Chapter 5 of:

Basic Electricity and Electronics for Control

Fundamentals and Applications, Fourth Edition

Basic Electricity and Electronics for Control

Fundamentals and Applications

Fourth Edition

By Lawrence M. Thompson
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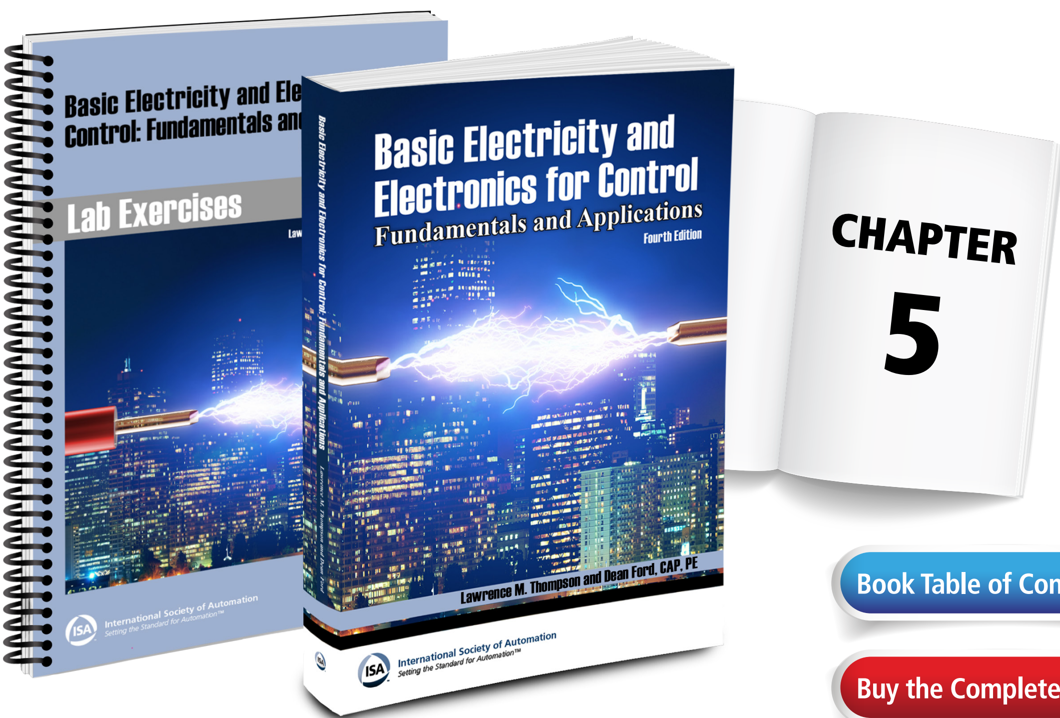

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5

AC Measurement

This unit explains alternating current (AC) measurement using rectification to convert the AC to direct current (DC) for measurement and rectifying instruments. Knowledge of the circuit principles behind how these devices operate will assist you in properly using and in making correct AC measurements. In Module 4, we explained the AC bridges used to measure reactive components (capacitors and inductors) but not the actual measurement of AC values.

One of the most common and economical methods of measuring AC is to rectify these currents and read the resultant DC on an analog or digital volt-ohm meter (VOM) scaled in AC values. Many factors must be considered when rectification is used, including what type of rectification is used, what scale conversion will be required, and the sensitivity of the meter employed.

Module 5: Objectives

After successfully completing this module, you will be able to:

- Describe both half-wave and full-wave rectification.
- Determine the operating characteristics of analog AC meters.
- Determine the operating characteristics of digital AC meters.
- Describe the operation of, and determine the operating values for, current transformers.

Module 5A: Rectification

AC periodically changes direction, which is why it is called alternating current. DC, on the other hand, maintains one direction, or polarity, of current. Rectification is the process of changing an AC into a DC. Whether we use one direction (half-cycle or half-wave), or both directions (full-cycle or full-wave) is determined by the circuitry.

The Diode

A diode operates exactly like a check valve for electrical current. Current may flow in only one direction through a diode. The diode obtains its name from *di-*, meaning "two," and *ode*, for "electrode." The electrodes are named the *anode* (positive electrode) and *cathode* (negative electrode). There are many types of diodes based on their chemical makeup. We will restrict ourselves here to just two solid-state types, germanium and silicon. There are some significant differences between the two types:

- Voltage necessary to maintain current flow in the positive direction
  - Germanium: approximately 0.01 to 0.3 V
  - Silicon: approximately 0.5 to 0.9 V
- Peak inverse voltage rating (explained later in this module)
- Power handling capability (Silicon is far more capable in part because of its much higher maximum operating temperature.)

Figure 5-1 represents a diode schematically. Current flow is shown as electronic, or from an electron perspective, meaning that the electron will flow from the negative to the positive following the laws discussed in Module 1.

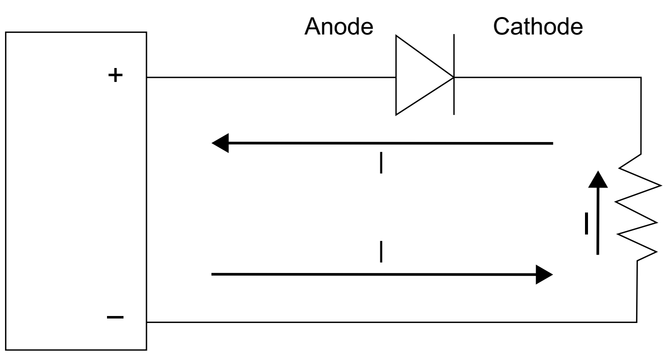

Figure 5-1. Schematic of a diode in a circuit.

