Applied Physics

(PHC-103/104)

Lecture 05 and 06

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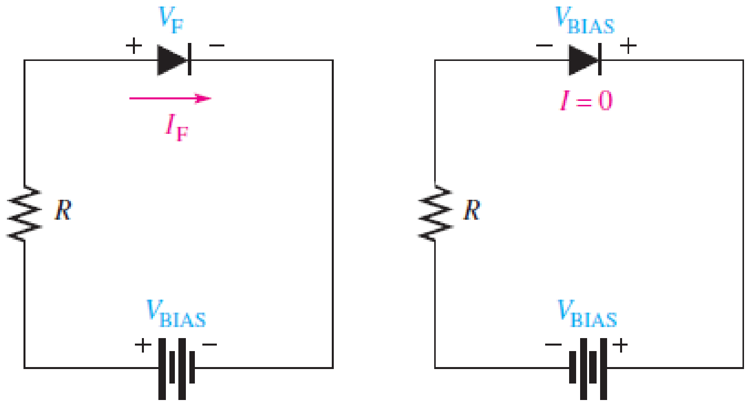
Diode Models

Bias Connections

Forward-Bias Recall that a diode is forward-biased when a voltage source is connected as shown in Figure 2–14(a). The positive terminal of the source is connected to the anode through a current-limiting resistor. The negative terminal of the source is connected to the cathode. The forward current (I_F) is from anode to cathode as indicated. The forward voltage drop (V_F) due to the barrier potential is from positive at the anode to negative at the cathode.

▶ FIGURE 2–14

Forward-bias and reverse-bias connections showing the diode symbol.



(a) Forward bias (b) Reverse bias

Reverse-Bias Connection A diode is reverse-biased when a voltage source is connected as shown in Figure 2–14(b). The negative terminal of the source is connected to the anode side of the circuit, and the positive terminal is connected to the cathode side. A resistor is not necessary in reverse bias but it is shown for circuit consistency. The reverse current is extremely small and can be considered to be zero. Notice that the entire bias voltage (V_{BIAS}) appears across the diode.

Diodes Approximations

The Ideal Diode Model The ideal model of a diode is the least accurate approximation and can be represented by a simple switch. When the diode is forward-biased, it ideally acts like a closed (on) switch, as shown in Figure 2–15(a). When the diode is reverse-biased, it ideally acts like an open (off) switch, as shown in part (b). Although the barrier potential, the forward dynamic resistance, and the reverse current are all neglected, this model is adequate for most troubleshooting when you are trying to determine if the diode is working properly.

In Figure 2–15(c), the ideal *V-I* characteristic curve graphically depicts the ideal diode operation. Since the barrier potential and the forward dynamic resistance are neglected, the diode is assumed to have a zero voltage across it when forward-biased, as indicated by the portion of the curve on the positive vertical axis.

$$V_F = 0\text{ V}$$

The forward current is determined by the bias voltage and the limiting resistor using Ohm's law.

