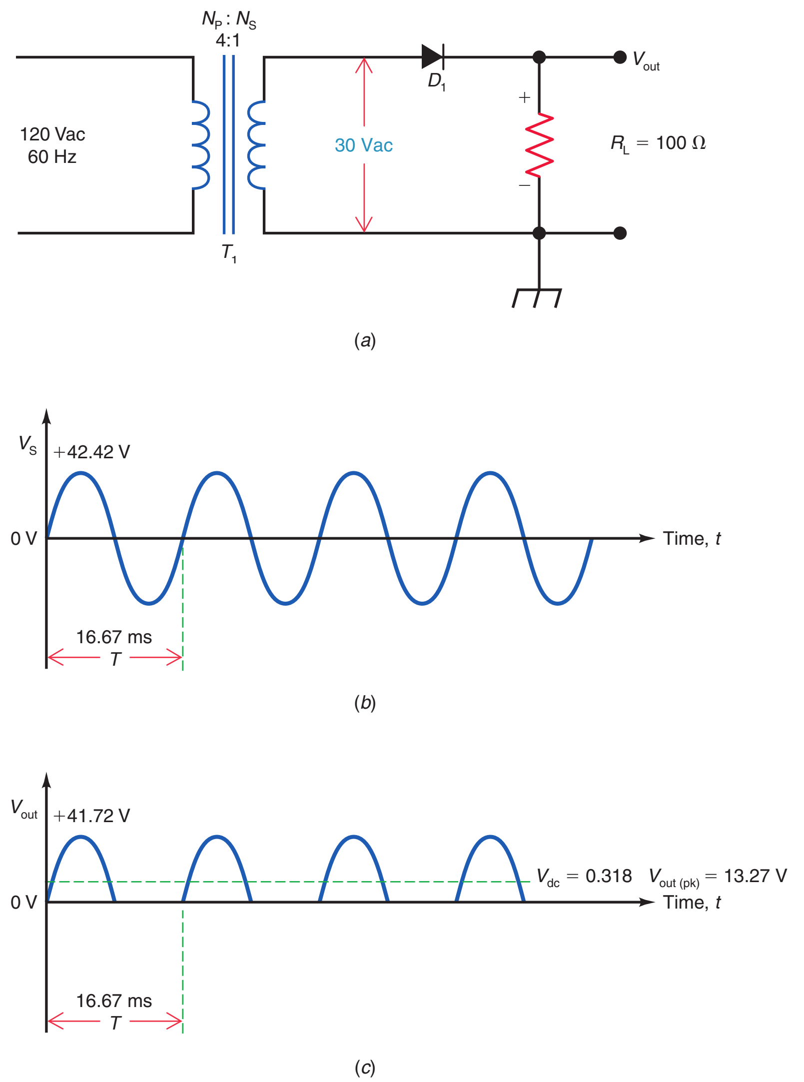
> **GOOD TO KNOW**
>
> The rms value of a half-wave signal can be determined using the following formula: $V_{rms} = 1.57\ V_{avg}$, where $V_{avg} = V_{dc} = 0.318\ V_p$. Another formula that works is $V_{rms} = \frac{V_p}{2}$. For any waveform, the rms value corresponds to the equivalent dc value that will produce the same heating effect.

power-line voltage to the required dc value is called a *power supply*. The most important components in power supplies are *rectifier diodes*, which convert ac line voltage to dc voltage. Diodes are able to produce a dc output voltage because they are unidirectional devices allowing current to flow through them in only one direction. For the circuits that follow, assume that all diodes are silicon.

The Half-Wave Rectifier

The circuit shown in Fig. 27–15*a* is called a *half-wave rectifier.* T_1 is a step-down transformer, which provides the secondary voltage, V_S, shown in Fig. 27–15*b*. When the top of the transformer secondary voltage is positive, D_1 is forward-biased, producing current flow in the load, R_L. When the top of the secondary is negative, D_1 is reverse-biased and acts like an open switch. This results in zero current in the load, R_L. As a result of this action, the output voltage is a series of positive pulses, as shown in Fig. 27–15*c*.

Figure 27–15 Half-wave rectifier. (*a*) Circuit. (*b*) Secondary voltage, V_S. (*c*) Output waveform, V_{out}.



Transformer Calculations

The transformer in Fig. 27–15*a* has a turns ratio, $N_P : N_S$, of 4:1. Therefore, the root-mean-square (rms) secondary voltage is calculated as shown:

$$V_S = \frac{N_S}{N_P} \times V_P$$

$$= \frac{1}{4} \times 120 \text{ Vac}$$

$$= 30 \text{ Vac}$$

This means that if the secondary voltage is measured with an ac meter, it would read 30 Vac.