The cathode is the bar, and the arrowhead is the anode. This schematic diagram came about because the original solid-state diode was as shown in Figure 5-2.

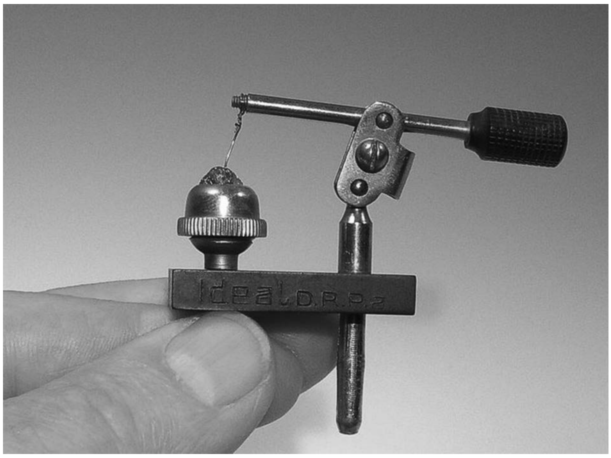

Figure 5-2. Cat whisker and crystal.

Source: Holger.Ellgaard [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0)].[1]

This was the original diode used in a crystal radio. The operator would scratch on the galena crystal until a rectifying junction was found. Then, along with the tuning circuit, usually an inductor capacitor (LC) parallel set, the operator would tune in a sufficiently strong AM radio station and would hear the audio in his headphones, no battery required. Note the similarity between the physical cat whisker device and the schematic of a diode.

Germanium diodes will forward conduct (again, electron flow from negative to positive) from almost 0 V, and the forward voltage drop varies with the current. In comparison, a silicon diode has a sharp "knee," around 0.7 V, so a diode with 0.6 V applied will practically be an "open circuit" equivalent, whereas a 0.7 V drop will be sustained to a high level of current. (See Figure 5-3.)

Forward Voltage Drop

Forward voltage drop is the amount of voltage required to maintain current through the diode. Just as in a mechanical check valve, where the fluid in the correct direction must have a pressure high enough to overcome the pressure on the reverse side of the check valve, and a bit more to overcome the spring of the check valve, a diode must have more than just equal voltages to conduct. The voltage needed ranges from 0.05 V to 0.9 V for germanium diodes and from 0.6 V to 0.9 V for silicon diodes.

1 Holger.Ellgaard, "Galena cat whisker detector from a 1920s' crystal radio," Wikipedia, last modified January 1, 2008, accessed October 25, 2022, https://en.wikipedia.org/wiki/Crystal_detector#/media/File:Kristallradio_(3).jpg.

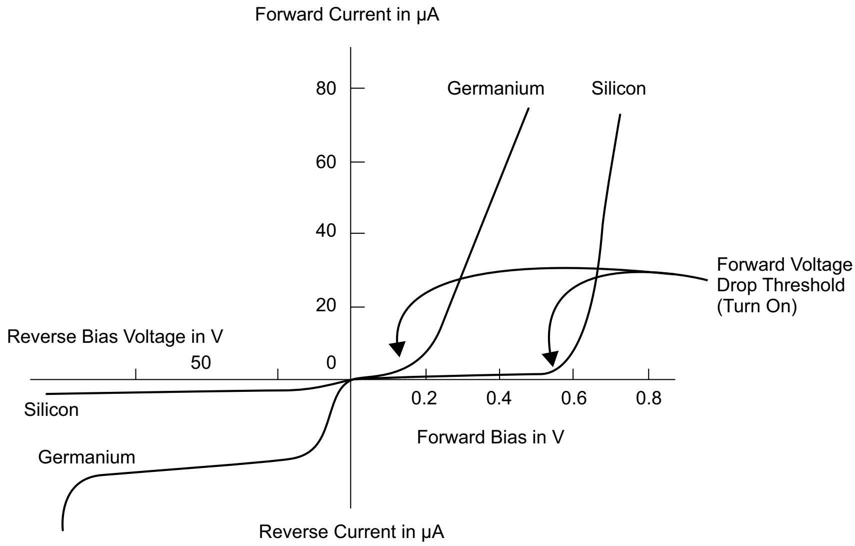

Figure 5-3. Germanium versus silicon voltage/current.

Forward Current

An important characteristic of a diode is that it will pass current in the forward direction when the forward voltage drop threshold is met. The nominal current the diode can safely pass is called forward current. The maximum current the diode can pass—only for a very short time (one or two cycles)—is called peak forward current. Exceeding either of these parameters for a relatively long period of time will damage or destroy the diode.

Peak Inverse Voltage

With the mechanical check valve, if pressure on the reverse side becomes high enough (in relation to the forward side), the valve will be destroyed. There is always a limit. Because voltage is pressure, this limit applies to rectifying diodes as well. (Rectifying diodes are standard diodes, as opposed to Zener and avalanche devices that exploit the peak inverse voltage, PIV, avalanche effect.) The specifications always provide the amount of voltage that the diode can withstand in the nonconducting direction. This is the reverse potential across the diode. If it is exceeded, a standard diode will be destroyed.

Rectification

The process of converting AC to DC will require one or more standard diodes. There are several rectifying circuits, each with its own advantages and disadvantages.

Half-Wave Rectifier

Figure 5-4 illustrates a half-wave rectifying circuit.