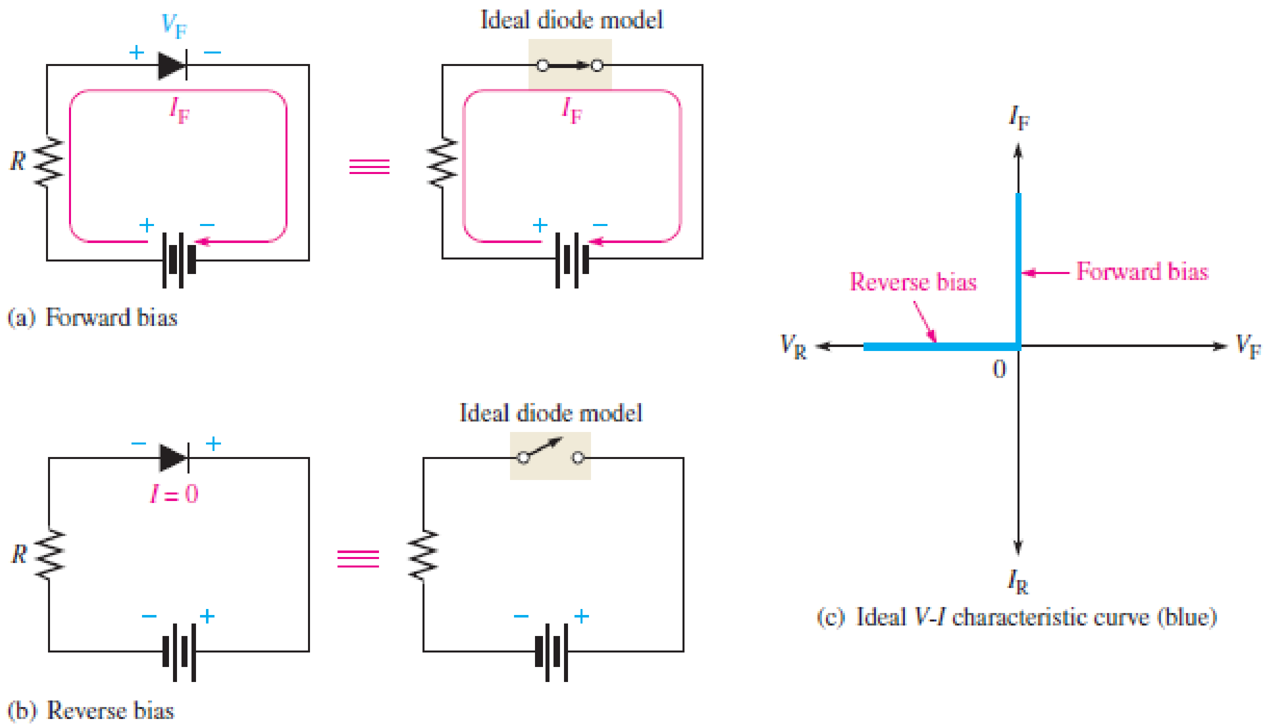
$$I_F = \frac{V_{BIAS}}{R_{LIMIT}}$$

Since the reverse current is neglected, its value is assumed to be zero, as indicated in Figure 2–15(c) by the portion of the curve on the negative horizontal axis.

$$I_R = 0\text{ A}$$

The reverse voltage equals the bias voltage.

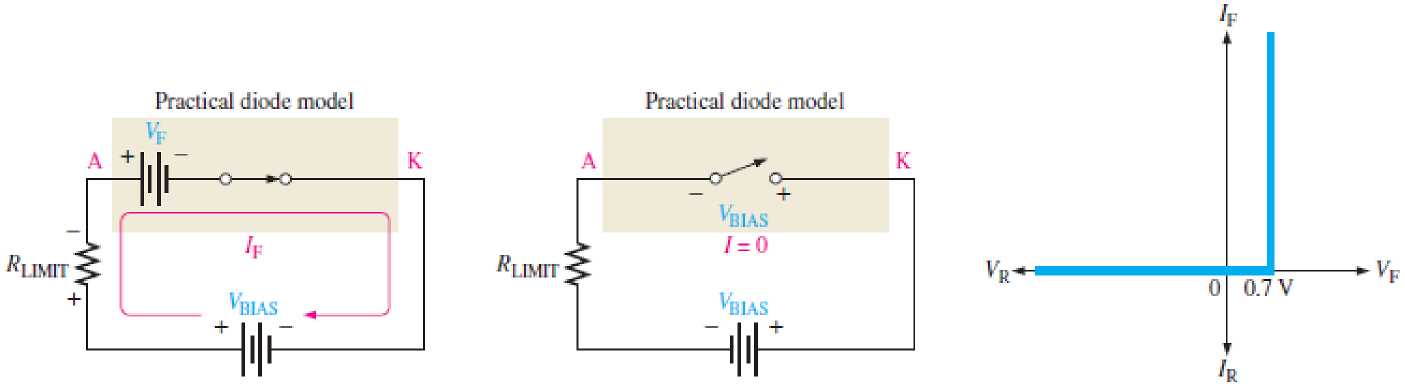
$$V_R = V_{BIAS}$$



▲ FIGURE 2–15

The ideal model of a diode.

The Practical Diode Model The practical model includes the barrier potential. When the diode is forward-biased, it is equivalent to a closed switch in series with a small equivalent voltage source (V_F) equal to the barrier potential (0.7 V) with the positive side toward the anode, as indicated in Figure 2–16(a). This equivalent voltage source represents the barrier potential that must be exceeded by the bias voltage before the diode will conduct and is not an active source of voltage. When conducting, a voltage drop of 0.7 V appears across the diode.



(a) Forward bias (b) Reverse bias (c) Characteristic curve (silicon)

▲ FIGURE 2–16

The practical model of a diode.

When the diode is reverse-biased, it is equivalent to an open switch just as in the ideal model, as shown in Figure 2–16(b). The barrier potential does not affect reverse bias, so it is not a factor.