To calculate the peak secondary voltage, we proceed as shown:

$$V_{S(pk)} = V_S \times 1.414$$

$$= 30 \text{ V} \times 1.414$$

$$= 42.42 \text{ V}$$

The peak-to-peak value of the secondary voltage equals $2 \times V_{S(pk)}$ or $2 \times 42.42 \text{ V} = 84.84 \text{ V}_{p\text{-}p}$. The values for the ac secondary voltage are shown in Fig. 27–15*b*.

Analyzing Circuit Operation

The output waveform for the half-wave rectifier of Fig. 27–15*a* is shown in Fig. 27–15*c*. Anytime the secondary voltage in Fig. 27–15*b* is positive, D_1 conducts and produces current flow in the load, R_L. Notice again that the output is a series of positive pulses. Notice also that when the secondary voltage in Fig. 27–15*b* is negative, the output voltage is zero.

Using the first approximation of a diode in Fig. 27–15*a*, the peak output voltage across R_L equals 42.42 V. Using the second approximation, the peak output voltage is 0.7 V less than the peak secondary voltage, which is 42.42 V − 0.7 V = 41.72 V.

The average or dc voltage at the output in Fig. 27–15*c* can be found using Formula (27–4) shown here:

$$V_{dc} = 0.318 \times V_{out(pk)} \qquad \textbf{(27–4)}$$

where $V_{out(pk)}$ is the peak value of the load voltage.

Using the second approximation of a diode, the dc output voltage in Fig. 27–15 is calculated as shown:

$$V_{dc} = 0.318 \times 41.72 \text{ V}$$

$$= 13.27 \text{ V}$$

This is the value of dc voltage that would be measured if a dc voltmeter were placed across the load, R_L. Notice also that this average value is depicted in Fig. 27–15*c*.

The dc load current is calculated as follows:

$$I_L = \frac{V_{dc}}{R_L}$$

$$= \frac{13.27 \text{ V}}{100 \ \Omega}$$

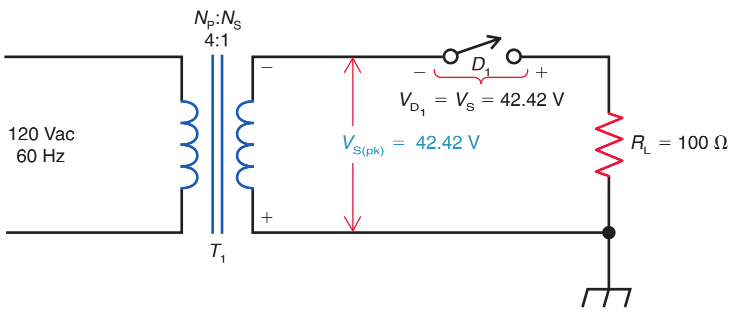
$$= 132.7 \text{ mA}$$

For a half-wave rectifier, the dc load current and dc diode current are the same. This is expressed in Formula (27–5):

$$I_{diode} = I_{L(dc)} \qquad \textbf{(27–5)}$$

In Fig. 27–15, the dc current carried by the diode equals the load current, I_L, which is 132.7 mA.

Figure 27–16 Half-wave rectifier circuit showing D_1 reverse-biased during negative alternation of secondary voltage. D_1 must withstand the peak secondary voltage $V_{S(pk)}$ of 42.42 V.



Frequency of the Output Waveform

By definition, a cycle includes the variations between two successive points having the same value and varying in the same direction. Since the frequency of the ac power line is 60 Hz, the period for one cycle is 16.67 ms, calculated as $1/f$, where $f =$ 60 Hz. The period for one cycle of secondary voltage is shown in Fig. 27–15*b*. Notice directly below in Fig. 27–15*c* that one cycle of output voltage also repeats every 16.67 ms. Therefore, the frequency of the output waveform in a half-wave rectifier equals the input frequency applied to the rectifier. Expressed as a formula,

$$f_{out} = f_{in} \tag{27–6}$$

In Fig. 27–15, $f_{out} = f_{in} = 60$ Hz.

PIV

During the negative alternation of secondary voltage, the diode D_1 is off because it is reverse-biased. The equivalent circuit for this condition is shown in Fig. 27–16. When zero current flows during the negative alternation of secondary voltage, the output voltage is zero.

Notice that the secondary of T_1 is in series with D_1 and R_L. Remember from basic circuit theory that the voltage across an open in a simple series circuit equals the input voltage, which in this case is the transformer secondary voltage.

As shown in Fig. 27–16, D_1 must be able to withstand the peak value of secondary voltage, which is 42.42 V. The peak inverse voltage (PIV) rating of D_1 must be greater than the peak value of secondary voltage or the diode will break down and become damaged. For any unfiltered half-wave rectifier, the PIV for the diode always equals the peak value of the full secondary voltage.

Example 27–4

If the turns ratio N_p:N_s = 3:1 in Fig. 27–15*a*, calculate the following: V_S, V_{dc}, I_L, I_{diode}, PIV for D_1, and f_{out}.