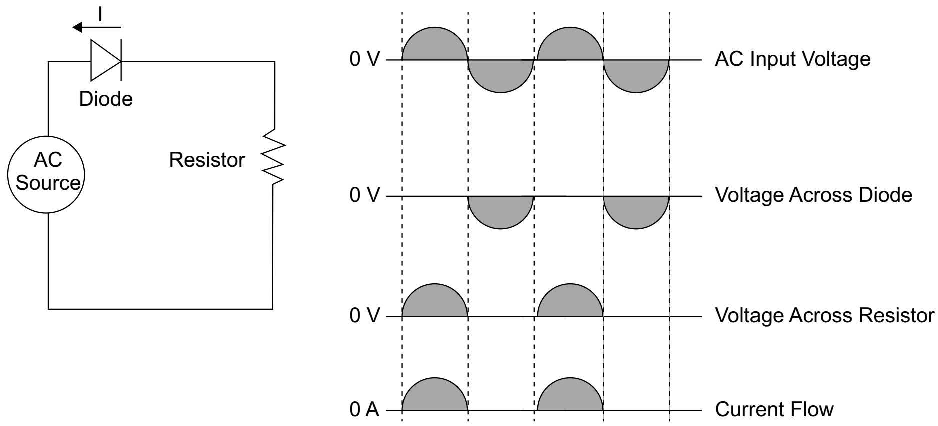

Figure 5-4. Half-wave rectification.

Of importance is the magnitude of these voltages. As shown in Figure 5-4, the current through the load (and through the diode) is for only half of the waveshape (which explains the name *half-wave rectifier*). The voltage across the resistor when the diode is conducting will range from just above 0 to the peak voltage input.

> **Example**
>
> If the AC source is 12.6 V rms, what is the voltage across the resistor? The diode?
>
> Because the input is in effective (rms), multiply the effective by 1.414 to obtain the peak.
>
> 12.6 • 1.414 = 17.8 V (peak)

This will be exhibited as a positive peak across the resistor (due to the direction of current flow), and when the diode is off, there will be a potential of 17.8 V peak across the diode and 0 V across the resistor because no current is flowing. Because the sum of all the voltage drops must equal the applied voltage, and 0 V is across the resistor, the applied voltage must appear across the diode.

Ripple Frequency

Previously, frequency has been discussed in regard to a sinusoidal waveform. However, the output across the resistor in the half-wave rectifier can be defined in terms of frequency because it is continuously changing in amplitude and occurs at a periodic rate. There will be one output waveform for each cycle of input waveform. The input frequency is the "ripple" frequency for the output of a half-wave rectifier.

Example

If the source voltage is at a 60 Hz rate, what is the ripple frequency for a half-wave rectifier?

Answer: 60 Hz. For half-wave circuits, the ripple frequency is the same as the input frequency.

Full-Wave Rectifier

A full-wave rectifier uses both alternations of the input waveshape to develop power across a load. There are two common circuits for producing full-wave rectification, the center tapped transformer and the bridge. The discussion here will be limited to the bridge circuit because today it is by far the most commonly used circuit for full-wave rectification. Figure 5-5 illustrates a bridge rectifier circuit.

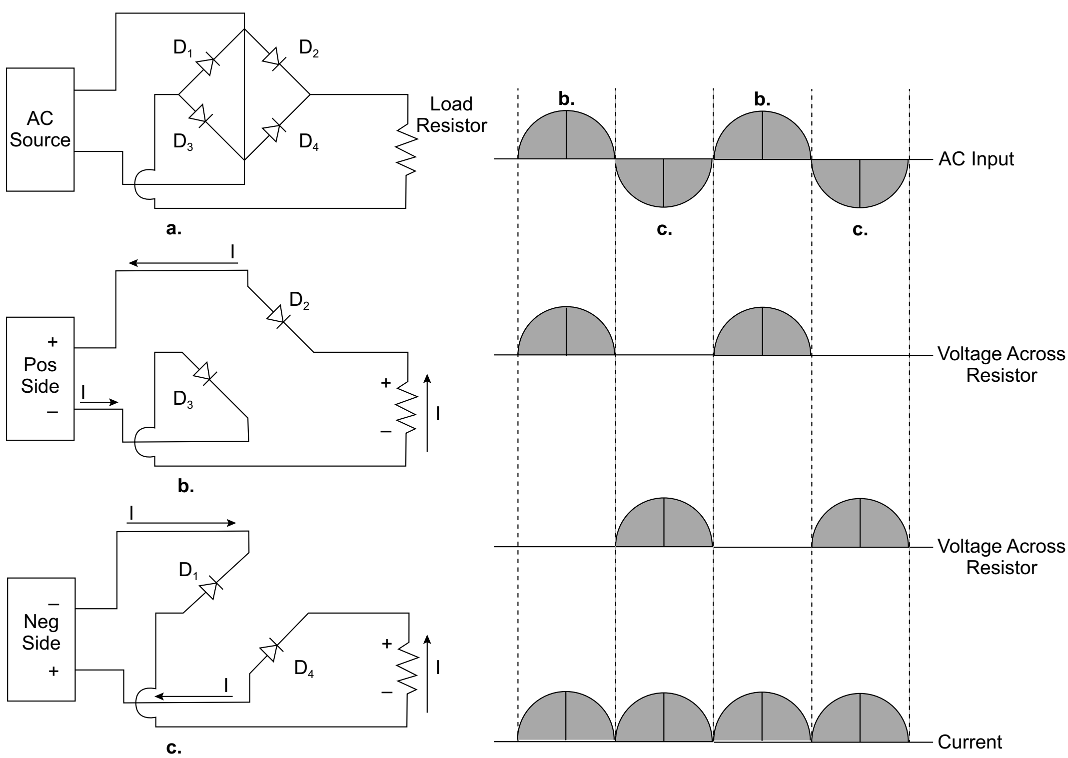

Figure 5-5. Full-wave rectifier.

