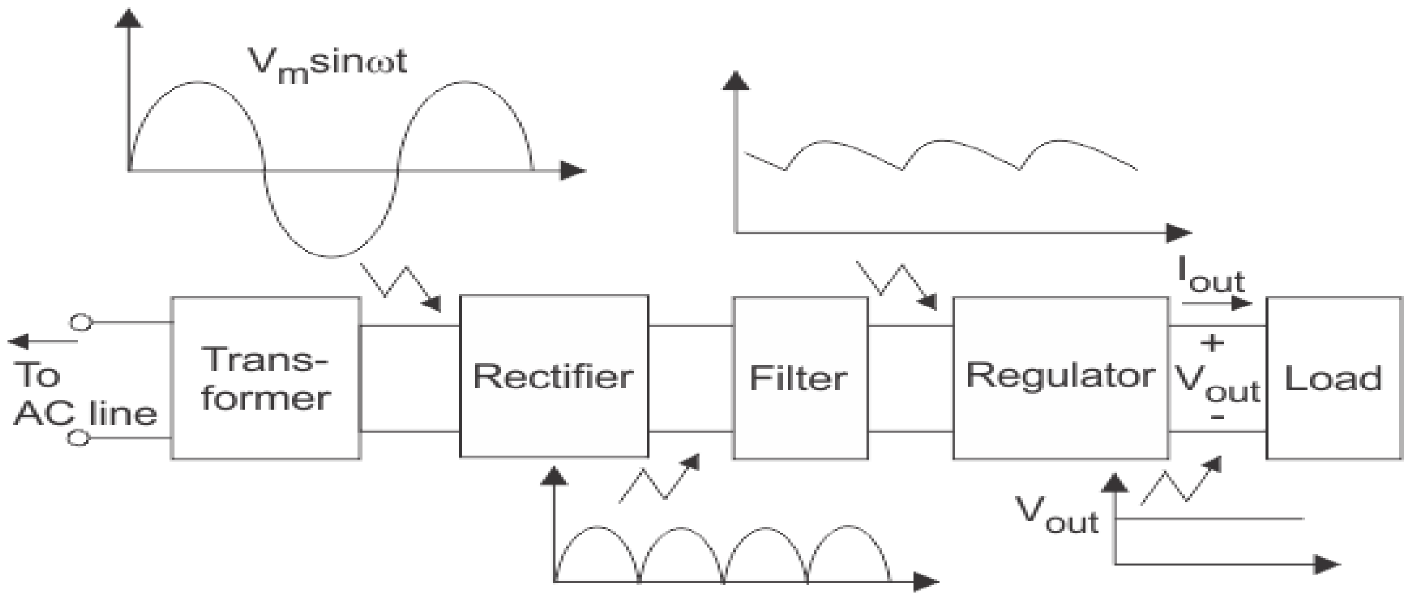
ELECTRONIC PRINCIPLES AND DEVICES

Department of Electronics and Communication.

UNIT - II: Voltage Regulator



Components of typical linear power supply

A regulator is a combination of elements designed to ensure that the output voltage of a supply remains fairly constant.

UNIT - II: Zener Diode

- Heavily Doped PN-Junction Device Specially Designed to operate under breakdown region

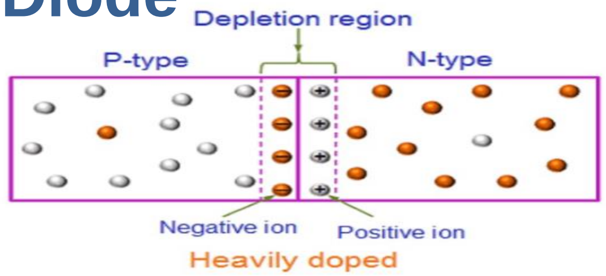
- Zener Diode under forward Bias condition works like a normal semiconductor diode

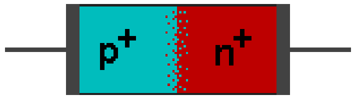
- Zener Diode under reverse bias condition acts like Voltage regulator

- Zener diodes are usually heavily doped diodes hence the depletion layer is very narrow. When the reverse voltage across the junction is increased the electric field across the depletion layer becomes high so that electrons are pulled out of covalent bonds resulting in a sudden rise in current which is known as zener breakdown.

