

# 3

## SPECIAL-PURPOSE DIODES

### CHAPTER OUTLINE

- 3-1 The Zener Diode
  - 3-2 Zener Diode Applications
  - 3-3 The Varactor Diode
  - 3-4 Optical Diodes
  - 3-5 Other Types of Diodes
  - 3-6 Troubleshooting
- Application Activity  
Green Tech Application 3: *Solar Power*

### CHAPTER OBJECTIVES

- ◆ Describe the characteristics of a zener diode and analyze its operation
- ◆ Apply a zener diode in voltage regulation
- ◆ Describe the varactor diode characteristic and analyze its operation
- ◆ Discuss the characteristics, operation, and applications of LEDs, quantum dots, and photodiodes
- ◆ Discuss the basic characteristics of several types of diodes
- ◆ Troubleshoot zener diode regulators

### KEY TERMS

- ◆ Zener diode
- ◆ Zener breakdown
- ◆ Varactor
- ◆ Light-emitting diode (LED)
- ◆ Electroluminescence
- ◆ Pixel
- ◆ Photodiode
- ◆ Laser

### VISIT THE COMPANION WEBSITE

Study aids and Multisim files for this chapter are available at <http://www.pearsonhighered.com/electronics>

### INTRODUCTION

Chapter 2 was devoted to general-purpose and rectifier diodes, which are the most widely used types. In this chapter, we will cover several other types of diodes that are designed for specific applications, including the zener, varactor (variable-capacitance), light-emitting, photo, laser, Schottky, tunnel, *pin*, step-recovery, and current regulator diodes.

### APPLICATION ACTIVITY PREVIEW

The Application Activity in this chapter is the expansion of the 16 V power supply developed in Chapter 2 into a 12 V regulated power supply with an LED power-on indicator. The new circuit will incorporate a voltage regulator IC, which is introduced in this chapter.

### 3-1 THE ZENER DIODE

A major application for zener diodes is as a type of voltage regulator for providing stable reference voltages for use in power supplies, voltmeters, and other instruments. In this section, you will see how the zener diode maintains a nearly constant dc voltage under the proper operating conditions. You will learn the conditions and limitations for properly using the zener diode and the factors that affect its performance.

After completing this section, you should be able to

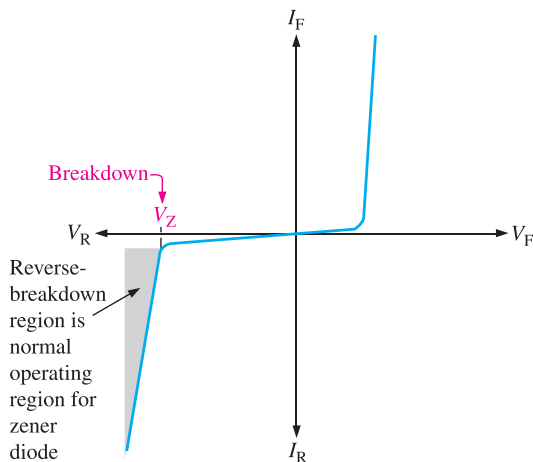
- Describe the characteristics of a zener diode and analyze its operation
- Recognize a zener diode by its schematic symbol
- Discuss zener breakdown
  - ♦ Define *avalanche breakdown*
- Explain zener breakdown characteristics
  - ♦ Describe zener regulation
- Discuss zener equivalent circuits
- Define *temperature coefficient*
  - ♦ Analyze zener voltage as a function of temperature
- Discuss zener power dissipation and derating
  - ♦ Apply power derating to a zener diode
- Interpret zener diode datasheets

The symbol for a zener diode is shown in Figure 3-1. Instead of a straight line representing the cathode, the zener diode has a bent line that reminds you of the letter Z (for zener). A **zener diode** is a silicon *pn* junction device that is designed for operation in the reverse-breakdown region. The breakdown voltage of a zener diode is set by carefully controlling the doping level during manufacture. Recall, from the discussion of the diode characteristic curve in Chapter 2, that when a diode reaches reverse breakdown, its voltage remains almost constant even though the current changes drastically, and this is the key to zener diode operation. This volt-ampere characteristic is shown again in Figure 3-2 with the normal operating region for zener diodes shown as a shaded area.