ANSWER We begin by calculating the secondary voltage, V_S:

$$\begin{aligned} V_S &= \frac{N_S}{N_P} \times V_P \\ &= \frac{1}{3} \times 120 \text{ Vac} \\ &= 40 \text{ Vac} \end{aligned}$$

Next we calculate the peak value of the secondary voltage:

$$\begin{aligned} V_{S(pk)} &= V_S \times 1.414 \\ &= 40 \text{ Vac} \times 1.414 \\ &= 56.56 \text{ V} \end{aligned}$$

Using the second approximation of a diode, the peak output voltage will be 0.7 V less than 56.56 V, which is 55.86 V.

To calculate the dc output voltage, we use Formula (27–4):

$$\begin{aligned} &= 0.318 \times V_{out(pk)} \\ &= 0.318 \times 55.86 \text{ V} \\ &= 17.76 \text{ V} \end{aligned}$$

The dc load current equals

$$\begin{aligned} I_L &= \frac{V_{dc}}{R_L} \\ &= \frac{17.76 \text{ V}}{100 \ \Omega} \\ &= 177.6 \text{ mA} \end{aligned}$$

The dc diode current is calculated using Formula (27–5):

$$\begin{aligned} I_{diode} &= I_L \\ &= 177.6 \text{ mA} \end{aligned}$$

Finally, the PIV for D1 equals the peak secondary voltage, which is 56.56 V. Also, the frequency of the output waveform equals 60 Hz.

Note that if it is desirable to obtain a negative output voltage in Fig. 27–15*a*, the diode, D_1, must be reversed.

The Full-Wave Rectifier

The circuit shown in Fig. 27–17*a* is called a full-wave rectifier. T_1 is a step-down transformer, which provides the secondary voltage as shown in Fig. 27–17*b* and *c*. When the top of the secondary is positive, D_1 is forward-biased, causing current to flow in the load, R_L. During this polarity of secondary voltage, D_2 is off because it is reverse-biased.

When the top of the secondary is negative, D_2 is forward-biased, causing current to flow in the load, R_L. During this polarity of secondary voltage, D_1 is off because it is reverse-biased. It is important to note that the direction of current through R_L is the same for both half-cycles of secondary voltage.

Transformer Calculations

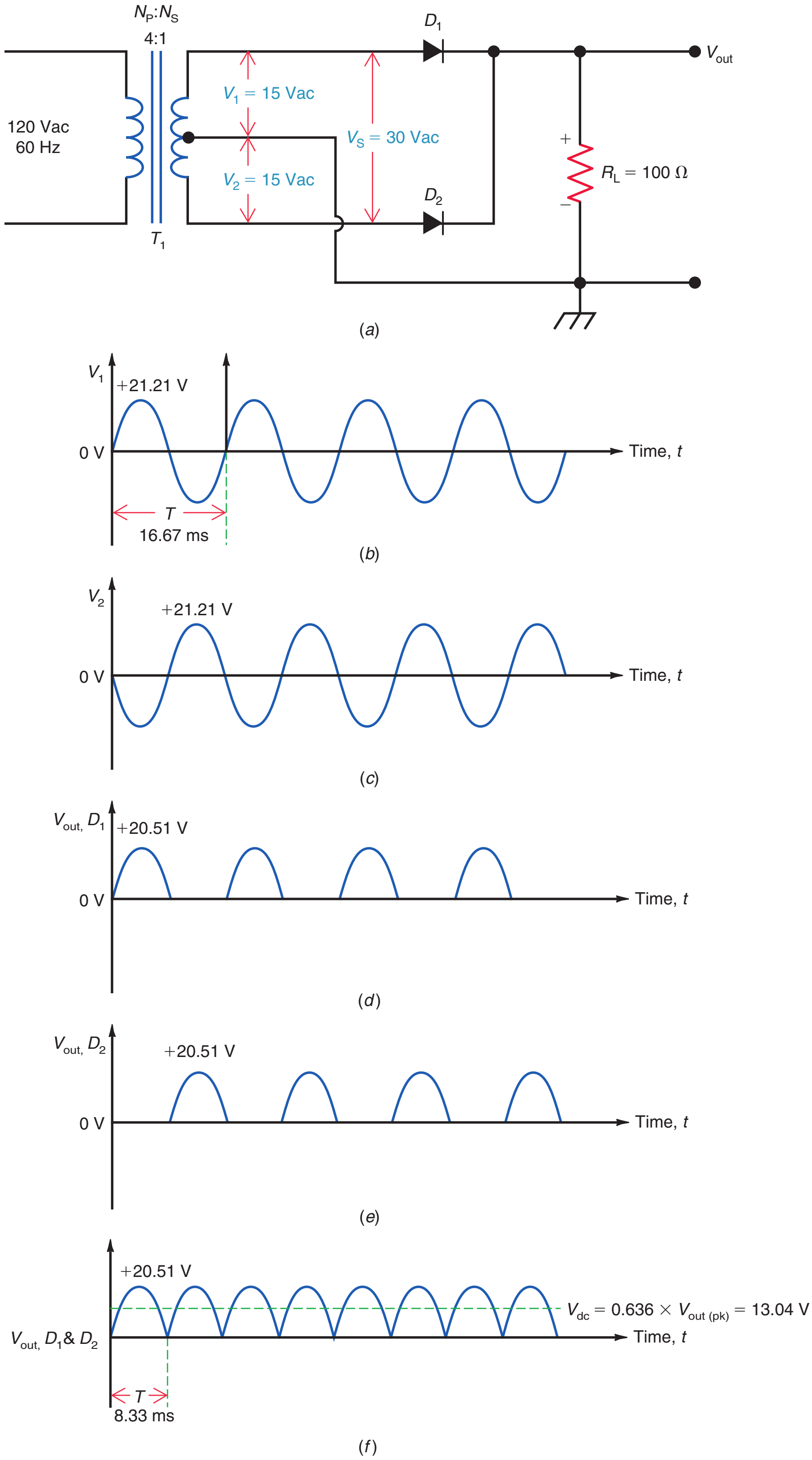
The transformer used for the half-wave rectifier in Fig. 27–15 is again used for the full-wave rectifier in Fig. 27–17*a*. Notice, however, that for the full-wave rectifier shown in Fig. 27–17*a*, the transformer secondary is center-tapped.

