Chapter 3: SPECIAL-PURPOSE DIODES

3–1 THE ZENER DIODE

- A **Zener diode** is a silicon *pn* junction device that is designed for operation in the reverse-breakdown region(set by carefully controlling the doping level).
- A **major application** for zener diodes is **voltage regulation** by 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.

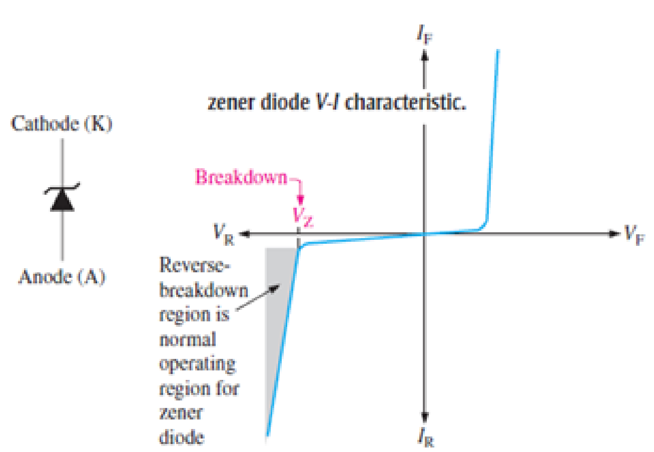
After completing this Chapter, you should be able to:

- Describe the characteristics of a zener diode, its operation, equivalent circuits
- Define *temperature coefficient and* power dissipation and derating. to a zener diode
- Interpret zener diode datasheets
- Analyze zener regulation with a variable input voltage and with a variable load
- Discuss zener limiting
- Discuss another special purpose diodes

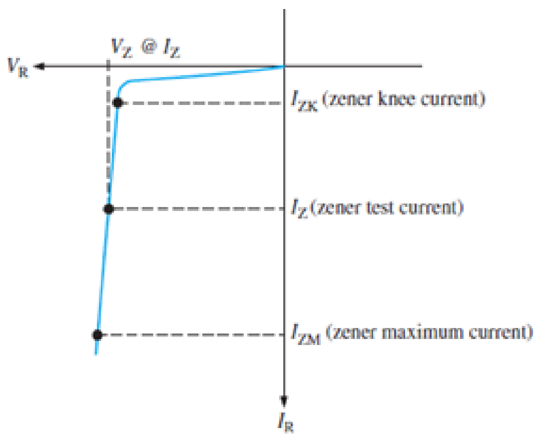
<u>Breakdown Characteristics:</u>

- As the reverse voltage (V_R) is increased to the breakdown point, the internal zener resistance (zener impedance Z_Z), begins to decrease as the reverse current (I_R) increases rapidly.
- The zener breakdown voltage (V_Z) remains essentially constant although it increases slightly as the zener current, I_Z, increases.

(a) Zener V-I characteristics



(b) Reverse Characteristic of a Zener



Zener Breakdown Types

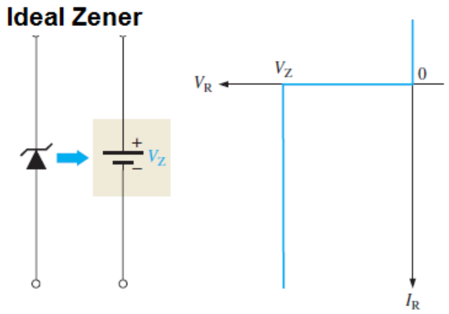
Zener diodes are designed to operate in reverse breakdown. Two types of reverse breakdown in a zener diode:

- **Avalanche effect**: high reverse voltage **&** available in zeners with breakdown voltages > 5 V.
- **Zener breakdown**: low reverse voltages **&** available in zeners with breakdown voltages < 5 V.

