Electronic Devices

Course Teacher
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Reference book:

Electronic Devices and Circuit Theory (Chapter-2)

Robert L. Boylestad and L. Nashelsky , (11^{th} Edition)

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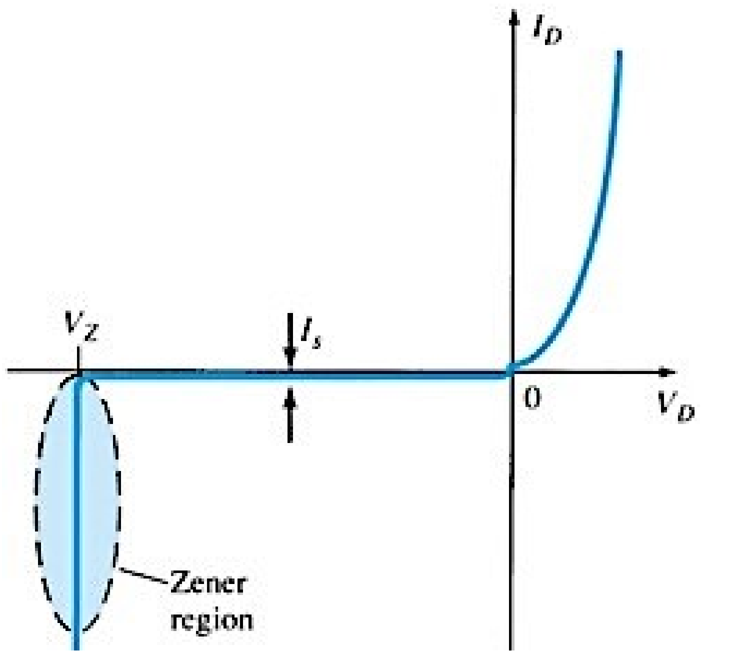
Objectives

- Become familiar with the analysis and the range of applications for Zener diodes.

ZENER REGION

- If the ***Diode is reverse biased and the voltage is increased***, a point will be reached when ***the diode enters reverse breakdown*** and current will flow with a very rapid rate.
- The direction of this current will be opposite to that of the positive voltage region.
- The reverse bias potential that results in ***this dramatic change in characteristics*** is called the ***Zener Potential /Voltage and is given by the symbol*** V_z.
- ***The reverse or Avalanche breakdown*** is often termed ***as Zener Breakdown (at very low levels).***
- The region where this sharp change in characteristics occur is known as ***Zener or Avalanche breakdown region*** and the current is termed as avalanche current.



ZENER REGION

- The maximum reverse-bias potential that can be applied before entering the Zener Region is called the peak inverse voltage (referred to simply as the PIV rating) or the peak reverse voltage (denoted by PRV rating).