The characteristic curve for the practical diode model is shown in Figure 2–16(c). Since the barrier potential is included and the dynamic resistance is neglected, the diode is assumed to have a voltage across it when forward-biased, as indicated by the portion of the curve to the right of the origin.

$$V_F = 0.7\text{ V}$$

The forward current is determined as follows by first applying Kirchhoff's voltage law to Figure 2–16(a):

$$V_{BIAS} - V_F - V_{R_{LIMIT}} = 0$$

$$V_{R_{LIMIT}} = I_F R_{LIMIT}$$

Substituting and solving for I_F,

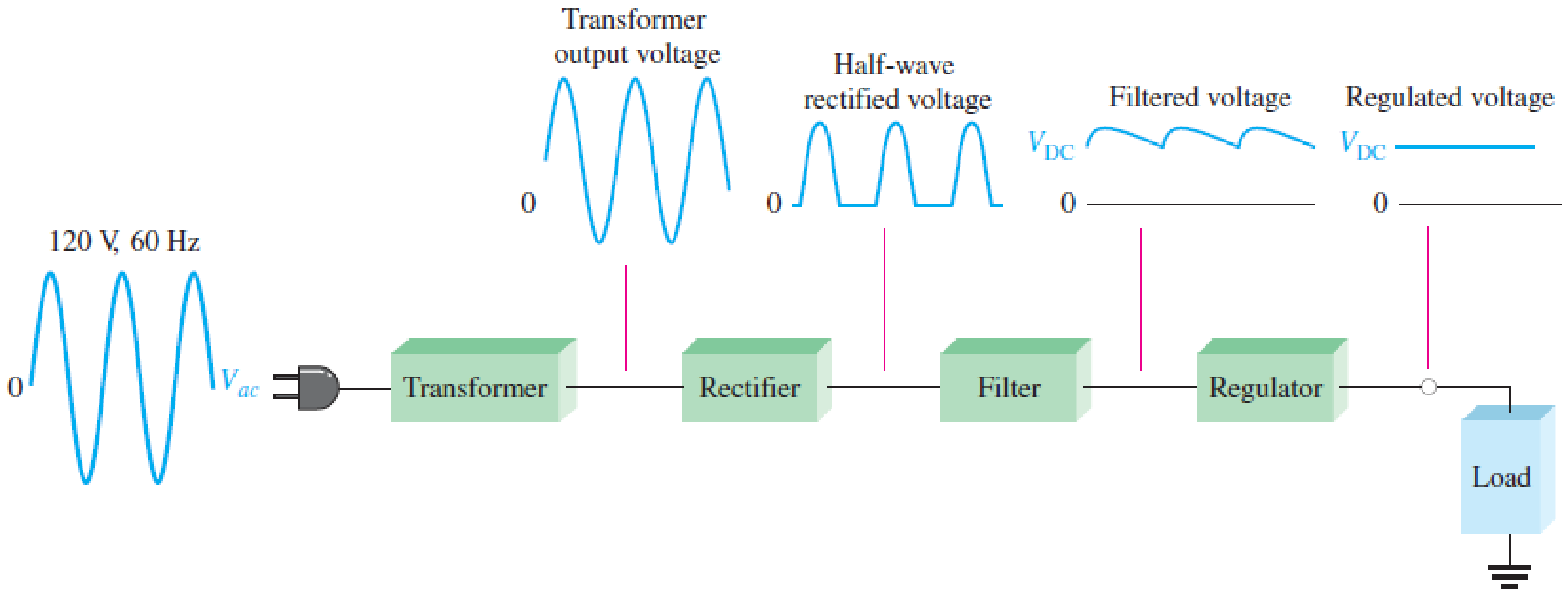
$$I_F = \frac{V_{BIAS} - V_F}{R_{LIMIT}}$$

The diode is assumed to have zero reverse current, as indicated by the portion of the curve on the negative horizontal axis.

$$I_R = 0\text{ A}$$

$$V_R = V_{BIAS}$$

Because of their ability to conduct current in one direction and block current in the other direction, diodes are used in circuits called **rectifiers** that **convert ac voltage into dc voltage**. Rectifiers are found in all dc power supplies that operate from an ac voltage source