UNIT - II: Zener Diode Characteristics

Structure of Zener Diode





Symbol of Zener Diode

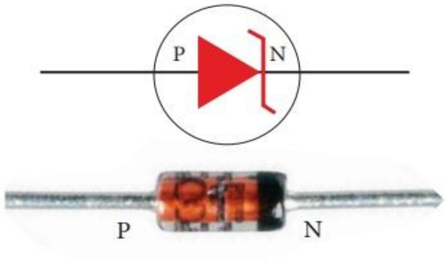


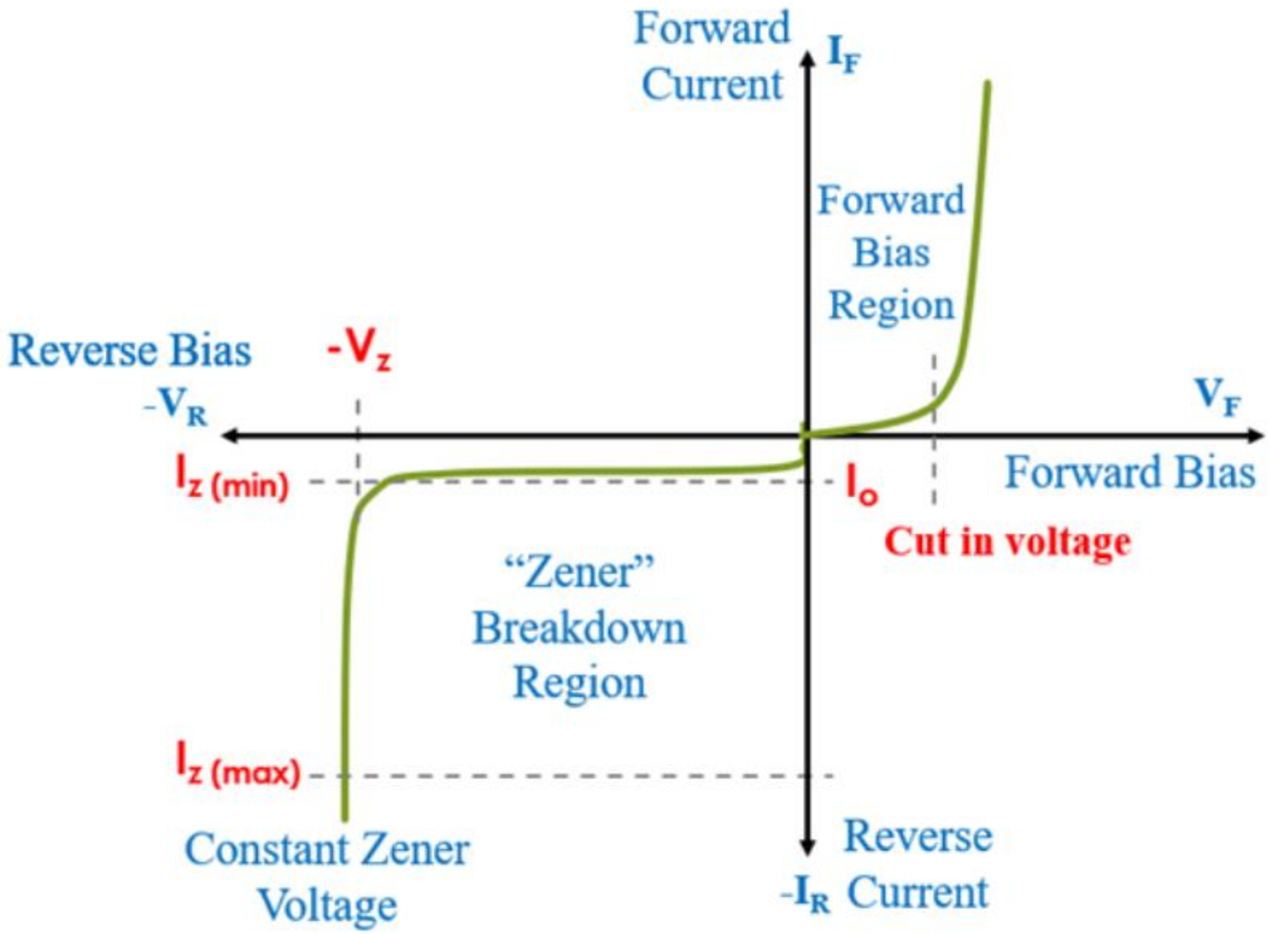
Figure (a) Zener diode and its symbol
(The black colour ring denotes the negative terminal of the Zener diode)

V-I Characteristics of Zener Diode

V-I Characteristics of Zener Diode in Forward Bias Condition

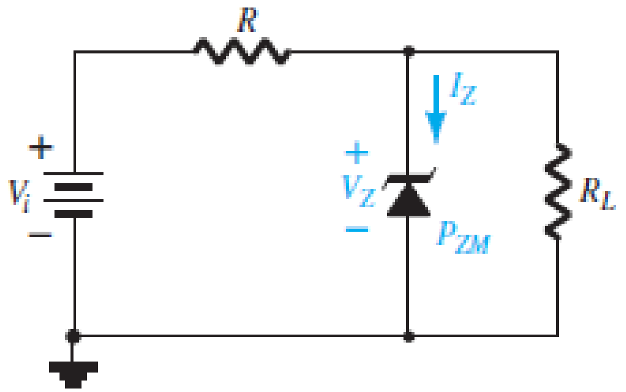
V-I Characteristics of Zener Diode in Reverse Bias Condition

V-I Characteristics

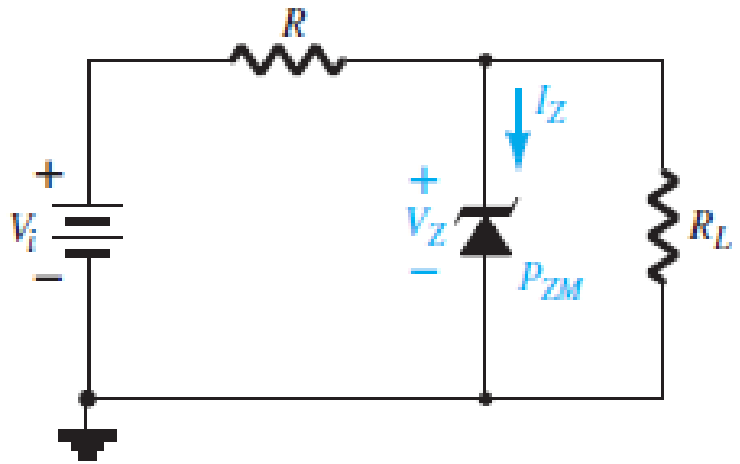


Conditions required to operate Zener Diode as Voltage Regulator

- Zener Diode should be in Reverse Biased Condition
- Vin should be Greater than Vz
- Iz should be greater than Izmin
- Iz should be less than or equal to Izmax



UNIT - II: Zener Diode as Voltage Regulator



Different operating conditions of Zener Regulator .

