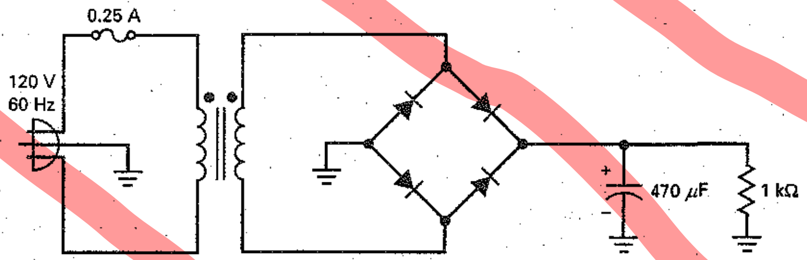
Example 4-11

When the circuit of Fig. 4-23 is working normally, it has an rms secondary voltage of 12.7 V, a load voltage of 18 V, and a peak-to-peak ripple of 318 mV. If the filter capacitor is open, what happens to the dc load voltage?

Figure 4-23



SOLUTION With an open filter capacitor, the circuit reverts to a bridge rectifier with no filter capacitor. Because there is no filtering, an oscilloscope across the load will display a full-wave signal with a peak value of 18 V. The average value is 63.6 percent of 18 V, which is 11.4 V.

Example 4-12

Suppose the load resistor of Fig. 4-23 is shorted. Describe the symptoms.

SOLUTION A short across the load resistor will increase the current to a very high value. This will blow out the fuse. Furthermore, it is possible that one or more diodes will be destroyed before the fuse blows. Often, when one diode shorts, it will cause the other rectifier diodes to also short. Because of the blown fuse, all voltages will measure zero. When you check the fuse visually or with an ohmmeter, you will see that it is open.

With the power off, you should check the diodes with an ohmmeter to see whether any of them have been destroyed. You should also measure the load resistance with an ohmmeter. If it measures zero or very low, you have more troubles to locate.

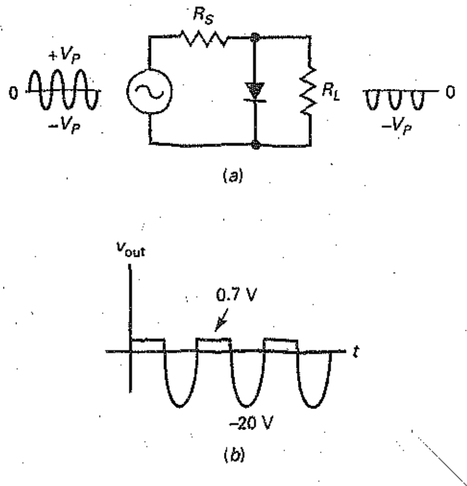
The trouble could be a solder bridge across the load resistor, incorrect wiring, or any number of possibilities. Fuses do occasionally blow out without a permanent short across the load. But the point is this: *When you get a blown fuse, check the diodes for possible damage and the load resistance for a possible short.*

A troubleshooting exercise at the end of the chapter has eight different troubles, including open diodes, filter capacitors, shorted loads, blown fuses, and open grounds.

4-10 Clippers and Limiters

The diodes used in low-frequency power supplies are *rectifier diodes.* These diodes are optimized for use at 60 Hz and have power ratings greater than 0.5 W. The typical rectifier diode has a forward current rating in amperes. Except for power supplies, rectifier diodes have little use because most circuits inside electronics equipment are running at much higher frequencies.

Figure 4-24 (*a*) Positive clipper; (*b*) output waveform.



(*a*)

(*b*)

Small-Signal Diodes

In this section, we will be using *small-signal diodes.* These diodes are optimized for use at high frequencies and have power ratings less than 0.5 W. The typical small-signal diode has a current rating in milliamperes. It is this smaller and lighter construction that allows the diode to work at higher frequencies.

The Positive Clipper

A **clipper** is a circuit that removes either positive or negative parts of a waveform. This kind of processing is useful for signal shaping, circuit protection, and communications. Figure 4-24*a* shows a *positive clipper.* The circuit removes all the positive parts of the input signal. This is why the output signal has only negative half cycles.

Here is how the circuit works: During the positive half cycle, the diode turns on and looks like a short across the output terminals. Ideally, the output voltage is zero. On the negative half cycle, the diode is open. In this case, a negative half cycle appears across the output. By deliberate design, the series resistor is much smaller than the load resistor. This is why the negative output peak is shown as $-V_p$ in Fig. 4-24*a*.

To a second approximation, the diode voltage is 0.7 V when conducting. Therefore, the clipping level is not zero, but 0.7 V. For instance, if the input signal has a peak value of 20 V, the output of the clipper will look like Fig. 4-24*b*.