Figure 5-5a is the complete circuit. Figure 5-5b is the current path when the upper source terminal is positive in respect to the lower source terminal. Figure 5-5c is the current path when the lower source terminal is positive in respect to the upper source terminal. Notice that both alternations of the input waveform are used. What is the ripple frequency for a full-wave rectifier?

Example

Determine the ripple frequency for the full-wave rectifier if the input frequency is 60 Hz.

Answer: The output now has two alternations, or occurrences, per input cycle. Therefore, the ripple frequency is two times the input frequency for a full-wave rectifier, and in this example, the ripple frequency would be: 2 • 60 = 120 Hz.

It should be obvious that the full-wave circuit will supply more power per input cycle than the half-wave circuit. Table 5-1 gives the conversion factors necessary to determine the effective and average values for half-wave and full-wave rectification.

Table 5-1. Conversion factors.

	Half-Wave	Full-Wave
Average	0.45 • rms	0.90 • rms
rms	1.11 • Average	2.22 • Average

The average current is measured by most meters (other than the true rms types).

Module 5A: Summary

- For half-wave rectifiers, only one polarity of the input sine wave is passed through.
- The ripple frequency for half-wave rectifiers is the same as the input line frequency.
- Full-wave rectifiers pass both portions of the sine wave input but with the same polarity.
- The ripple frequency for a full-wave rectifier is twice the input line frequency.
- Whatever portion of the input voltage that is not dropped across the load resistor will be dropped across the diode(s).

Module 5B: AC Meters

This section discusses full-wave and half-wave meters. We begin with analog full-wave meters for voltage measurement.

Full-Wave Meters

An analog AC meter is basically a DC meter behind an input rectifier. The meter deflection current is first rectified by the full-wave bridge whose rectified current activates the meter. However, this current is not true DC, but a pulsating DC. This will require correction both in the meter scale and in determining the multiplier resistance. The current that activates the meter is the average value of the input signal. Although some other meter types use the effective (rms) voltage, a typical rectifying meter uses the average current because there is no filtering of the pulsating DC, and the inertia of the meter movement limits the amount of travel the meter movement can make in trying to follow each pulsation. For very low frequency AC voltages, the meter movement may approach the rms value.

However, at 60 Hz, one of the more common AC frequencies, only the average value will be measured. As most measurements of AC are in rms, the *meter scale* is converted from average to rms. This means the DC scales cannot be used because the average voltage using full-wave rectification is 0.9 of the rms value for a sinusoidal waveform. *Sinusoidal waveforms* are the only ones included in the discussion of full-wave and half-wave rectifying meters. To determine the multiplier resistance, the average versus the rms scale must be considered.

Example

Suppose you want to measure 10 V rms at full scale. The meter movement is a 1 mA FSD with 100 Ω resistance. What is the multiplier resistor value?

Determine the average voltage for the value of rms at full scale. At 10 V rms (full scale), the average (for full-wave rectification) is 0.9 • rms, then 10 V • 0.9 = 9 V. Therefore, when 10 V rms is to be measured, you want 9 V to give FSD. This means the multiplier must be figured for 9 V, not 10 V.

The total resistance required to drop 9 V at 1.0 mA is 9000 Ω. The meter has 100 Ω, so the multiplier resistor will be 8900 Ω.

Even though the meter had a DC sensitivity of 1000 Ω/V, the AC sensitivity using full-wave rectification is 900 Ω/V. This is due to measuring the average voltage and converting the scale to rms.

The diode resistance must be considered when determining the multiplier resistor values.

Example

Any circuit path through the bridge must go through two diodes. Therefore, if the diode resistances of D through D_4 were 54 Ω (a realistic value), the total diode resistance for the diodes in this example is 108 Ω.

$$Rm + D + d + R = 9000\ \Omega$$

$$100 + 54 + 54 + R = 9000\ \Omega$$

$$R = 9000 - 208\ \Omega$$

$$R = 8792\ \Omega$$

where

R = multiplier resistance
R_m = meter resistance
D_x = one diode resistance in bridge
D_y = companion diode resistance in bridge

The diode resistances for a multirange meter are included in the computation of the first meter range only.

A factor that must be considered is the forward voltage drop of the diodes. The voltage drop across the diode obeys Ohm's law in the linear portion of the diode characteristic, as shown in Figure 5-6a and Figure 5-6b.

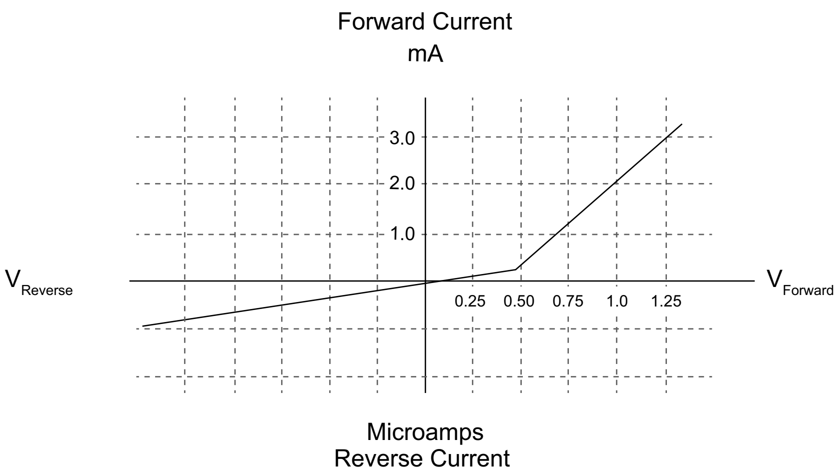

Figure 5-6a. Typical germanium diode curve.

