Reverse Bias Operation. Zener Diode

Zener Diodes

Zener diodes are specially manufactured to operate in the Zener region. These diodes are made by means of heavily doped regions near the metal contacts to the semiconductor. The high density of charge carriers provides the means for a substantial reverse breakdown current to be sustained. These diodes are useful in applications where one would like to hold some load voltage constant, for example, in voltage regulators. If the voltage a cross zener diode less than Vz but greater than 0 with the polarity indicated the zener diode is in off state and the equivalent circuit is at open circuit.

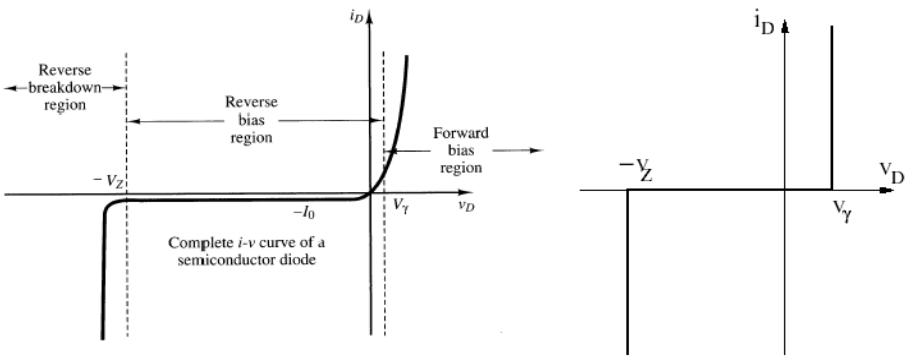


Fig. 13.1 IV characteristics

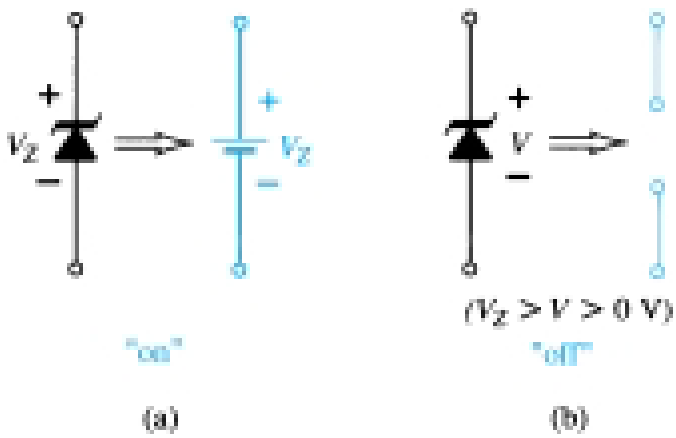
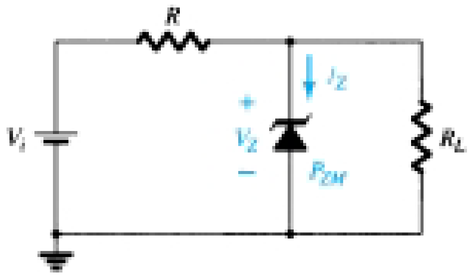


Fig. 13.2 Zener diode

equivalents for the (a) “on” and (b) “off” states

Voltage Regulator Circuit using a Zener Diode



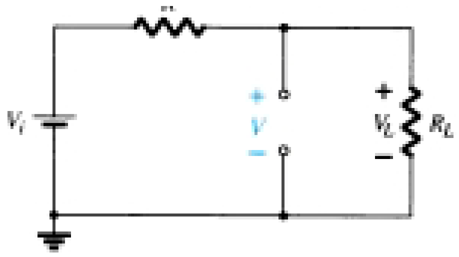
(a) Fig. 13.3 (a) Basic Zener regulator

Vi and R fixed

To analysis of zener diode circuits can be broken into steps: -

1. Remove zener diode from the Circuit and calculate open circuit voltage

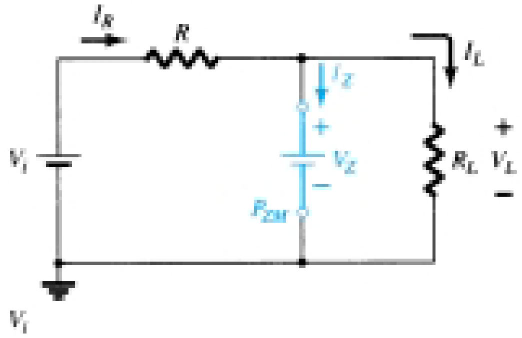
$$V = V_L = Vi\frac{R_L}{R_L + R}$$



(b) Determining the state of the Zener diode

-If *V*>Vz the zener diode is on and can be substituted by the equivalent model of (a)

-If *V*<Vz the zener diode is off and the equivalent model of (b) can be substituted.



