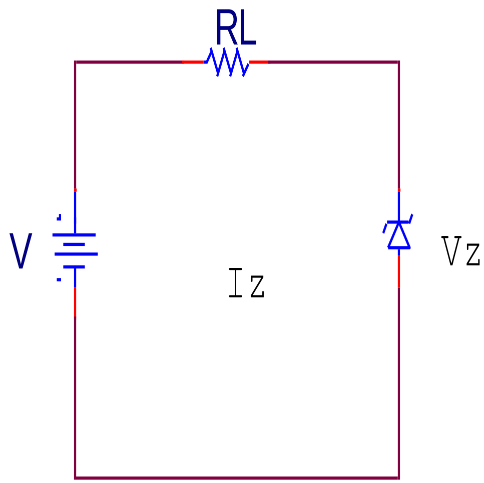
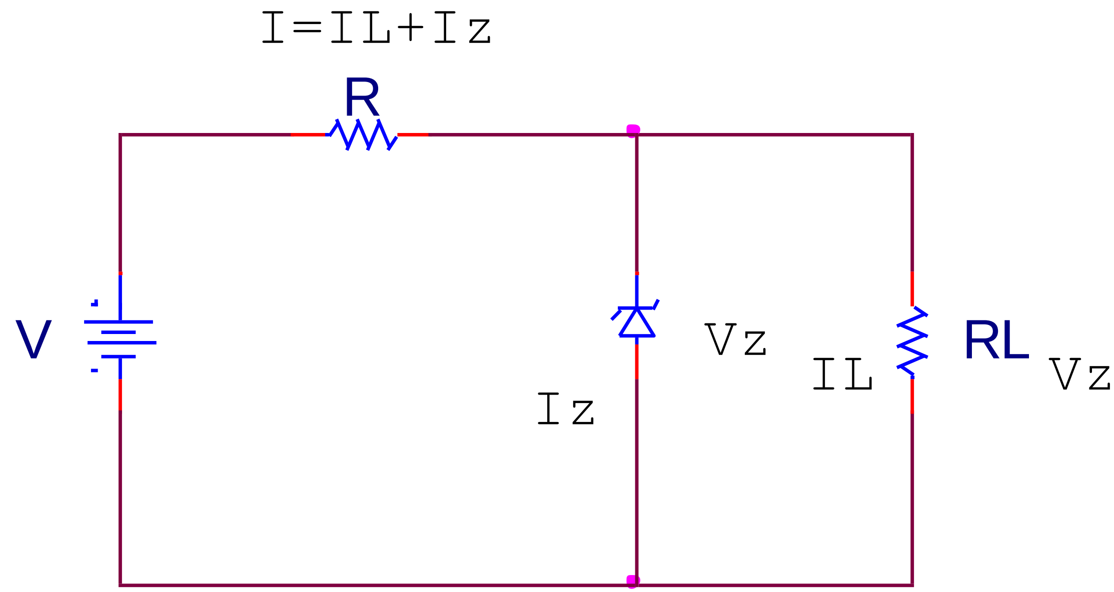
Zener Shunt Regulator

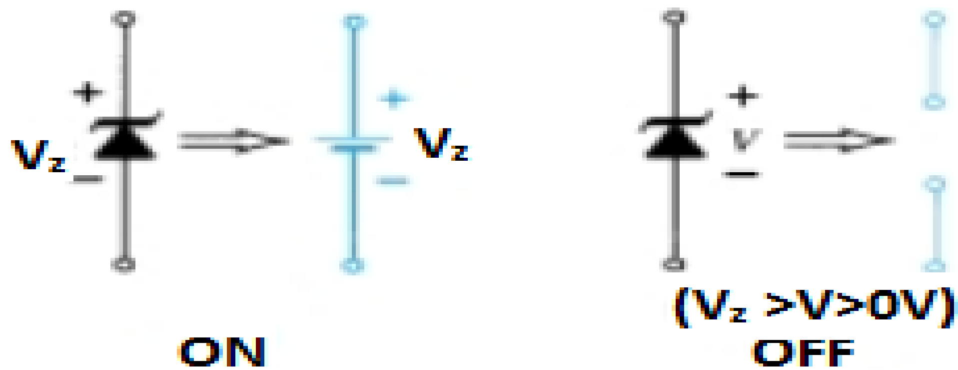




- Above circuit is used as voltage regulator to provide constant output voltage V_z