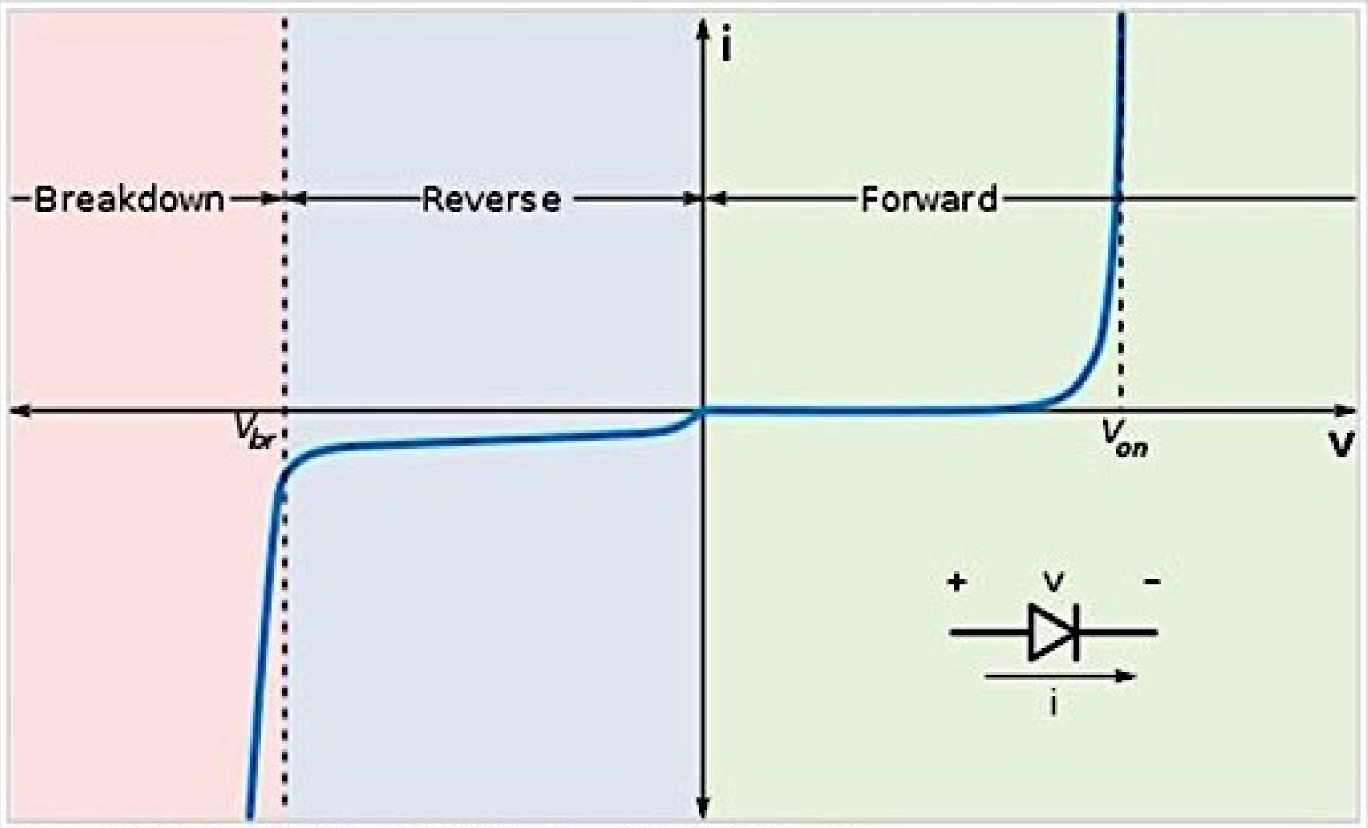


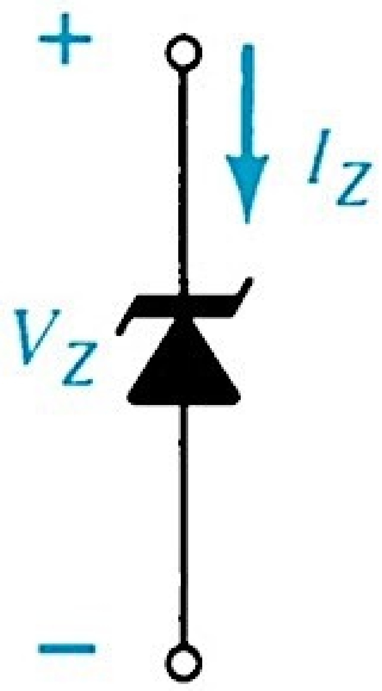
Figure 5: I–V characteristics of a P-N junction diode (not to scale).

ZENER DIODE

- Diodes that employ the dramatic characteristics of a p-n junction are called Zener Diodes.

- Therefore, a Zener diode operates in reverse bias.

- Common Zener Voltages: 1.8V to 200V.