▲ FIGURE 3-1

Zener diode symbol.



◀ FIGURE 3-2

General zener diode *V-I* characteristic.

#### Zener Breakdown

Zener diodes are designed to operate in reverse breakdown. Two types of reverse breakdown in a zener diode are *avalanche* and *zener*. The avalanche effect, discussed in Chapter 2, occurs in both rectifier and zener diodes at a sufficiently high reverse voltage. **Zener breakdown**

## HISTORY NOTE

Clarence Melvin Zener, an American physicist, was born in Indianapolis and earned his PhD from Harvard in 1930. He was the first to describe the properties of reverse breakdown that are exploited by the zener diode. As a result, Bell Labs, where the device was developed, named the diode after him. He was also involved in areas of superconductivity, metallurgy, and geometric programming.

occurs in a zener diode at low reverse voltages. A zener diode is heavily doped to reduce the breakdown voltage. This causes a very thin depletion region. As a result, an intense electric field exists within the depletion region. Near the zener breakdown voltage ( $V_Z$ ), the field is intense enough to pull electrons from their valence bands and create current.

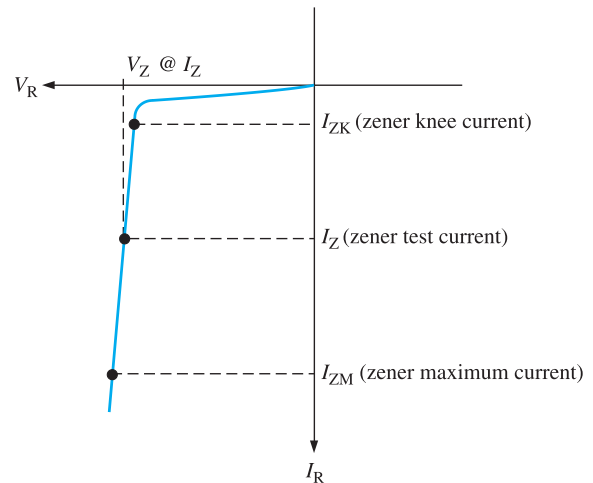
Zener diodes with breakdown voltages of less than approximately 5 V operate predominately in zener breakdown. Those with breakdown voltages greater than approximately 5 V operate predominately in **avalanche breakdown**. Both types, however, are called *zener diodes*. Zeners are commercially available with breakdown voltages from less than 1 V to more than 250 V with specified tolerances from 1% to 20%.

### 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 a value of the zener current known as the test current.

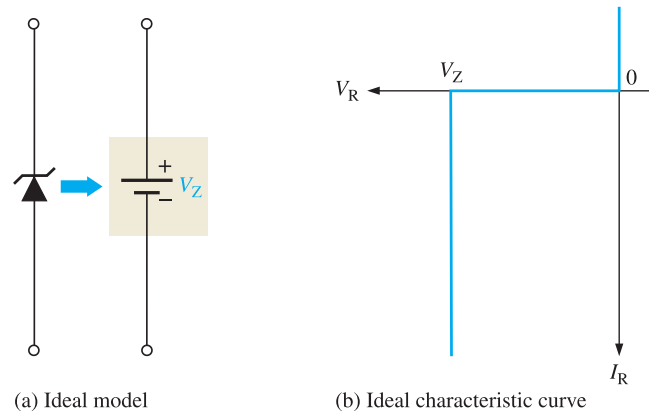


**Zener Regulation** The ability to keep the reverse voltage across its terminals essentially constant is the key feature of the zener diode. A zener diode operating in breakdown acts as a voltage regulator because it maintains a nearly constant voltage across its terminals over a specified range of 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,  $V_Z$ , is usually specified on a datasheet at a value of reverse current called the *zener test current*.

### Zener Equivalent Circuits

Figure 3–4 shows the ideal model (first approximation) of a zener diode in reverse breakdown and its ideal characteristic curve. It has a constant voltage drop equal to the nominal zener voltage. This constant voltage drop across the zener diode produced by reverse breakdown is represented by a dc voltage symbol even though the zener diode does not produce a voltage.