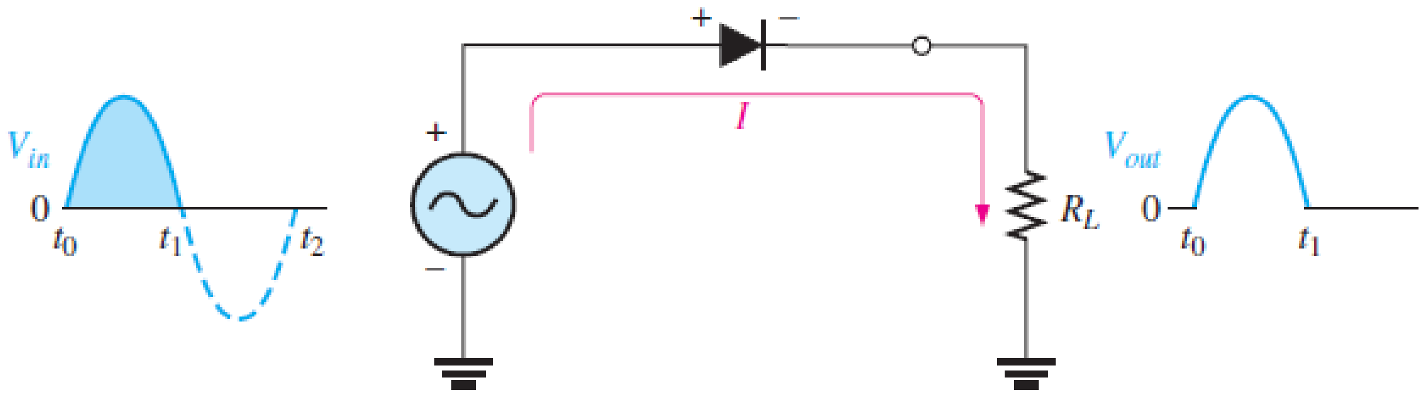


(a) Complete power supply with transformer, rectifier, filter, and regulator

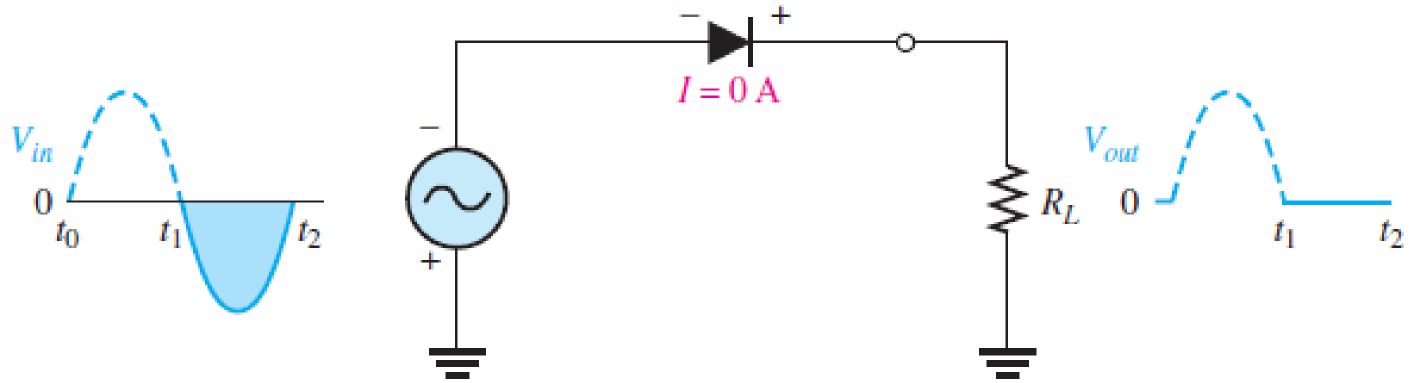
HALF-WAVE RECTIFIERS

Half-Wave Rectifier Operation

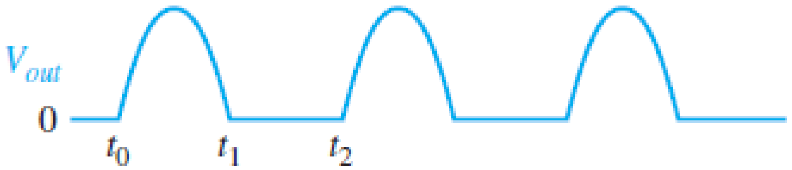
Figure 2–20 illustrates the process called *half-wave rectification.* A diode is connected to an ac source and to a load resistor, R_L, forming a **half-wave rectifier**. Keep in mind that all ground symbols represent the same point electrically. Let's examine what happens during one cycle of the input voltage using the ideal model for the diode. When the sinusoidal input voltage (V_{in}) goes positive, the diode is forward-biased and conducts current through the load resistor, as shown in part (a). The current produces an output voltage across the load R_L, which has the same shape as the positive half-cycle of the input voltage.



(a) During the positive alternation of the 60 Hz input voltage, the output voltage looks like the positive half of the input voltage. The current path is through ground back to the source.



(b) During the negative alternation of the input voltage, the current is 0, so the output voltage is also 0.



(c) 60 Hz half-wave output voltage for three input cycles

▲ FIGURE 2–20

Half-wave rectifier operation. The diode is considered to be ideal.

When the input voltage goes negative during the second half of its cycle, the diode is reverse-biased. There is no current, so the voltage across the load resistor is 0 V, as shown in Figure 2–20(b). The net result is that only the positive half-cycles of the ac input voltage appear across the load. Since the output does not change polarity, it is a pulsating dc voltage with a frequency of 60 Hz, as shown in part (c).