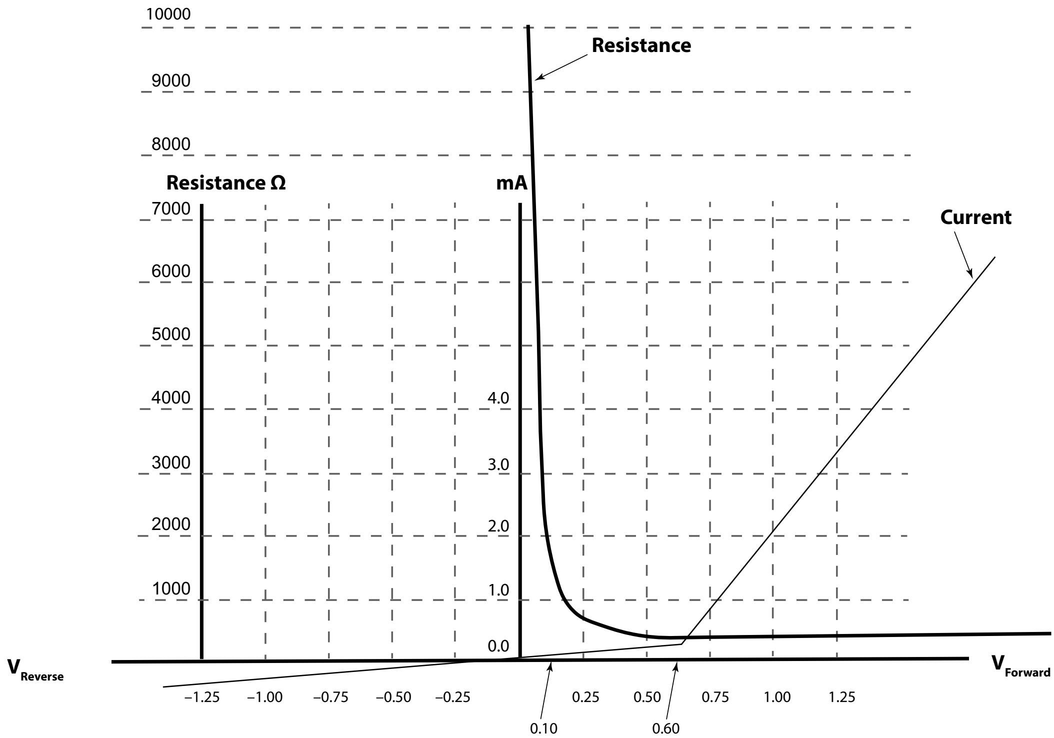

Figure 5-6b. Resistance curve of a diode.

The linear portion of the diode curve shown in Figure 5-6b has a 400 Ω forward resistance. Below the linear portion (approximately 0.6 V), the resistance rapidly increases. At 0.5 V, it is 1000 Ω and rises rapidly; at 0.1 V, it is approaching 10 kΩ.

The diode is a *current activated device*, the forward voltage drop across the diode being the result of the amount of forward current. A current more than 1.0 mA (requiring approximately 0.6 V) for the diode curve shown will cause the diode to operate in the linear portion of its characteristic curve.

For a bridge circuit, these voltage drops, as well as the diode forward resistance, must be added.

Example

In the circuit shown in Figure 5-5, if the diodes had a forward drop of 0.6 V (to operate in the linear portion of their curve), the combined drop would be 1.2 V. This drop has the effect of crowding the low end of the AC scale (in this case, any voltage below 1.2 V), requiring other techniques to be used to measure very small AC voltages.

Half-Wave Meters

To overcome some of the disadvantages of the bridge-type AC rectifier, the half-wave circuit shown in Figure 5-7 is used in most general-purpose analog multimeters.

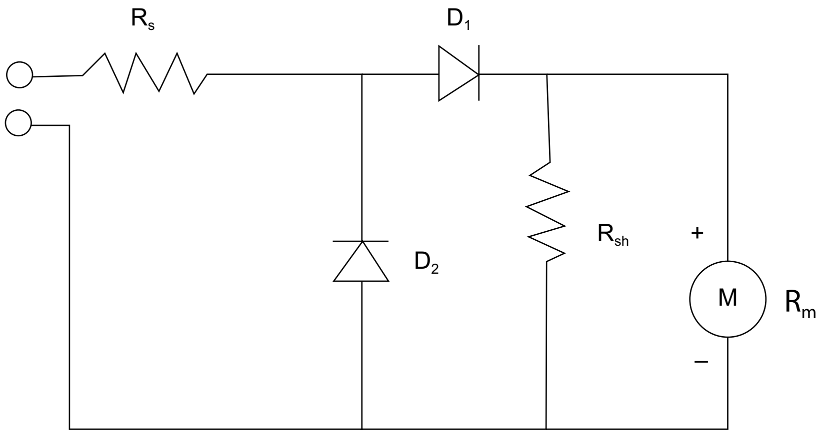

Figure 5-7. Half-wave meter.

D_2 is used to pass the negative alternation to ground, preventing a high peak inverse voltage across D_1 and the resultant leakage currents. R_{sh} is a shunt resistor, usually the same value as R_m but may be less. For $R_{sh} = R_m$, twice the current will flow for a given voltage. This will cause the diode to operate on the linear portion of its characteristic curve for lower applied voltages, reducing the sensitivity by half.

To determine the multiplier resistor value, the combined (total) current value must be used. Note that when using a half-wave circuit (and a sine wave input), the average current will be 0.45 of rms. This entails some vigorous meter scaling, particularly when using the shunt resistor.