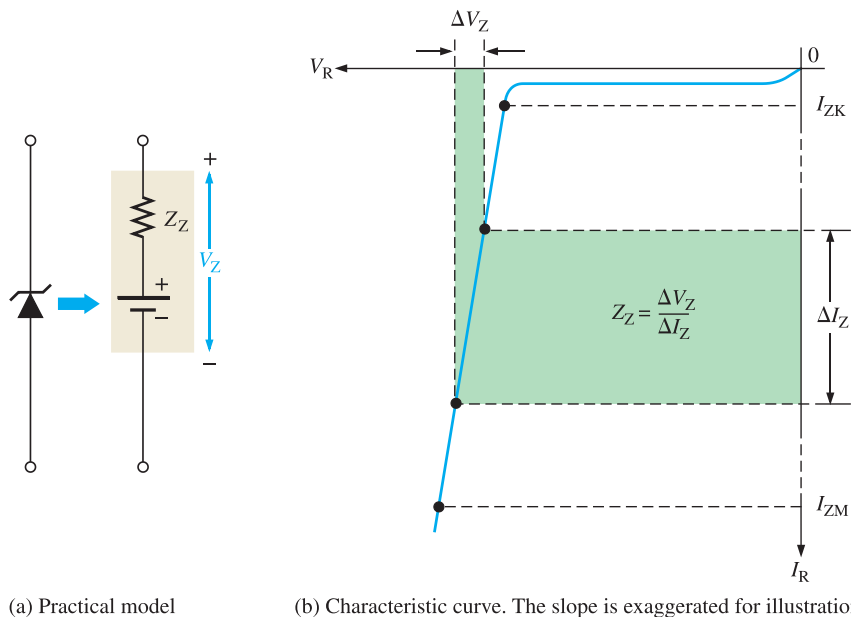
◀ **FIGURE 3-4**  
Ideal zener diode equivalent circuit model and the characteristic curve.

Figure 3-5(a) represents the practical model (second approximation) of a zener diode, where the zener impedance (resistance),  $Z_Z$ , is included. Since the actual voltage curve is not ideally vertical, a change in zener current ( $\Delta I_Z$ ) produces a small change in zener voltage ( $\Delta V_Z$ ), as illustrated in Figure 3-5(b). By Ohm's law, the ratio of  $\Delta V_Z$  to  $\Delta I_Z$  is the impedance, as expressed in the following equation:

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

**Equation 3-1**

Normally,  $Z_Z$  is specified at the zener test current. In most cases, you can assume that  $Z_Z$  is a small constant over the full range of zener current values and is purely resistive. It is best to avoid operating a zener diode near the knee of the curve because the impedance changes dramatically in that area.

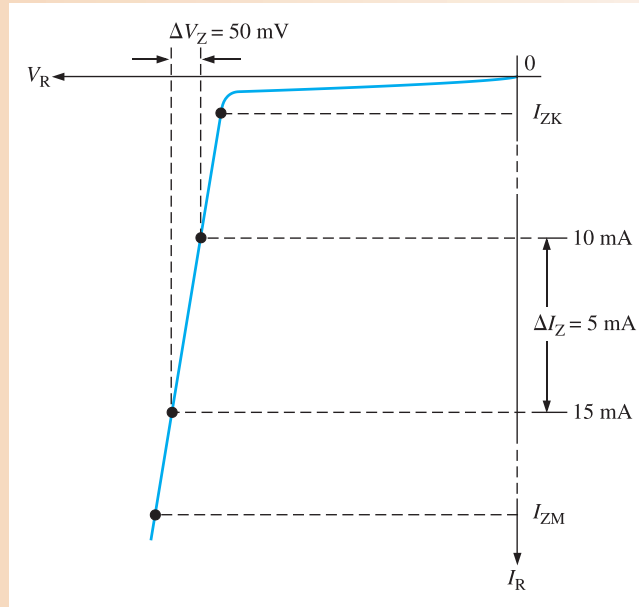


◀ **FIGURE 3-5**  
Practical zener diode equivalent circuit and the characteristic curve illustrating  $Z_Z$ .

For most circuit analysis and troubleshooting work, the ideal model will give very good results and is much easier to use than more complicated models. When a zener diode is operating normally, it will be in reverse breakdown and you should observe the nominal breakdown voltage across it. Most **schematics** will indicate on the drawing what this voltage should be.