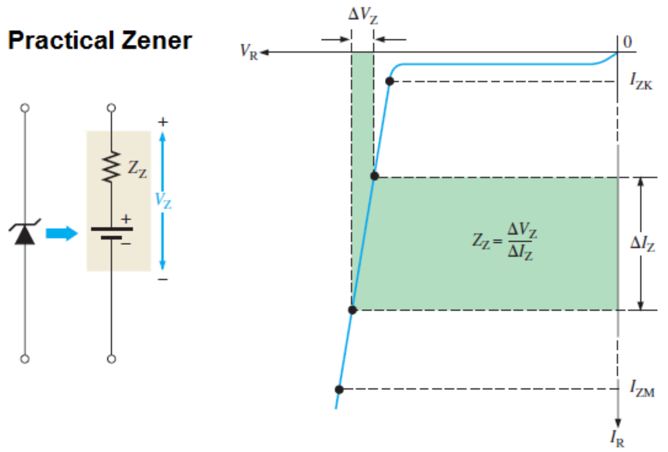
Zener Regulation

- The zener diode maintains a nearly constant voltage across its terminals for values of reverse current ranging from $\boldsymbol{I_{ZK}}$ ***to*** $\boldsymbol{I_{ZM}}$.
- There is a maximum current, $\boldsymbol{I_{ZM}}$, above which the diode may be damaged due to excessive power
- $\boldsymbol{V_Z}$, is usually specified on a datasheet at a value of reverse current called the **Zener Test Current**.

Zener Equivalent Circuits



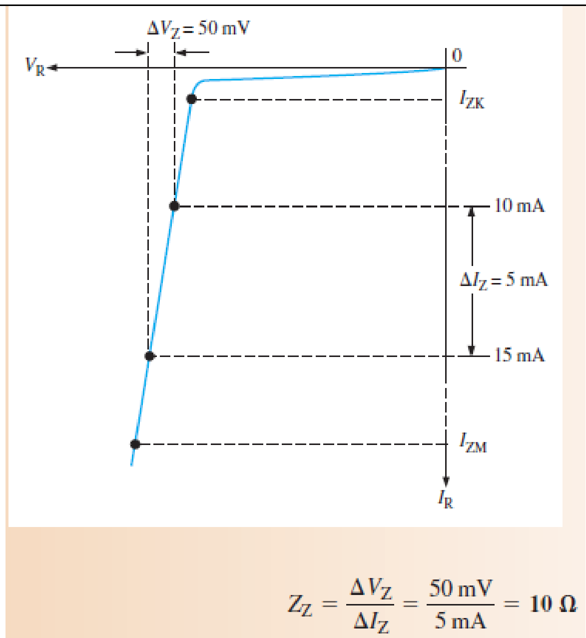
(a) Ideal model (b) Ideal characteristic curve



(a) Practical model (b) Characteristic curve. The slope is exaggerated for illustration.

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 the figure. What is the **zener impedance Zz**?



Temperature Coefficient (TC):

- The percent change in Vz for each degree Celsius change
- **For example**: a **12 V** zener diode with a positive temperature coefficient of **TC= 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:

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

Vz: @ 25C, **TC**: temp coefficient, **ΔT**: change in temp

- In some cases, the temperature coefficient is expressed in **mV/C** rather than **%/C**, and in this case ΔVz can be calculated as:

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

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

$$\Delta V_Z = V_Z \times TC \times \Delta T = (8.2\text{ V})(0.05\%/°\text{C})(60°\text{C} - 25°\text{C})$$
$$= (8.2\text{ V})(0.0005/°\text{C})(35°\text{C}) = 144\text{ mV}$$

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

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

Zener Power Dissipation

- **Maximum dc power dissipation $P_{D(max)}$:** maximum power that Zerner diodes are specified to operate.
- For example, the 1N746 zener is rated at a $P_{D(max)}$ of 500 mW.
- The dc power dissipation is determined by the formula:

$$P_D = V_Z I_Z$$

Zener Power De-rating

- **Derating** is the operation of a device at less than its rated maximum capability in order to prolong its life.
- The maximum power dissipation of a zener diode is typically specified for temperatures at or below a certain value.
- Above the specified temperature, the maximum power dissipation is reduced according to a **derating factor** expressed in mV/C.
- **The maximum derated power**:

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

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

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