(i) Fixed quantities, (Vi and R are fixed)

(ii) Fixed supply voltage and a variable load,(Fixed Vi and variable RL)

(iii) Fixed load and a variable supply.(Fixed RL and Variable Vi)

(iv) Variable Supply and Variable Load. (Variable Vi and Variable RL)

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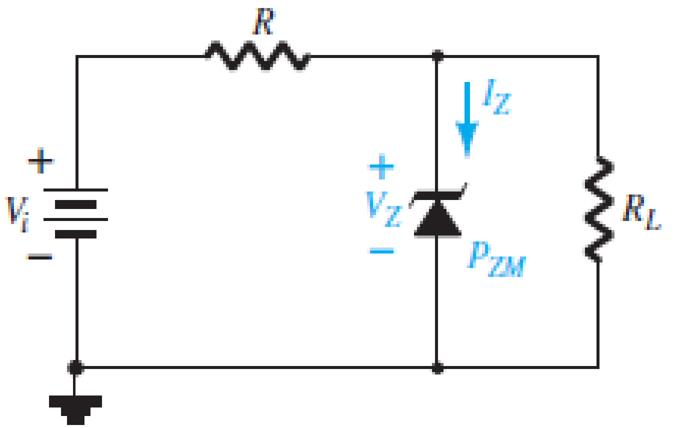
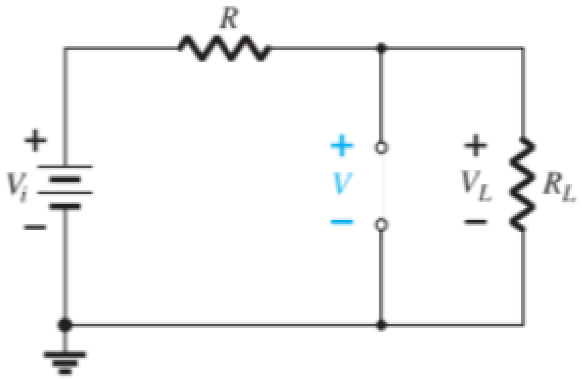
CASE-1: Fixed Vi and fixed R_L Voltage Regulator



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



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

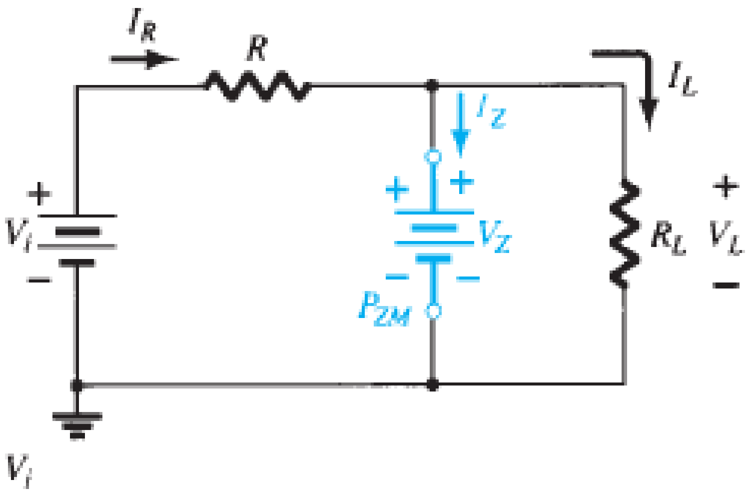
If $V \geq V_Z$, the Zener diode is on, and the appropriate equivalent model can be substituted.
If $V < V_Z$, the diode is off, and the open-circuit equivalence is substituted.

CASE-1: Fixed Vi and fixed R_L Voltage Regulator

Conclusion:

If the Zener diode is in the “on” state, the voltage across the diode is not *V volts.*

The Zener diode will turn on as soon as the voltage across the Zener diode is VZ volts.
It will then “lock in” at this level and never reach the higher level of V volts.

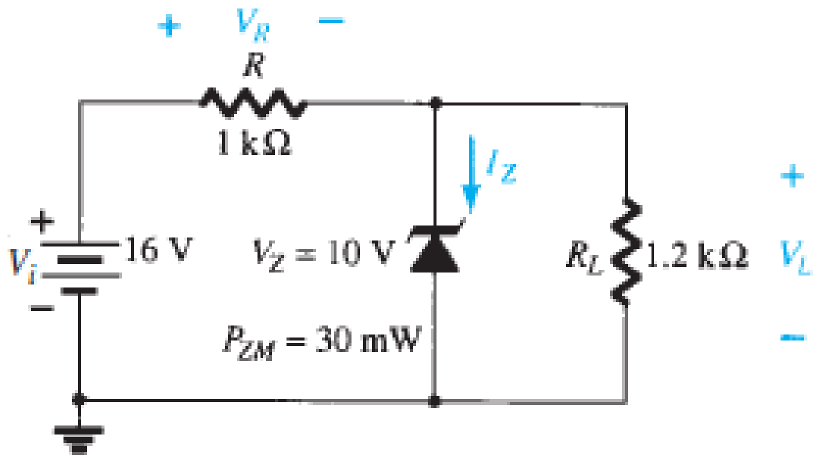


ELECTRONIC PRINCIPLES AND DEVICES

UNIT - II: Zener diode as Voltage Regulator

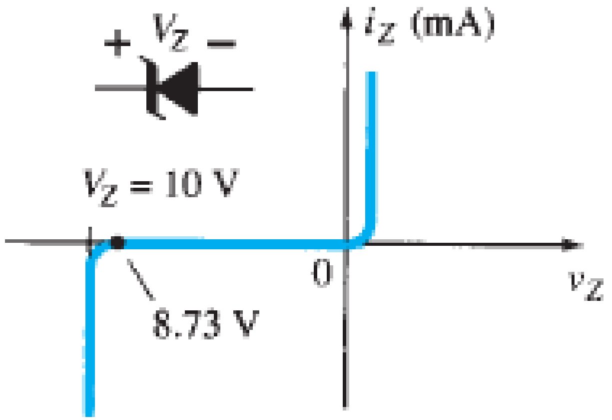
CASE-1: Fixed Vi and fixed R_L Voltage Regulator