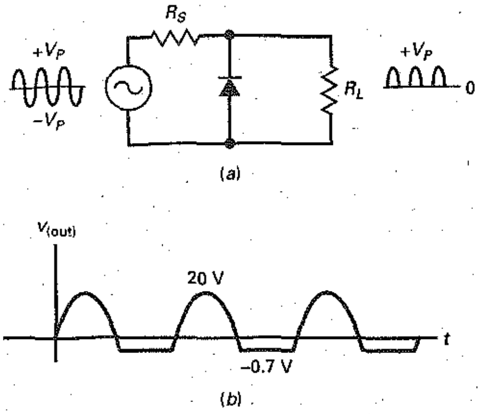
Defining Conditions

Small-signal diodes have a smaller junction area than rectifier diodes because they are optimized to work at higher frequencies. As a result, they have more bulk resistance. The data sheet of a small-signal diode like the 1N914 lists a forward current of 10 mA at 1 V. Therefore, the bulk resistance is:

$$R_B = \frac{1\text{ V} - 0.7\text{ V}}{10\text{ mA}} = 30\ \Omega$$

Why is bulk resistance important? Because the clipper will not work properly unless the series resistance R_S is much greater than the bulk resistance. Furthermore, the clipper won't work properly unless the series resistance R_S is

Figure 4-25 (*a*) Negative clipper; (*b*) output waveform.



much smaller than the load resistance. For a clipper to work properly, we will use this definition:

$$\textbf{Stiff clipper: } 100R_B < R_S < 0.01R_L \tag{4-17}$$

This says that the series resistance must be 100 times greater than the bulk resistance and 100 times smaller than the load resistance. When a clipper satisfies these conditions, we call it a *stiff clipper.* For instance, if the diode has a bulk resistance of 30 Ω, the series resistance should be at least 3 kΩ and the load resistance should be at least 300 kΩ.

The Negative Clipper

If we reverse the polarity of the diode as shown in Fig. 4-25*a*, we get a *negative clipper.* As you would expect, this removes the negative parts of the signal. Ideally, the output waveform has nothing but positive half cycles.

The clipping is not perfect. Because of the diode *offset voltage* (another way of saying *barrier potential*), the clipping level is at −0.7 V. If the input signal has a peak of 20 V, the output signal will look like Fig. 4-25*b*.

The Limiter or Diode Clamp

The clipper is useful for waveshaping, but the same circuit can be used in a totally different way. Take a look at Fig. 4-26*a*. The normal input to this circuit is a signal with a peak of only 15 mV. Therefore, the normal output is the same signal because neither diode is turned during the cycle.

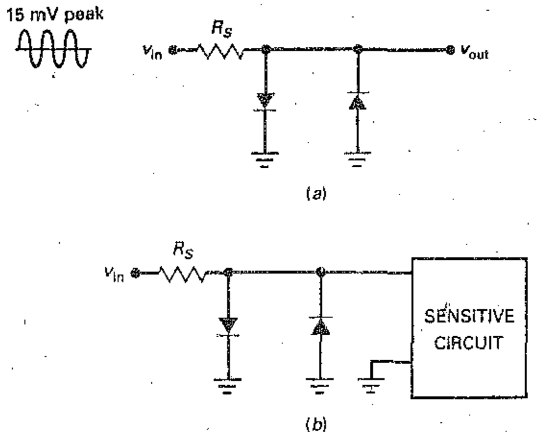
What good is the circuit if the diodes don't turn on? Whenever you have a sensitive circuit, one that cannot have too much input, you can use a positive-negative *limiter* to protect its input, as shown in Fig. 4-26*b*. If the input signal tries to rise above 0.7 V, the output is limited to 0.7 V. On the other hand, if the input signal tries to drop below −0.7 V, the output is limited to −0.7 V. In a circuit like this, normal operation means that the input signal is always smaller than 0.7 V in either polarity.

An example of a sensitive circuit is the *op amp,* an IC that will be discussed in later chapters. The typical input voltage to an op amp is less than 15 mV. Voltages greater than 15 mV are unusual, and voltages greater than 0.7 V are abnormal. A limiter on the input side of an op amp will prevent excessive input voltage from being accidentally applied.

GOOD TO KNOW

Negative diode clamps are often used on the inputs of digital TTL logic gates.

Figure 4-26 (*a*) Diode clamp; (*b*) protecting a sensitive circuit.



A more familiar example of a sensitive circuit is a moving-coil meter. By including a limiter, we can protect the meter movement against excessive input voltage or current.

The limiter of Fig. 4-26*a* is also called a *diode clamp*. The term suggests clamping or limiting the voltage to a specified range. With a diode clamp, the diodes remain off during normal operation. The diodes conduct only when something is abnormal, when the signal is too large.

Biased Clippers

The reference level (same as the clipping level) of a positive clipper is ideally zero, or 0.7 V to a second approximation. What can we do to change this reference level?

