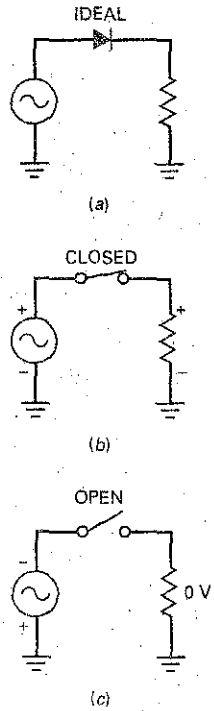
Figure 4-1 (*a*) Ideal half-wave rectifier; (*b*) on positive half cycle; (*c*) on negative half cycle.



4-1 The Half-Wave Rectifier

Figure 4-1*a* shows a **half-wave rectifier** circuit. The ac source produces a sinusoidal voltage. Assuming an ideal diode, the positive half cycle of source voltage will forward bias the diode. Since the switch is closed, as shown in Fig. 4-1*b*, the positive half cycle of source voltage will appear across the load resistor. On the negative half cycle, the diode is reverse biased. In this case, the ideal diode will appear as an open switch, as shown in Fig. 4-1*c*, and no voltage appears across the load resistor.

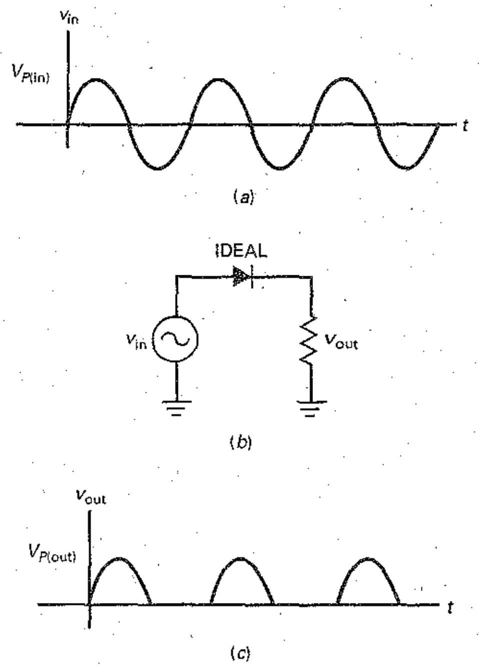
Ideal Waveforms

Figure 4-2*a* shows a graphical representation of the input voltage waveform. It is a sine wave with an instantaneous value of v_{in} and a peak value of $V_{p(in)}$. A pure sinusoid like this has an average value of zero over one cycle because each instantaneous voltage has an equal and opposite voltage half a cycle later. If you measure this voltage with a dc voltmeter, you will get a reading of zero because a dc voltmeter indicates the average value.

In the half-wave rectifier of Fig. 4-2*b*, the diode is conducting during the positive half cycles but is nonconducting during the negative half cycles. Because of this, the circuit clips off the negative half cycles, as shown in Fig. 4-2*c*. We call a waveform like this a *half-wave signal.* This half-wave voltage produces a **unidirectional load current.** This means that it flows in only one direction. If the diode were reversed, the output pulses would be negative.

A half-wave signal like the one in Fig. 4-2*c* is a pulsating dc voltage that increases to a maximum, decreases to zero, and then remains at zero during the negative half cycle. This is not the kind of dc voltage we need for electronics equipment. What we need is a constant voltage, the same as you get from a

Figure 4-2 (*a*) Input to half-wave rectifier; (*b*) circuit; (*c*) output of half-wave rectifier.



GOOD TO KNOW

The rms value of a half-wave signal can be determined with the following formula:

$$V_{rms} = 1.57V_{avg}$$

where $V_{avg} = V_{dc} = 0.318V_p$. Another formula that works is:

$$V_{rms} = \frac{V_p}{\sqrt{2}}$$

For any waveform, the rms value corresponds to the equivalent dc value that will produce the same heating effect.

battery. To get this kind of voltage, we need to **filter** the half-wave signal (discussed later in this chapter).