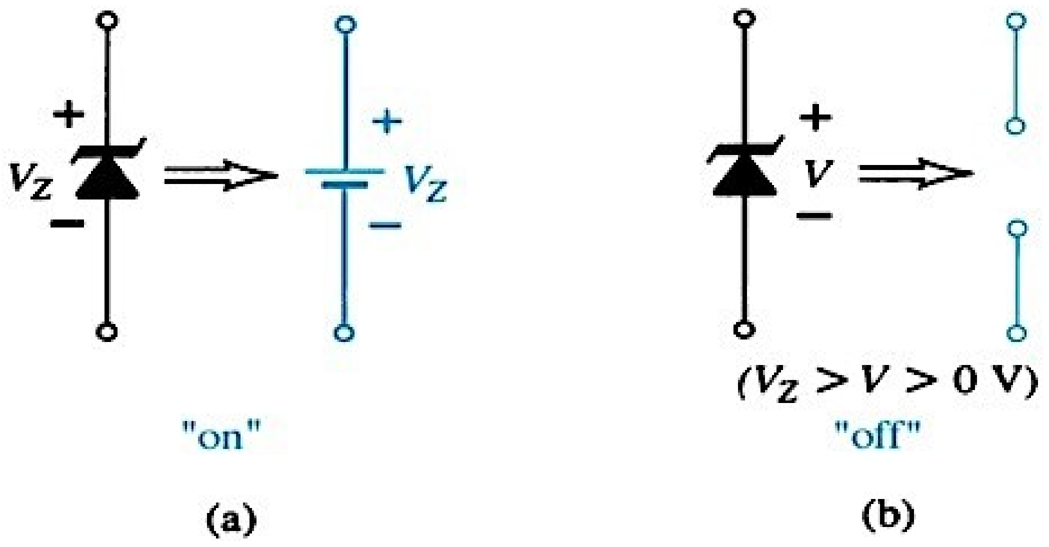


(a)

ZENER DIODE

- The state of the diode must be determined followed by a substitution of the appropriate model and a determination of the unknown quantities of the network.

- The ***off state*** is defined by a voltage ***less than V_z but greater than 0V***. The Zener equivalent is the open circuit.



ZENER DIODE

- The Zener diode is a heavily doped diode which, as a result of doping***, has a very narrow depletion region.*** This allows the diode to be operated in the reverse biased region of the characteristic curve without damaging the PN junction.
- "**Zener Effect**": The area of Zener diode operation (<5V) where the Diode maintains a constant voltage output while operating reverse biased.
- "**Avalanche Effect**": >5V applied to the diode while reverse biased which tends to cause the diode to eventually breakdown due to heat generation within the lattice structure of the crystal.
- Because of its higher temperature and current capability, ***silicon is usually preferred in manufacture of Zener Diodes.***
- Zener Diodes provide a stable reference voltage for use in power supplies, voltmeter & other instruments, voltage regulators.

ZENER DIODE EXAMPLE

EXAMPLE 2.25 The network of Fig. 2.110 is designed to limit the voltage to 20 V during the positive portion of the applied voltage and to 0 V for a negative excursion of the applied voltage. Check its operation and plot the waveform of the voltage across the system for the applied signal. Assume the system has a very high input resistance so it will not affect the behavior of the network.