Average Value of the Half-Wave Output Voltage The average value of the half-wave rectified output voltage is the value you would measure on a dc voltmeter. Mathematically, it is determined by finding the area under the curve over a full cycle, as illustrated in Figure 2–21, and then dividing by 2π, the number of radians in a full cycle. The result of this is expressed in Equation 2–3, where V_p is the peak value of the voltage.

$$V_{AVG} = \frac{V_p}{\pi}$$

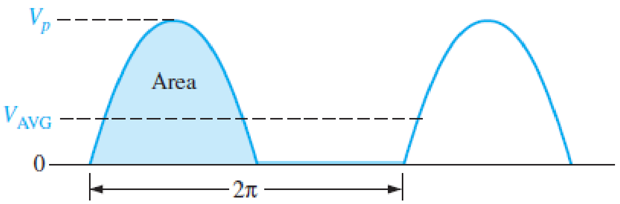
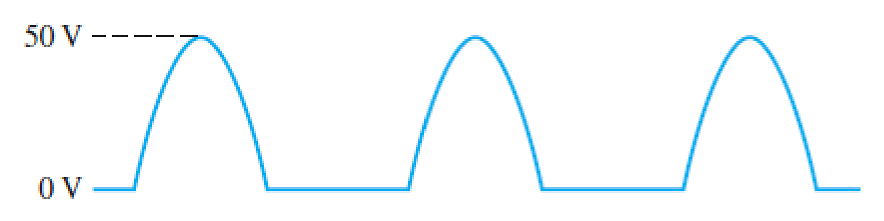


FIGURE 2–21

Average value of the half-wave rectified signal.

EXAMPLE 2–2 What is the average value of the half-wave rectified voltage in Figure 2–22?

FIGURE 2–22



Solution

$$V_{AVG} = \frac{V_p}{\pi} = \frac{50\text{ V}}{\pi} = \mathbf{15.9\ V}$$

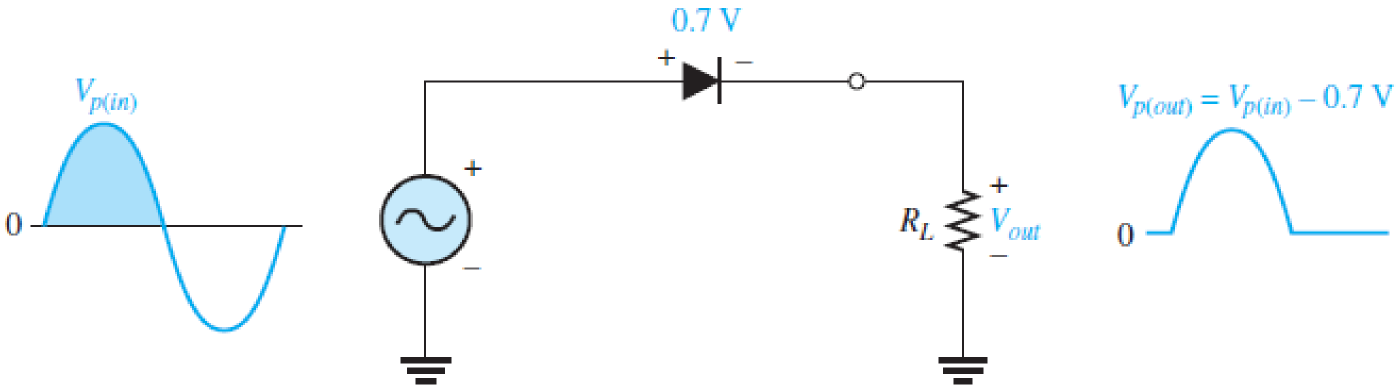
Notice that V_{AVG} is 31.8% of V_p.

Related Problem Determine the average value of the half-wave voltage if its peak amplitude is 12 V.

Effect of the Barrier Potential on the Half-Wave Rectifier Output

In the previous discussion, the diode was considered ideal. When the practical diode model is used with the barrier potential of 0.7 V taken into account, this is what happens. During the positive half-cycle, the input voltage must overcome the barrier potential before the diode becomes forward-biased. This results in a half-wave output with a peak value that is 0.7 V less than the peak value of the input, as shown in Figure 2–23. The expression for the peak output voltage is

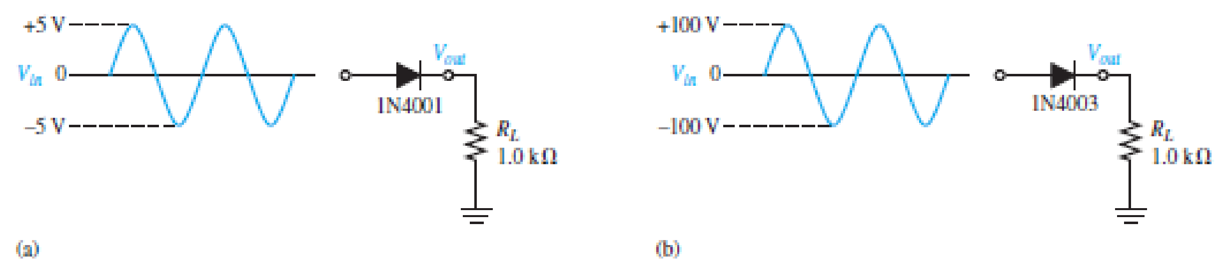
$$V_{p(out)} = V_{p(in)} - 0.7\text{ V} \qquad \text{Equation 2–4}$$



▲ FIGURE 2–23

The effect of the barrier potential on the half-wave rectified output voltage is to reduce the peak value of the input by about 0.7 V.