(c) Substituting the Zener equivalent for the "on" situation

2-Substitute the appropriate equivalent model for the network of on state

$$I_R = I_z + I_L$$

$$V_L = Vz$$

$$I_L = \frac{V_L}{R_L}$$

$$I_R = \frac{V_R}{R} = \frac{Vi - Vz}{R}$$

The power P=IV

The power dissipated by zener diode $P_z = I_z\ V_z$ must be less than P_{zm} specified for the device.

Example 13.1

Determine V_L, V_R, I_z *and* P_z. If Vi=16V, Vz=10V, R_1=1k, P_{zmax}=30mw

a-R_{Load}=1.2k, b- R_{Load}=3k

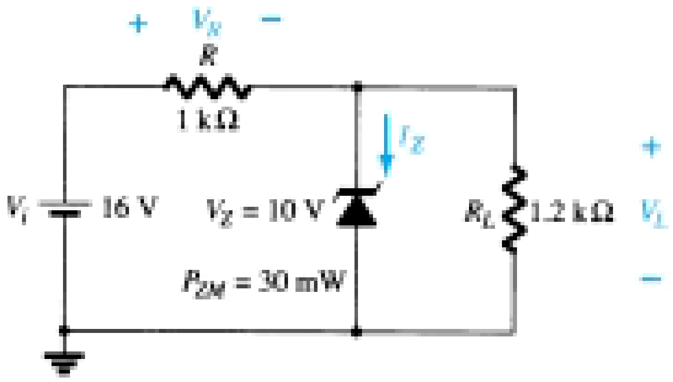


Fig. 13.4 Example 13,1

Solution

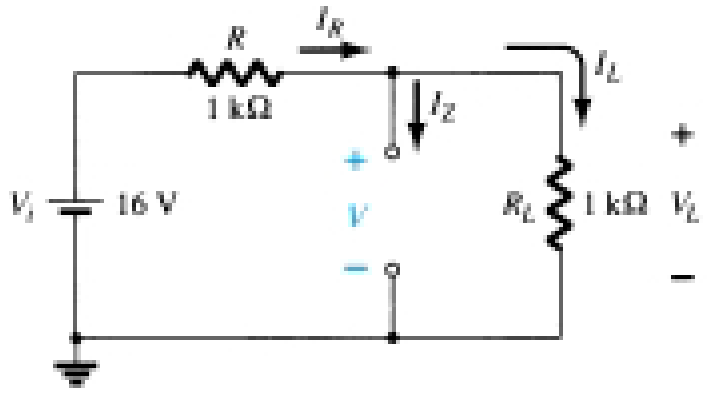


Fig. 13.5 Determining V for the regulator

(a)

$$V_L = Vi\frac{R_L}{R_L + R_1} = 16\frac{1.2}{1.2+1} = 8.73V$$

V=8.73V Less than V_z=10V then diode off

V_L=8.73V

V_R=Vi-Vz=16-8.73=7. 27V

I_z=0

P_z=0

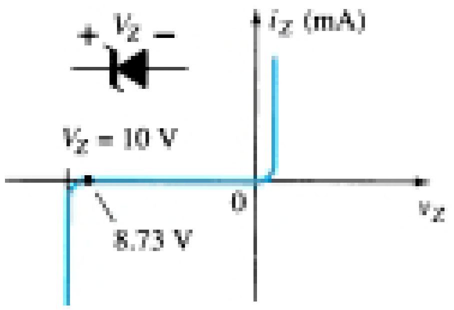


Fig. 13.6 Resulting operating point for the network

(b)

