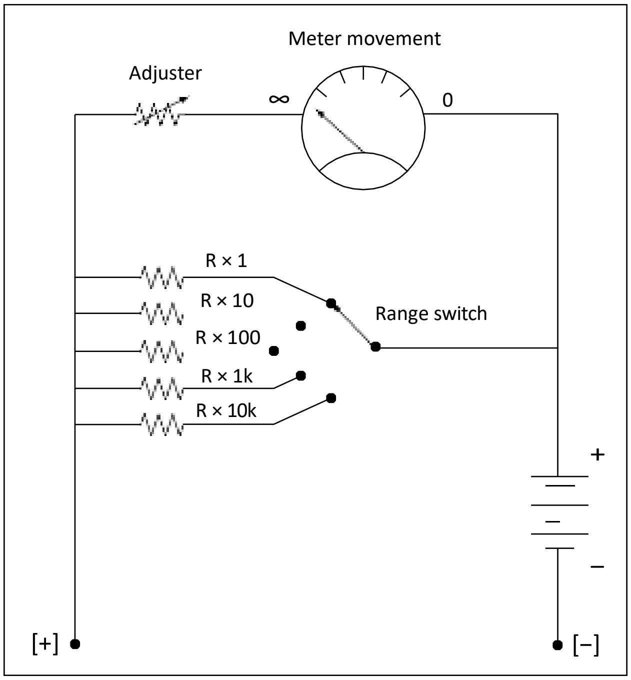

Figure 10-150. Multirange ohmmeter.

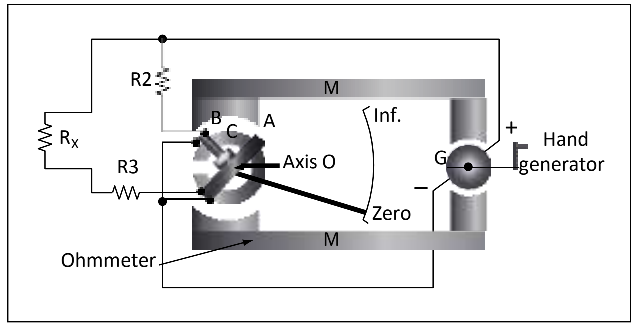

Figure 10-151. Simplified megger circuit.

highest ohm range. A common circuit arrangement is shown in Figure 10-150.

Megger (Megohmmeter)

The megger, or megohmmeter, is a high range ohmmeter containing a hand-operated generator. It is used to measure insulation resistance and other high resistance values. It is also used for ground, continuity, and short circuit testing of electrical power systems. The chief advantage of the megger over an ohmmeter is its capacity to measure resistance with a high potential, or "breakdown" voltage. This type of testing ensures that insulation or a dielectric material will not short or leak under potential electrical stress.

The megger consists of two primary elements, both of which are provided with individual magnetic fields from a common permanent magnet: (1) a hand-driven DC generator, G, which supplies the necessary current for making the measurement, and (2) the instrument portion, which indicates the value of the resistance being measured. The instrument portion is of the opposed coil type. Coils A and B are mounted on the movable member with a fixed angular relationship to each other and are free to turn as a unit in a magnetic field. Coil B tends to move the pointer counterclockwise and coil A, clockwise. The coils are mounted on a light, movable frame that is pivoted in jewel bearings and free to move about axis 0. [Figure 10-151]

Coil A is connected in series with R3 and the unknown resistance, R_X, to be measured. The series combination of coil A, R3, and R_X is connected between the + and − brushes of the DC generator. Coil B is connected in series with R2 and this combination is also connected across the generator. There are no restraining springs on the movable member of the instrument portion of the megger. When the generator is not in operation, the pointer floats freely and may come to rest at any position on the scale.

If the terminals are open circuited, no current flows in coil A, and the current in coil B alone controls the movement of the moving element. Coil B takes a position opposite the gap in the core (since the core cannot move and coil B can), and the pointer indicates infinity on the scale. When a resistance is connected between the terminals, current flows in coil A, tending to move the pointer clockwise. At the same time, coil B tends to move the pointer counterclockwise. Therefore, the moving element, composed of both coils and the pointer, comes to rest at a position at which the two forces are balanced. This position depends upon the value of the external resistance, which controls the relative magnitude of current of coil A. Because changes in voltage affect both coils A and B in the same proportion, the position of the moving element is independent of the voltage. If the terminals are short circuited, the pointer rests at zero because the current in A is relatively large. The instrument is not damaged under these circumstances because the current is limited by R3.

There are two types of hand-driven meggers: the variable type and the constant pressure type. The speed of the variable pressure megger is dependent on how fast the hand crank is turned. The constant pressure megger uses a centrifugal governor, or slip clutch. The governor becomes effective only when the megger is operated at a speed above its slip speed, at which speed its voltage remains constant.