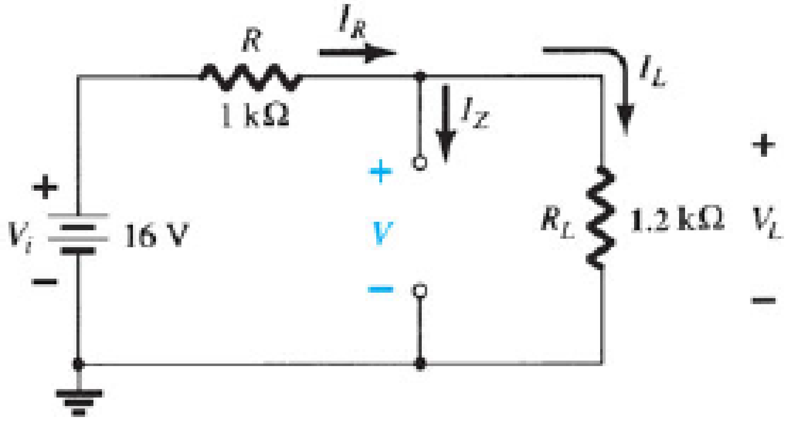
1. For the Zener diode network of Fig,
(i) Determine V_L , V_R , I_Z , and P_Z .
(ii) Repeat part (a) with $R_L = 3K\Omega$.



Solution (i):

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

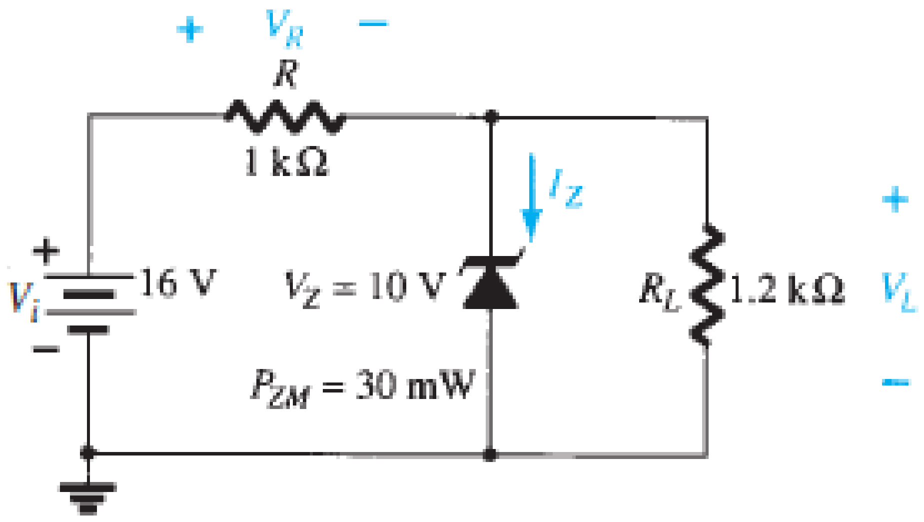




CASE-1: Fixed Vi and fixed R_L Voltage Regulator

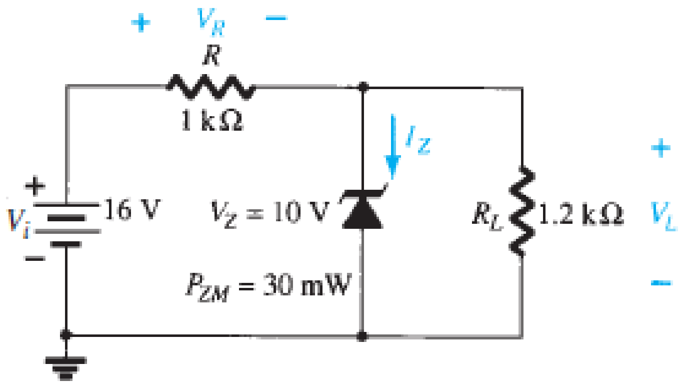
Solution (i):

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



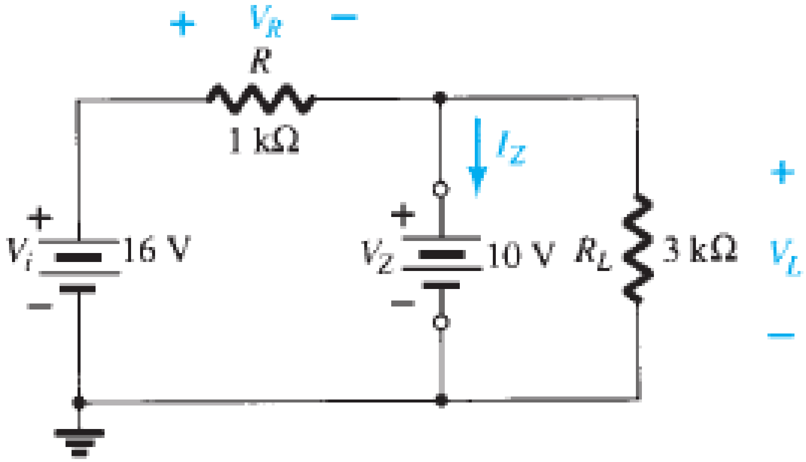
UNIT - II: Zener diode as Voltage Regulator

CASE-1: Fixed Vi and fixed R_L Voltage Regulator



Solution: (ii)