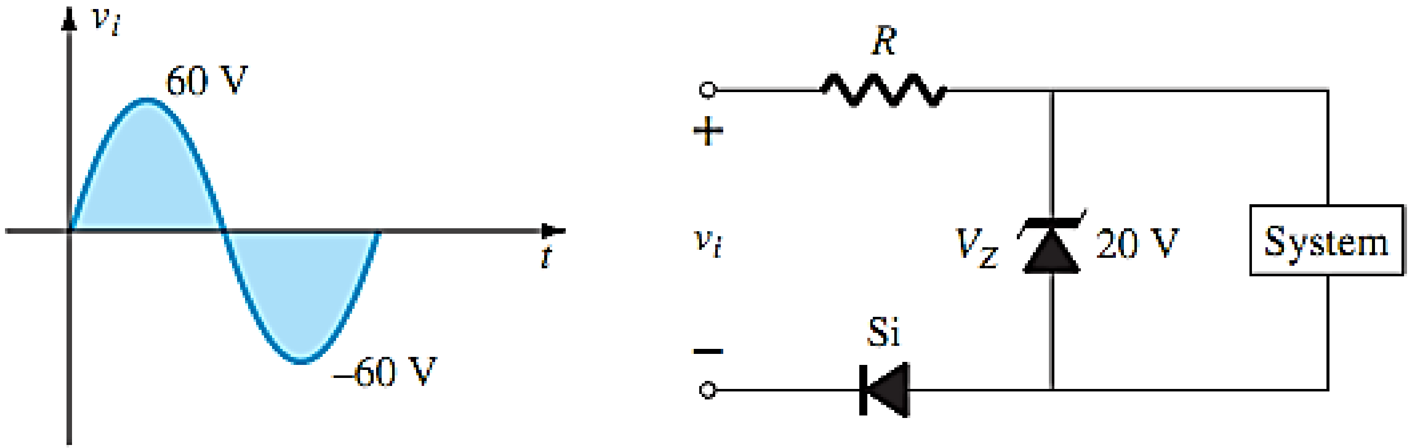


FIG. 2.110
Controlling network for Example 2.25.