**EXAMPLE 3-1**

A zener diode exhibits a certain change in  $V_Z$  for a certain change in  $I_Z$  on a portion of the linear characteristic curve between  $I_{ZK}$  and  $I_{ZM}$  as illustrated in Figure 3-6. What is the zener impedance?

▶ **FIGURE 3-6****Solution**

$$Z_Z = \frac{\Delta V_Z}{\Delta I_Z} = \frac{50 \text{ mV}}{5 \text{ mA}} = \mathbf{10 \Omega}$$

**Related Problem\***

Calculate the zener impedance if the change in zener voltage is 100 mV for a 20 mA change in zener current on the linear portion of the characteristic curve.

\*Answers can be found at [www.pearsonhighered.com/floyd](http://www.pearsonhighered.com/floyd).

**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  $0.01\%/^{\circ}\text{C}$  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

**Equation 3-2**

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

where  $V_Z$  is the nominal zener voltage at the reference temperature of  $25^{\circ}\text{C}$ ,  $TC$  is the temperature coefficient, and  $\Delta T$  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  $\text{mV}/^{\circ}\text{C}$  rather than as  $\%/^{\circ}\text{C}$ . For these cases,  $\Delta V_Z$  is calculated as

**Equation 3-3**

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

**EXAMPLE 3–2**

An 8.2 V zener diode (8.2 V at 25°C) has a positive temperature coefficient of 0.05%/°C. What is the zener voltage at 60°C?

**Solution** The change in zener voltage is

$$\begin{aligned}\Delta V_Z &= V_Z \times TC \times \Delta T = (8.2 \text{ V})(0.05\%/^\circ\text{C})(60^\circ\text{C} - 25^\circ\text{C}) \\ &= (8.2 \text{ V})(0.0005/^\circ\text{C})(35^\circ\text{C}) = 144 \text{ mV}\end{aligned}$$

Notice that 0.05%/°C was converted to 0.0005/°C. The zener voltage at 60°C is

$$V_Z + \Delta V_Z = 8.2 \text{ V} + 144 \text{ mV} = \mathbf{8.34 \text{ V}}$$

**Related Problem** A 12 V zener has a positive temperature coefficient of 0.075%/°C. How much will the zener voltage change when the junction temperature decreases 50 degrees Celsius?

## Zener Power Dissipation and Derating

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:

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

**EXAMPLE 3–3**

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.

**Solution**

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

**Related Problem** A certain 50 W zener diode must be derated with a derating factor of 0.5 W/°C above 75°C. Determine the maximum power it can dissipate at 160°C.

## Zener Diode Datasheet Information

The amount and type of information found on datasheets for zener diodes (or any category of electronic device) varies from one type of diode to the next. The datasheet for some zeners contains more information than for others. Figure 3–7 gives an example of the type of information you have studied that can be found on a typical datasheet. This particular information is for a zener series, the 1N4728A–1N4764A.



# 1N4728A - 1N4764A

## Zeners



DO-41 Glass case  
COLOR BAND DENOTES CATHODE

### Absolute Maximum Ratings \* $T_a = 25^\circ\text{C}$ unless otherwise noted

| Symbol         | Parameter   | Value       | Units                |
|----------------|---|-------------|----------------------|
| $P_D$          | Power Dissipation<br>@ $T_L \leq 50^\circ\text{C}$ , Lead Length = 3/8" | 1.0         | W                    |
|                | Derate above $50^\circ\text{C}$   | 6.67        | mW/ $^\circ\text{C}$ |
| $T_J, T_{STG}$ | Operating and Storage Temperature Range                                 | -65 to +200 | $^\circ\text{C}$     |

\* These ratings are limiting values above which the serviceability of the diode may be impaired.