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



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

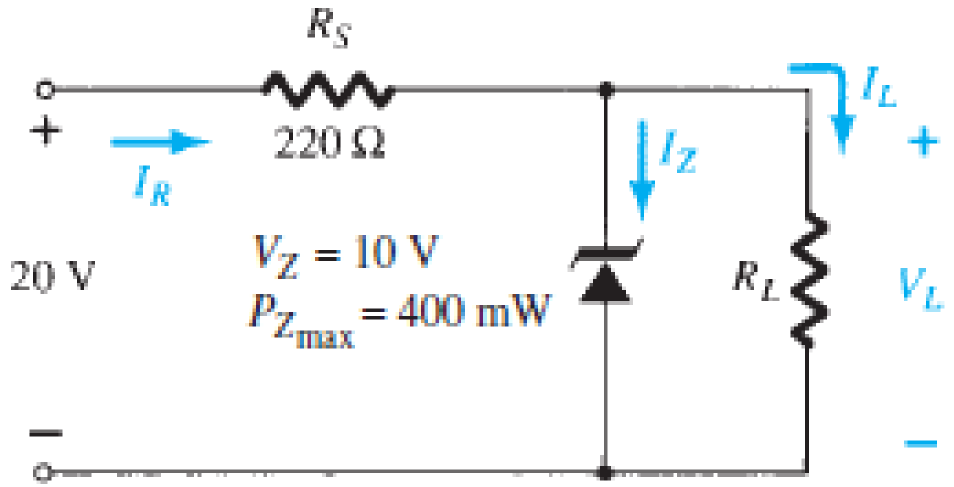
The power dissipated is

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

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

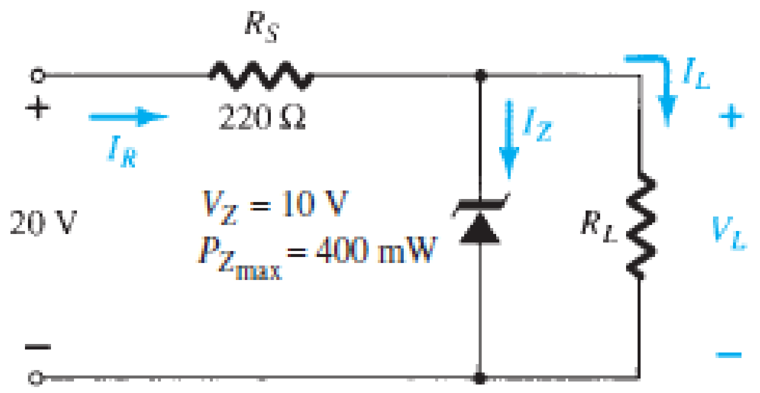
CASE-1: Fixed Vi and fixed R_L Voltage Regulator

2. (a) Determine V_L , I_L , I_Z , and I_R *for the network of Fig. if* R_L *=180 ohm .*
(b) Repeat part (a) if R_L *= 470 ohm .*



UNIT - II: Zener diode as Voltage Regulator

CASE-1: Fixed Vi and fixed R_L Voltage Regulator



Solution a:

In the absence of the Zener diode

$$V_L = \frac{180\ \Omega(20\ \text{V})}{180\ \Omega + 220\ \Omega} = 9\ \text{V}$$

$V_L = 9\ \text{V} < V_Z = 10\ \text{V}$ and diode non-conducting

Therefore, $I_L = I_R = \dfrac{20\ \text{V}}{220\ \Omega + 180\ \Omega} = \mathbf{50\ mA}$

with $I_Z = \mathbf{0\ mA}$
and $V_L = \mathbf{9\ V}$

Solution b:

In the absence of the Zener diode

$$V_L = \frac{470\ \Omega(20\ \text{V})}{470\ \Omega + 220\ \Omega} = 13.62\ \text{V}$$

$V_L = 13.62\ \text{V} > V_Z = 10\ \text{V}$ and Zener diode "on"

Therefore, $V_L = \mathbf{10\ V}$ and $V_{R_s} = 10\ \text{V}$

$I_{R_s} = V_{R_s} / R_s = 10\ \text{V}/220\ \Omega = \mathbf{45.45\ mA}$

$I_L = V_L/R_L = 10\ \text{V}/470\ \Omega = \mathbf{21.28\ mA}$

and $I_Z = I_{R_s} - I_L = 45.45\ \text{mA} - 21.28\ \text{mA} = \mathbf{24.17\ mA}$

CASE-2: Fixed supply voltage and a variable load

Conditions for R_L to Keep the Zener currnet I_Z in the operating limit
i.e $I_{Zmin} \leq I_Z < I_{Zmax}$

1: Condition for R_{Lmin} :

$$I_L = I_R - I_Z$$

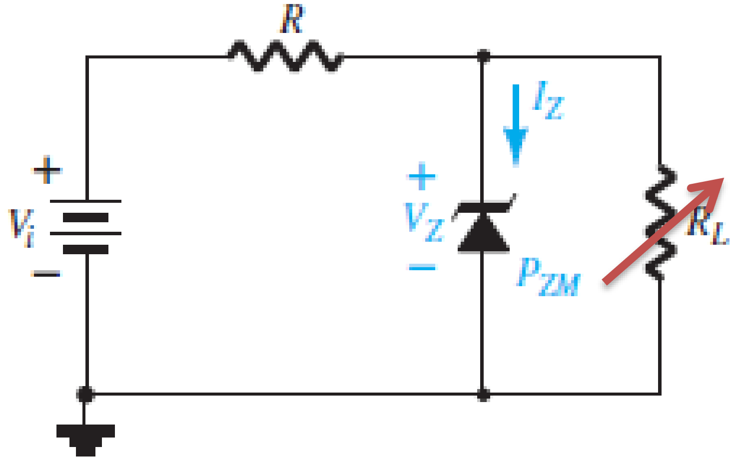
$$R_L = \frac{V_Z}{I_L}$$ *R_L is Minimum when I_L is Maximum*

$$I_{Lmax} = I_R - I_{Zmin}$$ where $$I_R = \frac{V_i - V_z}{R}$$

$$R_{Lmin} = \frac{V_Z}{I_{Lmax}}$$

If I_{Zmin} = 0 then I_{Lmax} = I_R

hence, $$R_{Lmin} = \frac{V_Z}{I_R} = \frac{V_Z R}{V_i - V_Z}$$



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CASE-2: Fixed supply voltage and a variable load