ZENER DIODE EXAMPLE

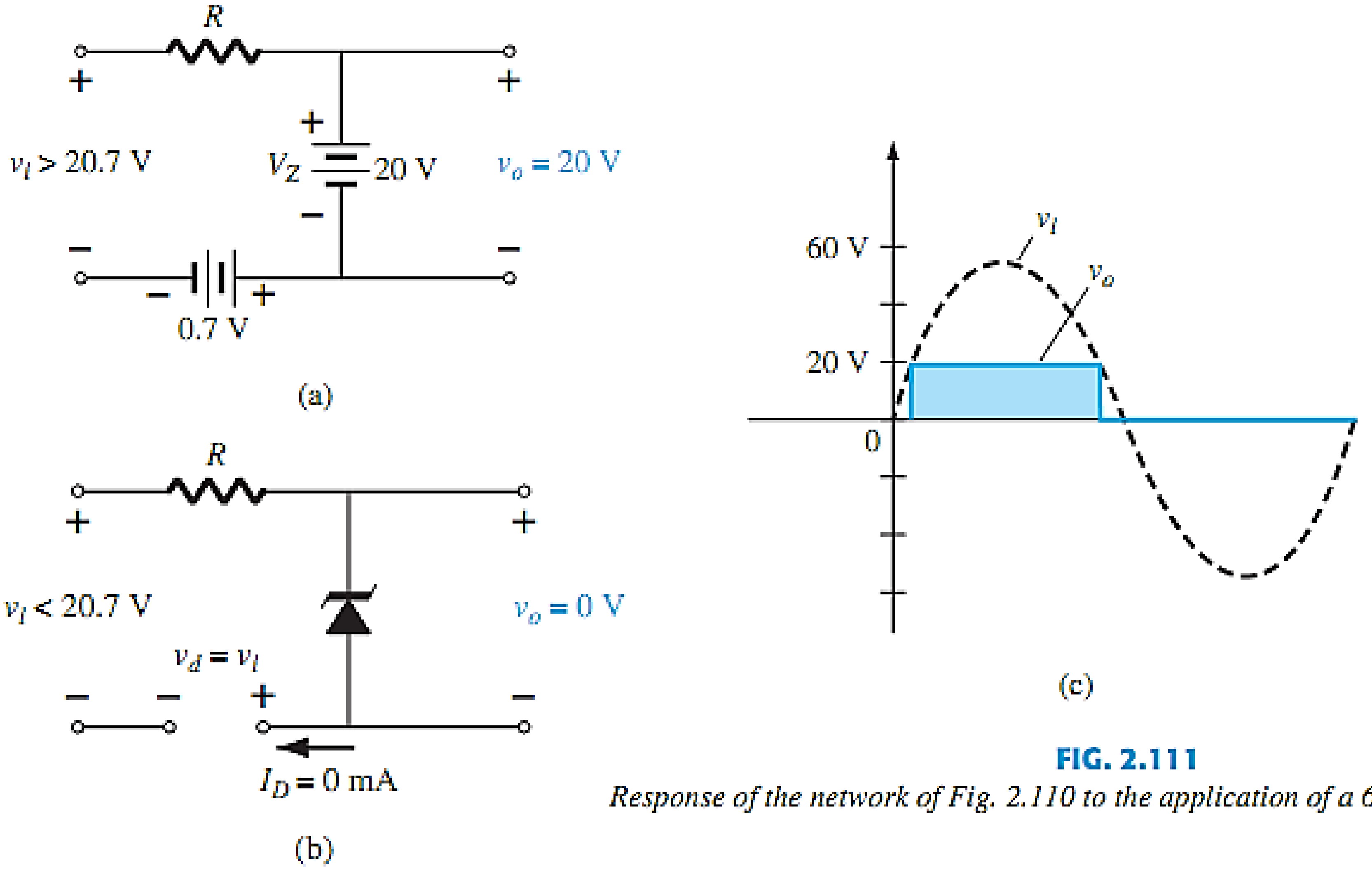


FIG. 2.111

Response of the network of Fig. 2.110 to the application of a 60-V sinusoidal signal.

1^{st} CONDITION: V_i AND R FIXED

- The simplest of Zener diode regulator networks appears in Fig. 2.112 . The applied dc voltage is fixed, as is the load resistor. The analysis can fundamentally be broken down into two steps.

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

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

- If $V \geq V_Z$, the Zener diode is on, and the appropriate equivalent model can be substituted.
- If $V < V_Z$, the diode is off, and the open-circuit equivalence is substituted.

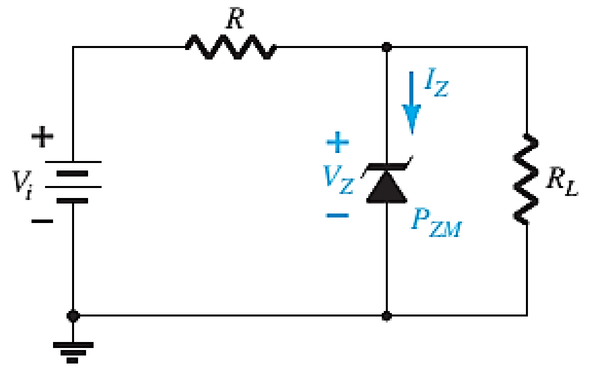


FIG. 2.112
Basic Zener regulator.

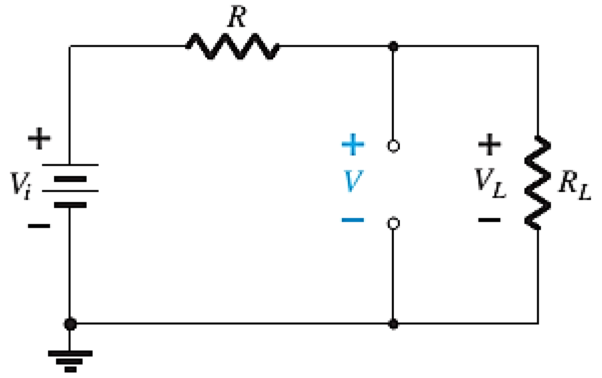


FIG. 2.113
Determining the state of the Zener diode.

1st CONDITION: V_i AND R FIXED

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

For the network of Fig. 2.112 , the "on" state will result in the equivalent network of Fig.2.114 . Since voltages across parallel elements must be the same, we find that

$$\boxed{V_L = V_Z} \quad \boxed{I_Z = I_R - I_L} \quad I_L = \frac{V_L}{R_L} \quad \text{and} \quad I_R = \frac{V_R}{R} = \frac{V_i - V_L}{R}$$

- The power dissipated by the Zener diode is determined by

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

That must be less than the P_{ZM} specified for the device.

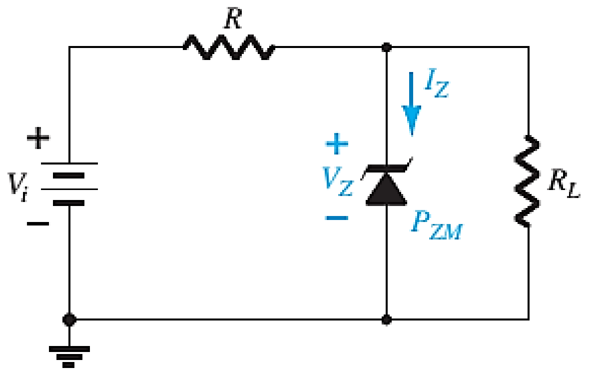


FIG. 2.112
Basic Zener regulator.