### Electrical Characteristics $T_a = 25^\circ\text{C}$ unless otherwise noted

| Device  | $V_Z$ (V) @ $I_Z$ (Note 1) |      |       | Test Current<br>$I_Z$ (mA) | Max. Zener Impedance          |                                     |                  | Leakage Current            |              |
|---------|----------------------------|------|-------|----------------------------|-------------------------------|-------------------------------------|------------------|----------------------------|--------------|
|         | Min.                       | Typ. | Max.  |                            | $Z_Z$ @ $I_Z$<br>( $\Omega$ ) | $Z_{ZK}$ @<br>$I_{ZK}$ ( $\Omega$ ) | $I_{ZK}$<br>(mA) | $I_R$<br>( $\mu\text{A}$ ) | $V_R$<br>(V) |
| 1N4728A | 3.315                      | 3.3  | 3.465 | 76                         | 10                            | 400                                 | 1                | 100                        | 1            |
| 1N4729A | 3.42                       | 3.6  | 3.78  | 69                         | 10                            | 400                                 | 1                | 100                        | 1            |
| 1N4730A | 3.705                      | 3.9  | 4.095 | 64                         | 9                             | 400                                 | 1                | 50                         | 1            |
| 1N4731A | 4.085                      | 4.3  | 4.515 | 58                         | 9                             | 400                                 | 1                | 10                         | 1            |
| 1N4732A | 4.465                      | 4.7  | 4.935 | 53                         | 8                             | 500                                 | 1                | 10                         | 1            |
| 1N4733A | 4.845                      | 5.1  | 5.355 | 49                         | 7                             | 550                                 | 1                | 10                         | 1            |
| 1N4734A | 5.32                       | 5.6  | 5.88  | 45                         | 5                             | 600                                 | 1                | 10                         | 2            |
| 1N4735A | 5.89                       | 6.2  | 6.51  | 41                         | 2                             | 700                                 | 1                | 10                         | 3            |
| 1N4736A | 6.46                       | 6.8  | 7.14  | 37                         | 3.5                           | 700                                 | 1                | 10                         | 4            |
| 1N4737A | 7.125                      | 7.5  | 7.875 | 34                         | 4                             | 700                                 | 0.5              | 10                         | 5            |
| 1N4738A | 7.79                       | 8.2  | 8.61  | 31                         | 4.5                           | 700                                 | 0.5              | 10                         | 6            |
| 1N4739A | 8.645                      | 9.1  | 9.555 | 28                         | 5                             | 700                                 | 0.5              | 10                         | 7            |
| 1N4740A | 9.5                        | 10   | 10.5  | 25                         | 7                             | 700                                 | 0.25             | 10                         | 7.6          |
| 1N4741A | 10.45                      | 11   | 11.55 | 23                         | 8                             | 700                                 | 0.25             | 5                          | 8.4          |
| 1N4742A | 11.4                       | 12   | 12.6  | 21                         | 9                             | 700                                 | 0.25             | 5                          | 9.1          |
| 1N4743A | 12.35                      | 13   | 13.65 | 19                         | 10                            | 700                                 | 0.25             | 5                          | 9.9          |
| 1N4744A | 14.25                      | 15   | 15.75 | 17                         | 14                            | 700                                 | 0.25             | 5                          | 11.4         |
| 1N4745A | 15.2                       | 16   | 16.8  | 15.5                       | 16                            | 700                                 | 0.25             | 5                          | 12.2         |
| 1N4746A | 17.1                       | 18   | 18.9  | 14                         | 20                            | 750                                 | 0.25             | 5                          | 13.7         |
| 1N4747A | 19                         | 20   | 21    | 12.5                       | 22                            | 750                                 | 0.25             | 5                          | 15.2         |
| 1N4748A | 20.9                       | 22   | 23.1  | 11.5                       | 23                            | 750                                 | 0.25             | 5                          | 16.7         |
| 1N4749A | 22.8                       | 24   | 25.2  | 10.5                       | 25                            | 750                                 | 0.25             | 5                          | 18.2         |
| 1N4750A | 25.65                      | 27   | 28.35 | 9.5                        | 35                            | 750                                 | 0.25             | 5                          | 20.6         |
| 1N4751A | 28.5                       | 30   | 31.5  | 8.5                        | 40                            | 1000                                | 0.25             | 5                          | 22.8         |
| 1N4752A | 31.35                      | 33   | 34.65 | 7.5                        | 45                            | 1000                                | 0.25             | 5                          | 25.1         |
| 1N4753A | 34.2                       | 36   | 37.8  | 7                          | 50                            | 1000                                | 0.25             | 5                          | 27.4         |
| 1N4754A | 37.05                      | 39   | 40.95 | 6.5                        | 60                            | 1000                                | 0.25             | 5                          | 29.7         |
| 1N4755A | 40.85                      | 43   | 45.15 | 6                          | 70                            | 1500                                | 0.25             | 5                          | 32.7         |
| 1N4756A | 44.65                      | 47   | 49.35 | 5.5                        | 80                            | 1500                                | 0.25             | 5                          | 35.8         |
| 1N4757A | 48.45                      | 51   | 53.55 | 5                          | 95                            | 1500                                | 0.25             | 5                          | 38.8         |
| 1N4758A | 53.2                       | 56   | 58.8  | 4.5                        | 110                           | 2000                                | 0.25             | 5                          | 42.6         |
| 1N4759A | 58.9                       | 62   | 65.1  | 4                          | 125                           | 2000                                | 0.25             | 5                          | 47.1         |
| 1N4760A | 64.6                       | 68   | 71.4  | 3.7                        | 150                           | 2000                                | 0.25             | 5                          | 51.7         |
| 1N4761A | 71.25                      | 75   | 78.75 | 3.3                        | 175                           | 2000                                | 0.25             | 5                          | 56           |
| 1N4762A | 77.9                       | 82   | 86.1  | 3                          | 200                           | 3000                                | 0.25             | 5                          | 62.2         |
| 1N4763A | 86.45                      | 91   | 95.55 | 2.8                        | 250                           | 3000                                | 0.25             | 5                          | 69.2         |
| 1N4764A | 95                         | 100  | 105   | 2.5                        | 350                           | 3000                                | 0.25             | 5                          | 76           |