Conditions for R_L to Keep the Zener currnet I_Z in the operating limit i.e

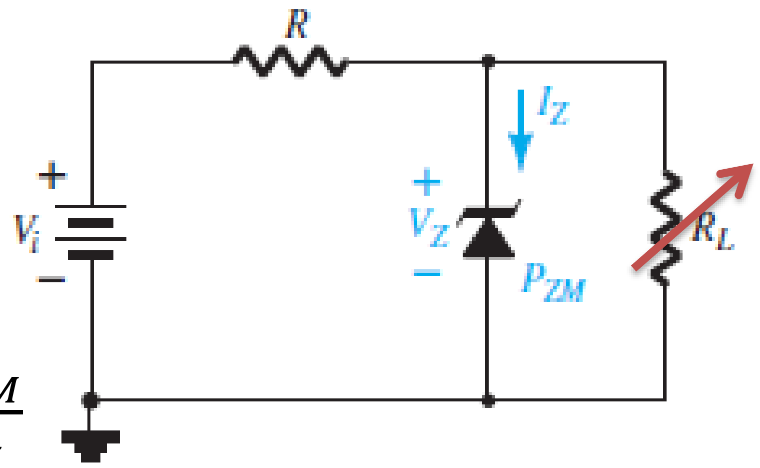
$$I_{Zmin} \leq I_Z < I_{Zmax}$$

 # 2: Condition for R_{Lmax} :

$$I_L = I_R - I_Z$$

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

R_L is Maximum when I_L is Minimum

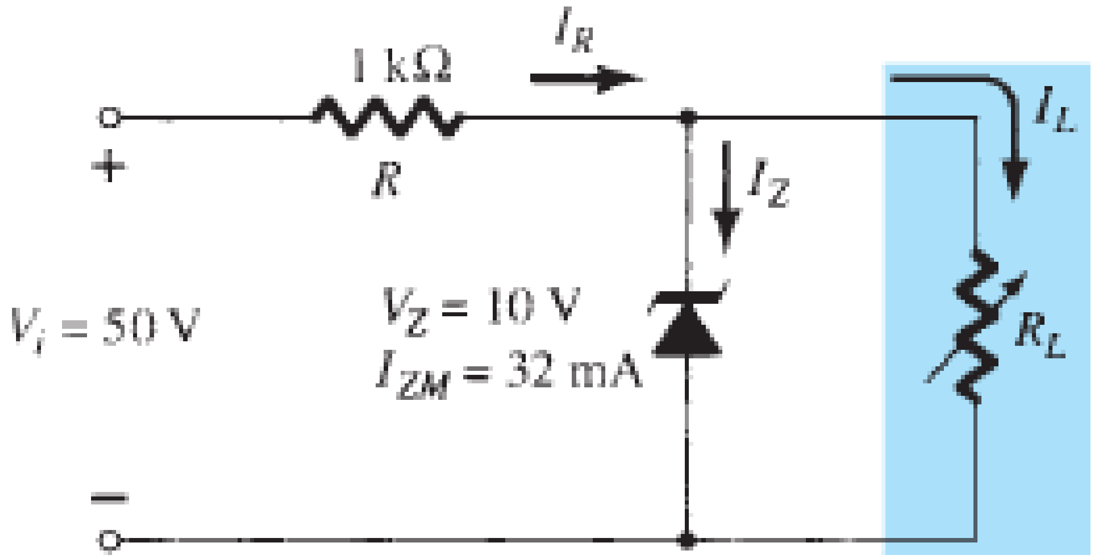


$$I_{Lmin} = I_R - I_{Zmax} \quad \text{where} \quad I_R = \frac{V_i - V_z}{R} \text{ and } I_{Zmax} = \frac{P_{ZM}}{V_Z}$$

$$R_{Lmax} = \frac{V_Z}{I_{Lmin}}$$

CASE-2: Fixed supply voltage and a variable load

3. For the network of Fig
(i) Determine the range of *R_L and I_L that will result in V_{RL}* being maintained at 10 V. Given I_{Zmin} = 1mA.
(ii) Determine the maximum wattage rating of the diode.



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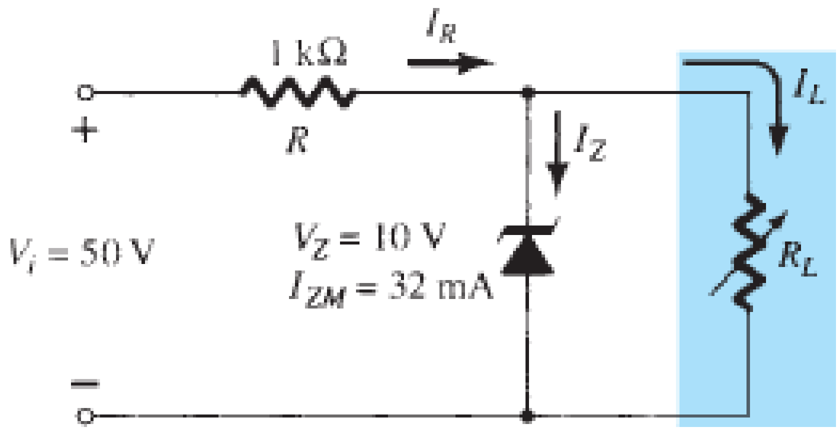
CASE-2: Fixed supply voltage and a variable load



(i) $$I_R = \frac{V_i - V_Z}{R} = \frac{50-10}{1\text{k}\Omega} = 40mA$$

$$\mathrm{I_{Lmax}} = \mathrm{I_R} - \mathrm{I_{Zmin}} = 40\text{mA} - 1\text{mA} = 39\text{mA}$$

$$\mathrm{I_{Lmin}} = \mathrm{I_R} - \mathrm{I_{Zmax}} = 40\text{mA} - 32\text{mA} = 8\text{mA}$$

$$R_{Lmax} = \frac{V_Z}{I_{Lmin}} = \frac{10}{8mA} = 1.25K\Omega$$

$$R_{Lmin} = \frac{V_Z}{I_{Lmax}} = \frac{10}{39mA} = 256.41\ \Omega$$

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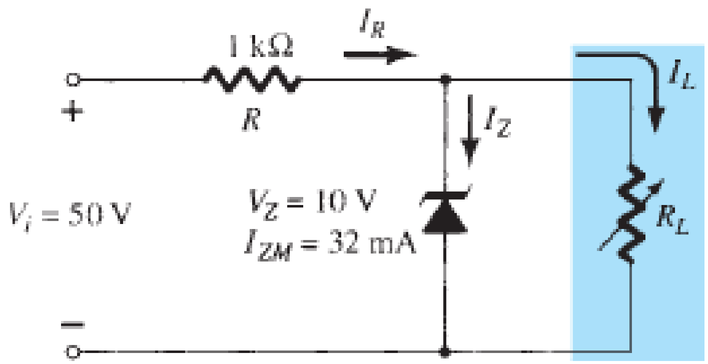
CASE-2: Fixed supply voltage and a variable load