EXAMPLE 2–3 Draw the output voltages of each rectifier for the indicated input voltages, as shown in Figure 2–24. The 1N4001 and 1N4003 are specific rectifier diodes.



▲ FIGURE 2–24

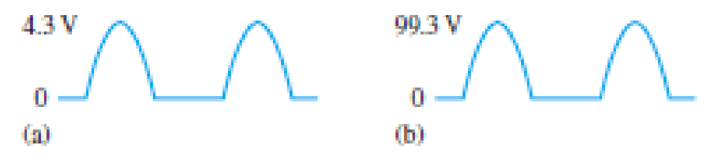
Solution The peak output voltage for circuit (a) is

$$V_{p(out)} = V_{p(in)} - 0.7\text{ V} = 5\text{ V} - 0.7\text{ V} = \mathbf{4.30\ V}$$

The peak output voltage for circuit (b) is

$$V_{p(out)} = V_{p(in)} - 0.7\text{ V} = 100\text{ V} - 0.7\text{ V} = \mathbf{99.3\ V}$$

The output voltage waveforms are shown in Figure 2–25. Note that the barrier potential could have been neglected in circuit (b) with very little error (0.7 percent); but, if it is neglected in circuit (a), a significant error results (14 percent).



▲ FIGURE 2–25

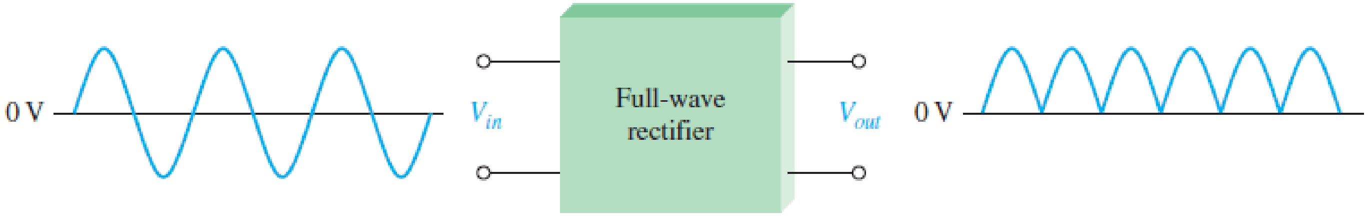
Output voltages for the circuits in Figure 2–24. They are not shown on the same scale.

Related Problem Determine the peak output voltages for the rectifiers in Figure 2–24 if the peak input in part (a) is 3 V and the peak input in part (b) is 50 V.

FULL-WAVE RECTIFIERS

Although half-wave rectifiers have some applications, the full-wave rectifier is the most commonly used type in dc power supplies.

A **full-wave rectifier** allows unidirectional (one-way) current through the load during the entire 360° of the input cycle, whereas a half-wave rectifier allows current through the load only during one-half of the cycle. The result of full-wave rectification is an output voltage with a frequency twice the input frequency and that pulsates every half-cycle of the input, as shown in Figure 2–29.



▲ FIGURE 2–29

Full-wave rectification.

The number of positive alternations that make up the full-wave rectified voltage is twice that of the half-wave voltage for the same time interval. The average value, which is the value measured on a dc voltmeter, for a full-wave rectified sinusoidal voltage is twice that of the half-wave, as shown in the following formula:

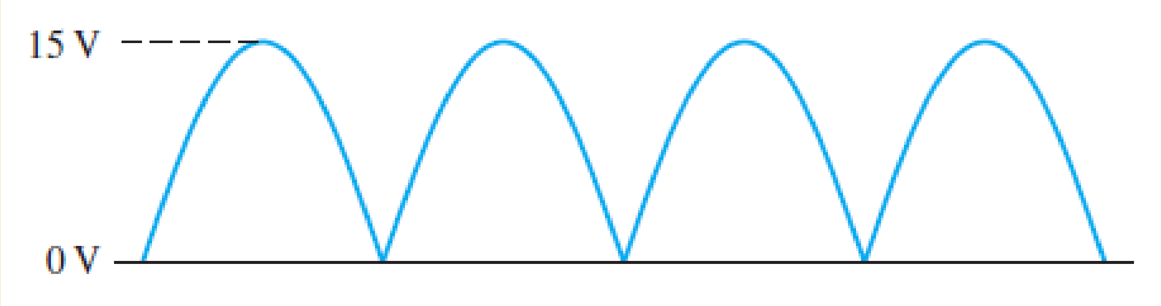
$$V_{AVG} = \frac{2V_p}{\pi}$$

Equation 2–6

V_{AVG} is approximately 63.7% of V_p for a full-wave rectified voltage.