Module 5B: Analog Meter Review

- An analog meter movement using rectifiers will measure average voltage.
- The average voltage (for full-wave rectifications of a sinusoid) is 0.9 times the rms voltage.
- Scales are calibrated to read in rms while measuring average.
- A full-wave rectifier circuit reduces accuracy on the lower scales because of diode voltage drops.

- The sensitivity of the meter is reduced because the meter measures average current but is scaled to rms values.
- To convert rms to average for a half-wave circuit, the factor 0.45 is used for sinusoidal waveforms.
- The half-wave rectifier meter uses a shunt resistor to measure lower voltages accurately.
- The half-wave circuit with a shunt resistor reduces the sensitivity of the circuit.
- Both half-wave and full-wave rectifying instruments require a sinusoidal waveform and have an upper frequency limit for measurement accuracy.
- The diode forward voltage drop is less in a half-wave meter circuit, thereby increasing the accuracy of the lower scale.

Digital AC Meters

The primary difference between digital and analog meters is that the analog types depend on the FSD current of the meter for their sensitivity, and to filter the pulsations. As we've learned previously, this is work (P = E • R) and why the meters read average voltage (although scaled to rms).

Digital meters have the advantage in that they are powered, usually by batteries or an AC line adapter, whereas analog meters are powered by the measured circuit voltage and current. However, with modern electronics, it takes very little power to perform many complex operations. Figure 5-8 is a block diagram of the AC measuring circuitry of a typical digital voltmeter (DVM).

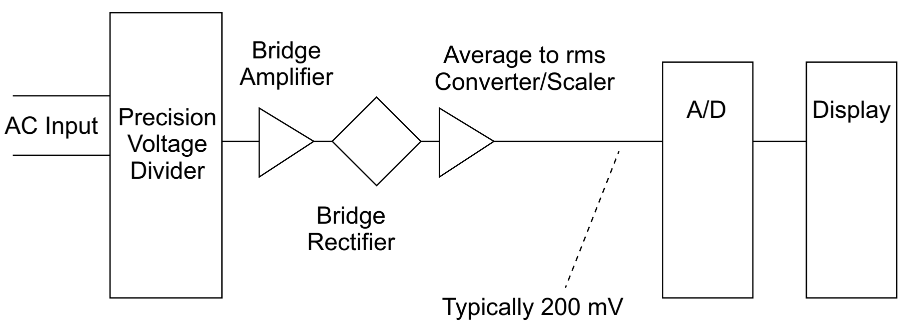

Figure 5-8. Typical AC portion of a DVM.

The precision divider generally divides in units of 10. The signal presented to the bridge amplifier/bridge rectifier is in the 0 to 200 mV range. The amplifier is used to bring the signals to an amplitude that will force the rectifiers (small signal germanium) to operate in the linear portion of their range (among other things). After rectification, the signal is filtered and applied to the converter/scaler, which outputs a DC signal proportional to the input on the 0 to 200 mV span input to the A/D, which is normally a dual slope converter. The measured signal, because it is rectified, is an average, but the scaler outputs the voltage as an rms value.

There are several calibration points on the digital multimeters, but calibration is normally performed in a calibration shop by experienced and qualified personnel.

Considerations When Using AC Meters

There are two main considerations when using AC meters.

1. Frequency of input signal
2. Waveform of input signal

Input Signal Frequency

The frequency of input signal affects both digital and analog meters, but it affects the analog meters more. As frequency continues upward, there are inductive and capacitive effects that tend to reduce the amount of AC available to operate the meter. As the frequency continues upward, the actual indicator response will drop off, so even if the source is at 10 V rms, the meter may not read 1 V rms or even less. This drop-off starts at a fairly low frequency for analog meters, generally anywhere above 500 Hz. Because of the way digital meters are constructed, the effects are not noticeable until (in many cases) 10 kHz or much higher. Remember, though, these devices generally use a slow integrating AC to DC converter, and at some frequency the sampling rate will not permit accurate measurement.

Input Signal Waveform

This affects both analog and digital meters that use rectification equally. All the conversions between peak and average, peak and rms, and so forth, discussed to date require a sinusoidal waveform. Many AC waveforms are not sinusoidal and are not measured well with a rectifying type of AC meter.

Example

Use Figure 5-9 to determine the average power and peak voltage.

Figure 5-9. Square wave.

If a half-wave rectifier meter is used with this signal input, the output would have one or the other alternation. In either case, the average voltage would equal half the peak (conversion factor of 0.5). In full-wave rectification, the average voltage would equal the peak voltage (conversion factor of 1.0). Obviously, if the meter is using the average voltage and scaling it to rms, this waveshape will not display correctly.

Few measurements of AC involve pure sine waves. Even the 60 Hz power line has harmonic (multiples of the frequency) information. This is why the oscilloscope was necessary historically and is still necessary to view nonsinusoidal waveforms.

Module 5B: Summary

- The frequency of the input signal has an effect on the measurement by rectifying meters.
- The waveshape of the input signal affects the measurement taken by rectifying meters.

Module 5B: Review

1. Using Figure R5-1, draw the waveforms that will be present across the resistor and the diode. Label each waveform with the voltage level.