- Here V_z is breakdown voltage of zener diode

Zener Shunt Regulator



- If voltage across terminals of zener is less than V_z it works like a normal diode in revers bias condition, so replaced by open circuit.
- If voltage across terminals of zener is more than V_z it works in breakdown region, so provide constant voltage V_z , so replaced by voltage source of value V_z

Conditions for Proper Operation of Zener Regulator

When a zener diode is connected in a circuit for voltage regulation, the following conditions must be satisfied :

(*i*) The zener must operate in the breakdown region or regulating region *i.e.* between $I_{Z\,(max)}$ and $I_{Z\,(min)}$. The current $I_{Z\,(min)}$ (generally 10 mA) is the minimum zener current to put the zener diode in the *ON state i.e.* regulating region. The current $I_{Z\,(max)}$ is the maximum zener current that zener diode can conduct without getting destroyed due to excessive heat.

(*ii*) The zener should not be allowed to exceed maximum dissipation power otherwise it will be destroyed due to excessive heat. If maximum power dissipation of a zener is $P_{Z\,(max)}$ and zener voltage is V_Z, then,

$$P_{Z\,(max)} = V_Z\, I_{Z\,(max)}$$

$$\therefore \qquad I_{Z\,(max)} = \frac{P_{Z\,(max)}}{V_Z}$$

(*iii*) There is a minimum value of R_L to ensure that zener diode will remain in the regulating region *i.e.* breakdown region. If the value of R_L falls below this minimum value, the proper voltage will not be available across the zener to drive it into the breakdown region.

Zener Diodes V_i and R Fixed

1. Determine the state of the Zener diode by removing it from the network and calculating the voltage across the resulting open circuit.

$$\boxed{V = V_L = \frac{R_L V_i}{R + R_L}}$$

If *V > VZ, the Zener diode is "on"*

V< VZ, the diode is "off"

2. Substitute the appropriate equivalent circuit and solve for the desired unknowns.

$$\boxed{V_L = V_Z}$$

$$I_R = I_Z + I_L$$

$$\boxed{I_Z = I_R - I_L}$$

$$I_L = \frac{V_L}{R_L} \qquad I_R = \frac{V_R}{R} = \frac{V_i - V_L}{R}$$

$$\boxed{P_Z = V_Z I_Z}$$

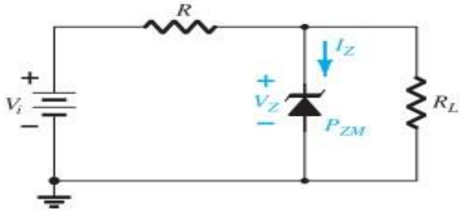


FIG. 2.112
Basic Zener regulator.

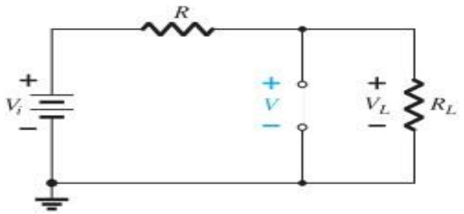


FIG. 2.113
Determining the state of the Zener diode.

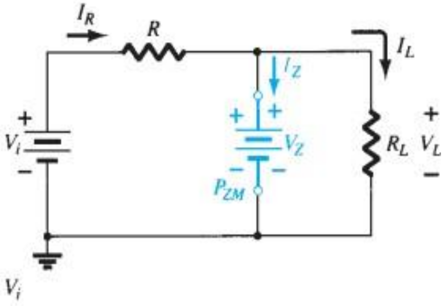


FIG. 2.114
Substituting the Zener equivalent for the "on" situation.