Notes:

1. Zener Voltage ( $V_Z$ )  
The zener voltage is measured with the device junction in the thermal equilibrium at the lead temperature ( $T_L$ ) at  $30^\circ\text{C} \pm 1^\circ\text{C}$  and 3/8" lead length.

▲ FIGURE 3-7

Partial datasheet for the 1N4728A–1N4764A series 1 W zener diodes. Copyright Fairchild Semiconductor Corporation. Used by permission. Datasheets are available at [www.fairchildsemi.com](http://www.fairchildsemi.com).

**Absolute Maximum Ratings** The maximum power dissipation,  $P_D$ , is specified as 1.0 W up to 50°C. Generally, the zener diode should be operated at least 20% below this maximum to assure reliability and longer life. The power dissipation is derated as shown on the datasheet at 6.67 mW for each degree above 50°C. For example, using the procedure illustrated in Example 3–3, the maximum power dissipation at 60°C is

$$P_D = 1 \text{ W} - 10^\circ\text{C}(6.67 \text{ mW}/^\circ\text{C}) = 1 \text{ W} - 66.7 \text{ mW} = 0.9333 \text{ W}$$

At 125°C, the maximum power dissipation is

$$P_D = 1 \text{ W} - 75^\circ\text{C}(6.67 \text{ mW}/^\circ\text{C}) = 1 \text{ W} - 500.25 \text{ mW} = 0.4998 \text{ W}$$

Notice that a maximum reverse current is not specified but can be determined from the maximum power dissipation for a given value of  $V_Z$ . For example, at 50°C, the maximum zener current for a zener voltage of 3.3 V is

$$I_{ZM} = \frac{P_D}{V_Z} = \frac{1 \text{ W}}{3.3 \text{ V}} = 303 \text{ mA}$$

The operating junction temperature,  $T_J$ , and the storage temperature,  $T_{STG}$ , have a range of from  $-65^\circ\text{C}$  to  $200^\circ\text{C}$ .

**Electrical Characteristics** The first column in the datasheet lists the zener type numbers, 1N4728A through 1N4764A.

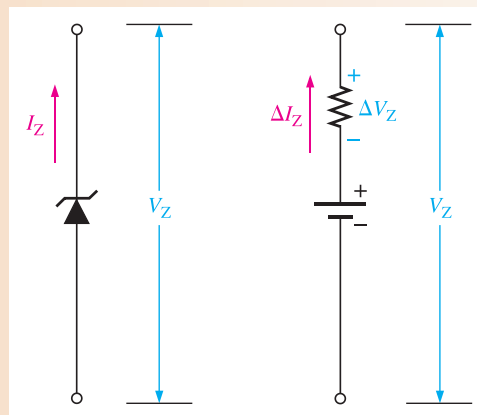
**Zener voltage,  $V_Z$ , and zener test current,  $I_Z$**  For each device type, the minimum, typical, and maximum zener voltages are listed.  $V_Z$  is measured at the specified zener test current,  $I_Z$ . For example, the zener voltage for a 1N4728A can range from 3.315 V to 3.465 V with a typical value of 3.3 V at a test current of 76 mA.