AC Measuring Instruments

A DC meter, such as an ammeter, connected in an AC circuit will indicate zero, because the meter movements used in a d'Arsonval type movement is restricted to direct current. Since the field of a permanent magnet in the d'Arsonval type meter remains constant and in the same direction at all times, the moving coil follows the polarity of the current. The coil attempts to move in one direction during half of the AC cycle and in the reverse direction during the other half when the current reverses.

The current reverses direction too rapidly for the coil to follow, causing the coil to assume an average position. Since the current is equal and opposite during each half of the AC cycle, the direct current meter indicates zero, which is the average value. Thus, a meter with a permanent magnet cannot be used to measure alternating voltage and current. For AC measurements of current and voltage, additional circuitry is required. The additional circuitry has a rectifier, which converts AC to DC. There are two basic types of rectifiers: One is the half-wave rectifier and the other is the full-wave rectifier. Both of these are depicted in block diagram form in Figure 10-152.

Figure 10-152 also shows a simplified block diagram of an AC meter. In this depiction, the full-wave rectifier precedes the meter movement. The movement responds to the average value of the pulsating DC. The scale can then be calibrated to show anything the designer wants. In most cases, it will be root mean square (RMS) value or peak value.

Electrodynamometer Meter Movement

The electrodynamometer can be used to measure alternating or direct voltage and current. It operates on the same principles as the permanent magnet moving coil meter, except that the permanent magnet is replaced by an air core electromagnet. The field of the electrodynamometer is developed by the same current that flows through the moving coil. [Figure 10-153]

Because this movement contains no iron, the electrodynamometer can be used as a movement for both AC and DC instruments. Alternating current can be measured by connecting the stationary and moving coils in series. Whenever the current in the moving coil reverses, the magnetic field produced by the stationary coil reverses. Regardless of the direction of the current, the needle will move in a clockwise direction.

However, for either voltmeter or ammeter applications, the electrodynamometer is too expensive to economically compete with the d'Arsonval type movement.

Moving Iron Vane Meter

The moving iron vane meter is another basic type of meter. It can be used to measure either AC or DC. Unlike the d'Arsonval meter, which employs permanent magnets, it depends on induced magnetism for its operation. It utilizes the principle of repulsion between two concentric iron vanes, one fixed and one movable, placed inside a solenoid. A pointer is attached to the movable vane. [Figure 10-154]

When current flows through the coil, the two iron vanes become magnetized with north poles at their upper ends

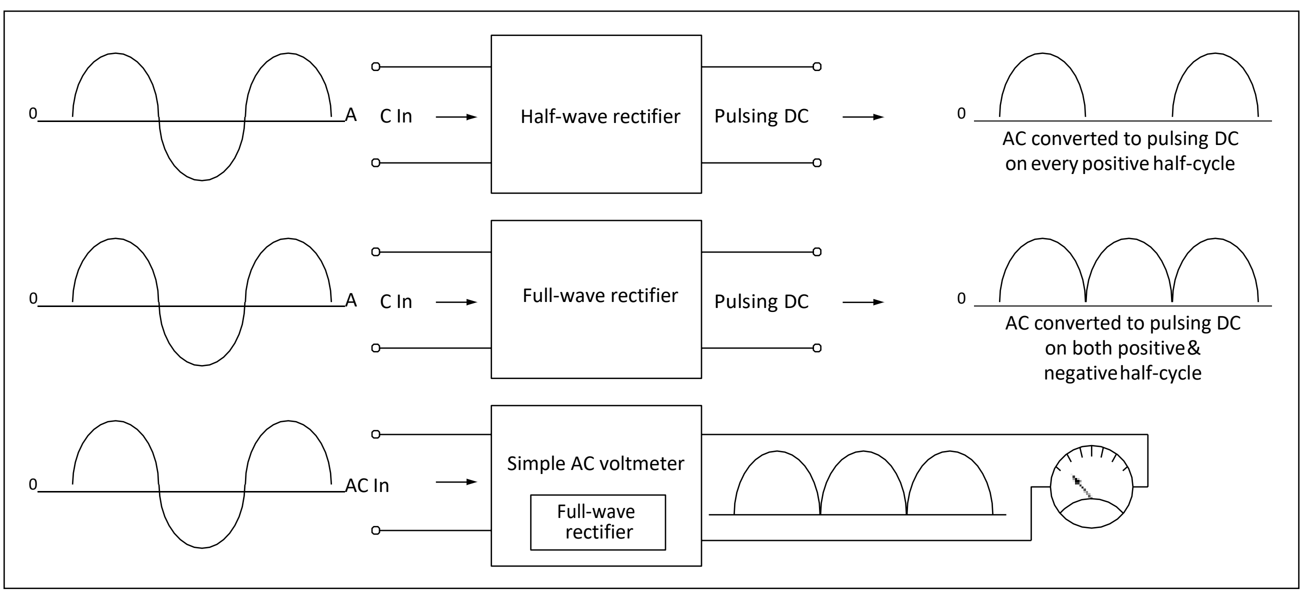

Figure 10-152. Simplified block diagram of AC meter.