3. For the network of Fig
(ii) Determine the maximum wattage rating of the diode.

(ii) Maximum Watage P_{Zmax} = Vz * I_{zmax} = 320mW



CASE-2: Fixed supply voltage and a variable load

4. Determine the value of R_L that will establish maximum power conditions for the Zener diode. Determine the minimum value of R_L to ensure that the Zener diode is in the "on" state.

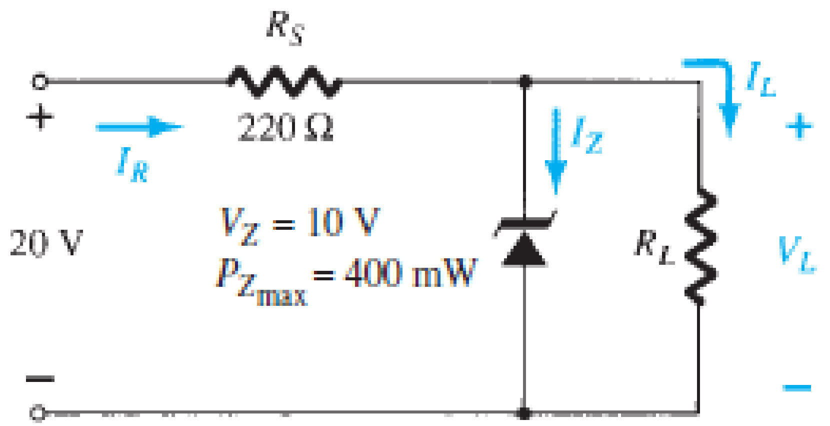
$$P_{Z_{max}} = 400 \text{ mW} = V_Z I_Z = (10 \text{ V})(I_Z)$$

$$I_Z = \frac{400 \text{ mW}}{10 \text{ V}} = 40 \text{ mA}$$

$$I_{L_{min}} = I_{R_s} - I_{Z_{max}} = 45.45 \text{ mA} - 40 \text{ mA} = 5.45 \text{ mA}$$

$$R_L = \frac{V_L}{I_{L_{min}}} = \frac{10 \text{ V}}{5.45 \text{ mA}} = \mathbf{1{,}834.86\ \Omega}$$

Large R_L reduces I_L and forces more of I_{R_s} to pass through Zener diode.



In the absence of the Zener diode

$$V_L = 10 \text{ V} = \frac{R_L(20 \text{ V})}{R_L + 220\ \Omega}$$

$$10R_L + 2200 = 20R_L$$

$$10R_L = 2200$$

$$R_L = \mathbf{220\ \Omega}$$

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CASE-3: Fixed R_L , Variable Vi

Conditions for Vi to Keep the Zener current I_Z in the operating limit i.e $I_{Zmin} \leq I_Z < I_{Zmax}$

1: Condition for Vi_{min} :

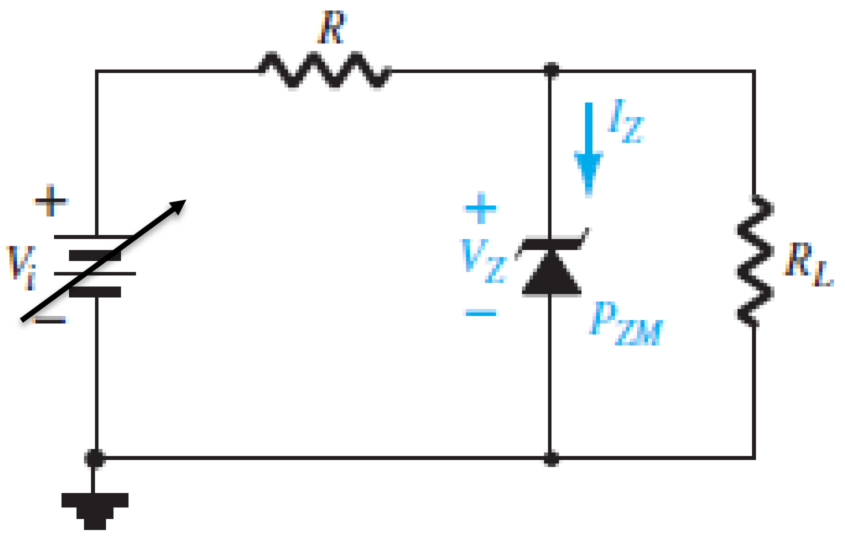
$$I_R = I_Z + I_L$$

$$I_{Rmin} = I_{Zmin} + I_L$$

$$I_{Rmin} = \frac{V_{imin} - V_z}{R}$$

$$V_{imin} = V_Z + I_{Rmin} R$$

If $I_{Zmin} = 0\ ;\ then\ I_{Rmin} = I_L;\ V_{imin} = V_Z + I_L R = \frac{V_Z(R_L+R)}{R_L}$



CASE-3: Fixed R_L , Variable Vi

Conditions for Vi to Keep the Zener currnet I_Z in the operating limit i.e $I_{Zmin} \leq I_Z < I_{Zmax}$