**Maximum zener impedance**  $Z_Z$  is the maximum zener impedance at the specified test current,  $I_Z$ . For example, for a 1N4728A,  $Z_Z$  is 10  $\Omega$  at 76 mA. The maximum zener impedance,  $Z_{ZK}$ , at the knee of the characteristic curve is specified at  $I_{ZK}$ , which is the current at the knee of the curve. For example,  $Z_{ZK}$  is 400  $\Omega$  at 1 mA for a 1N4728A.

**Leakage current** Reverse leakage current is specified for a reverse voltage that is less than the knee voltage. This means that the zener is not in reverse breakdown for these measurements. For example  $I_R$  is 100  $\mu\text{A}$  for a reverse voltage of 1 V in a 1N4728A.

#### EXAMPLE 3–4

From the datasheet in Figure 3–7, a 1N4736A zener diode has a  $Z_Z$  of 3.5  $\Omega$ . The datasheet gives  $V_Z = 6.8 \text{ V}$  at a test current,  $I_Z$ , of 37 mA. What is the voltage across the zener terminals when the current is 50 mA? When the current is 25 mA? Figure 3–8 represents the zener diode.



▲ FIGURE 3–8



**Solution** For  $I_Z = 50$  mA: The 50 mA current is a 13 mA increase above the test current,  $I_Z$ , of 37 mA.

$$\Delta I_Z = I_Z - 37 \text{ mA} = 50 \text{ mA} - 37 \text{ mA} = +13 \text{ mA}$$

$$\Delta V_Z = \Delta I_Z Z_Z = (13 \text{ mA})(3.5 \Omega) = +45.5 \text{ mV}$$

The change in voltage due to the increase in current above the  $I_Z$  value causes the zener terminal voltage to increase. The zener voltage for  $I_Z = 50$  mA is

$$V_Z = 6.8 \text{ V} + \Delta V_Z = 6.8 \text{ V} + 45.5 \text{ mV} = \mathbf{6.85 \text{ V}}$$

For  $I_Z = 25$  mA: The 25 mA current is a 12 mA decrease below the test current,  $I_Z$ , of 37 mA.

$$\Delta I_Z = -12 \text{ mA}$$

$$\Delta V_Z = \Delta I_Z Z_Z = (-12 \text{ mA})(3.5 \Omega) = -42 \text{ mV}$$

The change in voltage due to the decrease in current below the test current causes the zener terminal voltage to decrease. The zener voltage for  $I_Z = 25$  mA is

$$V_Z = 6.8 \text{ V} - \Delta V_Z = 6.8 \text{ V} - 42 \text{ mV} = \mathbf{6.76 \text{ V}}$$

**Related Problem** Repeat the analysis for  $I_Z = 10$  mA and for  $I_Z = 30$  mA using a 1N4742A zener with  $V_Z = 12$  V at  $I_Z = 21$  mA and  $Z_Z = 9 \Omega$ .

### SECTION 3-1 CHECKUP

Answers can be found at [www.pearsonhighered.com/floyd](http://www.pearsonhighered.com/floyd).

1. In what region of their characteristic curve are zener diodes operated?
2. At what value of zener current is the zener voltage normally specified?
3. How does the zener impedance affect the voltage across the terminals of the device?
4. What does a positive temperature coefficient of  $0.05\%/^{\circ}\text{C}$  mean?
5. Explain power derating.

## 3-2 ZENER DIODE APPLICATIONS

The zener diode can be used as a type of voltage regulator for providing stable reference voltages. In this section, you will see how zeners can be used as voltage references, regulators, and as simple limiters or clippers.

After completing this section, you should be able to

- **Apply a zener diode in voltage regulation**
- Analyze zener regulation with a variable input voltage
- Discuss zener regulation with a variable load
- Describe zener regulation from no load to full load
- Discuss zener limiting

### Zener Regulation with a Variable Input Voltage

Zener diode regulators can provide a reasonably constant dc level at the output, but they are not particularly efficient. For this reason, they are limited to applications that require only low current to the load. Figure 3-9 illustrates how a zener diode can be used to regulate a dc