input filter have on the load voltage? The easiest way to solve this problem is to use the superposition theorem. Recall what this theorem says: If you have two or more sources, you can analyze the circuit for each source separately and then add the individual voltages to get the total voltage.

The rectifier output has two different components: a dc voltage (the average value) and an ac voltage (the fluctuating part), as shown in Fig. 4-11*b*. Each of these voltages acts like a separate source. As far as the ac voltage is concerned, X_L is much greater than X_C, and this results in very little ac voltage across the load resistor. Even though the ac component is not a pure sine wave, Eq. (4-9) is still a close approximation for the ac load voltage.

The circuit acts like Fig. 4-11*c* as far as dc voltage is concerned. At 0 Hz, the inductive reactance is zero and the capacitive reactance is infinite. Only the series resistance of the inductor windings remains. Making R_S much smaller than R_L causes most of the dc component to appear across the load resistor.

That's how a choke-input filter works: Almost all of the dc component is passed on to the load resistor, and almost all of the ac component is blocked. In this way, we get an almost perfect dc voltage, one that is almost constant, like the voltage out of a battery. Figure 4-11*d* shows the filtered output for a full-wave signal. The only deviation from a perfect dc voltage is the small ac load voltage shown in Fig. 4-11*d*. This small ac load voltage is called **ripple.** With an oscilloscope, we can measure its peak-to-peak value.

Main Disadvantage

A **power supply** is the circuit inside electronics equipment that converts the ac input voltage to an almost perfect dc output voltage. It includes a rectifier and a filter. The trend nowadays is toward low-voltage, high-current power supplies. Because line frequency is only 60 Hz, large inductances have to be used to get enough reactance for adequate filtering. But large inductors have large winding resistances, which create a serious design problem with large load currents. In other words, too much dc voltage is dropped across the choke resistance. Furthermore, bulky inductors are not suitable for modern semiconductor circuits, where the emphasis is on lightweight designs.

Switching Regulators

One important application does exist for the choke-input filter. A **switching regulator** is a special kind of power supply used in computers, monitors, and an increasing variety of equipment. The frequency used in a switching regulator is much higher than 60 Hz. Typically, the frequency being filtered is above 20 kHz. At this much higher frequency, we can use much smaller inductors to design efficient choke-input filters. We will discuss the details in a later chapter.

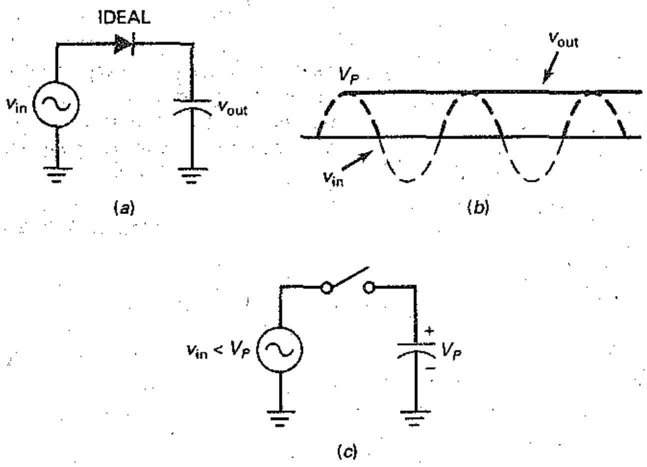
4-6 The Capacitor-Input Filter

The choke-input filter produces a dc output voltage equal to the average value of the rectified voltage. The **capacitor-input filter** produces a dc output voltage equal to the peak value of the rectified voltage. This type of filter is the most widely used in power supplies.

Basic Idea

Figure 4-12*a* shows an ac source, a diode, and a capacitor. The key to understanding a capacitor-input filter is understanding what this simple circuit does during the first quarter cycle.

Figure 4-12 (*a*) Unloaded capacitor-input filter; (*b*) output is pure dc voltage; (*c*) capacitor remains charged when diode is off.



Initially, the capacitor is uncharged. During the first quarter cycle of Fig. 4-12*b*, the diode is forward biased. Since it ideally acts like a closed switch, the capacitor charges, and its voltage equals the source voltage at each instant of the first quarter cycle. The charging continues until the input reaches its maximum value. At this point, the capacitor voltage equals V_p.

After the input voltage reaches the peak, it starts to decrease. As soon as the input voltage is less than V_p, the diode turns off. In this case, it acts like the open switch of Fig. 4-12*c*. During the remaining cycles, the capacitor stays fully charged and the diode remains open. This is why the output voltage of Fig. 4-12*b* is constant and equal to V_p.

Ideally, all that the capacitor-input filter does is charge the capacitor to the peak voltage during the first quarter cycle. This peak voltage is constant, the perfect dc voltage we need for electronics equipment. There's only one problem: There is no load resistor.