In electronics, ***bias*** means applying an external voltage to change the reference level of a circuit. Figure 4-27*a* is an example of using bias to change the reference level of a positive clipper. By adding a dc voltage source in series with the diode, we can change the clipping level. The new V must be less than V_p for normal operation. With an ideal diode, conduction starts as soon as the input

Figure 4-27 (*a*) Biased positive clipper; (*b*) biased negative clipper.

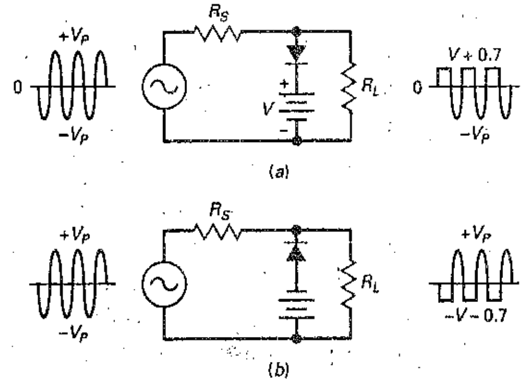


Figure 4-28 Biased positive-negative clipper.

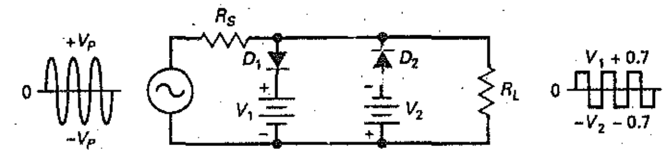
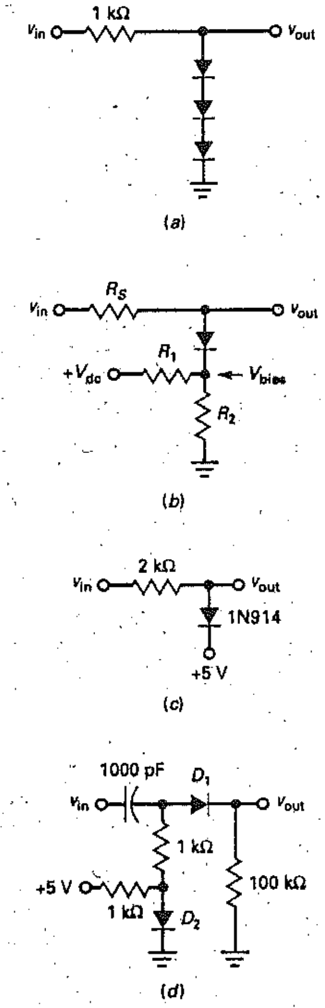


Figure 4-29 (a) Clipper with three offset voltages; (b) voltage divider biases clipper; (c) diode clamp protects above 5.7 V; (d) diode D_2 biases D_1 to remove offset voltage.



voltage is greater than V. To a second approximation, it starts when the input voltage is greater than $V + 0.7$ V.

Figure 4-27*b* shows how to bias a negative clipper. Notice that the diode and battery have been reversed. Because of this, the reference level changes to $-V - 0.7$ V. The output waveform is negatively clipped at the bias level.

Combination Clipper

We can combine the two biased clippers as shown in Fig. 4-28. Diode D_1 clips off positive parts above the positive bias level, and diode D_2 clips off parts below the negative bias level. When the input voltage is very large compared to the bias levels, the output signal is a *square wave*, as shown in Fig. 4-28. This is another example of the signal shaping that is possible with clippers.

Variations

Using batteries to set the clipping level is impractical. One approach is to add more silicon diodes because each produces a bias of 0.7 V. For instance, Fig. 4-29*a* shows three diodes in a positive clipper. Since each diode has an offset of around 0.7 V, the three diodes produce a clipping level of approximately +2.1 V. The application does not have to be a clipper (waveshaping). We can use the same circuit as a diode clamp (limiting) to protect a sensitive circuit that cannot tolerate more than a 2.1-V input.

Figure 4-29*b* shows another way to bias a clipper without batteries. This time, we are using a voltage divider (R_1 and R_2) to set the bias level. The bias level is given by:

$$V_{bias} = \frac{R_2}{R_1 + R_2} V_{dc} \qquad (4\text{-}18)$$

In this case, the output voltage is clipped or limited when the input is greater than $V_{bias} + 0.7$ V.

Figure 4-29*c*, shows a biased diode clamp. It can be used to protect sensitive circuits from excessive input voltages. The bias level is shown as +5 V. It can be any bias level you want it to be. With a circuit like this, a destructively large voltage of +100 V never reaches the load because the diode limits the output voltage to a maximum value of +5.7 V.

Sometimes a variation like Fig. 4-29*d* is used to remove the offset of the limiting diode D_1. Here is the idea: Diode D_2 is biased slightly into forward conduction, so that it has approximately 0.7 V across it. This 0.7 V is applied to 1 kΩ in series with D_1 and 100 kΩ. This means that diode D_1 is on the verge of conduction. Therefore, when a signal comes in, diode D_1 conducts near 0 V.