$$V_L = Vi\frac{R_L}{R_L + R_1} = 16\frac{3}{3+1} = 12V$$

V=12V more than V_z=10V then diode on

$V_L=V_z=10V$

$V_R=Vi-V_z=16-10=6V$

$$I_R = Iz + I_L$$

$$I_L = \frac{V_L}{R_L} = \frac{10}{3k} = 3.33mA$$

$$I_R = \frac{V_R}{R} = \frac{6}{1k} = 6mA$$

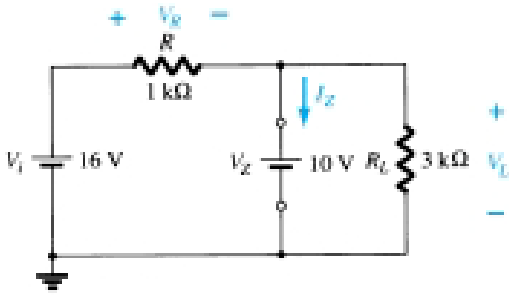


Fig. 13.7 Network in the "on" state

$$I_z = I_R - I_L = 6 - 3.33 = 2.67mA$$

$P_z=I_z\ V_z=2.67\times10^{-3}\times10=26.7$mw Which is less than P_{zmax} 30mw

Note :- The zener is in the on state as soon as the voltage a cross the zener diode is *Vz* volt. It will then lock in at this level and never reach the higher level. Zener diode used in regulator networks to maintained a fixed voltage a cross R_L.

Vi fixed, variable R_L

Too small R_L will result V_L less than *Vz* and the zener device will be in the off state. To determine the minimum load resistance that will turn the zener diode **on**, simply calculate the value of R_L that will result $V_L=V_z$

$$R_{L\min} = \frac{RVz}{Vi - Vz}$$

Any load resistance value greater than R_{Lmin} will ensure that the zener diode **on.**

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

Since I_z is limited to I_{zmax} as provided in data sheet

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

$$I_{L\min} = I_R - I_{Z\max}$$

And maximum resistance load

$$R_{L\max} = \frac{Vz}{I_{L\min}}$$

<u>Example 13.2</u>

Determine the (a) range of R_L and I_L that will result in V_{RL} maintained at 10V, (b) maximum wattage

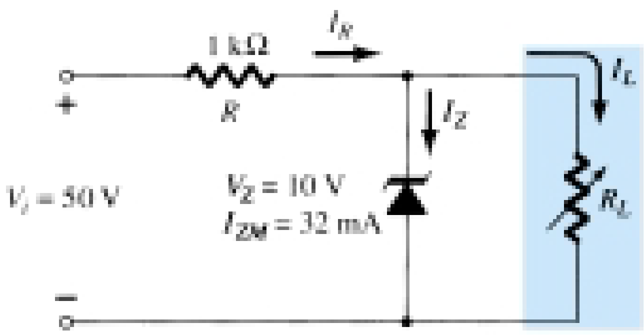


Fig. 13.8 Example 13.2

Solution

$$R_{L\min} = \frac{RVz}{Vi - Vz} = \frac{1k \times 10}{50 - 10} = 250\Omega$$

$$R_{L\max} = \frac{Vz}{I_{L\min}}$$

$$I_{L\min} = I_R - I_{Z\max}$$

$$I_{L\min} = \frac{Vi - Vz}{R} - I_{Z\max}$$

$$I_{L\min} = \frac{50 - 10}{1k} - 32m = 8mA$$

$$R_{L\max} = \frac{10}{8m} = 1.25k\Omega$$

$$I_{L\max} = \frac{V_Z}{R_{L\min}} = \frac{10}{250} = 40mA$$

$P_{zmax} = I_{zm} V_z = 32 \times 10^{-3} \times 10 = 320\text{mw}$

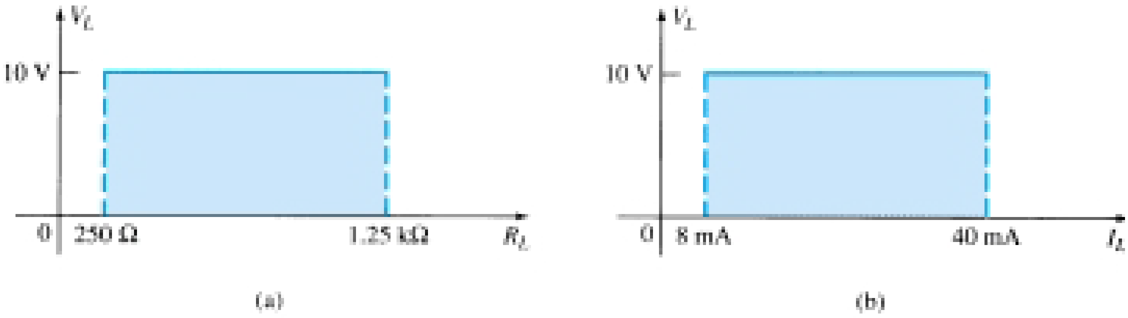


Fig. 13.9 VL versus RL and IL for the regulator

R_L fixed, variable Vi

For fixed values of R_L, the voltage Vi must be sufficiently large to turn the zener diode on. The minimum turn on voltage $Vi=Vi_{min}$