Effect of Load Resistor

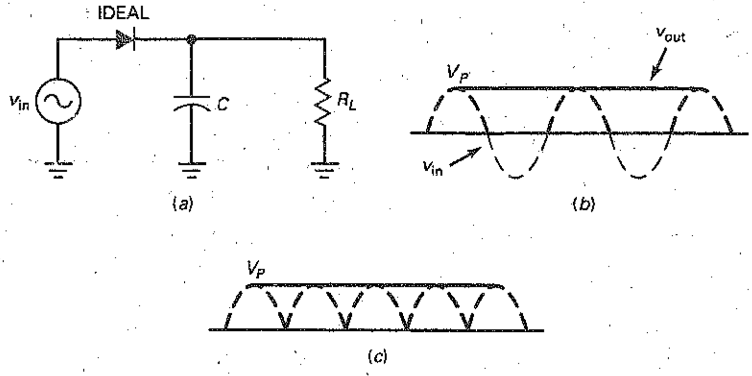
For the capacitor-input filter to be useful, we need to connect a load resistor across the capacitor, as shown in Fig. 4-13*a*. As long as the R_LC time constant is much greater than the period, the capacitor remains almost fully charged and the load voltage is approximately V_p. The only deviation from a perfect dc voltage is the small ripple seen in Fig. 4-13*b*. The smaller the peak-to-peak value of this ripple, the more closely the output approaches a perfect dc voltage.

Between peaks, the diode is off and the capacitor discharges through the load resistor. In other words, the capacitor supplies the load current. Since the capacitor discharges only slightly between peaks, the peak-to-peak ripple is small. When the next peak arrives, the diode conducts briefly and recharges the capacitor to the peak value. A key question is: What size should the capacitor be for proper operation? Before discussing capacitor size, consider what happens with the other rectifier circuits.

Full-Wave Filtering

If we connect a full-wave or bridge rectifier to a capacitor-input filter, the peak-to-peak ripple is cut in half. Figure 4-13*c* shows why. When a full-wave voltage is

Figure 4-13 (*a*) Loaded capacitor-input filter; (*b*) output is direct current with small ripple; (*c*) full wave output has less ripple.



applied to the *RC* circuit, the capacitor discharges for only half as long. Therefore, the peak-to-peak ripple is half the size it would be with a half-wave rectifier.

The Ripple Formula

Here is a derivation we will use to estimate the peak-to-peak ripple out of any capacitor-input filter:

$$V_R = \frac{I}{fC} \tag{4-10}$$

where V_R = peak-to-peak ripple voltage
I = dc load current
f = ripple frequency
C = capacitance

This is an approximation, not an exact derivation. We can use this formula to estimate the peak-to-peak ripple. When a more accurate answer is needed, one solution is to use a computer with a circuit simulator like MultiSim.

For instance, if the dc load current is 10 mA and the capacitance is 200 μF, the ripple with a bridge rectifier and a capacitor-input filter is:

$$V_R = \frac{10\text{ mA}}{(120\text{ Hz})(200\ \mu\text{F})} = 0.417\text{ V pp}$$

In using this derivation, remember two things. First, the ripple is in peak-to-peak (pp) voltage. This is useful because you normally measure ripple voltage with an oscilloscope. Second, the formula works with half-wave or full-wave voltages. Use 60 Hz for half-wave, and 120 Hz for full-wave.

You should use an oscilloscope for ripple measurements if one is available. If not, you can use an ac voltmeter, although there will be a significant error in the measurement. Most ac voltmeters are calibrated to read the rms value of a sine wave. Since the ripple is not a sine wave, you may get a measurement error of as much as 25 percent, depending on the design of the ac voltmeter. But this should be no problem when you are troubleshooting, since you will be looking for much larger changes in ripple.

GOOD TO KNOW

Another, more accurate formula can be used to determine the ripple out of any capacitor input filter. It is

$$V_R = V_{P(\text{out})}\,(1 - \epsilon^{-t/R_LC})$$

Time t represents the length of time the filter capacitor C is allowed to discharge. For a half-wave rectifier, t can be approximated as 16.67 ms, whereas 8.33 ms can be used for a full-wave rectifier.

If you do use an ac voltmeter to measure the ripple, you can convert the peak-to-peak value given by Eq. (4-10) to an rms value using the following formula for a sine wave:

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

Dividing by 2 converts the peak-to-peak value to a peak value, and dividing by $\sqrt{2}$ gives the rms value of a sine wave with the same peak-to-peak value as the ripple voltage.

Exact DC Load Voltage

It is difficult to calculate the exact dc load voltage in a bridge rectifier with a capacitor-input filter. To begin with, we have the two diode drops that are subtracted from the peak voltage. Besides the diode drops, an additional voltage drop occurs, as follows: The diodes conduct heavily when recharging the capacitor because they are on for only a short time during each cycle. This brief but large current has to flow through the transformer windings and the bulk resistance of the diodes. In our examples, we will calculate either the ideal output or the output with the second approximation of a diode, remembering that the actual dc voltage is slightly lower.

Example 4-6

What is the dc load voltage and ripple in Fig. 4-14?

SOLUTION The rms secondary voltage is:

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

The peak secondary voltage is:

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

Assuming an ideal diode and small ripple, the dc load voltage is:

$$V_L = 34\text{ V}$$

To calculate the ripple, we first need to get the dc load current:

$$I_L = \frac{V_L}{R_L} = \frac{34\text{ V}}{5\text{ k}\Omega} = 6.8\text{ mA}$$

Figure 4-14 Half-wave rectifier and capacitor-input filter.