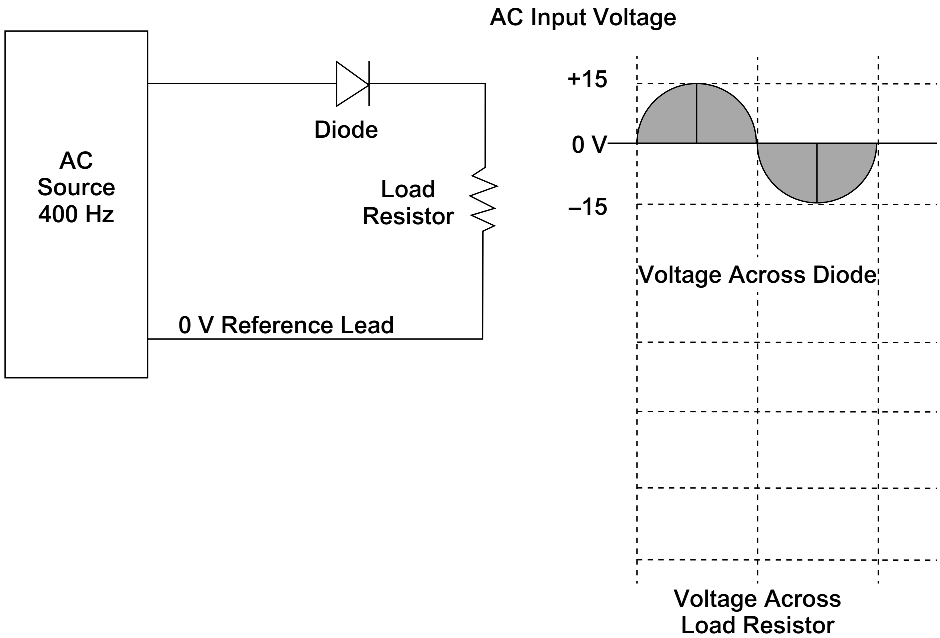

Figure R5-1.

2. Draw the output waveform for a full-wave rectifier (without a filter), assuming an input frequency of 400 Hz at 100 V rms.

3. In the waveform you just drew, what is the average voltage? What is the peak voltage?

   Average voltage ______________

   Peak voltage ______________

Module 5C: Current Transformers

A current transformer (CT) produces an output in proportion to the current flowing through the primary winding. The CT is an instrument transformer designed to generate an AC in its secondary winding that is proportional to the current flowing in its primary winding. CTs reduce high-voltage currents to a much lower value and provide a method of safely monitoring the actual high-potential electrical current flowing in an AC load using a standard ammeter. A typical CT is illustrated in Figure 5-10.

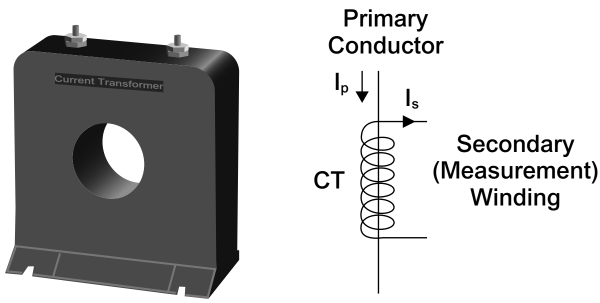

Figure 5-10. Typical CT.

The principle of operation of a basic CT is slightly different from that of an ordinary voltage transformer. The difference between previously described transformers and the CT is that the CT primary winding consists of only one or very few turns. This primary winding can be a coil of wire wrapped around the core or just a conductor or bus bar placed through a central hole in the CT as shown in Figure 5-10.

The secondary winding has many coil turns wound on a laminated core of low-loss magnetic material. Due to the core's large cross-sectional area, the magnetic flux density is low, and by using a much smaller gauge wire, the secondary current is independent of the secondary connected load (within reason).

The secondary winding supplies current into either a short circuit (an ammeter) or a resistive load. This current will increase until the current induced in the secondary saturates the core or the core fails because of an excessive voltage breakdown.

The primary current of a CT does not depend on the secondary load current but on the external load. Typically, the secondary current is rated at a 1 A (or 5 A for larger primary current ratings).

CTs are generally constructed in one of three ways:

- **Wound current transformer** – The primary winding is physically connected in series with the load conductor. The secondary current depends on the turns ratio of the transformer.
- **Bar-type current transformer** – This type uses the actual cable or bus bar of the main circuit as the primary winding (equivalent to a single turn).

- **Toroidal current transformer** – There is no primary winding. The line that carries the load current is placed through the center hole in the toroidal transformer. Typically, CTs have a split core that can be opened, installed, and closed without disconnecting the load circuit.

CTs can step down currents from thousands of amperes to a secondary output of 1 A (or 5 A for high currents). Because of this reduction, standard instrumentation may be used with CTs as they are isolated from any high-voltage power.

Typically, CTs and ammeters are produced as a connected set; the design provides a maximum secondary current that corresponds to the full-scale deflection of the ammeter. For this reason, a CT is generally calibrated for a specific type of ammeter.

CTs have a standard secondary rating of 1 A or 5 A, with the primary and secondary currents being a ratio such as 100:1 or 100:5. A ratio of 100:1 means the primary current in the secondary circuit is 100 times greater than the secondary current. A 100:5 ratio means there is 20 times greater current in the primary than in the secondary circuit. In either case, when 100 A is flowing in the primary conductor, it will result in either 1 A (100:1) or 5 A (100:5) in the secondary. A CT of 300:5 will produce 5 A in the secondary for 300 A in the primary conductor.

Note that by increasing the number of secondary windings, the secondary current will be smaller. This increases the ratio, so the secondary current will decrease for a specific primary current. The number of primary turns and the primary current and the number of secondary windings is in an inverse proportion.

A CT must conform to the amp-turn equation more commonly known as the turns ratio. As discussed in Module 2G on transformers, the turns ratio for voltage transformers is equal to:

$$\text{Turns Ratio} = n = \frac{Np}{Ns} = \frac{Is}{Ip} \tag{5-1}$$

With a little algebraic dexterity,

$$\text{Secondary Current} = Is = Ip\,\frac{Np}{Ns} \tag{5-2}$$

The primary typically consists of one or two turns, whereas the secondary may have up to several hundred turns.

