SOLUTION The transformer has a turns ratio of 5:1. This means that the rms secondary voltage is one-fifth of the primary voltage:

$$V_2 = \frac{120\ \text{V}}{5} = 24\ \text{V}$$

and the peak secondary voltage is:

$$V_p = \frac{24\ \text{V}}{0.707} = 34\ \text{V}$$

With an ideal diode, the peak load voltage is:

$$V_{p(\text{out})} = 34\ \text{V}$$

The dc load voltage is:

$$V_{\text{dc}} = \frac{V_p}{\pi} = \frac{34\ \text{V}}{\pi} = 10.8\ \text{V}$$

With the second approximation, the peak load voltage is:

$$V_{p(\text{out})} = 34\ \text{V} - 0.7\ \text{V} = 33.3\ \text{V}$$

and the dc load voltage is:

$$V_{\text{dc}} = \frac{V_p}{\pi} = \frac{33.3\ \text{V}}{\pi} = 10.6\ \text{V}$$

PRACTICE PROBLEM 4-2 Using Fig. 4-5, change the transformer's turns ratio to 2:1 and solve for the ideal dc load voltage.

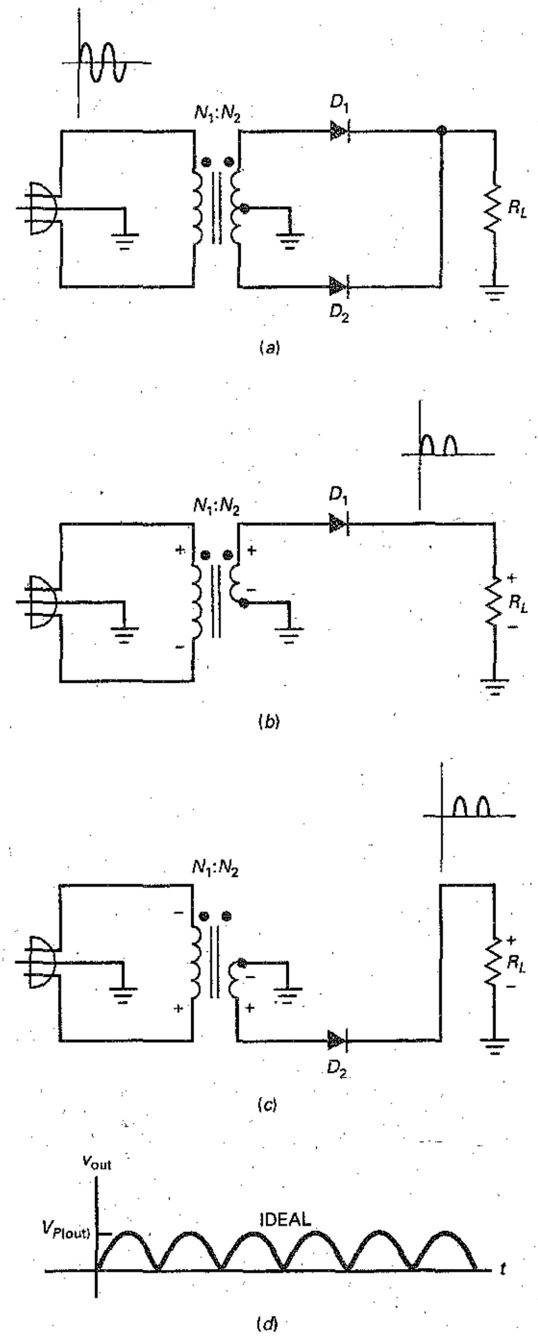
4-3 The Full-Wave Rectifier

Figure 4-6*a* shows a **full-wave rectifier** circuit. Notice the grounded center tap on the secondary winding. The full-wave rectifier is equivalent to two half-wave rectifiers. Because of the center tap, each of these rectifiers has an input voltage equal to half the secondary voltage. Diode D_1 conducts on the positive half cycle, and diode D_2 conducts on the negative half cycle. As a result, the rectified load current flows during both half cycles. The full-wave rectifier acts the same as two back-to-back half-wave rectifiers.

Figure 4-6*b* shows the equivalent circuit for the positive half cycle. As you see, D_1 is forward biased. This produces a positive load voltage as indicated by the plus-minus polarity across the load resistor. Figure 4-6*c* shows the equivalent circuit for the negative half cycle. This time, D_2 is forward biased. As you can see, this also produces a positive load voltage.

In both half cycles, the load voltage has the same polarity and the load current is in the same direction. The circuit is called a *full-wave rectifier* because it has changed the ac input voltage to the pulsating dc output voltage shown in Fig. 4-6*d*. This waveform has some interesting properties that we will now discuss.

Figure 4-6 (*a*) Full-wave rectifier; (*b*) equivalent circuit for positive half cycle; (*c*) equivalent circuit for negative half cycle; (*d*) full-wave output.



GOOD TO KNOW

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

DC or Average Value

Since the full-wave signal has twice as many positive cycles as the half-wave signal, the dc or average value is twice as much, given by:

$$\textbf{Full wave: } V_{dc} = \frac{2V_p}{\pi} \tag{4-6}$$

Since $2/\pi = 0.636$, you may see Eq. (4-6) written as:

$$V_{dc} \approx 0.636V_p$$

In this form, you can see that the dc or average value equals 63.6 percent of the peak value. For instance, if the peak voltage of the full-wave signal is 100 V, the dc voltage or average value is 63.6 V.