In Fig. 27–17*a* each half of the secondary has a voltage of 15 Vac, which is one-half the total secondary voltage, V_S, of 30 Vac. The voltage for the top half of the secondary is designated V_1, whereas the voltage for the bottom half of the secondary is designated V_2. The secondary voltages V_1 and V_2 are shown

GOOD TO KNOW

The rms value of a full-wave signal is $V_{rms} = 0.707\ V_p$ which is the same as V_{rms} for a full sine wave.

Figure 27–17 Full-wave rectifier with center tap in the transformer secondary. (*a*) Circuit. (*b*) Top half of secondary voltage, V_1. (*c*) Bottom half of secondary voltage, V_2. (*d*) Output voltage produced when D_1 conducts. (*e*) Output voltage produced when D_2 conducts. (*f*) Combined output voltage produced by D_1 and D_2 conducting during opposite alternations of secondary voltage.



in Fig. 27–17*b* and *c*, respectively. To calculate the peak voltage for V_1 and V_2, proceed as follows:

$$\begin{aligned} V_{1(pk)} = V_{2(pk)} &= 1.414 \times \frac{V_S}{2} \\ &= 1.414 \times 15 \text{ V ac} \\ &= 21.21 \text{ V} \end{aligned}$$

Notice in Fig. 27–17*b* and *c* that V_1 are V_2 are 180° out of phase. V_1 reaches its positive peak at the same time V_2 reaches its negative peak. Likewise, V_2 reaches its positive peak at the same time V_1, reaches its negative peak.

Analyzing Circuit Operation

Look at the waveforms shown in Fig. 27–17. Whenever the secondary voltage, V_1 (shown in Fig. 27–17*b*), is positive, D_1 conducts and provides the output waveform in Fig. 27–17*d*. Likewise, whenever the secondary voltage, V_2 (shown in Fig. 27–17*c*), becomes positive, D_2 conducts and provides the output waveform in Fig. 27–17*e*. Notice that D_1 and D_2 conduct on opposite half-cycles of the secondary voltage, V_S. When V_1 is positive, D_2 is off. Likewise, when V_2 is positive, D_1 is off. Each diode provides a half-wave rectified waveform for the load, R_L. The combined effects of D_1 and D_2 are shown in Fig. 27–17*f*.

The average or dc voltage at the output of an unfiltered full-wave rectifier can be calculated using Formula (27–7):

$$V_{dc} = 0.636 \times V_{out(pk)} \qquad \textbf{(27–7)}$$

Using the second approximation of a diode, the peak load voltage across R_L = 21.21 V − 0.7 V = 20.51 V. The dc output voltage in Fig. 27–17*f* is calculated as follows:

$$\begin{aligned} V_{dc} &= 0.636 \times V_{out(pk)} \\ &= 0.636 \times 20.51 \text{ V} \\ &= 13.04 \text{ V} \end{aligned}$$

This is the value that would be measured if a dc voltmeter were placed across the load resistor, R_L.