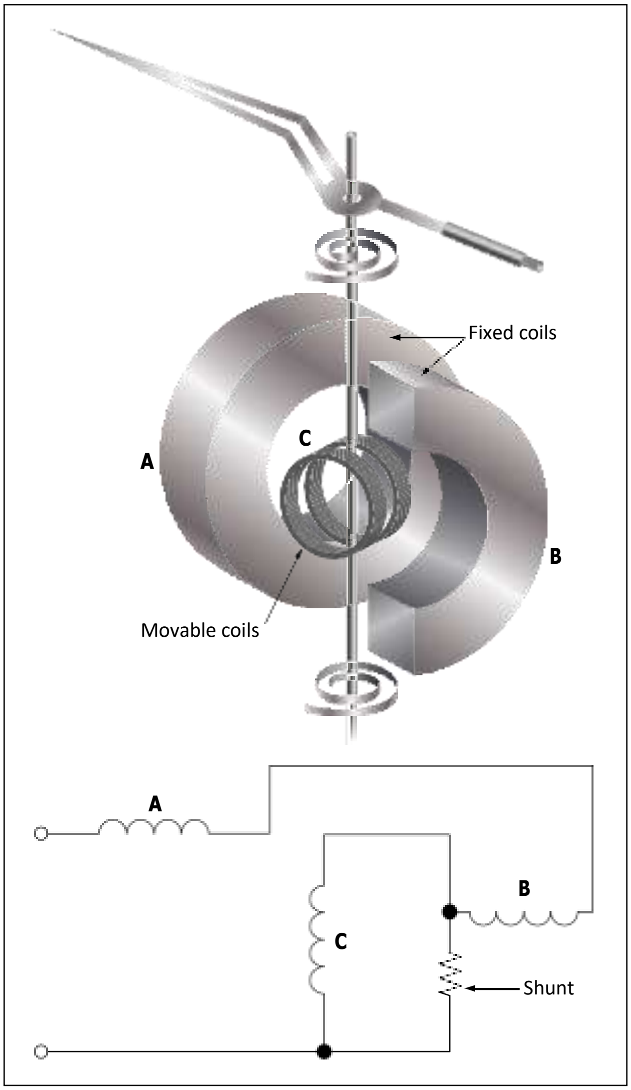

Figure 10-153. Simplified diagram of an electrodynamometer movement.

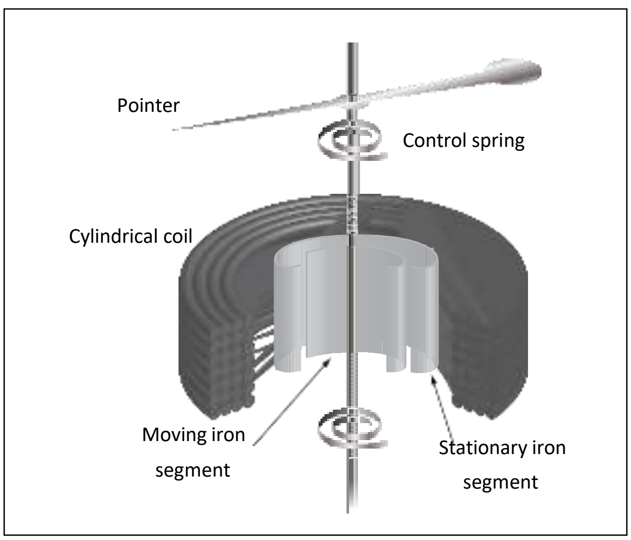

Figure 10-154. Moving iron vane meter.

and south poles at their lower ends for one direction of current through the coil. Because like poles repel, the unbalanced component of force, tangent to the movable element, causes it to turn against the force exerted by the springs.

The movable vane is rectangular in shape and the fixed vane is tapered. This design permits the use of a relatively uniform scale.

When no current flows through the coil, the movable vane is positioned so that it is opposite the larger portion of the tapered fixed vane, and the scale reading is zero. The amount of magnetization of the vanes depends on the strength of the field, which, in turn, depends on the amount of current flowing through the coil.