Output Frequency

With a half-wave rectifier, the output frequency equals the input frequency. But with a full-wave rectifier, something unusual happens to the output frequency. The ac line voltage has a frequency of 60 Hz. Therefore, the input period equals:

$$T_{in} = \frac{1}{f} = \frac{1}{60\text{ Hz}} = 16.7\text{ ms}$$

Because of the full-wave rectification, the period of the full-wave signal is half the input period:

$$T_{out} = 0.5(16.7\text{ ms}) = 8.33\text{ ms}$$

(If there is any doubt in your mind, compare Fig. 4-6*d* to Fig. 4-2*c*.) When we calculate the output frequency, we get:

$$f_{out} = \frac{1}{T_{out}} = \frac{1}{8.33\text{ ms}} = 120\text{ Hz}$$

The frequency of the full-wave signal is double the input frequency. This makes sense. A full-wave output has twice as many cycles as the sine-wave input has. The full-wave rectifier inverts each negative half cycle, so that we get double the number of positive half cycles. The effect is to double the frequency. As a derivation:

$$\textbf{Full wave: } f_{out} = 2f_{in} \tag{4-7}$$

Second Approximation

Since the full-wave rectifier is like two back-to-back half-wave rectifiers, we can use the second approximation given earlier. The idea is to subtract 0.7 V from the ideal peak output voltage. The following example will illustrate the idea.

Example 4-3

MultiSim

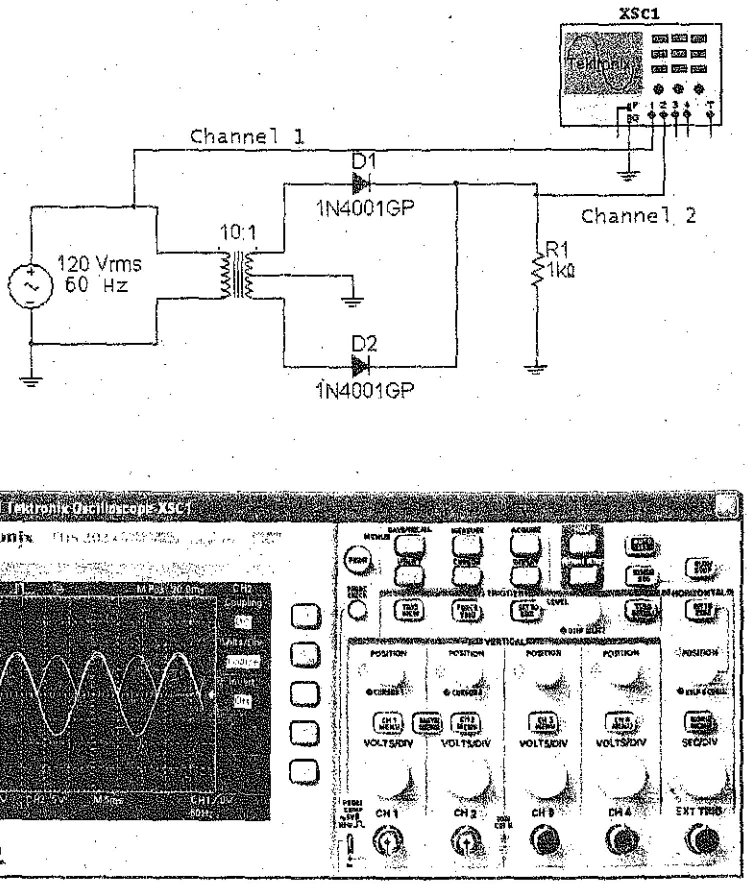
Figure 4-7 shows a full-wave rectifier that you can build on lab bench or on a computer screen with MultiSim. Channel 1 of the oscilloscope displays the primary voltage (the sine wave), and channel 2 displays the load voltage (the full-wave signal). Calculate the peak input and output voltages. Then compare the theoretical values to the measured values.

SOLUTION

The peak primary voltage is:

$$V_{p(1)} = \frac{V_{rms}}{0.707} = \frac{120\text{ V}}{0.707} = 170\text{ V}$$

Figure 4-7 Lab example of full-wave rectifier.



Because of the 10:1 step-down transformer, the peak secondary voltage is:

$$V_{p(2)} = \frac{V_{p(1)}}{N_1/N_2} = \frac{170\text{ V}}{10} = 17\text{ V}$$

The full-wave rectifier acts like two back-to-back half-wave rectifiers. Because of the center tap, the input voltage to each half-wave rectifier is only half the secondary voltage:

$$V_{p(\text{in})} = 0.5(17\text{ V}) = 8.5\text{ V}$$

Ideally, the output voltage is:

$$V_{p(\text{out})} = 8.5\text{ V}$$

Using the second approximation:

$$V_{p(\text{out})} = 8.5\text{ V} - 0.7\text{ V} = 7.8\text{ V}$$

Now, let's compare the theoretical values with the measured values. The sensitivity of channel 1 is 100 V/Div. Since the sine-wave input reads approximately 1.7 divisions, its peak value is approximately 170 V. Channel 2 has a