The dc load current is calculated as follows:

$$\begin{aligned} I_L &= \frac{V_{dc}}{R_L} \\ &= \frac{13.04 \text{ V}}{100\ \Omega} \\ &= 130.4 \text{ mA} \end{aligned}$$

For a full-wave rectifier, the dc current carried by each diode equals one-half the dc load current. This is clearly expressed in Formula (27–8):

$$I_{diode} = \frac{I_L}{2} \qquad \textbf{(27–8)}$$

For Fig. 27–17*a*, each diode has a dc current calculated as follows:

$$\begin{aligned} I_{diode} &= \frac{I_L}{2} \\ &= \frac{130.4 \text{ mA}}{2} \\ &= 65.2 \text{ mA} \end{aligned}$$

The fact that the dc diode current is one-half the dc load current is best explained by examining the waveforms in Fig. 27–17*d* and *e*. If the peak value of output voltage is 20.51V for each waveform, the peak load current at this instant is 205.1 mA, calculated as 20.51V/100 Ω. Since the waveforms in Fig. 27–17*d* and *e* are each half-wave rectified waveforms, the average dc current passed by each diode is calculated as follows:

$$\begin{aligned} I_{dc} &= 0.318 \times I_{out(pk)} \\ &= 0.318 \times 205.1 \text{ mA} \\ &= 65.2 \text{ mA} \end{aligned}$$

This proves that each diode in a full-wave rectifier passes only half of the dc load current. Again, this is because each diode supplies its own half-wave rectified waveform to the load, R_L.

Frequency of the Output Waveform

Figure 27–17*b* shows that one cycle of secondary voltage has a period, T, of 16.67 ms, which equals $1/f$ where $f = 60$ Hz. Now look at the output waveform in Fig. 27–17*f*. Notice that one cycle is completed every 8.33 ms. Therefore, the frequency of the output waveform equals:

$$\begin{aligned} f_{out} &= \frac{1}{T} \\ &= \frac{1}{8.33 \text{ ms}} \\ &= 120 \text{ Hz} \end{aligned}$$

Therefore, for a full-wave rectifier, the following formula is true:

$$f_{out} = 2f_{in} \qquad \textbf{(27–9)}$$

We must remember that the definition of a cycle states that it includes the variations between two successive points having the same value and varying in the same direction.

PIV

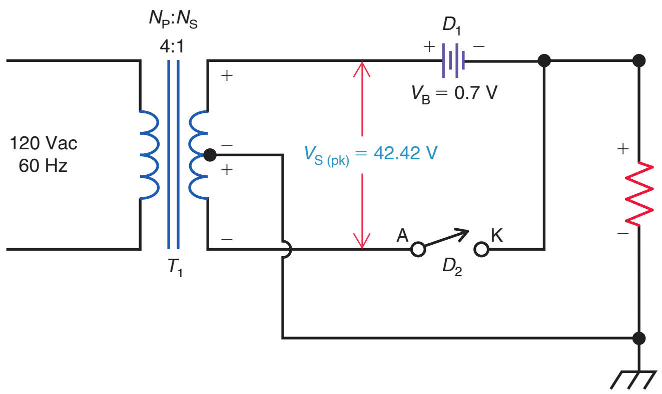
Figure 27–18 shows the diodes D_1 and D_2 represented using the second approximation. The circuit shows the voltages at the instant the top of the secondary reaches its positive peak of 42.42 V. To calculate the peak inverse voltage to which D_2 will be subjected, we use Kirchhoff's voltage law.

Starting at the anode (A) terminal of D_2 and going clockwise back to the cathode terminal,

$$\begin{aligned} V_{AK} &= -V_{S(pk)} + V_B \\ &= -42.42 \text{ V} + 0.7 \text{ V} \\ &= -41.72 \text{ V} \end{aligned}$$

Notice that this value is 0.7 V less than the peak value of the full secondary voltage.

Figure 27–18 Full-wave rectifier circuit showing D_2 reverse-biased during positive alternation of secondary voltage. Both diodes D_1 and D_2 must withstand a peak inverse voltage that is 0.7 V less than the peak value of the full secondary voltage.



The same analogy can also be used to find the peak inverse voltage across the diode D_1 for the opposite polarity of the secondary voltage. Incidentally, the PIV for D_1 also equals -41.72 V. For any full-wave rectifier using a center-tapped transformer, the PIV for each diode will be 0.7 V less than the peak value of the full secondary voltage.

Example 27-5

If the turns ratio $N_P{:}N_S = 3{:}1$ in Fig. 27–17*a*, calculate the following: V_{dc}, I_L, I_{diode}, PIV for D_1, and f_{out}.

ANSWER Begin by calculating the total secondary voltage, V_S:

$$V_S = \frac{N_S}{N_P} \times V_P$$
$$= \frac{1}{3} \times 120 \text{ Vac}$$
$$= 40 \text{ Vac}$$

Next, we must realize that because of the secondary center tap, $V_1 = V_2 = \frac{V_S}{2} = 20$ Vac . To calculate the peak value for V_1 and V_2, we proceed as follows:

$$V_{1(pk)} = V_{2(pk)} = 1.414 \times \frac{V_S}{2}$$
$$= 1.414 \times 20 \text{ Vac}$$
$$= 28.28 \text{ V}$$

Using the second approximation of a diode, the peak output voltage will be 0.7 V less than 28.28 V, which is 27.58 V.