Zener Diodes Fixed V_i , Variable R_L

$$V_L = V_Z = \frac{R_L V_i}{R_L + R}$$

$$\boxed{R_{L\,\min} = \frac{R V_Z}{V_i - V_Z}}$$

$$\boxed{I_{L\,\max} = \frac{V_L}{R_L} = \frac{V_Z}{R_{L\,\min}}}$$

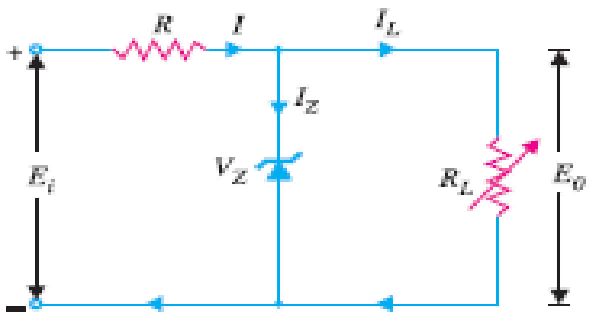
$$\boxed{V_R = V_i - V_Z}$$

$$\boxed{I_R = \frac{V_R}{R}}$$

$$\boxed{I_Z = I_R - I_L}$$

$$\boxed{I_{L\,\min} = I_R - I_{ZM}}$$

$$\boxed{R_{L\,\max} = \frac{V_Z}{I_{L\,\min}}}$$



Izm stands for Iz maximum

Zener Diodes
Fixed R_L, Variable V_i

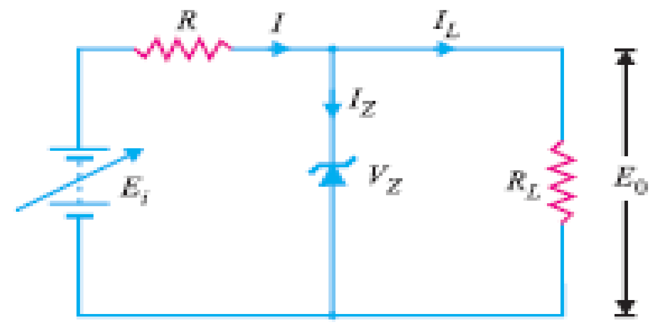
$$V_L = V_Z = \frac{R_L V_i}{R_L + R}$$

$$\boxed{V_{i_{\min}} = \frac{(R_L + R)V_Z}{R_L}}$$

$$\boxed{I_{R_{\max}} = I_{ZM} + I_L}$$

$$V_{i_{\max}} = V_{R_{\max}} + V_Z$$

$$\boxed{V_{i_{\max}} = I_{R_{\max}} R + V_Z}$$



EXAMPLE 2.26

(a) For the Zener diode network of Fig. 2.109, determine V_L, V_R, I_Z, and P_Z.
(b) Repeat part (a) with $R_L = 3\ \text{k}\Omega$.

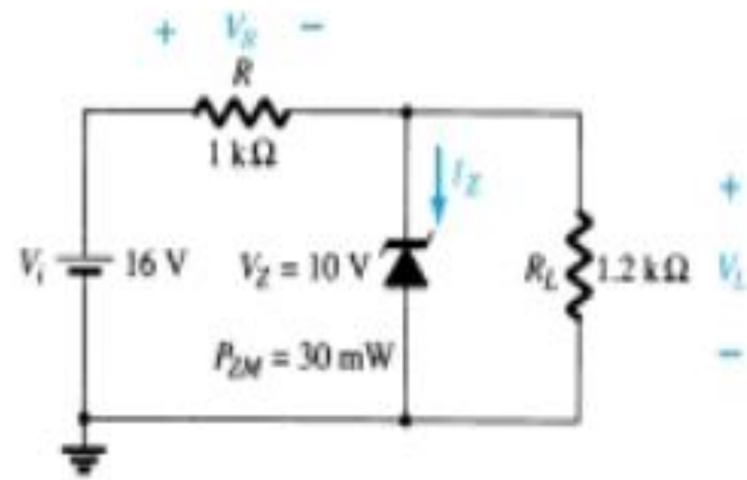


Figure 2.109 Zener diode regulator for Example 2.26.