$$V_{i\,min} = \frac{(R_L + R)Vz}{R_L}$$

$$V_{i\,max} = I_{R\,max} R + V_Z$$

$$I_{R\,max} = I_{z\,max} + I_L$$

Example 13.3

Determine the range of *Vi* that will maintain zener diode in the on state

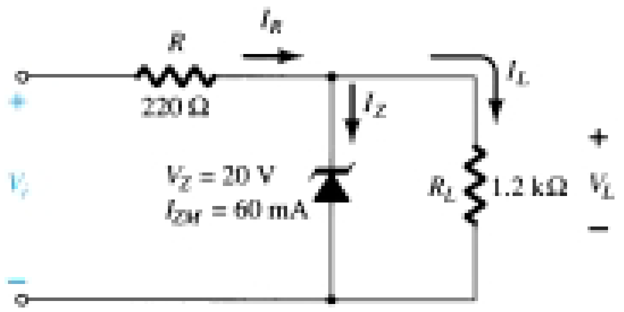


Fig.13.10 Example 13.3

Solution

$$V_{i\,min} = \frac{(R_L + R)V_z}{R_L}$$

$$V_{i\,min} = \frac{(1200 + 220)20}{1200} = 23.67V$$

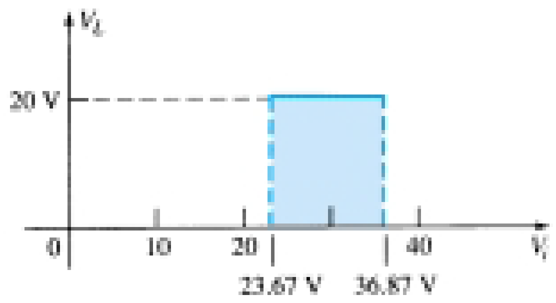


Fig. 13.11 VL versus Vi for the regulator

$$I_{R\max} = I_{z\max} + I_L$$

$$V_{i\max} = I_{R\max} R + V_Z$$

$$I_{R\max} = 60m + \frac{20}{1.2k} = 76.67mA$$

$$V_{i\max} = 76.67m \times 220 + 20 = 36.87V$$

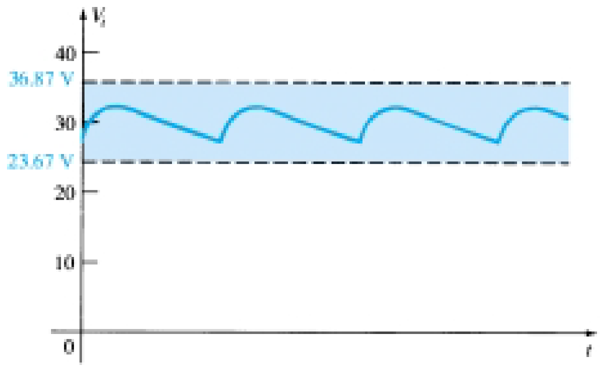


Fig.13.12 Waveform generated by a filtered rectified signal

Note: The input could appear as shown and the output would remain constant at 20V.

Two or more reference level can be established by placing zener diodes in series. As long as Vi is greater than the sum of V_{z1} and V_{z2} both diodes will be in the on state and the three reference voltages will be available.

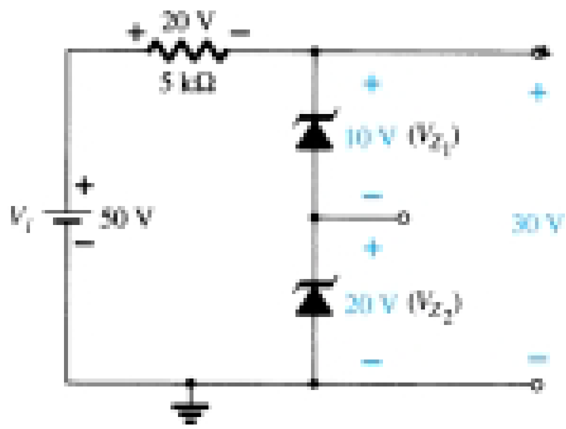


Fig. 13.13 Establishing three reference voltage levels.

