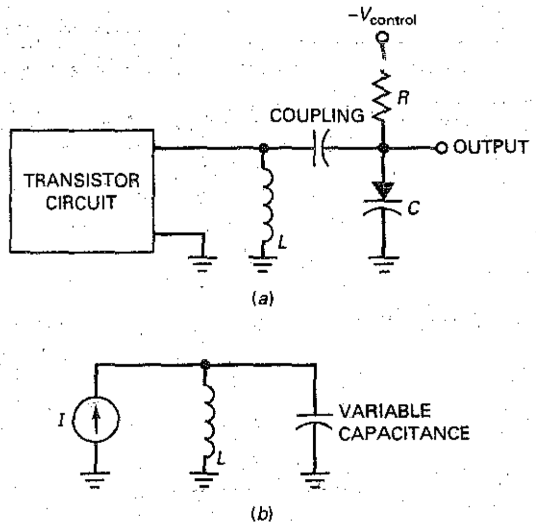
Example 5-17

What does the circuit of Fig. 5-34*a* do?

SOLUTION As mentioned in Chap. 1, a transistor is a semiconductor device that acts like a current source. In Fig. 5-34*a*, the transistor pumps a fixed number of milliamperes into the resonant *LC* tank circuit. A negative dc voltage reverse-biases the varactor. By varying this dc control voltage, we can vary the resonant frequency of the *LC* circuit.

As far as the ac signal is concerned, we can use the equivalent circuit shown in Fig. 5-34*b*. The coupling capacitor acts like a short circuit. An ac current source drives a resonant *LC* tank circuit. The varactor acts like variable capacitance, which means that we can change the resonant frequency by changing the dc control voltage. This is the basic idea behind the tuning of radio and television receivers.

Figure 5-34 Varactors can tune resonant circuits. (*a*) Transistor (current source) drives tuned *LC* tank; (*b*) ac equivalent circuit.



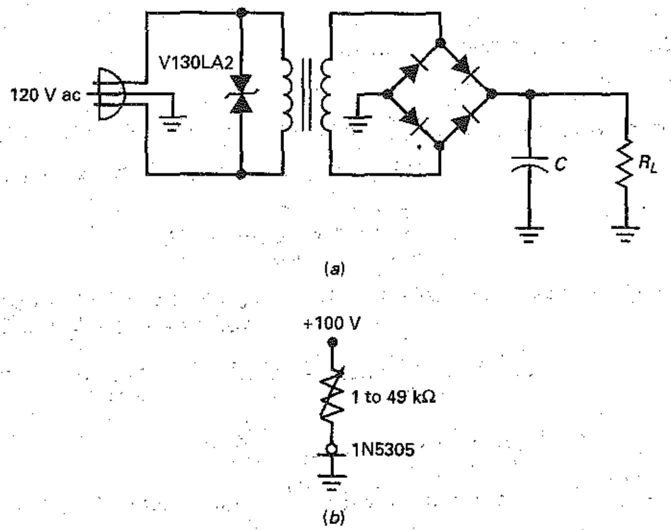
5-11 Other Diodes

Besides the special-purpose diodes discussed so far, there are others you should know about. Because they are so specialized, only a brief description follows.

Varistors

Lightning, power-line faults, and transients can pollute the ac line voltage by superimposing dips and spikes on the normal 120 V rms. *Dips* are severe voltage drops lasting microseconds or less. *Spikes* are very brief overvoltages up to 2000 V

Figure 5-35 (*a*) Varistor protects primary from ac line transients; (*b*) current-regulator diode.



or more. In some equipment, filters are used between the power line and the primary of the transformer to eliminate the problems caused by ac line transients.

One of the devices used for line filtering is the **varistor** (also called a *transient suppressor*). This semiconductor device is like two back-to-back zener diodes with a high breakdown voltage in both directions. Varistors are commercially available with breakdown voltages from 10 to 1000 V. They can handle peak transient currents in the hundreds or thousands of amperes.

For instance, a V130LA2 is a varistor with a breakdown voltage of 184 V (equivalent to 130 V rms) and a peak current rating of 400 A. Connect one of these across the primary winding as shown in Fig. 5-35*a*, and you don't have to worry about spikes. The varistor will clip all spikes at the 184-V level and protect your power supply.

Current-Regulator Diodes

These are diodes that work in a way exactly opposite to the way zener diodes work. Instead of holding the voltage constant, these diodes hold the current constant. Known as **current-regulator diodes** (or *constant-current diodes*), these devices keep the current through them fixed when the voltage changes. For example, the 1N5305 is a constant-current diode with a typical current of 2 mA over a voltage range of 2 to 100 V. Figure 5-35*b* shows the schematic symbol of a current-regulator diode. In Fig. 5-35*b*, the diode will hold the load current constant at 2 mA even though the load resistance is varied from 1 to 49 kΩ.

Step-Recovery Diodes

The **step-recovery diode** has the unusual doping profile shown in Fig. 5-36*a*. This graph indicates that the density of carriers decreases near the junction. This unusual distribution of carriers causes a phenomenon called *reverse snap-off*.