The force of repulsion is greater opposite the larger end of the fixed vane than it is nearer the smaller end. Therefore, the movable vane moves toward the smaller end through an angle that is proportional to the magnitude of the coil current. The movement ceases when the force of repulsion is balanced by the restraining force of the spring.

Because the repulsion is always in the same direction (toward the smaller end of the fixed vane), regardless of the direction of current flow through the coil, the moving iron vane instrument operates on either DC or AC circuits.

Mechanical damping in this type of instrument can be obtained by the use of an aluminum vane attached to the shaft so that, as the shaft moves, the vane moves in a restricted air space.

When the moving iron vane meter is used as an ammeter, the coil is wound with relatively few turns of large wire in order to carry the rated current.

When the moving iron vane meter is used as a voltmeter, the solenoid is wound with many turns of small wire. Portable voltmeters are made with self-contained series resistance for ranges up to 750 volts. Higher ranges are obtained by the use of additional external multipliers.

The moving iron vane instrument may be used to measure direct current but has an error due to residual magnetism in the vanes. Reversing the meter connections and averaging the readings may minimize the error. When used on AC circuits, the instrument has an accuracy of 0.5 percent. Because of its simplicity, relatively low cost, and the fact that no current is conducted to the moving element, this type of movement is used extensively to measure current and voltage in AC power circuits. However, because the reluctance of the magnetic circuit is high, the moving iron vane meter requires much more power to produce full-scale deflection than is required by a d'Arsonval meter of the same range. Therefore, the moving iron vane meter is seldom used in high resistance low power circuits.

Inclined Coil Iron Vane Meter

The principle of the moving iron vane mechanism is applied to the inclined coil type of meter, which can be used to measure both AC and DC. The inclined coil, iron vane meter has a coil mounted at an angle to the shaft. Attached obliquely to the shaft, and located inside the coil, are two soft iron vanes. When no current flows through the coil, a control spring holds the pointer at zero, and the iron vanes lie in planes parallel to the plane of the coil. When current flows through the coil, the vanes tend to line up with magnetic lines passing through the center of the coil at right angles to the plane of the coil. Thus, the vanes rotate against the spring action to move the pointer over the scale.

The iron vanes tend to line up with the magnetic lines regardless of the direction of current flow through the coil. Therefore, the inclined coil, iron vane meter can be used to measure either alternating current or direct current. The aluminum disk and the drag magnets provide electromagnetic damping.

Like the moving iron vane meter, the inclined coil type requires a relatively large amount of current for full-scale deflection and is seldom used in high resistance low power circuits.

As in the moving iron vane instruments, the inclined coil instrument is wound with few turns of relatively large wire when used as an ammeter and with many turns of small wire when used as a voltmeter.

Varmeters

Multiplying the volts by the amperes in an AC circuit gives the apparent power: the combination of the true power (which does the work) and the reactive power (which does no work and is returned to the line). Reactive power is measured in units of vars (volt-amperes reactive) or kilovars (kilovolt-amperes reactive, abbreviated kVAR). When properly connected, wattmeters measure the reactive power. As such, they are called varmeters. Figure 10-155 shows a varmeter connected in an AC circuit.

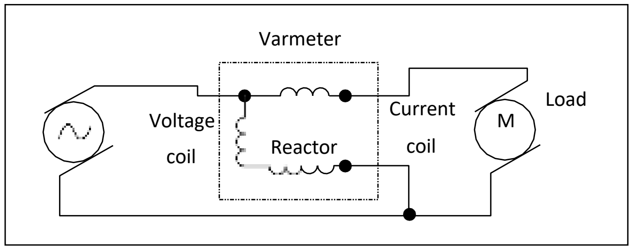

Figure 10-155. A varmeter connected in an AC circuit.

Wattmeter

Electric power is measured by means of a wattmeter. Because electric power is the product of current and voltage, a wattmeter must have two elements, one for current and the other for voltage. For this reason, wattmeters are usually of the electrodynamometer type. [Figure 10-156]

The movable coil with a series resistance forms the voltage element, and the stationary coils constitute the current element. The strength of the field around the potential coil depends on the amount of current that flows through it. The current, in turn, depends on the load voltage applied across the coil and the high resistance in series with it. The strength of the field around the current coils depends on the amount of current flowing through the load. Thus, the meter deflection is proportional to the product of the voltage across the potential coil and the current through the current coils. The effect is almost the same (if the