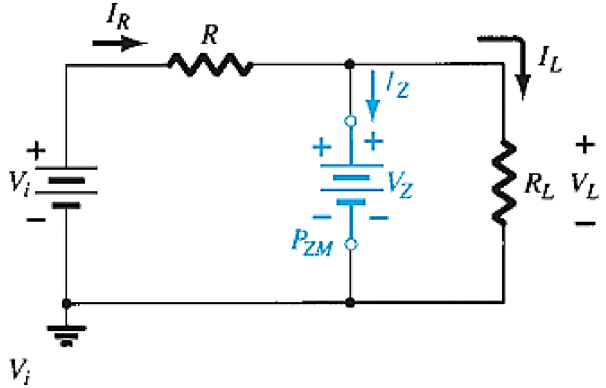


FIG. 2.114
Substituting the Zener equivalent for the "on" situation.

1^{st} CONDITION: V_i AND R FIXED

EXAMPLE 2.26

a. For the Zener diode network of Fig. 2.115, determine V_L, V_R, I_Z, and P_Z.

b. Repeat part (a) with $R_L = 3\text{ k}\Omega$.

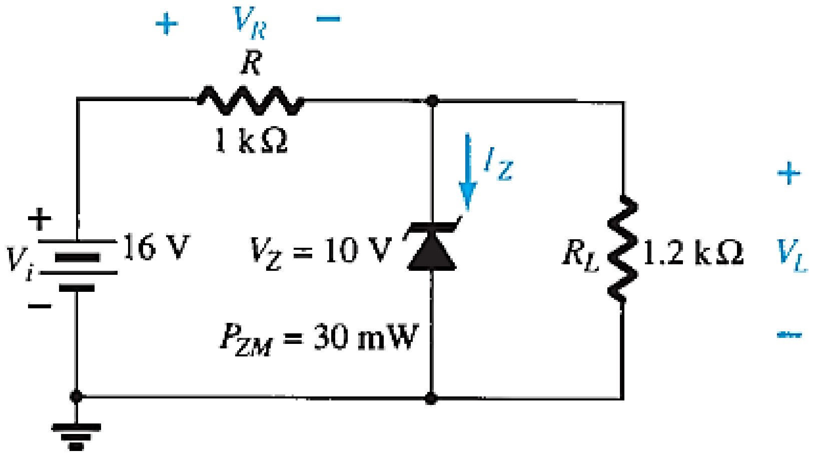


FIG. 2.115
Zener diode regulator for Example 2.26.

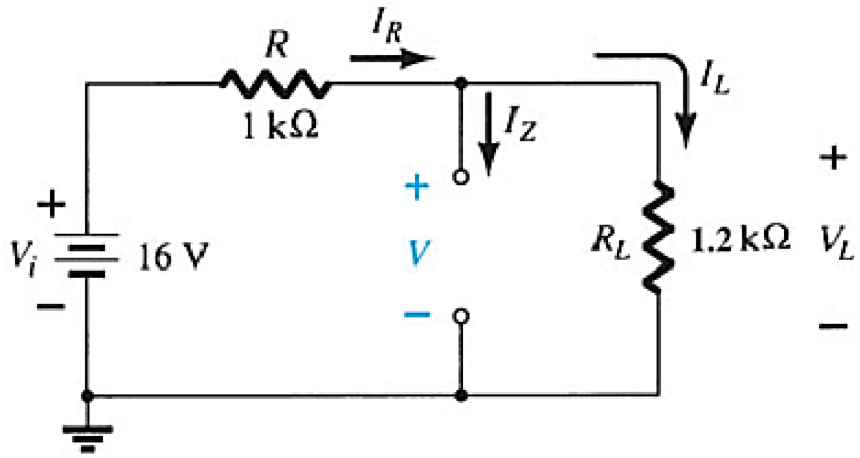


FIG. 2.116
Determining V for the regulator of Fig. 2.115.