Solution

(a) Following the suggested procedure the network is redrawn as shown in Fig. 2.110. Applying Eq. (2.16) gives

$$V = \frac{R_L V_i}{R + R_L} = \frac{1.2\ \text{k}\Omega(16\ \text{V})}{1\ \text{k}\Omega + 1.2\ \text{k}\Omega} = 8.73\ \text{V}$$

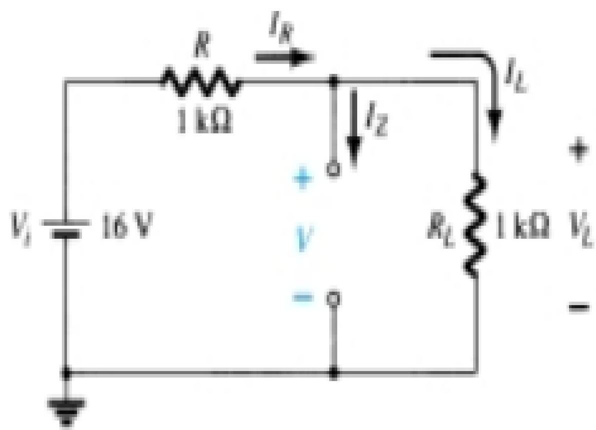


Figure 2.110 Determining V for the regulator of Fig. 2.109.

Since $V = 8.73$ V is less than $V_Z = 10$ V, the diode is in the "off" state as shown on the characteristics of Fig. 2.111. Substituting the open-circuit equivalent will result in the same network as in Fig. 2.110, where we find that

$$V_L = V = \mathbf{8.73\ V}$$

$$V_R = V_i - V_L = 16\ V - 8.73\ \text{V} = \mathbf{7.27\ V}$$

$$I_Z = \mathbf{0\ A}$$

and $$P_Z = V_Z I_Z = V_Z(0\ \text{A}) = \mathbf{0\ W}$$

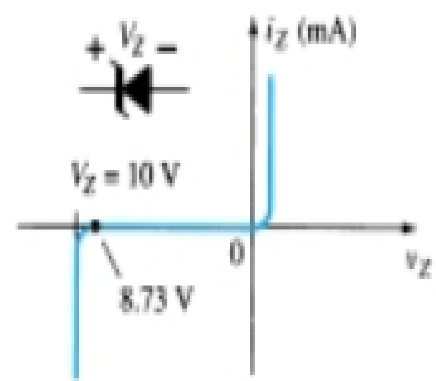


Figure 2.111 Resulting operating point for the network of Fig. 2.109.

(b) Applying Eq. (2.16) will now result in

$$V = \frac{R_L V_i}{R + R_L} = \frac{3\ \text{k}\Omega(16\ \text{V})}{1\ \text{k}\Omega + 3\ \text{k}\Omega} = 12\ \text{V}$$

Since $V = 12$ V is greater than $V_Z = 10$ V, the diode is in the "on" state and the network of Fig. 2.112 will result. Applying Eq. (2.17) yields

$$V_L = V_Z = \mathbf{10\ V}$$

and $$V_R = V_i - V_L = 16\ \text{V} - 10\ \text{V} = \mathbf{6\ V}$$

with $$I_L = \frac{V_L}{R_L} = \frac{10\ \text{V}}{3\ \text{k}\Omega} = 3.33\ \text{mA}$$

and $$I_R = \frac{V_R}{R} = \frac{6\ \text{V}}{1\ \text{k}\Omega} = 6\ \text{mA}$$

so that $$\begin{aligned} I_Z &= I_R - I_L\ [\text{Eq. (2.18)}] \\ &= 6\ \text{mA} - 3.33\ \text{mA} \\ &= \mathbf{2.67\ mA} \end{aligned}$$

The power dissipated,

$$P_Z = V_Z I_Z = (10\ \text{V})(2.67\ \text{mA}) = \mathbf{26.7\ mW}$$

which is less than the specified $P_{ZM} = 30$ mW.