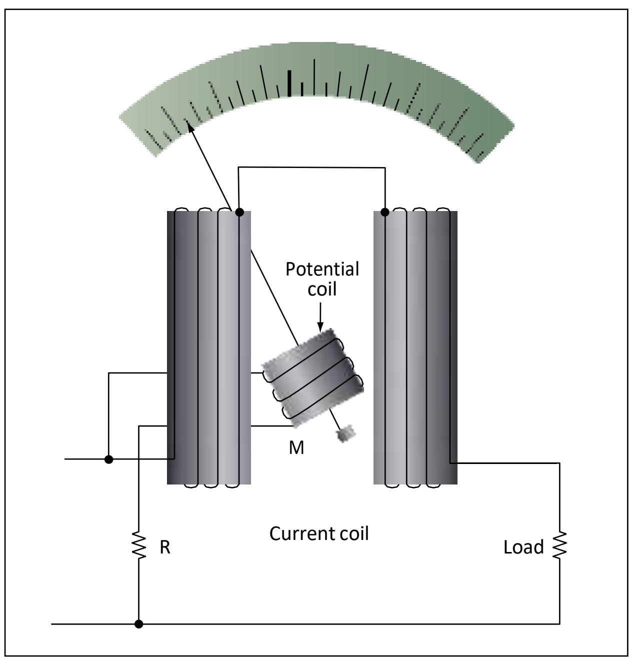

Figure 10-156. Simplified electrodynamometer wattmeter circuit.

scale is properly calibrated) as if the voltage applied across the load and the current through the load were multiplied together.

If the current in the line is reversed, the direction of current in both coils and the potential coil is reversed, the net result is that the pointer continues to read up scale. Therefore, this type of wattmeter can be used to measure either AC or DC power.

Frequency Measurement/Oscilloscope

The oscilloscope is by far one of the more useful electronic measurements available. The viewing capabilities of the oscilloscope make it possible to see and quantify various waveform characteristics such as phase relationships, amplitudes, and durations. While oscilloscopes come in a variety of configurations and presentations, the basic operation is typically the same. Most oscilloscopes in general bench or shop applications use a cathode-ray tube (CRT), which is the device or screen that displays the waveforms.

The CRT is a vacuum instrument that contains an electron gun, which emits a very narrow and focused beam of electrons. A phosphorescent coat applied to the back of the screen forms the screen. The beam is electronically aimed and accelerated so that the electron beam strikes the screen. When the electron beam strikes the screen, light is emitted at the point of impact.

Figure 10-157 shows the basic components of the CRT with a block diagram. The heated cathode emits electrons. The magnitude of voltage on the control grid determines the actual flow of electrons and thus controls the intensity of the electron beam. The acceleration anodes increase the speed of the electrons, and the focusing anode narrows the beam down to a fine point. The surface of the screen is also an anode and will assist in the acceleration of the electron beam.

The purpose of the vertical and horizontal deflection plates is to bend the electron beam and position it to a specific point of the screen. Figure 10-158 illustrates how the deflection plates are used to position the beam on the screen. By providing a neutral or zero voltage to a deflection plate, the electron beam will be unaffected. By applying a negative voltage to a plate, the electron beam with be repelled and driven away from the plate. Finally, by applying a positive voltage, the electron beam will be drawing to the plate. Figure 10-158 provides a few possible plate voltage combinations and the resultant beam position.

Horizontal Deflection

To get a visual representation of the input signal, an internally generated saw-tooth voltage is generated and then applied to the horizontal deflection plates. Figure 10-159 illustrates that the saw-tooth is a pattern of voltage applied, which begins at a negative voltage and increases at a constant rate to a positive voltage. This applied varying voltage will draw or trace the electron beam from the far left of the screen to the far right side of the screen. The resulting display is a straight line, if the sweep rate is fast enough. This saw-tooth applied voltage is a repetitive signal so that the beam is repeatedly swept across the tube. The rate at which the saw-tooth voltage goes from negative to positive is determined by the frequency. This rate then establishes the sweep rate of the beam. When the saw-tooth reaches the end of its sweep from left to right, the beam then rapidly returns to the left side and is ready to make another sweep. During this time, the electron beam is stopped or blanked out and does