When you are troubleshooting, you can use the ideal diode to analyze a half-wave rectifier. It's useful to remember that the peak output voltage equals the peak input voltage:

$$\textbf{Ideal half wave: } V_{p(\text{out})} = V_{p(\text{in})} \tag{4-1}$$

DC Value of Half-Wave Signal

The **dc value of a signal** is the same as the average value. If you measure a signal with a dc voltmeter, the reading will equal the average value. In basic courses the dc value of a half-wave signal is derived. The formula is:

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

The proof of this derivation requires calculus because we have to work out the average value over one cycle.

Since $1/\pi \approx 0.318$, you may see Eq. (4-2) written as:

$$V_{dc} \approx 0.318V_p$$

When the equation is written in this form, you can see that the dc or average value equals 31.8 percent of the peak value. For instance, if the peak voltage of the half-wave signal is 100 V, the dc voltage or average value is 31.8 V.

Output Frequency

The output frequency is the same as the input frequency. This makes sense when you compare Fig. 4-2*c* with Fig. 4-2*a*. Each cycle of input voltage produces one cycle of output voltage. Therefore, we can write:

$$\textbf{Half wave: } f_{\text{out}} = f_{\text{in}} \tag{4-3}$$

We will use this derivation later with filters.

Second Approximation

We don't get a perfect half-wave voltage across the load resistor. Because of the barrier potential, the diode does not turn on until the ac source voltage reaches approximately 0.7 V. When the peak source voltage is much greater than 0.7 V, the load voltage will resemble a half-wave signal. For instance, if the peak source voltage is 100 V, the load voltage will be very close to a perfect half-wave voltage. If the peak source voltage is only 5 V, the load voltage will have a peak of only 4.3 V. When you need to get a better answer, use this derivation:

$$\textbf{2d half wave: } V_{p(\text{out})} = V_{p(\text{in})} - 0.7\text{ V} \tag{4-4}$$

Higher Approximations

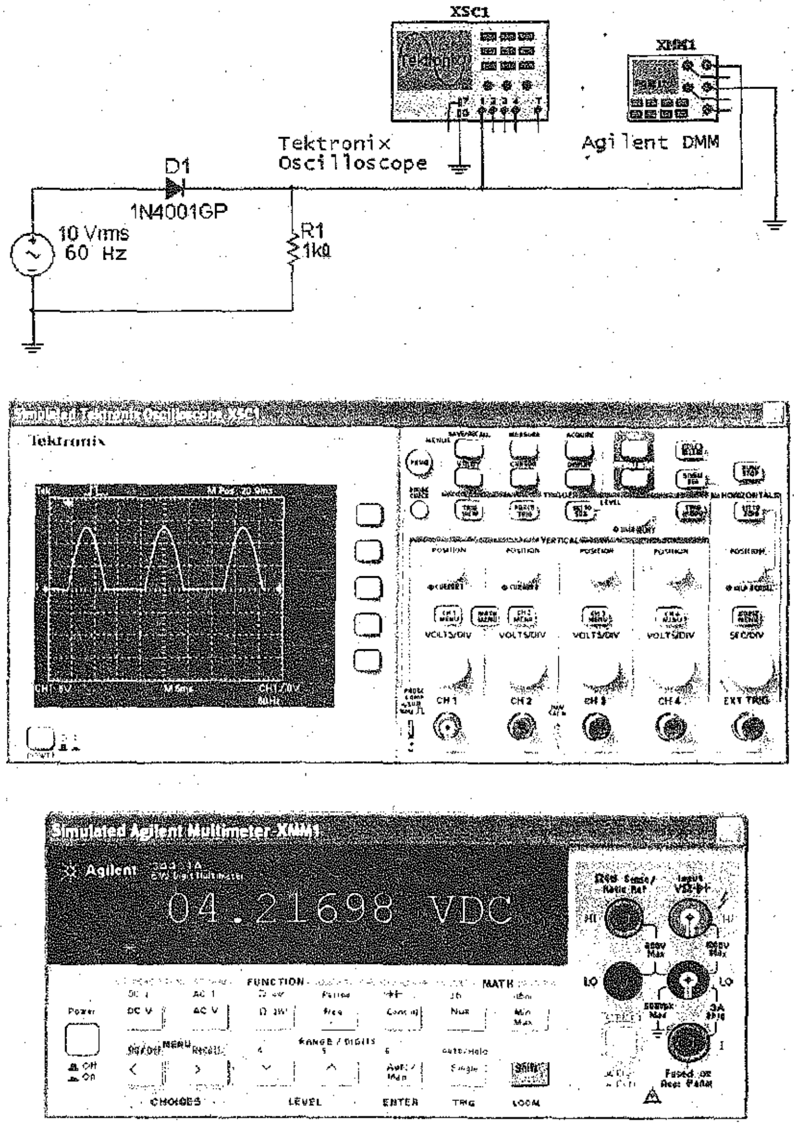
Most designers will make sure that the bulk resistance is much smaller than the Thevenin resistance facing the diode. Because of this, we can ignore bulk resistance in almost every case. If you must have better accuracy than you can get with the second approximation, you should use a computer and a circuit simulator like MultiSim.