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

1^{st} CONDITION: V_i AND R FIXED

Since $V = 8.73$ V is less than $V_Z = 10$ V, the diode is in the "off" state.

$$V_L = V = \mathbf{8.73\ V}$$
$$V_R = V_i - V_L = 16\ \text{V} - 8.73\ \text{V} = \mathbf{7.27\ V}$$
$$I_Z = \mathbf{0\ A}$$
$$P_Z = V_Z I_Z = V_Z(0\ \text{A}) = \mathbf{0\ W}$$

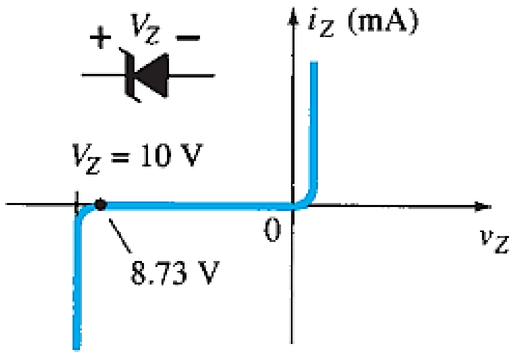


FIG. 2.117
Resulting operating point for the network of Fig. 2.115.

b. Applying Eq. (2.16) results 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

1^{st} CONDITION: V_i AND R FIXED

$$V_L = V_Z = \mathbf{10\ V}$$
$$V_R = V_i - V_L = 16\text{ V} - 10\text{ V} = \mathbf{6\ V}$$
$$I_L = \frac{V_L}{R_L} = \frac{10\text{ V}}{3\text{ k}\Omega} = 3.33\text{ mA}$$
$$I_R = \frac{V_R}{R} = \frac{6\text{ V}}{1\text{ k}\Omega} = 6\text{ mA}$$
$$\begin{aligned} I_Z &= I_R - I_L\ [\text{Eq. (2.18)}] \\ &= 6\text{ mA} - 3.33\text{ mA} \\ &= \mathbf{2.67\ mA} \end{aligned}$$

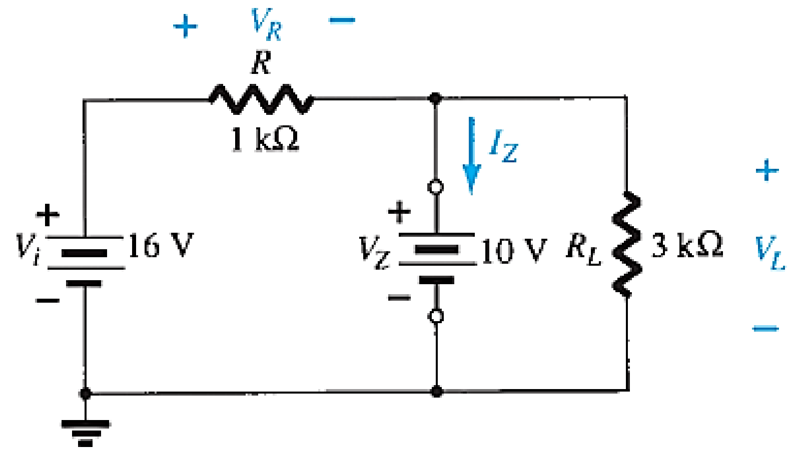


FIG. 2.118
Network of Fig. 2.115 in the "on" state.

The power dissipated is

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

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

2^{nd} CONDITION: FIXED V_i, VARIABLE R_L

- Due to the offset voltage V_z, there is a specific range of resistor values (and therefore load current) which will ensure that the Zener diode is in the on state.

- Too small R_L → $V_L < V_z$ → Zener diode will be in the off state.