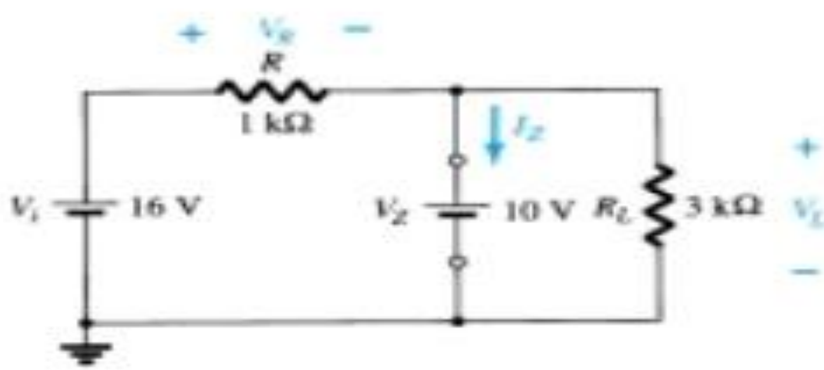


Figure 2.112 Network of Fig. 2.109 in the "on" state.

EXAMPLE 2.27

(a) For the network of Fig. 2.113, determine the range of R_L and I_L that will result in V_{R_L} being maintained at 10 V.
(b) Determine the maximum wattage rating of the diode.

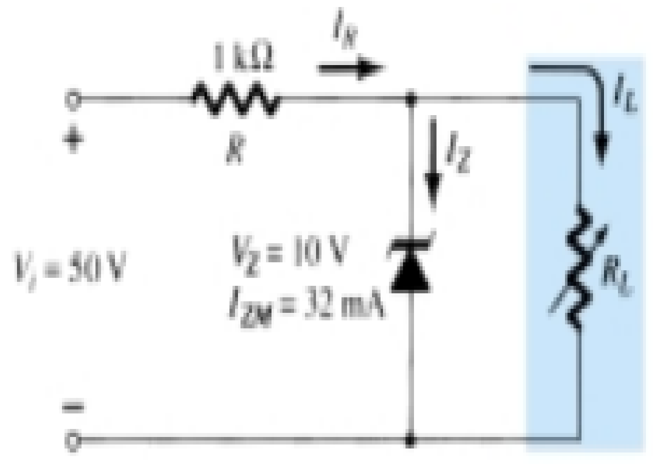


Figure 2.113 Voltage regulator for Example 2.27.

Solution

(a) To determine the value of R_L that will turn the Zener diode on, apply Eq. (2.20):

$$R_{L_{\min}} = \frac{RV_Z}{V_i - V_Z} = \frac{(1\text{ k}\Omega)(10\text{ V})}{50\text{ V} - 10\text{ V}} = \frac{10\text{ k}\Omega}{40} = \mathbf{250\ \Omega}$$

The voltage across the resistor R is then determined by Eq. (2.22):

$$V_R = V_i - V_Z = 50\text{ V} - 10\text{ V} = \mathbf{40\ V}$$

and Eq. (2.23) provides the magnitude of I_R:

$$I_R = \frac{V_R}{R} = \frac{40\text{ V}}{1\text{ k}\Omega} = \mathbf{40\ mA}$$

The minimum level of I_L is then determined by Eq. (2.25):

$$I_{L_{\min}} = I_R - I_{ZM} = 40\text{ mA} - 32\text{ mA} = \mathbf{8\ mA}$$

with Eq. (2.26) determining the maximum value of R_L:

$$R_{L_{\max}} = \frac{V_Z}{I_{L_{\min}}} = \frac{10\text{ V}}{8\text{ mA}} = \mathbf{1.25\ k\Omega}$$

(b) $P_{\max} = V_Z I_{ZM}$

$$= (10\text{ V})(32\text{ mA}) = \mathbf{320\ mW}$$

EXAMPLE 2.28 Determine the range of values of V_i that will maintain the Zener diode of Fig. 2.115 in the "on" state.