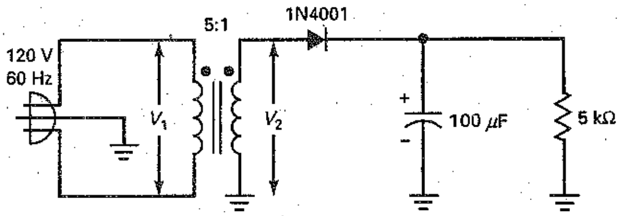
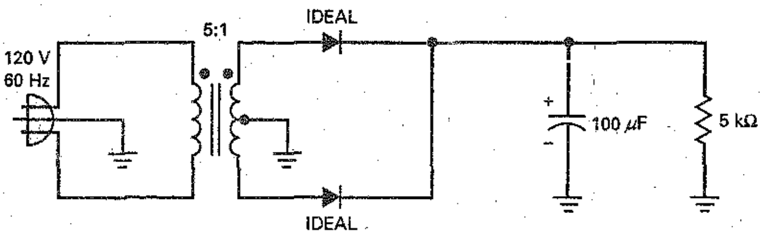


Figure 4-15 Full-wave rectifier and capacitor-input filter.



Now we can use Eq. (4-10) to get:

$$V_R = \frac{6.8\ \text{mA}}{(60\ \text{Hz})(100\ \mu\text{F})} = 1.13\ \text{V pp} \approx 1.1\ \text{V pp}$$

We rounded the ripple to two significant digits because it is an approximation and cannot be accurately measured with an oscilloscope with greater precision.

Here is how to improve the answer slightly: There is about 0.7 V across a silicon diode when it is conducting. Therefore, the peak voltage across the load will be closer to 33.3 V than to 34 V. The ripple also lowers the dc voltage slightly. So the actual dc load voltage will be closer to 33 V than to 34 V. But these are minor deviations. Ideal answers are usually adequate for troubleshooting and preliminary analysis.

A final point about the circuit. The plus sign on the filter capacitor indicates a **polarized capacitor,** one whose plus side must be connected to the positive rectifier output. In Fig. 4-15, the plus sign on the capacitor case is correctly connected to the positive output voltage. You must look carefully at the capacitor case when you are building or troubleshooting a circuit to find out whether it is polarized or not.

Power supplies often use polarized electrolytic capacitors because this type can provide high values of capacitance in small packages. As discussed in earlier courses, *electrolytic capacitors must be connected with the correct polarity* to produce the oxide film. If an electrolytic capacitor is connected in opposite polarity, *it becomes hot and may explode.*

Example 4-7

MultiSim

What is the dc load voltage and ripple in Fig. 4-15?

SOLUTION Since the transformer is 5:1 step-down like the preceding example, the peak secondary voltage is still 34 V. Half this voltage is the input to each half-wave section. Assuming an ideal diode and small ripple, the dc load voltage is:

$$V_L = 17\ \text{V}$$

The dc load current is:

$$I_L = \frac{17\ \text{V}}{5\ \text{k}\Omega} = 3.4\ \text{mA}$$

Now, Eq. (4-10) gives:

$$V_R = \frac{3.4\ \text{mA}}{(120\ \text{Hz})(100\ \mu\text{F})} = 0.283\ \text{V pp} \approx 0.28\ \text{V pp}$$

Because of the 0.7 V across the conducting diode, the actual dc load voltage will be closer to 16 V than to 17 V.

PRACTICE PROBLEM 4-7 Using Fig. 4-15, change R_L to 2 KΩ and calculate the new ideal dc load voltage and ripple.

Example 4-8

MultiSim

What is the dc load voltage and ripple in Fig. 4-16? Compare the answers with those in the two preceding examples.

SOLUTION Since the transformer is 5:1 step-down as in the preceding example, the peak secondary voltage is still 34 V. Assuming an ideal diode and small ripple, the dc load voltage is:

$$V_L = 34\text{ V}$$

The dc load current is:

$$I_L = \frac{34\text{ V}}{5\text{ k}\Omega} = 6.8\text{ mA}$$

Now, Eq. (4-10) gives:

$$V_R = \frac{6.8\text{ mA}}{(120\text{ Hz})(100\ \mu\text{F})} = 0.566\text{ V pp} \approx 0.57\text{ V pp}$$

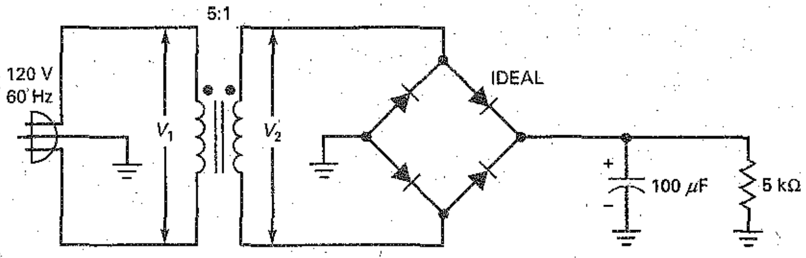
Because of the 1.4 V across two conducting diodes and the ripple, the actual dc load voltage will be closer to 32 V than to 34 V.

We have calculated the dc load voltage and ripple for the three different rectifiers. Here are the results:

Half wave: 34 V and 1.13 V
Full wave: 17 V and 0.288 V
Bridge: 34 V and 0.566 V

For a given transformer, the bridge rectifier is better than the half-wave rectifier because it has less ripple, and it's better than the full-wave rectifier because it produces twice as much output voltage. Of the three, *the bridge rectifier has emerged as the most popular.*

Figure 4-16 Bridge rectifier and capacitor-input filter.