To calculate the dc output voltage, we use Formula (27–7):

$$V_{dc} = 0.636 \times V_{out(pk)}$$
$$= 0.636 \times 27.58 \text{ V}$$
$$= 17.54 \text{ V}$$

The dc load current equals

$$I_L = \frac{V_{dc}}{R_L}$$
$$= \frac{17.54 \text{ V}}{100 \ \Omega}$$
$$= 175.4 \text{ mA}$$

The dc diode current is calculated using Formula (27–8):

$$I_{diode} = \frac{I_L}{2}$$
$$= \frac{175.4 \text{ mA}}{2}$$
$$= 87.7 \text{ mA}$$

The PIV for D_1 and D_2 equals 55.86 V, which is 0.7 V less than the peak value of the full secondary voltage. The frequency of the output waveform is 120 Hz, the same as before.

If it is desirable to obtain a negative output voltage in Fig. 27–17*a*, the diodes D_1 and D_2 must be reversed.

GOOD TO KNOW

When a bridge rectifier, as opposed to a two-diode full-wave rectifier, is used, the same dc output voltage can be obtained with a transformer having a higher turns ratio, N_P:N_S. This means that with a bridge rectifier, fewer turns of wire are needed in the secondary of the transformer. Therefore, the transformer used with a bridge rectifier will be smaller, lighter, and will probably cost less. These benefits alone outweigh using four diodes instead of two in a conventional two-diode full-wave rectifier.

The Full-Wave Bridge Rectifier

The circuit shown in Fig. 27–19*a* is called a *full-wave bridge rectifier*. T_1 is a step-down transformer, which provides the secondary voltage shown in Fig. 27–19*b*. When the top of the secondary is positive, diodes D_2 and D_3 are forward-biased. This produces current flow in the load, R_L. For this polarity of secondary voltage, D_1 and D_4 are reverse-biased and do not conduct.

When the top of the secondary is negative, D_1 and D_4 are forward-biased, producing current flow in the load R_L. For this polarity of secondary voltage, D_2 and D_3 are reverse-biased and do not conduct. It is important to note that the direction of current through R_L is the same for both half-cycles of the secondary voltage. For the diode connections shown, the output voltage is positive.

Transformer Calculations

The transformer used for the half-wave rectifier in Fig. 27–15*a* is again used for the full-wave bridge rectifier in Fig. 27–19*a*. Remember that the rms value of secondary voltage was 30 Vac for the turns ratio N_P:N_S = 4:1. Likewise, the peak value of the secondary voltage is 42.42 V.

Analyzing Circuit Operation

Look at the waveforms in Fig. 27–19*b* through *e*. When the secondary voltage, V_S, in Fig. 27–19*b* is positive, diodes D_2 and D_3 conduct, thus creating the output waveform shown in Fig. 27–19*c*. Likewise, when the top of the secondary is negative, diodes D_1 and D_4 conduct, giving the output waveform shown in Fig. 27–19*d*. Notice that the diode pairs D_2-D_3 and D_1-D_4 conduct on opposite half-cycles of the secondary voltage. The combined effects of D_2-D_3 and D_1-D_4 are shown in Fig. 27–19*e*. Each diode pair provides a half-wave rectified waveform for the load, R_L.

Using the second approximation of a diode, the peak load voltage across R_L equals 42.42 V − 1.4 V = 41.02 V. Notice that two diode voltage drops are subtracted from the peak secondary voltage. This is explained by the fact that when the diode pairs conduct, they are in series with the transformer secondary and the load, R_L.

The dc voltage at the output of an unfiltered full-wave bridge rectifier can be determined by using Formula (27–7). The calculations are

$$\begin{aligned} V_{dc} &= 0.636 \times V_{out(pk)} \\ &= 0.636 \times 41.02 \text{ V} \\ &= 26.09 \text{ V} \end{aligned}$$

The dc load current is calculated as follows:

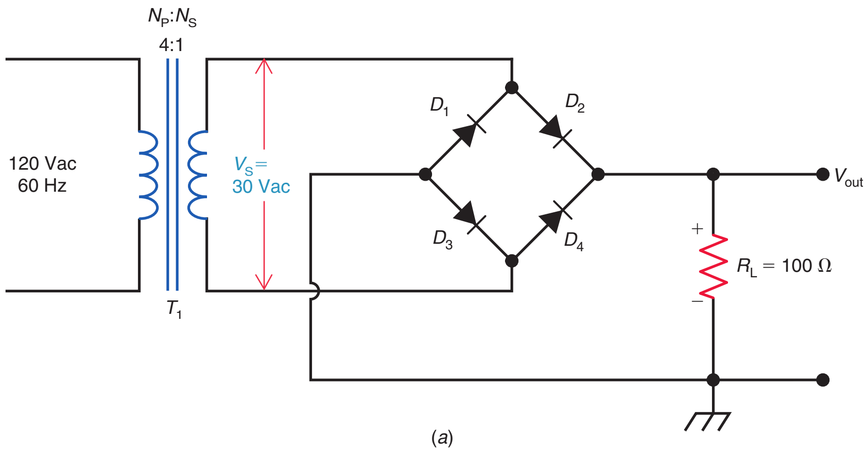
$$\begin{aligned} I_L &= \frac{V_{dc}}{R_L} \\ &= \frac{26.09 \text{ V}}{100\ \Omega} \\ &= 260.9 \text{ mA} \end{aligned}$$