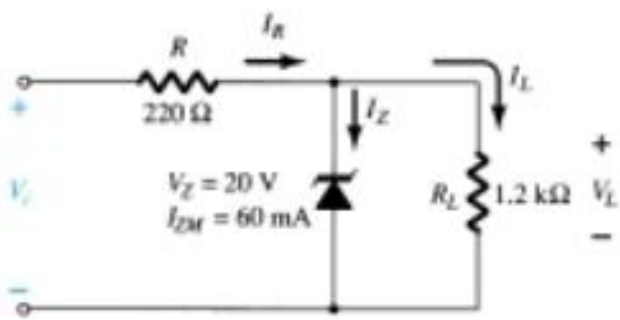


Figure 2.115 Regulator for Example 2.28.

Solution

$$\text{Eq. (2.27):}\quad V_{i_{min}} = \frac{(R_L + R)V_Z}{R_L} = \frac{(1200\ \Omega + 220\ \Omega)(20\ \text{V})}{1200\ \Omega} = \mathbf{23.67\ V}$$

$$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L} = \frac{20\ \text{V}}{1.2\ \text{k}\Omega} = 16.67\ \text{mA}$$

$$\text{Eq. (2.28):}\quad I_{R_{max}} = I_{ZM} + I_L = 60\ \text{mA} + 16.67\ \text{mA}$$

$$= 76.67\ \text{mA}$$

$$\text{Eq. (2.29):}\quad V_{i_{max}} = I_{R_{max}}R + V_Z$$

$$= (76.67\ \text{mA})(0.22\ \text{k}\Omega) + 20\ \text{V}$$

$$= 16.87\ \text{V} + 20\ \text{V}$$

$$= \mathbf{36.87\ V}$$

A plot of V_L versus V_i is provided in Fig. 2.116.

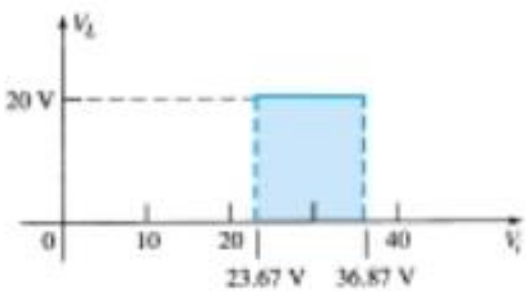


Figure 2.116 V_L versus V_i for the regulator of Fig. 2.115.

Diode Resistance

- When some external voltage is applied across a diode, some current flows.
- Therefore, the diode can be imagined to have some resistive behavior.
- This resistive behavior of diode is generally called diode resistance.
- On the basis of type of applied voltage, diode resistance can be divided into two parts.

  1) Static resistance or DC resistance.

  2) Dynamic resistance or AC resistance.