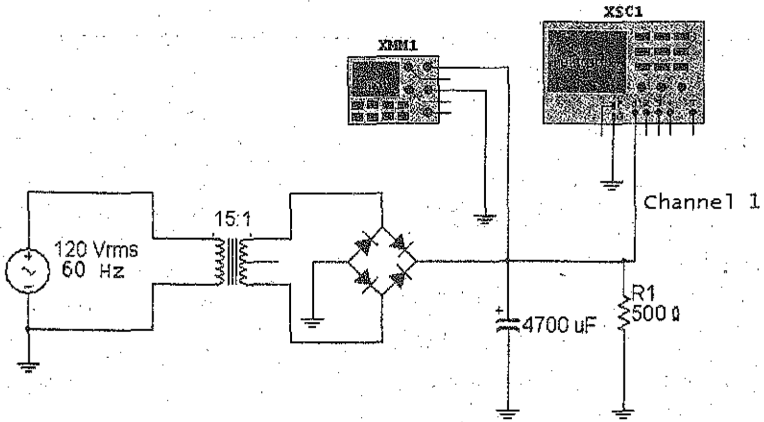


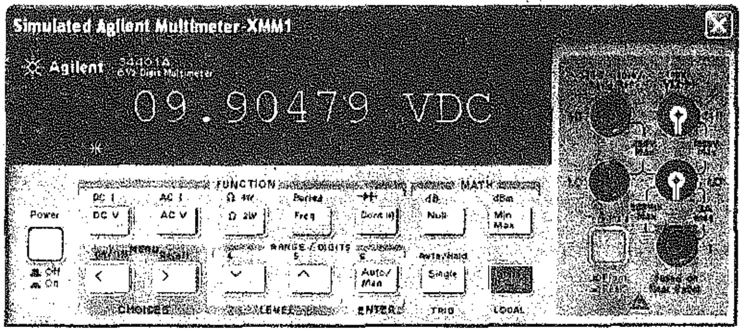
Example 4-9

MultiSim

Figure 4-17 shows the values measured with MultiSim. Calculate the theoretical load voltage and ripple and compare them to the measured values.

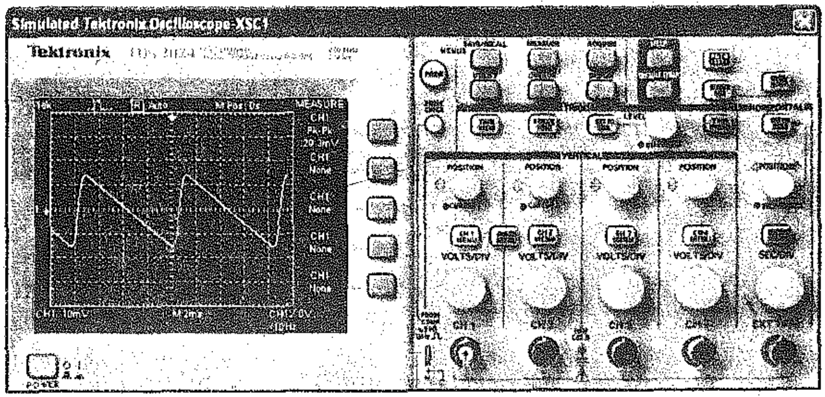
Figure 4-17 Lab example of bridge rectifier and capacitor-input filter.




Simulated Agilent Multimeter-XMM1

Agilent 34401A 6½ Digit Multimeter

09.90479 VDC


Simulated Tektronix Oscilloscope-XSC1

Tektronix

MEASURE CH1 Pk-Pk 20.3mV

CH1 10mV M 2ms CH1 / 0V 10Hz

SOLUTION The transformer is a 15 : 1 step-down, so the rms secondary voltage is

$$V_2 = \frac{120\text{ V}}{15} = 8\text{ V}$$

and the peak secondary voltage is:

$$V_p = \frac{8\text{ V}}{0.707} = 11.3\text{ V}$$

Let's use the second approximation of the diodes to get the dc load voltage:

$$V_L = 11.3\text{ V} - 1.4\text{ V} = 9.9\text{ V}$$

To calculate the ripple, we first need to get the dc load current:

$$I_L = \frac{9.9\text{ V}}{500\ \Omega} = 19.8\text{ mA}$$

Now, we can use Eq. (4-10) to get:

$$V_R = \frac{19.8\text{ mA}}{(120\text{ Hz})(4700\ \mu\text{F})} = 35\text{ mV pp}$$

In Fig. 4-17, a multimeter reads a dc load voltage of 9.9 V.

Channel 1 of the oscilloscope is set to 10 mV/Div. The peak-to-peak ripple is approximately 2.9 Div and the measured ripple is 29.3 mV. This is less than the theoretical value of 35 mV, which emphasizes the point made earlier. Equation (4-10) is to be used for *estimating* ripple. If you need more accuracy, use computer simulation software.

PRACTICE PROBLEM 4-9 Change the capacitor value in Fig. 4-17 to 1,000 μF. Calculate the new V_R value.