Figure 5-36*b* shows the schematic symbol for a step-recovery diode. During the positive half cycle, the diode conducts like any silicon diode. But during the negative half cycle, reverse current exists for a while because of the stored charges, and then suddenly drops to zero.

Figure 5-36 Step-recovery diode. (*a*) Doping profile shows less doping near junction; (*b*) circuit rectifying an ac input signal; (*c*) snap-off produces a positive voltage step rich in harmonics.

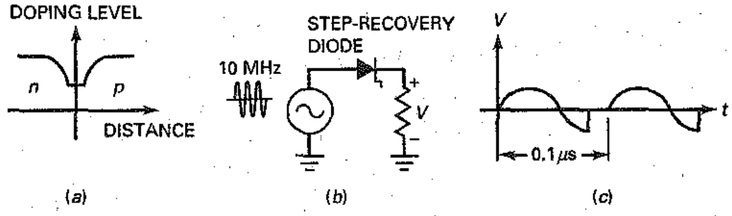


Figure 5-36*c* shows the output voltage. It's as though the diode conducts reverse current for a while, and then suddenly snaps open. This is why the step-recovery diode is also known as a *snap diode.* The sudden step in current is rich in harmonics and can be filtered to produce a sine wave of a higher frequency. (*Harmonics* are multiples of the input frequency like $2f_{in}$, $3f_{in}$, and $4f_{in}$.) Because of this, step-recovery diodes are useful in frequency multipliers, circuits whose output frequency is a multiple of the input frequency.

Back Diodes

Zener diodes normally have breakdown voltages greater than 2 V. By increasing the doping level, we can get the zener effect to occur near zero. Forward conduction still occurs around 0.7 V, but now reverse conduction (breakdown) starts at approximately −0.1 V.

A diode with a graph like Fig. 5-37*a* is called a **back diode** because it conducts better in the reverse than in the forward direction. Figure 5-34*b* shows a sine wave with a peak of 0.5 V driving a back diode and a load resistor. (Notice that the zener symbol is used for the back diode.) The 0.5 V is not enough to turn on the diode in the forward direction, but it is enough to break down the diode in the reverse direction. For this reason, the output is a half-wave signal with a peak of 0.4 V, as shown in Fig. 5-37*b*.

Back diodes are occasionally used to rectify weak signals with peak amplitudes between 0.1 and 0.7 V.

Tunnel Diodes

By increasing the doping level of a back diode, we can get breakdown to occur at 0 V. Furthermore, the heavier doping distorts the forward curve, as shown in Fig. 5-38*a*. A diode with this graph is called a **tunnel diode.**

Figure 5-38*b* shows the schematic symbol for a tunnel diode. This type of diode exhibits a phenomenon known as **negative resistance.** This means that

Figure 5-37 Back diode. (*a*) Breakdown occurs at −0.1 V; (*b*) circuit rectifying weak ac signal.

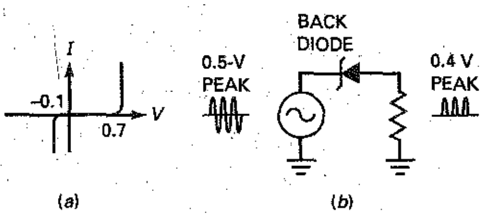
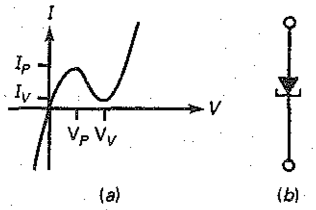


Figure 5-38 Tunnel diode. (*a*) Breakdown occurs at 0 V; (*b*) schematic symbol.



an increase in forward voltage produces a decrease in forward current, at least over the part of the graph between V_P and V_V. The negative resistance of tunnel diodes is useful in high-frequency circuits called *oscillators*. These circuits are able to generate a sinusoidal signal, similar to that produced by an ac generator. But unlike the ac generator that converts mechanical energy to a sinusoidal signal, an oscillator converts dc energy to a sinusoidal signal. Later chapters will show you how to build oscillators.

PIN Diodes

A **PIN diode** is a semiconductor device that operates as a variable resistor at RF and microwave frequencies. Figure 5-39*a* shows its construction. It consists of an intrinsic (pure) semiconductor material sandwiched between p-type and n-type materials. Figure 5-39*b* shows the schematic symbol for the PIN diode.

When the diode is forward biased, it acts like a current-controlled resistance. Figure 5-39*c* shows how the PIN diode's series resistance R_S decreases as its forward current increases. When reverse biased, the PIN diode acts like a fixed capacitor. The PIN diode is widely used in RF and microwave modulator circuits.

Table of Devices

Summary Table 5-1 lists all the special-purpose devices in this chapter. The zener diode is useful in voltage regulators, the LED as a dc or an ac indicator, the seven-segment indicator in measuring instruments, and so on. You should study the table and remember the ideas it contains.

Figure 5-39 PIN diode. (*a*) Construction; (*b*) schematic symbol; (*c*) series resistance.