The dc diode current is calculated using Formula (27–8):

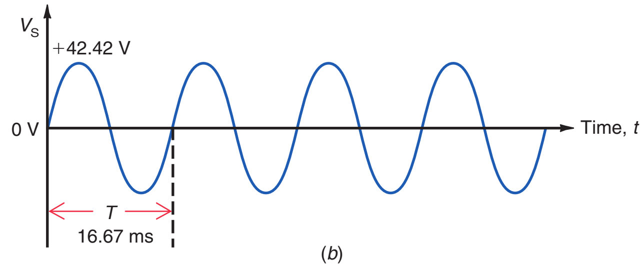
$$\begin{aligned} I_{diode} &= \frac{I_L}{2} \\ &= \frac{260.9 \text{ mA}}{2} \\ &= 130.4 \text{ mA} \end{aligned}$$

The dc diode current is one-half the dc load current because each diode pair in the bridge rectifier supplies a half-wave rectified waveform to the load, R_L.

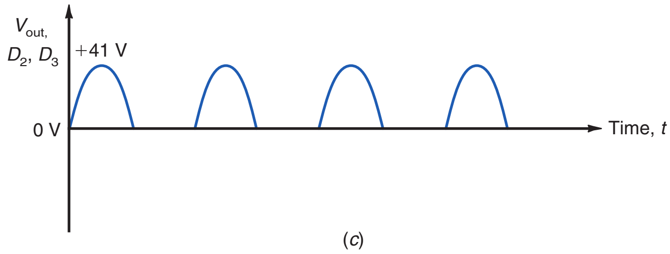
MultiSim **Figure 27–19** Full-wave bridge rectifier. (*a*) Circuit. (*b*) Secondary voltage, V_S. (*c*) Output voltage produced when diodes D_2 and D_3 conduct. (*d*) Output voltage produced when diodes D_1 and D_4 conduct. (*e*) Combined output voltage.



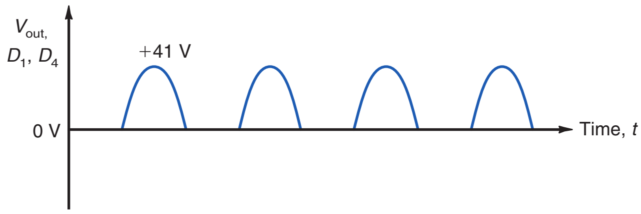
(*a*)



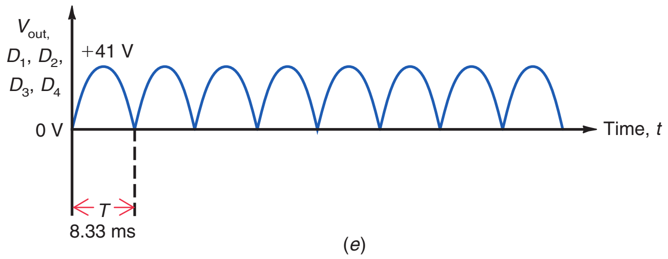
(*b*)



(*c*)

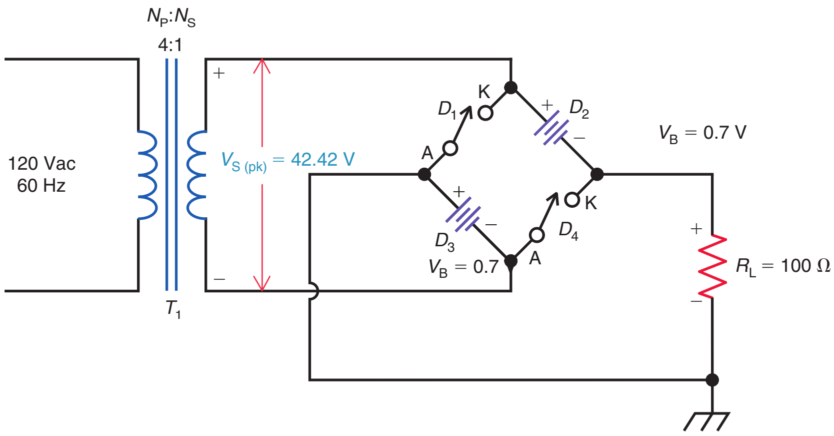


(*d*)



(*e*)

Figure 27–20 Full-wave bridge rectifier showing diodes D_1 and D_4 reverse-biased during positive alternation of secondary voltage. Each diode in the bridge must withstand a peak inverse voltage that is 0.7 V less than the peak value of the full secondary voltage.