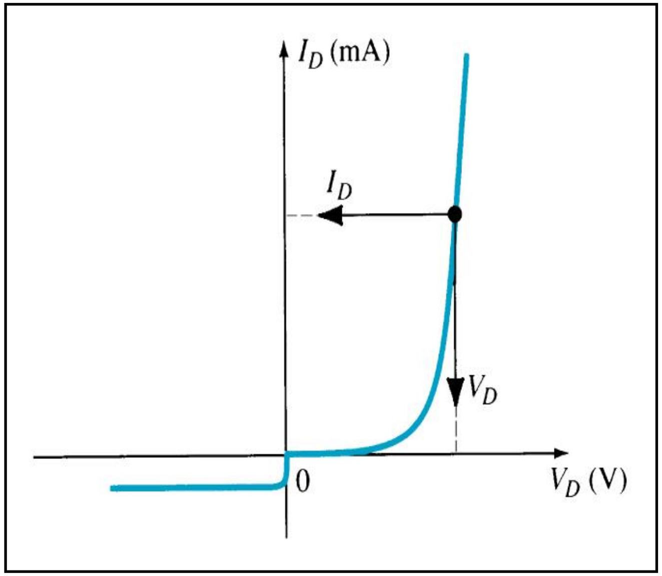
Static Resistance

- The resistive behavior of diode in presence of DC source is called static resistance or DC resistance. It can be defined as the ratio of applied DC voltage across diode and its respective current.

$$R_D = \frac{V_D}{I_D}$$

For FB $$R_F = \frac{V_F}{I_F}$$

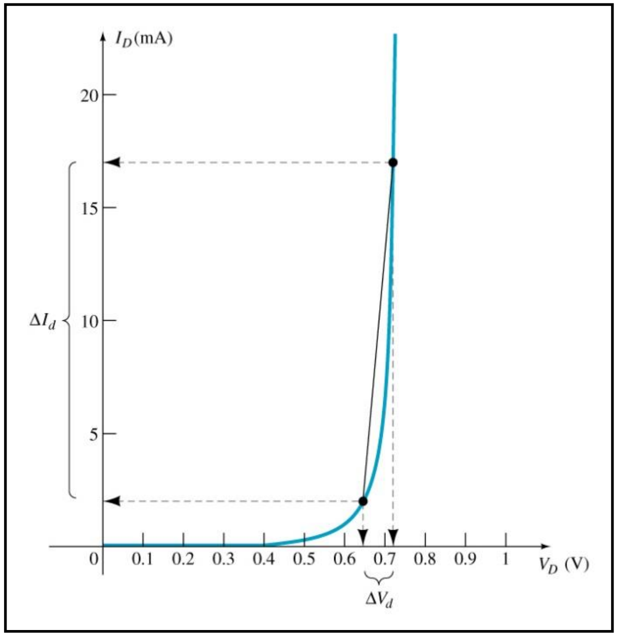
For RB $$R_R = \frac{V_R}{I_R}$$



Dynamic Resistance

- Resistive behavior of diode in presence of ac source is called dynamic resistance or AC resistance.
- AC resistance can be calculated using the current and voltage values for two points on the diode characteristic curve and is given as:

$$r_d = \frac{\Delta v_d}{\Delta i_d}$$



Dynamic resistance (r_d) from diode current equation

Shockley diode current equation is given by:

$$I_D = I_O\left(e^{V_D/\eta V_T} - 1\right) \ldots\ldots 1$$

$$I_D = I_O e^{V_D/\eta V_T} - I_O$$

$$I_O e^{V_D/\eta V_T} = I_D + I_O \ldots\ldots..2$$

Now differentiating equation 1 w.r.t. V_D

$$\frac{dI_D}{dV_D} = \frac{d}{dV_D} I_O\left(e^{V_D/\eta V_T} - 1\right)$$

$$= I_O e^{V_D/\eta V_T}\left(\frac{1}{\eta V_T}\right) - o$$

$$= I_O e^{V_D/\eta V_T}\left(\frac{1}{\eta V_T}\right)$$

Using equation 2 we can write

$$\frac{dI_D}{dV_D} = \frac{I_D + I_O}{\eta V_T}$$

$$or \quad \frac{dV_D}{dI_D} = \frac{\eta V_T}{I_D + I_O}$$

Since $\frac{dV_D}{dI_D} = r_d$ and $I_D \gg I_O$

So $\boxed{r_d = \frac{\eta V_T}{I_D + I_O}}$

$$\boxed{r_d \cong \frac{\eta V_T}{I_D}}$$

Where η=1(for Ge) and η=2(for Si)

and $V_T = \frac{T\ (^0K)}{11600}\ (in\ V)$