Zener Diode

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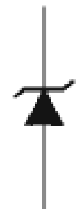
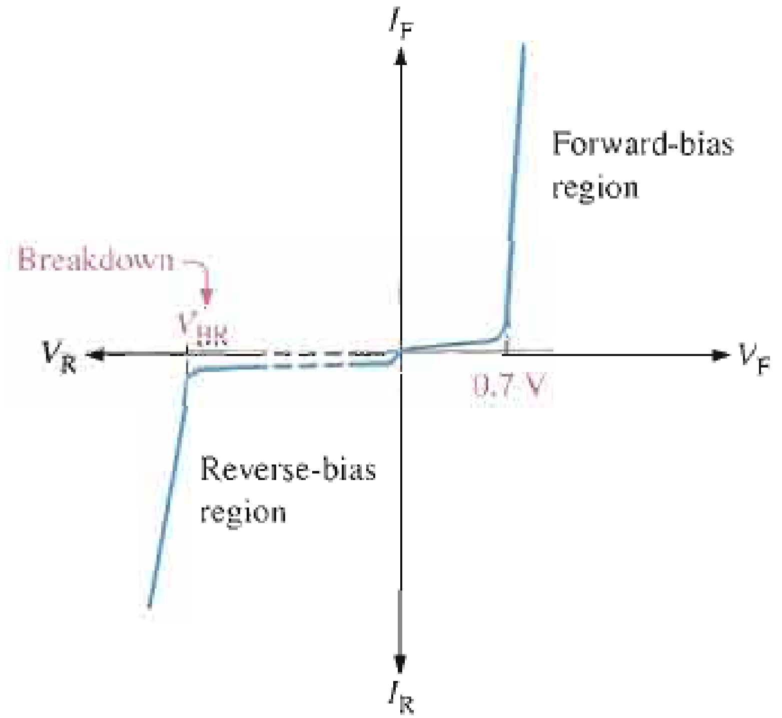
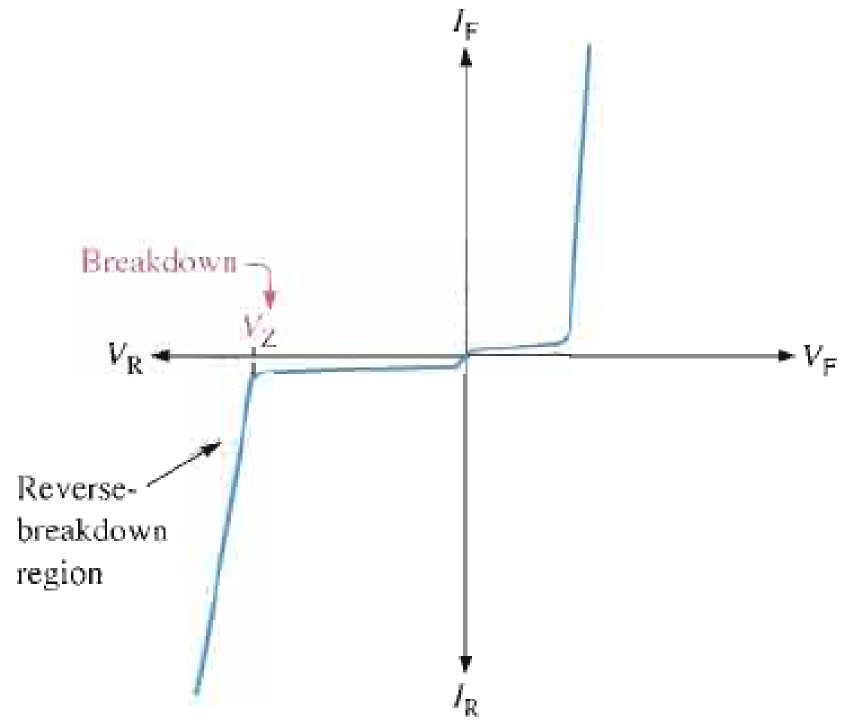
ZENER DIODE:





(a) The normal operating regions for a rectifier diode are shown as shaded areas.



(b) The normal operating region for a zener diode is shaded.

Breakdown Characteristics

Figure 3–3 shows the reverse portion of a zener diode's characteristic curve. Notice that as the reverse voltage (V_R) is increased, the reverse current (I_R) remains extremely small up to the "knee" of the curve. The reverse current is also called the zener current, I_Z. At this point, the breakdown effect begins; the internal zener resistance, also called zener impedance (Z_Z), begins to decrease as the reverse current increases rapidly. From the bottom of the knee, the zener breakdown voltage (V_Z) remains essentially constant although it increases slightly as the zener current, I_Z, increases.