4-7 Peak Inverse Voltage and Surge Current

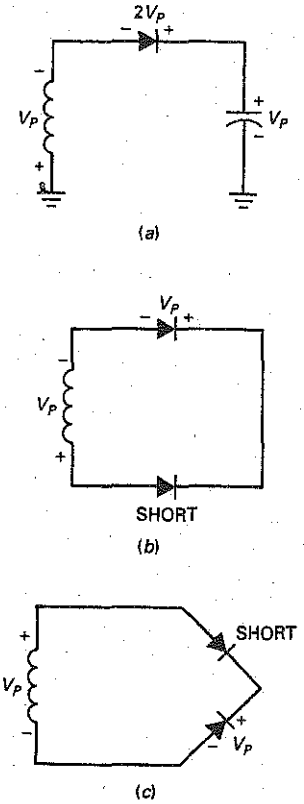
The **peak inverse voltage (PIV)** is the maximum voltage across the nonconducting diode of a rectifier. *This voltage must be less than the breakdown voltage of the diode; otherwise, the diode will be destroyed.* The peak inverse voltage depends on the type of rectifier and filter. The worst case occurs with the capacitor-input filter.

As discussed earlier, data sheets from various manufacturers use many different symbols to indicate the maximum reverse voltage rating of a diode. Sometimes, these symbols indicate different conditions of measurement. Some of the data sheet symbols for the maximum reverse voltage rating are PIV, PRV, V_B, V_{BR}, V_R, V_{RRM}, V_{RWM}, and $V_{R(max)}$.

Half-Wave Rectifier with Capacitor-Input Filter

Figure 4-18*a* shows the critical part of a half-wave rectifier. This is the part of the circuit that determines how much reverse voltage is across the diode. The rest of the circuit has no effect and is omitted for the sake of clarity. In the worse case, the peak secondary voltage is on the negative peak and the capacitor is fully charged

Figure 4-18 (*a*) Peak inverse voltage in half-wave rectifier; (*b*) peak inverse voltage in full-wave rectifier; (*c*) peak inverse voltage in bridge-wave rectifier.



with a voltage of V_p. Apply Kirchhoff's voltage law, and you can see right away that the peak inverse voltage across the nonconducting diode is:

$$\text{PIV} = 2V_p \tag{4-11}$$

For instance, if the peak secondary voltage is 15 V, the peak inverse voltage is 30 V. As long as the breakdown voltage of the diode is greater than this, the diode will not be damaged.

Full-Wave Rectifier with Capacitor-Input Filter

Figure 4-18*b* shows the essential part of a full-wave rectifier needed to calculate the peak inverse voltage. Again, the secondary voltage is at the negative peak. In this case, the lower diode acts like a short (closed switch) and the upper diode is open. Kirchhoff's law implies:

$$\text{PIV} = V_p \tag{4-12}$$

Bridge Rectifier with Capacitor-Input Filter

Figure 4-18*c* shows part of a bridge rectifier. This is all you need to calculate the peak inverse voltage. Since the upper diode is shorted and the lower one is open, the peak inverse voltage across the lower diode is:

$$\text{PIV} = V_p \tag{4-13}$$

Another advantage of the bridge rectifier is that it has the lowest peak inverse voltage for a given load voltage. To produce the same load voltage, the full-wave rectifier would need twice as much secondary voltage.

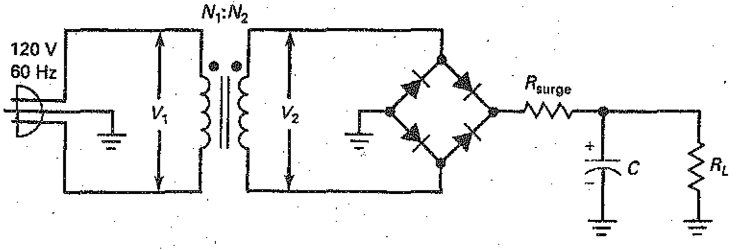
Surge Resistor

Before the power is turned on, the filter capacitor is uncharged. At the first instant the power is applied, this capacitor looks like a short. Therefore, the initial charging current may be very large. All that exists in the charging path to impede the current is the resistance of the transformer windings and the bulk resistance of the diodes. The initial rush of current when the power is turned on is called the **surge current.**

Ordinarily, the designer of the power supply will select a diode with enough current rating to withstand the surge current. The key to the surge current is the size of the filter capacitor. Occasionally, a designer may decide to use a **surge resistor** rather than select another diode.

Figure 4-19 illustrates the idea. A small resistor is inserted between the bridge rectifier and the capacitor-input filter. Without the resistor, the surge current might destroy the diodes. By including the surge resistor, the designer reduces the surge current to a safe level. Surge resistors are not used very often and are mentioned just in case you see one used in a power supply.

Figure 4-19 Surge resistor limits surge current.



Example 4-10

What is the peak inverse voltage in Fig. 4-19 if the turns ratio is 8:1? A 1N4001 has a breakdown voltage of 50 V. Is it safe to use a 1N4001 in this circuit?

SOLUTION The rms secondary voltage is:

$$V_2 = \frac{120\text{ V}}{8} = 15\text{ V}$$

The peak secondary voltage is:

$$V_p = \frac{15\text{ V}}{0.707} = 21.2\text{ V}$$

The peak inverse voltage is:

$$\text{PIV} = 21.2\text{ V}$$

The 1N4001 is more than adequate, since the peak inverse voltage is much less than the breakdown voltage of 50 V.