Example

With a primary winding current rating of 200 A, the secondary has the standard rating of 5 A, which means that when the primary has a 200 A current, the secondary will output 5 A. The ratio between the primary and the secondary currents is 40:1.

If the secondary is not shorted (connected to an ammeter) when not in use, high voltages can appear at the terminals. Remember that we are doing current ratios; the actual windings might be 1 on the primary and up to 200 on the secondary. In this case, an *unsafe* condition may result. Always short the secondary windings until they are connected to the actual instrumentation (and ensure that a terminating resistance is connected). If the ammeter (or load) is to be removed, a short circuit should be placed across the secondary terminals prior to removal to eliminate the risk of shock.

Clamp-on Ammeters

Many specialized types of current transformers are available. One type, which can be used to measure circuit loading without disconnecting the load circuits, is called a *clamp-on ammeter*. Typical clamp-on ammeters are illustrated in Figure 5-11.

Clamp-on ammeters open and close the ferrous core around a current-carrying conductor and measure its current by determining the magnetic field around it. This provides a quick measurement reading (usually on a digital display) without disconnecting or opening the circuit.

Clamp-on ammeters are available for measuring currents from 0.004 to 5000 A, with square window sizes from 1 to over 12 in (from 25 to 300 mm). There are also multi-range meters that can measure from 10 to 5000 A in full range.

Figure 5-11. Typical clamp-on ammeters.

DC Clamp-on Ammeters

DC clamp-on ammeters look similar to, and operate similarly to, the AC types; in fact, most DC types offer AC measurements as well. Because this type of ammeter uses a clamp-on ferrous detector, there is no need to break the circuit. In addition, because a DC clamp-on ammeter is contactless, it is much safer than using an ammeter that is inserted in-line. Using a clamp-on ammeter to measure control circuits is less disturbing to the circuit and much more convenient, and the process is not bumped. Current probes for oscilloscopes use the Hall effect rather than an inductive pickup.

To measure DC, the ammeter uses a Hall effect device to measure the axial magnetic field generated in the primary wire by the current flowing through it. The clamp surrounds the wire (which is creating a magnetic field around it, according to Ampere's law). The magnetic field is concentrated by a ferrous core contained in the clamp. This magnetic field is sensed at an air gap that contains a semiconductor Hall effect detector. Current flowing through the Hall effect chip is deflected by the magnetic field, creating a voltage perpendicular to the direction of electron flow. This voltage is detected, amplified, and converted to amperes by internal circuitry and then displayed.

The polarity of the magnetic field depends on the direction of current flow in the wire and is indicated by the plus and minus readings. Indicators on the clamp ring specify which direction the primary flow must be for a positive reading.

Module 5C: Summary

- The current transformer (CT) is an instrument transformer that uses a magnetic core to convert a primary current into a secondary current. The secondary winding provides a greatly reduced current (relative to the primary current) that can be used to detect and display primary current conditions.
- A CT's primary coil is always connected in series with the load conductor, which may then be referred to as a *series transformer*. The nominal secondary current is rated at 1 A or 5 A for ease of measurement. Construction can be one single primary turn as in toroidal or bar types, or a few wound primary turns, usually for low current ratios.
- CTs are intended to be used as current, not voltage, devices. A CT's secondary winding should never be operated in an open circuit.
- The high voltages that result from open circuiting the secondary circuit of an energized CT are hazardous to both equipment and personnel, so their terminals must be short-circuited if the ammeter is to be removed or when a CT is not in use *before* powering up the system.

Module 5C: Review

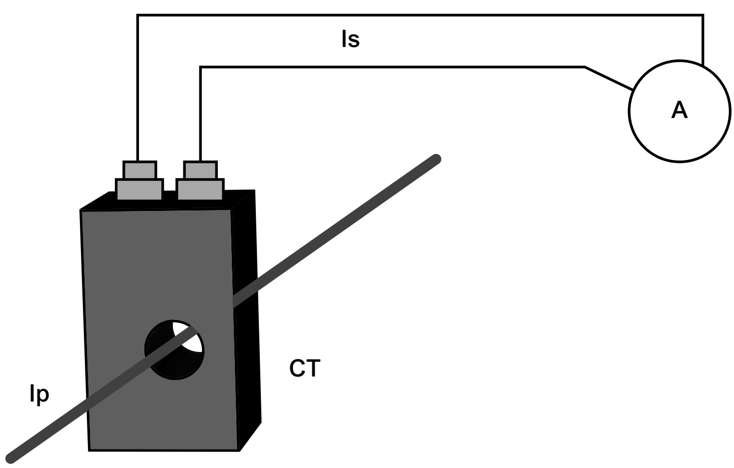

Figure R5-2.

For the circuit shown in Figure R5-2, the CT has a 250:5 ratio.

1. If 125 A flows in the primary, what will the Is value be?

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2. At 125 A in the primary, what should the meter read if the meter is scaled 0 to 250 A?

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Conclusion

You have reached the end of Module 5. Please reread the module objectives (in the "Objectives" section). If you have met these objectives, continue to the next module. If you are having difficulty, please reread the text. If the difficulty persists, locate a peer, mentor, supervisor, or someone who has technical knowledge of AC measurement and ask them to assist you.

Further Information

For additional information on the topics in this module, search for the following topics at your public or company library, or on the Internet.

- AC meters
- AC voltage measurement
- Waveform effects on AC measurements
- Digital AC multimeters
- Analog-to-digital conversions
- Current transformer operations
- Clamp-on ammeters
- 4–20 mA clamp-on ammeters

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