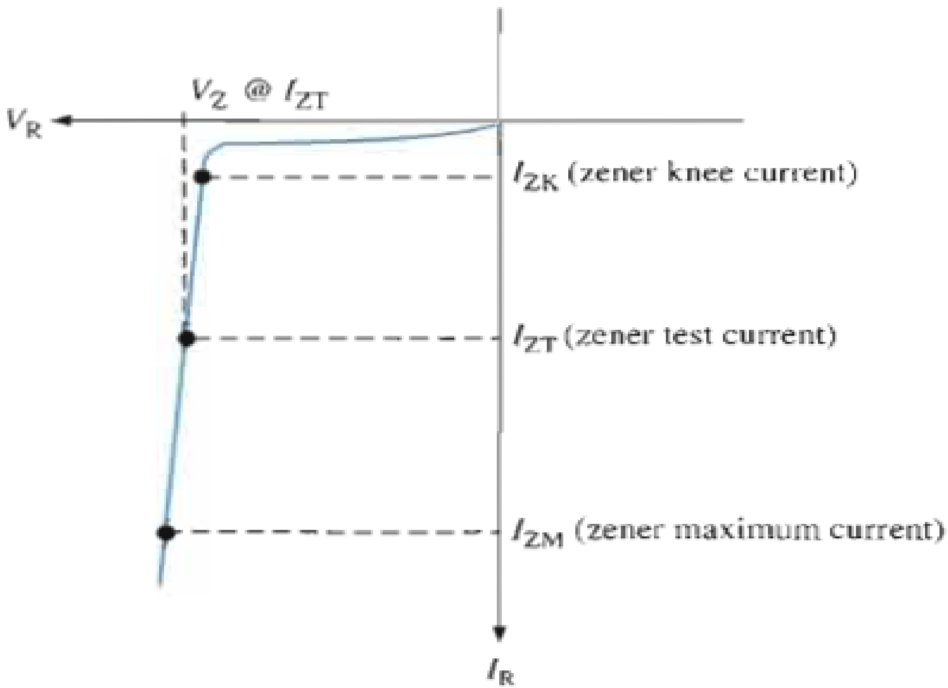


FIGURE 3–3

Reverse characteristic of a zener diode. V_Z is usually specified at the zener test current, I_{ZT}, and is designated V_{ZT}.

Zener Regulation The ability to keep the reverse voltage across its terminals essentially constant is the key feature of the zener diode. A zener diode operating in breakdown acts as a voltage regulator because it maintains a nearly constant voltage across its terminals over a specified range of reverse-current values.

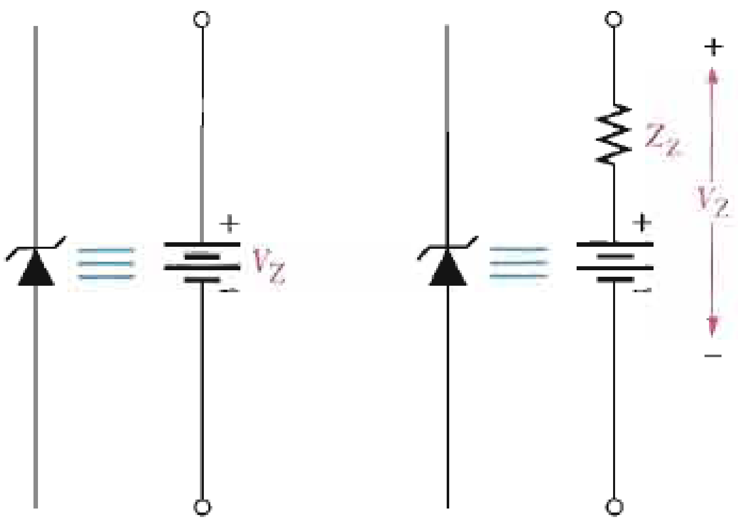
A minimum value of reverse current, I_{ZK}, must be maintained in order to keep the diode in breakdown for voltage regulation. You can see on the curve in Figure 3–3 that when the reverse current is reduced below the knee of the curve, the voltage decreases drastically and regulation is lost. Also, there is a maximum current, I_{ZM}, above which the diode may be damaged due to excessive power dissipation. So, basically, the zener diode maintains a nearly constant voltage across its terminals for values of reverse current ranging from I_{ZK} to I_{ZM}. A nominal zener voltage, V_{ZT}, is usually specified on a data sheet at a value of reverse current called the *zener test current*, I_{ZT}.

Zener Equivalent Circuit

Figure 3–4(a) shows the ideal model of a zener diode in reverse breakdown. It has a constant voltage drop equal to the nominal zener voltage. This constant voltage drop is represented by a dc voltage source even though the zener diode does not actually produce an emf voltage. The dc source simply indicates that the effect of reverse breakdown is a constant voltage across the zener terminals.