PRACTICE PROBLEM 4-10 Using Fig. 4-19, change the transformer's turns ratio to 2:1. Which 1N4000 series of diodes should you use?

4-8 Other Power-Supply Topics

You have a basic idea of how power-supply circuits work. In the preceding sections, you have seen how an ac input voltage is rectified and filtered to get a dc voltage. There are a few additional ideas you need to know about.

Commercial Transformers

The use of turns ratios with transformers applies only to ideal transformers. Iron-core transformers are different. In other words, the transformers you buy from a parts supplier are not ideal because the windings have resistance, which produces power losses. Furthermore, the laminated core has eddy currents, which produce additional power losses. Because of these unwanted power losses, the turns ratio is only an approximation. In fact, the data sheets for transformers rarely list the turns ratio. Usually, all you get is the secondary voltage at a rated current.

For instance, Fig. 4-20*a* shows an F-25X, an industrial transformer whose data sheet gives only the following specifications: for a primary voltage of 115 V ac, the secondary voltage is 12.6 V ac when the secondary current is 1.5 A. If the secondary current is less than 1.5 A in Fig. 4-20*a*, the secondary voltage will be more than 12.6 V ac because of lower power losses in the windings and laminated core.

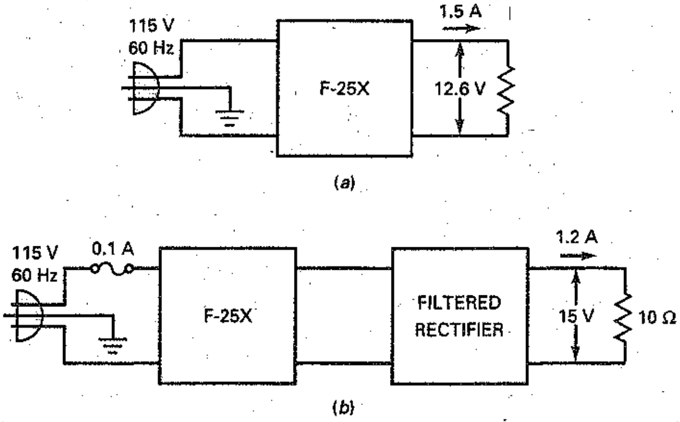
If it is necessary to know the primary current, you can estimate the turns ratio of a real transformer by using this definition:

$$\frac{N_1}{N_2} = \frac{V_1}{V_2} \qquad \textbf{(4-14)}$$

GOOD TO KNOW

When a transformer is unloaded, the secondary voltage usually measures a value that is 5 to 10 percent higher than its rated value.

Figure 4-20 (*a*) Rating on real transformer; (*b*) calculating fuse current.



For instance, the F25X has $V_1 = 115$ V and $V_2 = 12.6$ V. The turns ratio at the rated load current of 1.5 A is:

$$\frac{N_1}{N_2} = \frac{115}{12.6} = 9.13$$

This is an approximation because the calculated turns ratio decreases when the load current decreases.

Calculating Fuse Current

When troubleshooting, you may need to calculate the primary current to determine whether a fuse is adequate or not. The easiest way to do this with a real transformer is to assume that the input power equals the output power: $P_{in} = P_{out}$. For instance, Fig. 4-20*b* shows a fused transformer driving a filtered rectifier. Is the 0.1-A fuse adequate?

Here is how to estimate the primary current when troubleshooting. The output power equals the dc load power:

$$P_{out} = VI = (15\text{ V})(1.2\text{ A}) = 18\text{ W}$$

Ignore the power losses in the rectifier and the transformer. Since the input power must equal the output power:

$$P_{in} = 18\text{ W}$$

Since $P_{in} = V_1 I_1$, we can solve for the primary current:

$$I_1 = \frac{18\text{ W}}{115\text{ V}} = 0.156\text{ A}$$

This is only an estimate because we ignored the power losses in the transformer and rectifier. The actual primary current will be higher by about 5 to 20 percent because of these additional losses. In any case, the fuse is inadequate. It should be at least 0.25 A.

Slow-Blow Fuses

Assume that a capacitor-input filter is used in Fig. 4-20*b*. If an ordinary 0.25-A fuse is used in Fig. 4-20*b*, it will blow out when you turn the power on. The reason is the surge current, described earlier. Most power supplies use a slow-blow fuse, one that can temporarily withstand overloads in current. For instance, a 0.25-A slow-blow fuse can withstand

2 A for 0.1 s
1.5 A for 1 s
1 A for 2 s

and so on. With a slow-blow fuse, the circuit has time to charge the capacitor. Then, the primary current drops down to its normal level with the fuse still intact.

Calculating Diode Current

Whether a half-wave rectifier is filtered or not, the average current through the diode has to equal the dc load current because there is only one path for current. As a derivation:

Half wave: $I_{\text{diode}} = I_{\text{dc}}$ (4-15)

On the other hand, the average current through a diode in the full-wave rectifier equals only half the dc load current because there are two diodes in the circuit, each sharing the load. Similarly, each diode in a bridge rectifier has to withstand an average current of half the dc load current. As a derivation:

Full wave: $I_{\text{diode}} = 0.5I_{\text{dc}}$ (4-16)

Summary Table 4-2 compares the properties of the three capacitor-input filtered rectifiers.