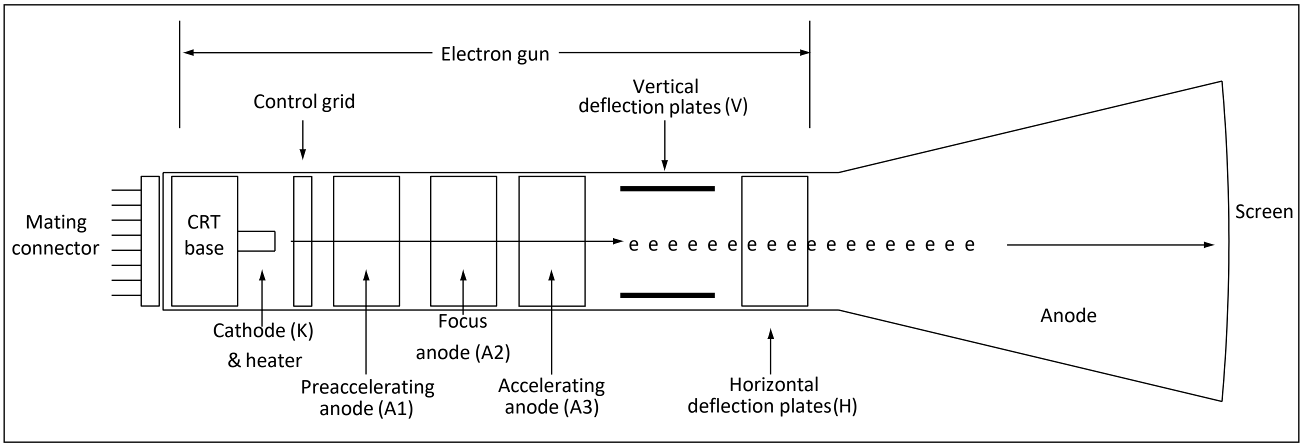

Figure 10-157. Basic components of the CRT with a block diagram.

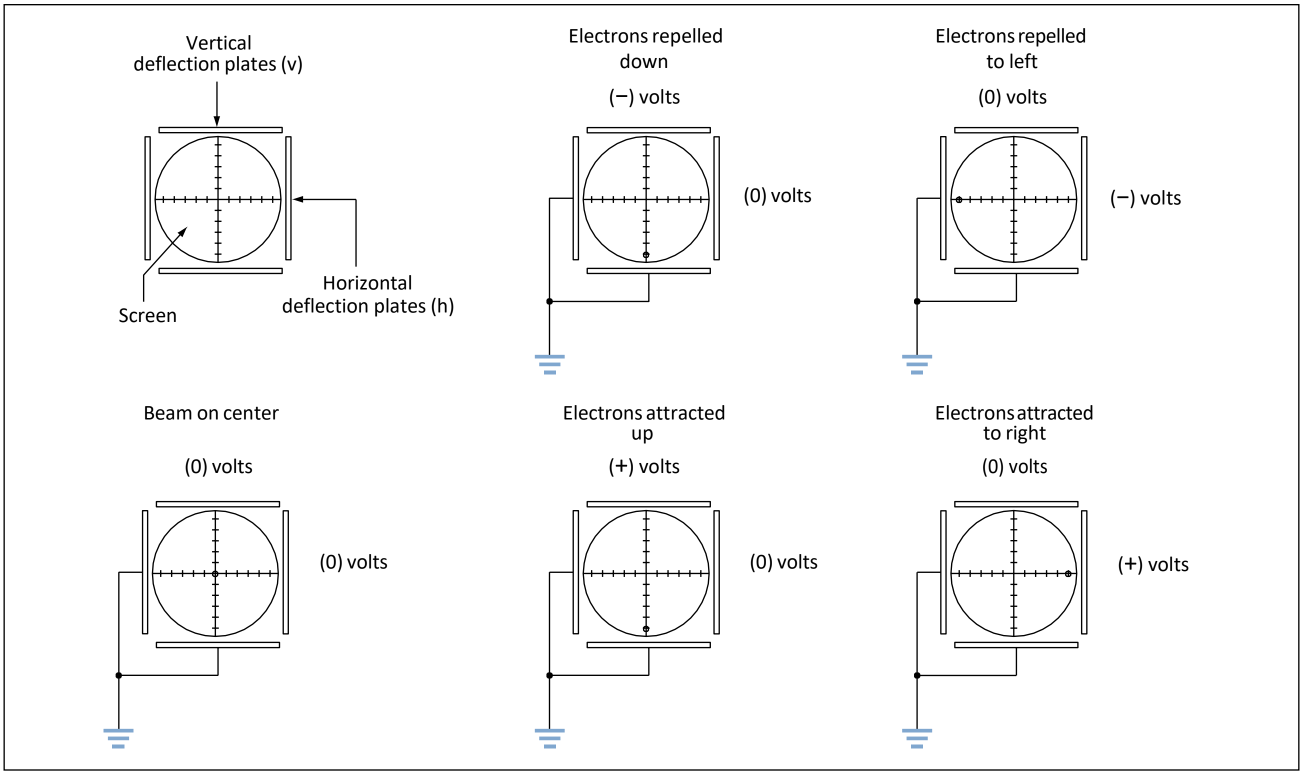

Figure 10-158. Possible plate voltage combinations and the resultant beam position.