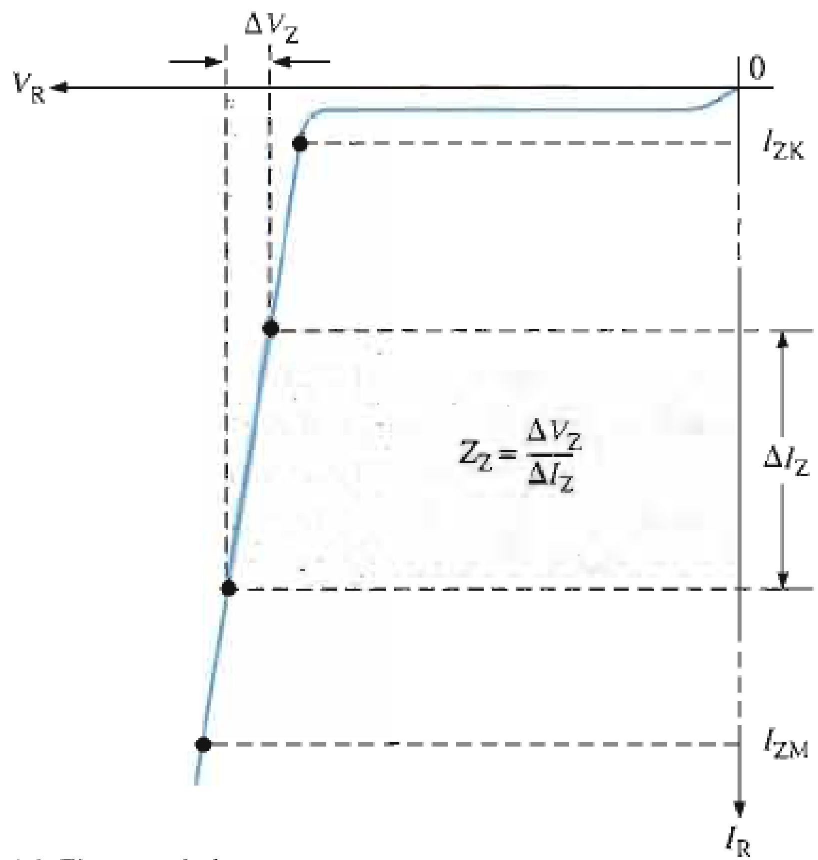
$$Z_Z = \frac{\Delta V_Z}{\Delta I_Z}$$

Normally, Z_Z is specified at I_{ZT}, the zener test current, and is designated Z_{ZT}. In most cases, you can assume that Z_Z is constant over the full linear range of zener current values and is purely resistive.



(a) Ideal

(b) Practical



(c) Characteristic curve

Maximum Ratings

Temperature Coefficient

The temperature coefficient specifies the percent change in zener voltage for each degree Celsius change in temperature. For example, a 12 V zener diode with a positive temperature coefficient of 0.01%/°C will exhibit a 1.2 mV increase in V_Z when the junction temperature increases one degree Celsius. The formula for calculating the change in zener voltage for a given junction temperature change, for a specified temperature coefficient, is

$$\Delta V_Z = V_Z \times TC \times \Delta T$$

where V_Z is the nominal zener voltage at the reference temperature of 25°C, TC is the temperature coefficient, and ΔT is the change in temperature from the reference temperature. A positive TC means that the zener voltage increases with an increase in temperature or decreases with a decrease in temperature. A negative TC means that the zener voltage decreases with an increase in temperature or increases with a decrease in temperature.

In some cases, the temperature coefficient is expressed in mV/°C rather than as %/°C. For these cases, ΔV_Z is calculated as

$$\Delta V_Z = TC \times \Delta T$$

Power Dissipation

Zener diodes are specified to operate at a maximum power called the maximum dc power dissipation, $P_{D(max)}$. For example, the 1N746 zener is rated at a $P_{D(max)}$ of 500 mW and the 1N3305A is rated at a $P_{D(max)}$ of 50 W. The dc power dissipation is determined by the formula,

$$P_D = V_Z I_Z$$

Power Derating The maximum power dissipation of a zener diode is typically specified for temperatures at or below a certain value (50°C, for example). Above the specified temperature, the maximum power dissipation is reduced according to a derating factor. The derating factor is expressed in mW/°C. The maximum derated power can be determined with the following formula:

$$P_{D(derated)} = P_{D(max)} - (\text{mW}/^\circ\text{C})\Delta T$$

Example

A certain zener diode has a maximum power rating of 400 mW at 50°C and a derating factor of 3.2 mW/°C. Determine the maximum power the zener can dissipate at a temperature of 90°C.

$$\begin{aligned} P_{D(derated)} &= P_{D(max)} - (\text{mW}/°\text{C})\Delta T \\ &= 400\text{ mW} - (3.2\text{ mW}/°\text{C})(90°\text{C} - 50°\text{C}) \\ &= 400\text{ mW} - 128\text{ mW} = \mathbf{272\text{ mW}} \end{aligned}$$