Reading a Data Sheet

Refer to the data sheet of the 1N4001 in Chap. 3, Fig. 3-16. The maximum peak repetitive reverse voltage, V_{RRM} on the data sheet, is the same as the peak inverse voltage discussed earlier. The data sheet says that the 1N4001 can withstand a voltage of 50 V in the reverse direction.

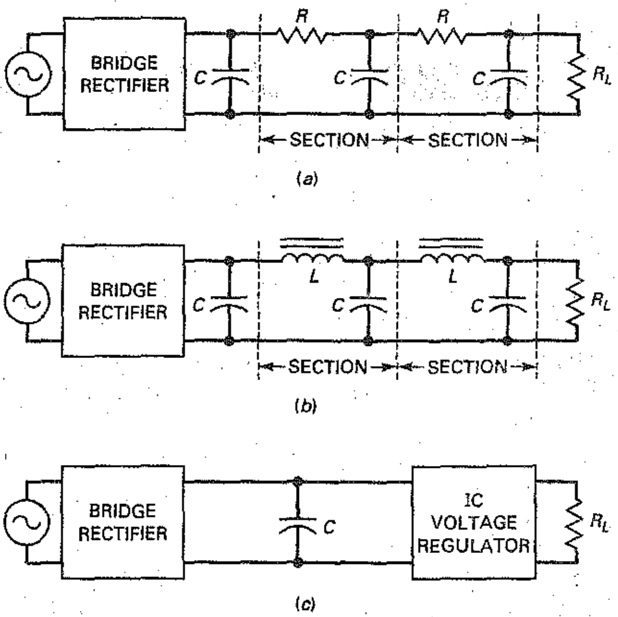
The average rectified forward current—$I_{F(\text{av})}$, $I_{(\text{max})}$, or I_0—is the dc or average current through the diode. For a half-wave rectifier, the diode current equals the dc load current. For a full-wave or bridge rectifier, it equals half the dc load current. The data sheet says that a 1N4001 can have a dc current of 1 A, which means that the dc load current can be as much as 2 A in a bridge rectifier.

Summary Table 4-2 Capacitor-Input Filtered Rectifiers*

	Half-wave	Full-wave	Bridge
Number of diodes	1	2	4
Rectifier input	$V_{p(2)}$	$0.5V_{p(2)}$	$V_{p(2)}$
DC output (ideal)	$V_{p(2)}$	$0.5V_{p(2)}$	$V_{p(2)}$
DC output (2d)	$V_{p(2)} - 0.7$ V	$0.5V_{p(2)} - 0.7$ V	$V_{p(2)} - 1.4$ V
Ripple frequency	f_{in}	$2f_{in}$	$2f_{in}$
PIV	$2V_{p(2)}$	$V_{p(2)}$	$V_{p(2)}$
Diode current	I_{dc}	$0.5I_{dc}$	$0.5I_{dc}$

*$V_{p(2)}$ = peak secondary voltage; $V_{p(\text{out})}$ = peak output voltage; I_{dc} = dc load current.

Figure 4-21 (*a*) *RC* filtering; (*b*) *LC* filtering; (*c*) voltage-regulator filtering.



Notice also the surge-current rating I_{FSM}. The data sheet says that a 1N4001 can withstand 30 A during the first cycle when the power is turned on.

RC Filters

Before the 1970s, **passive filters** (*R*, *L*, and *C* components) were often connected between the rectifier and the load resistance. Nowadays, you rarely see passive filters used in semiconductor power supplies, but there might be special applications, such as audio power amplifiers, in which you might encounter them.

Figure 4-21*a* shows a bridge rectifier and a capacitor-input filter. Usually, a designer will settle for a peak-to-peak ripple of as much as 10 percent across the filter capacitor. The reason for not trying to get even lower ripple is because the filter capacitor would become too large. Additional filtering is then done by *RC* sections between the filter capacitor and the load resistor.

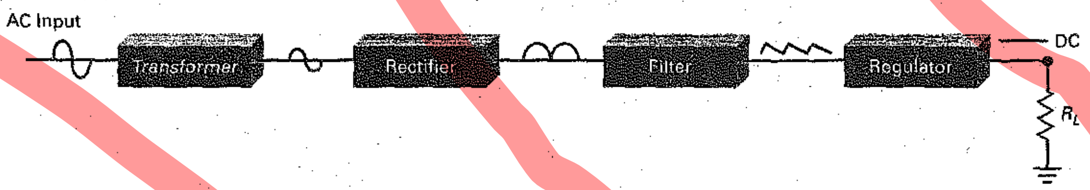
The *RC* sections are examples of a passive filter, one that uses only *R*, *L*, or *C* components. By deliberate design, *R* is much greater than X_C at the ripple frequency. Therefore, the ripple is reduced before it reaches the load resistor. Typically, *R* is at least 10 times greater than X_C. This means that each section attenuates (reduces) the ripple by a factor of at least 10. The disadvantage of an *RC* filter is the loss of dc voltage across each *R*. Because of this, the *RC* filter is suitable only for very light loads (small load current or large load resistance).