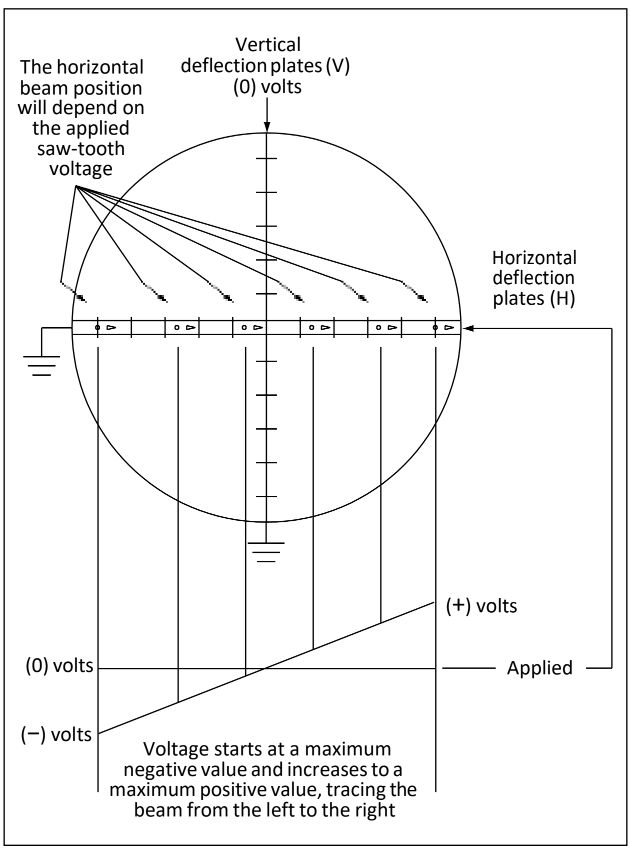

Figure 10-159. Saw-tooth applied voltage.

not produce any kind of a trace. This period of time is called flyback.

Vertical Deflection

If this same signal were applied to the vertical plates, it would also produce a vertical line by causing the beam to trace from the down position to the up position.

Tracing a Sine Wave

Reproducing the sine wave on the oscilloscope combines both the vertical and horizontal deflection patterns. [Figure 10-160] If the sine wave voltage signal is applied across the vertical deflection plates, the result will be the vertical beam oscillation up and down on the screen. The amount that the beam moves above the centerline will depend on the peak value of the voltage.

While the beam is being swept from the left to the right by the horizontal plates, the sine wave voltage is being applied to the vertical plates, causing the form of the input signal to be traced out on the screen.

Control Features on an Oscilloscope

While there are many different styles of oscilloscopes, which range from the simple to the complex, they all have some controls in common. Apart from the screen