EXAMPLE 2–5 Find the average value of the full-wave rectified voltage in Figure 2–30.

▶ FIGURE 2–30



Solution

$$V_{AVG} = \frac{2V_p}{\pi} = \frac{2(15\text{ V})}{\pi} = \mathbf{9.55\ V}$$

V_{AVG} is 63.7% of V_p.

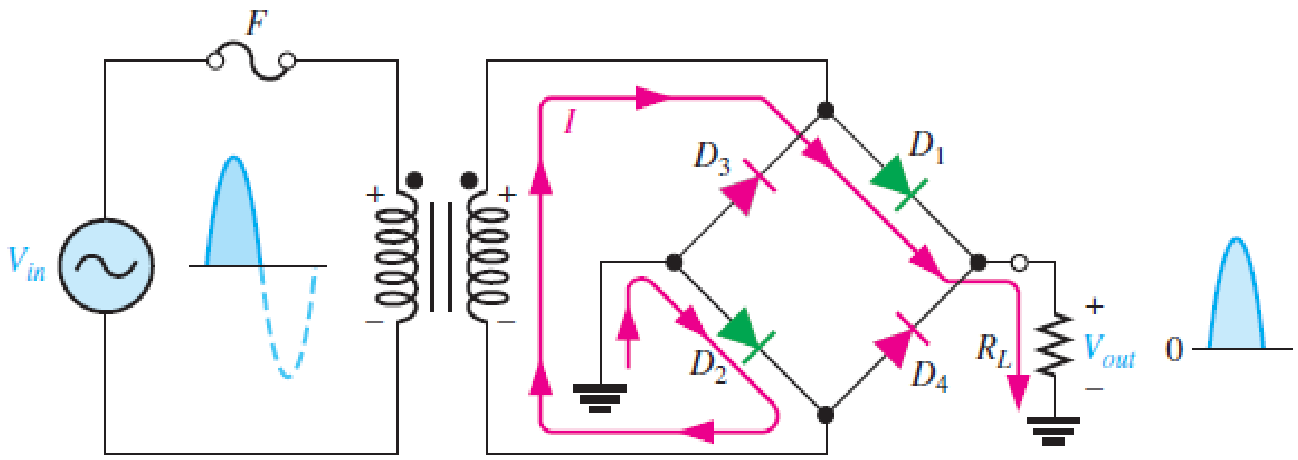
Related Problem Find the average value of the full-wave rectified voltage if its peak is 155 V.

Bridge Full-Wave Rectifier Operation

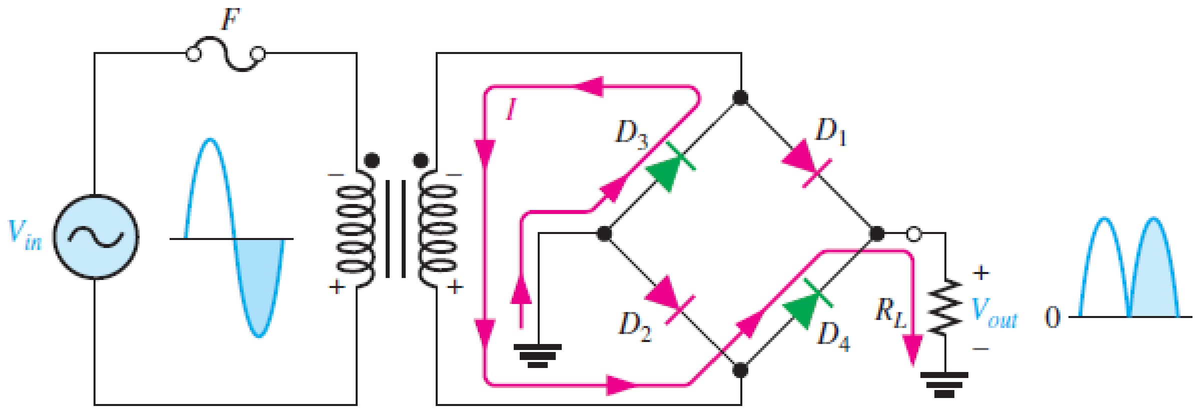
The **bridge rectifier** uses four diodes connected as shown in Figure 2–38. When the input cycle is positive as in part (a), diodes D_1 and D_2 are forward-biased and conduct current in the direction shown. A voltage is developed across R_L that looks like the positive half of the input cycle. During this time, diodes D_3 and D_4 are reverse-biased.

◀ FIGURE 2–38

Operation of a bridge rectifier.



(a) During the positive half-cycle of the input, D_1 and D_2 are forward-biased and conduct current. D_3 and D_4 are reverse-biased.