LC Filter

When the load current is large, the *LC* filters of Fig. 4-21*b* are an improvement over *RC* filters. Again, the idea is to drop the ripple across the series components, in this case, the inductors. By making X_L much greater than X_C, we can reduce the ripple to a very low level. The dc voltage drop across the inductors is much smaller than it is across the resistors of *RC* sections because the winding resistance is smaller.

The *LC* filter was very popular at one time. Now, it's becoming obsolete in typical power supplies because of the size and cost of inductors. For low-voltage

Summary Table 4-3 Power Supply Block Diagram



Purpose	Provides proper secondary ac voltage and ac ground isolation	Changes ac input to pulsating dc	Smooths out dc pulses	Provides a constant output voltage under varying loads and ac input voltage
Types	Step-up, step-down, isolation (1:1)	Half-wave, full-wave, full-wave bridge	Choke-input, capacitor input	Discrete components, integrated circuit (IC)

GOOD TO KNOW

A filter made of an inductor placed in between two capacitors is often called a pi (π) filter.

power supplies, the *LC* filter has been replaced by an **integrated circuit (IC).** This is a device that contains diodes, transistors, resistors, and other components in a miniaturized package to perform a specific function.

Figure 4-21*c* illustrates the idea. An **IC voltage regulator,** one type of integrated circuit, is between the filter capacitor and the load resistor. This device not only reduces the ripple, it also holds the output voltage constant. We will discuss IC voltage regulators in a later chapter. Because of their low cost, IC voltage regulators are now the standard method used for ripple reduction.

Summary Table 4-3 breaks the power supply down into functional blocks.

4-9 Troubleshooting

Almost every piece of electronics equipment has a power supply, typically a rectifier driving a capacitor-input filter followed by a voltage regulator (discussed later). This power supply produces the dc voltages needed by transistors and other devices. If a piece of electronics equipment is not working properly, start your troubleshooting with the power supply. More often than not, *equipment failure is caused by troubles in the power supply.*

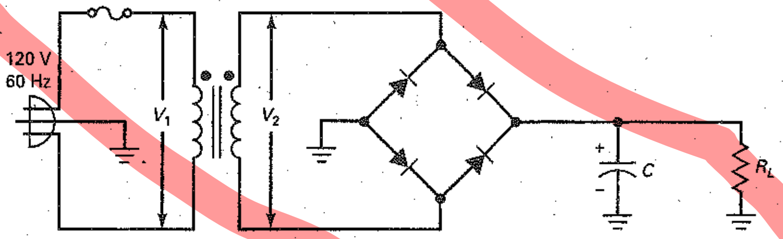
Procedure

Assume that you are troubleshooting the circuit of Fig. 4-22. You can start by measuring the dc load voltage. It should be approximately the same as the peak secondary voltage. If not, there are two possible courses of action.

First, if there is no load voltage, you can use a floating VOM or DMM to measure the secondary voltage (ac range). The reading is the rms voltage across the secondary winding. Convert this to peak value. You can estimate the peak value by adding 40 percent to the rms value. If this is normal, the diodes may be defective. If there is no secondary voltage, either the fuse is blown or the transformer is defective.

Second, if there is dc load voltage, but it is lower than it should be, look at the dc load voltage with an oscilloscope and measure the ripple. A peak-to-peak ripple around 10 percent of the ideal load voltage is reasonable. The ripple may be

Figure 4-22 Troubleshooting.



somewhat more or less than this, depending on the design. Furthermore, the ripple frequency should be 120 Hz for a full-wave or bridge rectifier. If the ripple is 60 Hz, one of the diodes may be open.

Common Troubles

Here are the most common troubles that arise in bridge rectifiers with capacitor-input filters:

1. If the fuse is open, there will be no voltages anywhere in the circuit.
2. If the filter capacitor is open, the dc load voltage will be low because the output will be an unfiltered full-wave signal.
3. If one of the diodes is open, the dc load voltage will be low because there will be only half-wave rectification. Also, the ripple frequency will be 60 Hz instead of 120 Hz. If all diodes are open, there will be no output.
4. If the load is shorted, the fuse will be blown. Possibly, one or more diodes may be ruined or the transformer may be damaged.
5. Sometimes the filter capacitor becomes leaky with age, and this reduces the dc load voltage.
6. Occasionally, shorted windings in the transformer reduce the dc output voltage. In this case, the transformer often feels very warm to the touch.
7. Besides these troubles, you can have solder bridges, cold-solder joints, bad connections, and so on.

Summary Table 4-4 lists these troubles and their symptoms.

Summary Table 4-4 **Typical Troubles for Capacitor-Input Filtered Bridge Rectifier**

	V_1	V_2	$V_{L(dc)}$	V_R	f_{ripple}	Scope on Output
Fuse blown	Zero	Zero	Zero	Zero	Zero	No output
Capacitor open	OK	OK	Low	High	120 Hz	Full-wave signal
One diode open	OK	OK	Low	High	60 Hz	Half-wave ripple
All diodes open	OK	OK	Zero	Zero	Zero	No output
Load shorted	Zero	Zero	Zero	Zero	Zero	No output
Leaky capacitor	OK	OK	Low	High	120 Hz	Low output
Shorted windings	OK	Low	Low	OK	120 Hz	Low output