Example 4-1

Figure 4-3 shows a half-wave rectifier that you can build on the lab bench or on a computer screen with MultiSim. An oscilloscope is across the 1 kΩ. This will show us the half-wave load voltage. Also, a multimeter is across the 1 kΩ to read the dc load voltage. Calculate the theoretical values of peak load voltage and the dc load voltage. Then, compare these values to the readings on the oscilloscope and the multimeter.

SOLUTION Figure 4-3 shows an ac source of 10 V and 60 Hz. Schematic diagrams usually show ac source voltages as effective or rms values. Recall that the *effective value* is the value of a dc voltage that produces the same heating effect as the ac voltage.

Figure 4-3 Lab example of half-wave rectifier.



Since the source voltage is 10 V rms, the first thing to do is calculate the peak value of the ac source. You know from earlier courses that the rms value of a sine wave equals:

$$V_{rms} = 0.707V_p$$

Therefore, the peak source voltage in Fig. 4-3 is:

$$V_p = \frac{V_{rms}}{0.707} = \frac{10\text{ V}}{0.707} = 14.1\text{ V}$$

With an ideal diode, the peak load voltage is:

$$V_{p(out)} = V_{p(in)} = 14.1\text{ V}$$

The dc load voltage is:

$$V_{dc} = \frac{V_p}{\pi} = \frac{14.1\text{ V}}{\pi} = 4.49\text{ V}$$

With the second approximation, we get a peak load voltage of:

$$V_{p(out)} = V_{p(in)} - 0.7\text{ V} = 14.1\text{ V} - 0.7\text{ V} = 13.4\text{ V}$$

and a dc load voltage of:

$$V_{dc} = \frac{V_p}{\pi} = \frac{13.4\text{ V}}{\pi} = 4.27\text{ V}$$

Figure 4-3 shows you the values that an oscilloscope and a multimeter will read. Channel 1 of the oscilloscope is set at 5 V per major division (5 V/Div). The half-wave signal has a peak value between 13 and 14 V, which agrees with the result from our second approximation. The multimeter also gives good agreement with theoretical values, because it reads approximately 4.22 V.

PRACTICE PROBLEM 4-1 Using Fig. 4-3, change the ac source voltage to 15 V. Calculate the second approximation dc load voltage V_{dc}.

4-2 The Transformer

Power companies in the United States supply a nominal line voltage of 120 V rms and a frequency of 60 Hz. The actual voltage coming out of a power outlet may vary from 105 to 125 V rms, depending on the time of day, the locality, and other factors. Line voltage is too high for most of the circuits used in electronics equipment. This is why a transformer is commonly used in the power-supply section of almost all electronics equipment. The transformer steps the line voltage down to safer and lower levels that are more suitable for use with diodes, transistors, and other semiconductor devices.

Basic Idea

Earlier courses discussed the transformer in detail. All we need in this chapter is a brief review. Figure 4-4 shows a transformer. Here you see line voltage applied to the primary winding of a transformer. Usually, the power plug has a third prong to ground the equipment. Because of the turns ratio N_1/N_2, the secondary voltage is stepped down when N_1 is greater than N_2.

Phasing Dots

Recall the meaning of the phasing dots shown at the upper ends of the windings. Dotted ends have the same instantaneous phase. In other words, when a positive half cycle appears across the primary, a positive half cycle appears across the