(b) During the negative half-cycle of the input, D_3 and D_4 are forward-biased and conduct current. D_1 and D_2 are reverse-biased.

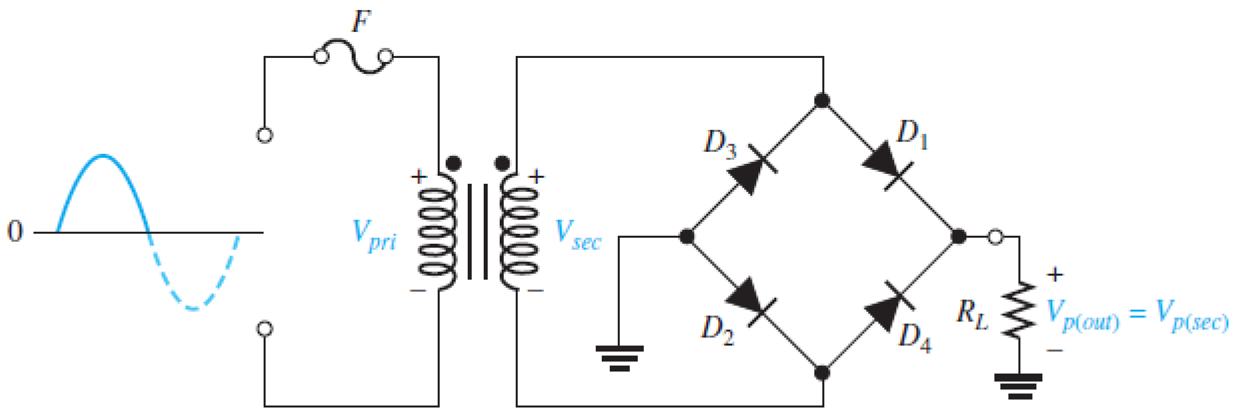
When the input cycle is negative as in Figure 2–38(b), diodes D_3 and D_4 are forward-biased and conduct current in the same direction through R_L as during the positive half-cycle. During the negative half-cycle, D_1 and D_2 are reverse-biased. A full-wave rectified output voltage appears across R_L as a result of this action.

Bridge Output Voltage A bridge rectifier with a transformer-coupled input is shown in Figure 2–39(a). During the positive half-cycle of the total secondary voltage, diodes D_1 and D_2 are forward-biased. Neglecting the diode drops, the secondary voltage appears across the load resistor. The same is true when D_3 and D_4 are forward-biased during the negative half-cycle.

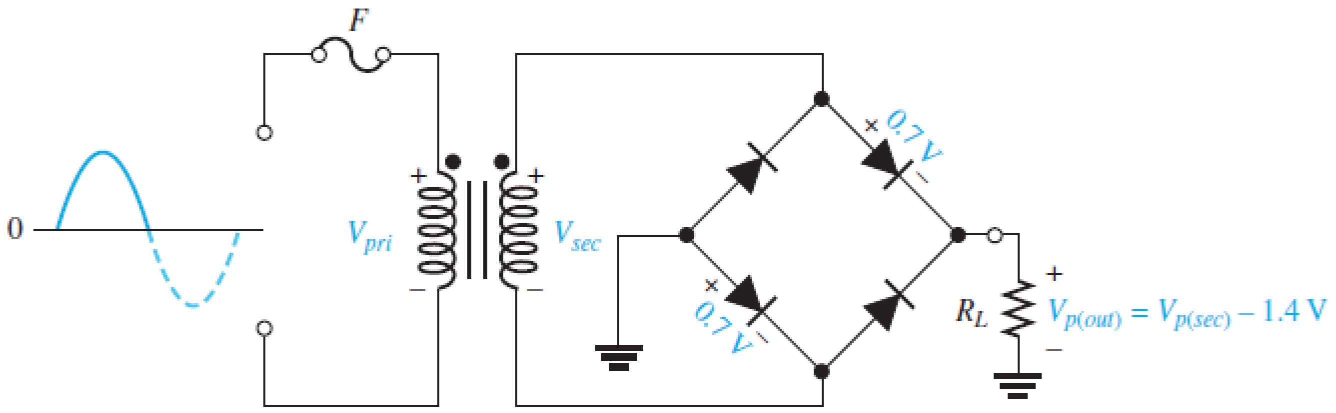
$$V_{p(out)} = V_{p(sec)}$$

As you can see in Figure 2–39(b), two diodes are always in series with the load resistor during both the positive and negative half-cycles. If these diode drops are taken into account, the output voltage is

$$\mathbf{V_{p(out)} = V_{p(sec)} - 1.4\ V} \qquad \text{Equation 2–9}$$



(a) Ideal diodes



(b) Practical diodes (Diode drops included)

▲ FIGURE 2–39

Bridge operation during a positive half-cycle of the primary and secondary voltages.