Two back to back zener diodes can also be used as shown as long as *Vi* is greater than the *Vz*, Z2 turn on as a zener diode while Z1 is forward bias as short circuit, if *Vi* (*Vi*=10V) is smaller than the *Vz*, Z2 turn off as an open circuit and then *Vo*=10V.

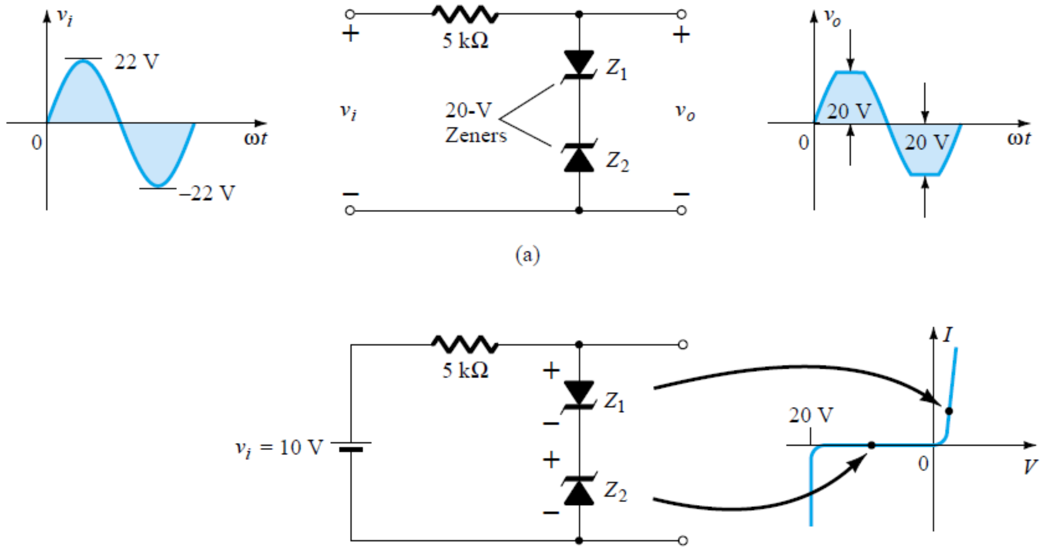


Fig. 13.14 Sinusoidal ac regulation: (a) 40-V peak-to-peak sinusoidal ac regulator; (b) circuit operation at vi = 10 V.

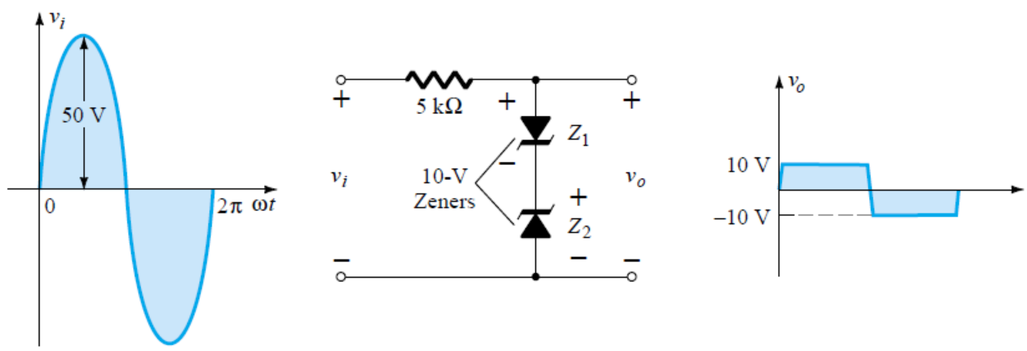


Fig. 13.15 Simple square-wave generator.

Problem

Q1: Design a voltage regulator that will maintain an input voltage of 20V across 1kΩ load with an input that will vary between 30 to 50V. Determine the proper value of R_s and the maximum current.

(Ans: R_s=0.5kΩ, I_{zm}=40mA)

Q2. (a) Design the network to maintain V_L at 12 V for a load variation (I_L) from 0

to 200 mA. That is, determine *Rs* and V_Z.

(b) Determine *PZ*max for the Zener diode of part (a).