Frequency of the Output Waveform

Since the bridge rectifier in Fig. 27–19*a* provides a full-wave output, the frequency of the output waveform is found using Formula (27–9):

$$\begin{aligned} f_{out} &= 2f_{in} \\ &= 2 \times 60 \text{ Hz} \\ &= 120 \text{ Hz} \end{aligned}$$

PIV

Figure 27–20 shows the equivalent circuit of the bridge rectifier at the instant the secondary voltage reaches its maximum positive peak. Notice that diodes D_2 and D_3 are forward-biased and are replaced with their second approximation equivalent circuit. Notice also, that for this polarity of secondary voltage, diodes D_1 and D_4 are reverse-biased and are represented as open switches.

To calculate the peak inverse voltage (PIV) to which D_1 and D_4 will be subjected, use Kirchhoff's voltage law. For D_1, start at the anode (A) terminal and go clockwise around the loop back to its cathode (K) terminal. This gives

$$\begin{aligned} V_{AK}(D_1) &= V_B - V_{S(pk)} \\ &= 0.7 \text{ V} - 42.42 \text{ V} \\ &= -41.72 \text{ V} \end{aligned}$$

For D_4, start at its anode (A) terminal and go clockwise around the loop back to its cathode (K) terminal:

$$\begin{aligned} V_{AK}(D_4) &= -V_{S(pk)} + V_B \\ &= -42.42 \text{ V} + 0.7 \text{ V} \\ &= -41.72 \text{ V} \end{aligned}$$

Note that the PIV for each diode in a bridge rectifier will always be 0.7 V less than the peak value of the full secondary voltage.

Example 27–6

If the turns ratio N_P:N_S = 3:1 in Fig. 27–19*a*, calculate the following: V_{dc}, I_L, I_{diode}, PIV for each diode, and f_{out}.

ANSWER We already know from the previous examples that the secondary voltage equals 40 Vac when the transformer turns ratio $N_P:N_S = 3:1$. Also, the peak secondary voltage equals 56.56 V. Subtracting two diode voltage drops gives us a peak load voltage of 56.56 V − 1.4 V = 55.16 V. To calculate the dc load voltage use Formula (27–7):

$$\begin{aligned} V_{dc} &= 0.636 \times V_{out(pk)} \\ &= 0.636 \times 55.16 \text{ V} \\ &= 35.08 \text{ V} \end{aligned}$$

To calculate the dc load current, I_L, proceed as follows:

$$\begin{aligned} I_L &= \frac{V_{dc}}{R_L} \\ &= \frac{35.08 \text{ V}}{100 \ \Omega} \\ &= 350.8 \text{ mA} \end{aligned}$$

The dc diode current is one-half the dc load current. This is calculated using Formula (27–8):

$$\begin{aligned} I_{diode} &= \frac{I_L}{2} \\ &= \frac{350.8 \text{ mA}}{2} \\ &= 175.4 \text{ mA} \end{aligned}$$

The *PIV* for each diode equals 56.56 V − 0.7 V = 55.86 V. Also, the frequency of the output waveform equals 120 Hz.

If it is desirable to obtain a negative output voltage in Fig. 27–19*a*, the diodes D_1, D_2, D_3, and D_4 must be reversed.

Capacitor Input Filter

The unfiltered output from a half-wave or full-wave rectifier is a pulsating dc voltage. For most applications, this dc voltage must be smoothed or filtered to be useful. One way to smooth out the pulsations in dc voltage is to connect a capacitor at the output of the rectifier. Figure 27–21*a* shows a half-wave rectifier with its output filtered by the capacitor, *C*. The filter capacitors used in this application are electrolytic capacitors with values typically larger than 100 μF.

Half-Wave Rectifier Filtering

When the top of the secondary goes positive initially in Fig. 27–21*a*, the diode, D_1, conducts and the capacitor, *C*, charges. Notice the time before t_0 in Fig. 27–21*b*. During this time, the capacitor voltage follows the positive-going secondary voltage. At time t_0, the voltage across *C* reaches its peak positive value.

Since $N_P:N_S = 8:1$, $V_S = \frac{1}{8} \times 120$ Vac = 15 Vac. To calculate the peak voltage to which *C* charges, we must first calculate the peak secondary voltage.

$$\begin{aligned} V_{S(pk)} &= V_S \times 1.414 \\ &= 15 \text{ Vac} \times 1.414 \\ &= 21.21 \text{ V} \end{aligned}$$

Subtracting 0.7 V for the voltage drop across D_1 gives us a peak capacitor voltage of 20.51 V. This is the dc output voltage under ideal conditions.