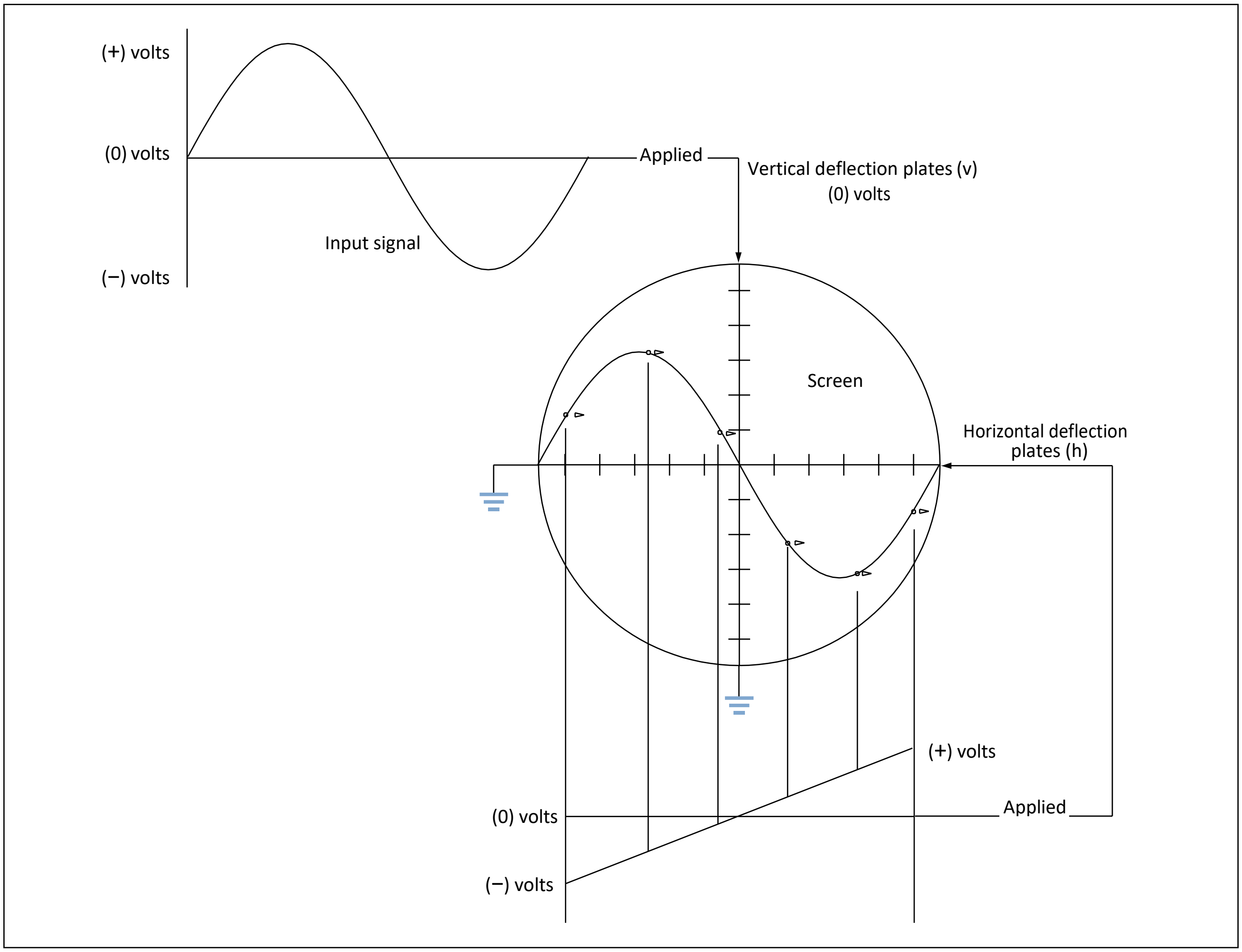

Figure 10-160. Sine wave voltage signal.

and the ON/OFF switch, some of these controls are listed below.

Horizontal Position: allows for the adjustment of the neutral horizontal position of the beam. Use this control to reposition the waveform display in order to have a better view of the wave or to take measurements.

Vertical Position: moves the traced image up or down allowing better observations and measurements.

Focus: controls the electron beam as it is aimed and converges on the screen. When the beam is in sharp focus, it is narrowed down to a very fine point and does not have a fuzzy appearance.

Intensity: essentially the brightness of the trace. Controlling the flow of electrons onto the screen varies the intensity. Do not keep the intensity too high for extended testing or when the beam is motionless and forms a dot on the screen. This can damage the screen.

Seconds/Division: a time-based control, which sets the horizontal sweep rate. Basically, the switch is used to select the time interval that each division on the horizontal scale will represent. These divisions can be seconds, milliseconds or even microseconds. A simple example would be if the technician had the seconds/division control set to 10 µS. If this technician is viewing a waveform that has a period of 4 divisions on the screen, then the period would be 40 µS. The frequency of this waveform can then be determined by taking the inverse of the period. In this case, 1/40 µS will equal a frequency of 25 kHz.

Volts/Division: used to select the voltage interval that each division on the vertical scale will represent. For example, suppose each vertical division was set to equal 10 mV. If a waveform was measured and had a peak value of 4 divisions, then the peak value in voltage would be 40 mV.

Trigger: The trigger control provides synchronization between the saw-tooth horizontal sweep and the applied signal on the vertical plates. The benefit is that the waveform on the screen appears to be stationary and fixed and not drifting across the screen. A triggering circuit is used to initiate the start of a sweep rather than the fixed saw-tooth sweep rate. In a typical oscilloscope, this triggering signal comes from the input signal itself at a selected point during the signal's cycle. The horizontal signal goes through one sweep, retraces back to the left side and waits there until it is triggered again by the input signal to start another sweep.

Flat Panel Color Displays for Oscilloscopes

While the standard CRT design of oscilloscope is still in service, the technology of display and control has evolved into use of the flat panel monitors. Furthermore, the newer oscilloscopes can even be integrated with the common personal computer (PC). This level of integration offers many diagnostic options unheard of only a few years ago. Some of the features of this technology include easy data capture, data transfer, documentation, and data analysis.

Digital Multimeter

Traditionally, the meters that technicians have used have been the analog voltmeter, ammeter, and the ohmmeter. These have usually been combined into the same instrument and called a multimeter or a VOM (volt-ohm-milliammeter). This approach has been both convenient and economical. Digital multimeters (DMM) and digital voltmeters (DVM) have now become more common due to their ease of use. These meters are easier to read and provide greater accuracy when compared to the older analog units with needle movement. The multimeter's single-coil movement requires a number of scales, which are not always easy to read accurately. In addition, the loading characteristics due to the internal resistance sometimes affect the circuit and the measurements. Not only does the DVM offer greater accuracy and less ambiguity, but also higher input resistance, which has less of a loading effect and influence on a circuit.