- To determine the min R_L that will turn the Zener diode on :

$$\boxed{R_{L_{\min}} = \frac{RV_Z}{V_i - V_Z}} \qquad V_L = V_Z = \frac{R_L V_i}{R_L + R}$$

- Any load resistance value greater than the R_L min will ensure that the Zener diode is in the on state and the diode can be replaced by its V_z source equivalent.

- The max I_L

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

2^{nd} CONDITION: FIXED V_i, VARIABLE R_L

- Once the diode is in the on state, the voltage across R remains fixed at:

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

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

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

- I_z is limited to I_{ZM} as provided on the data sheet, it does affect the range of R_L and therefore I_L.

$$\boxed{I_{L_{\min}} = I_R - I_{ZM}}$$

- The maximum load resistance

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

- ***See Example 2.27.***

3rd CONDITION: FIXED R_L, VARIABLE V_i

- For fixed values of R_L, the voltage V_i must be sufficiently large to turn the Zener diode on. The min turn-on voltage $V_i = V_{i\,min}$:

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

- The max value of V_i is limited by the max Zener current I_{ZM}.

$$V_L = V_Z = \frac{R_L V_i}{R_L + R} \qquad \boxed{I_{R_{\max}} = I_{ZM} + I_L}$$

- Since I_L is fixed at V_Z/R_L and I_{ZM} is the max value of I_Z, the max V_i is defined by:

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

3rd CONDITION: FIXED R_L, VARIABLE V_i

EXAMPLE 2.28 Determine the range of values of V_i that will maintain the Zener diode of Fig. 2.121 in the "on" state.

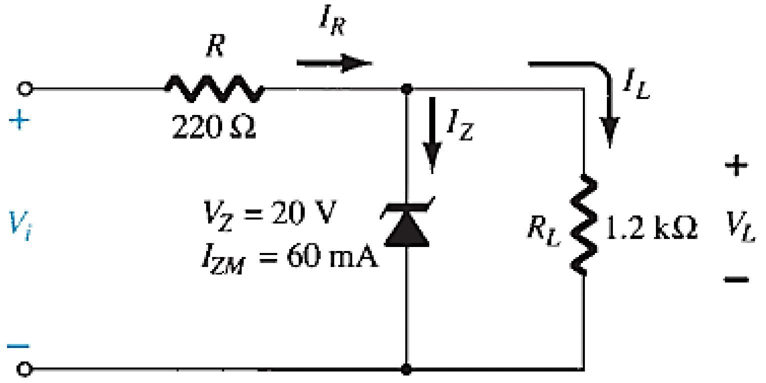


FIG. 2.121
Regulator for Example 2.28.

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

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

$$\begin{aligned} I_{R_{\max}} &= I_{ZM} + I_L = 60\ \text{mA} + 16.67\ \text{mA} \\ &= 76.67\ \text{mA} \end{aligned}$$

$$\begin{aligned} V_{i_{\max}} &= I_{R_{\max}} R + V_Z \\ &= (76.67\ \text{mA})(0.22\ \text{k}\Omega) + 20\ \text{V} \\ &= 16.87\ \text{V} + 20\ \text{V} \\ &= \mathbf{36.87\ V} \end{aligned}$$

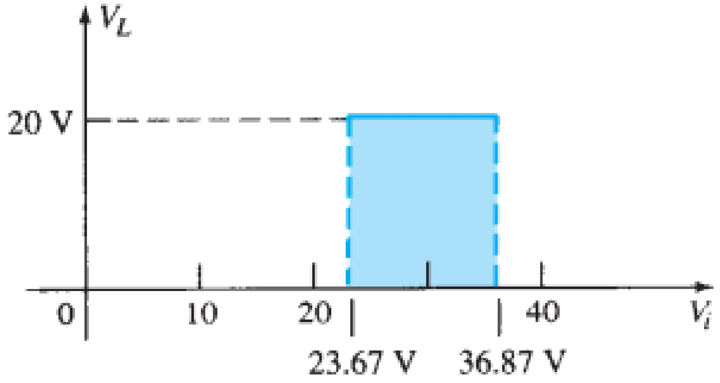


FIG. 2.122
V_L versus V_i for the regulator of Fig. 2.121.

Thank You