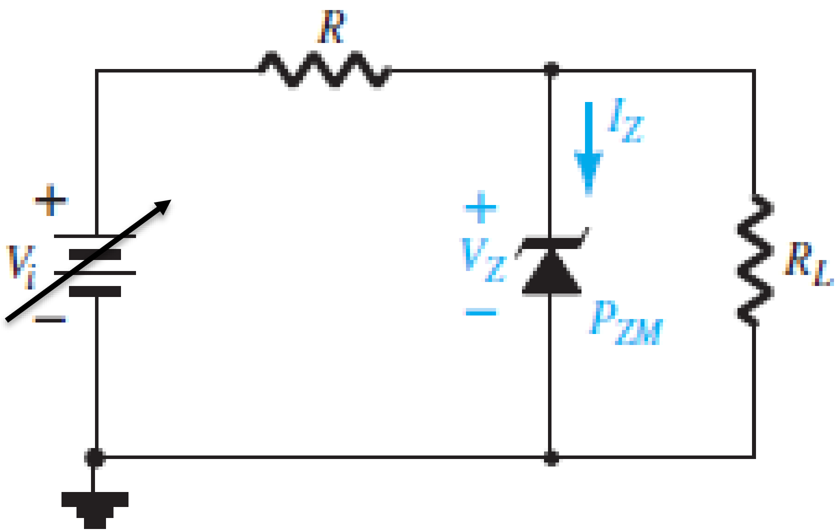
2: Condition for Vi_{max} :

$$I_R = I_Z + I_L$$

$$I_{Rmax} = I_{Zmax} + I_L \qquad I_L = \frac{V_Z}{R_L}$$

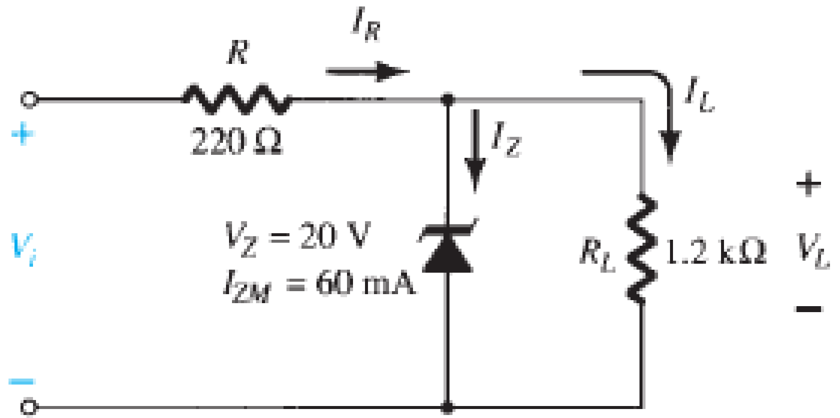
$$I_{Rmax} = \frac{V_{imax} - V_z}{R} \qquad I_{Zmax} = \frac{P_{ZM}}{V_Z}$$

$$V_{imax} = V_Z + I_{Rmax} R$$



CASE-3: Fixed R_L , Variable Vi

5. Determine the range of values of *Vi that will maintain the Zener diode of* Fig. in the "on" state. Given I_{Zmin} = 2mA



$$V_{imin} = V_Z + I_{Rmin}R$$

$$\mathrm{I_{Rmin}} = \mathrm{I_{Zmin}} + \mathrm{I_L}$$

$$I_L = \frac{V_Z}{R_L} = \frac{20}{1.2K\Omega} = 16.67mA$$

$$I_{Rmin} = 2mA + 16.67mA = 18.67mA$$

$$V_{imin} = 20 + 18.67mA * 220\Omega = 24.107V$$

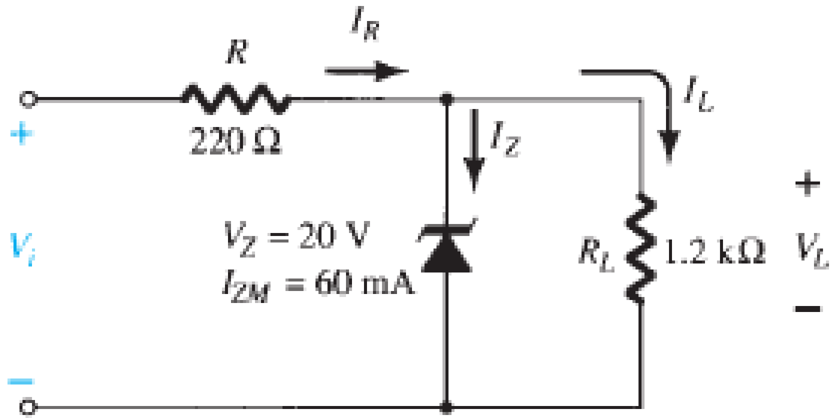
$$V_{imax} = V_Z + I_{Rmax}R$$

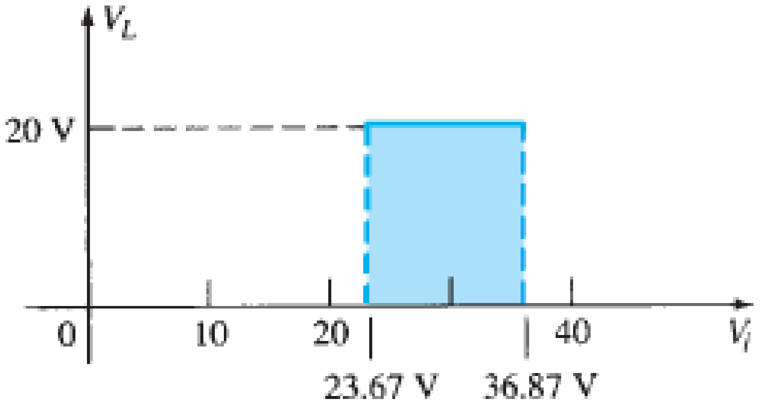
$$\mathrm{I_{Rmax}} = \mathrm{I_{Zmax}} + \mathrm{I_L}$$

$$I_{Rmax} = 60mA + 16.67mA = 76.67mA$$

$$V_{imax} = 20 + 76.67mA * 220\Omega = 36.86V$$

CASE-3: Fixed RL , Variable Vi

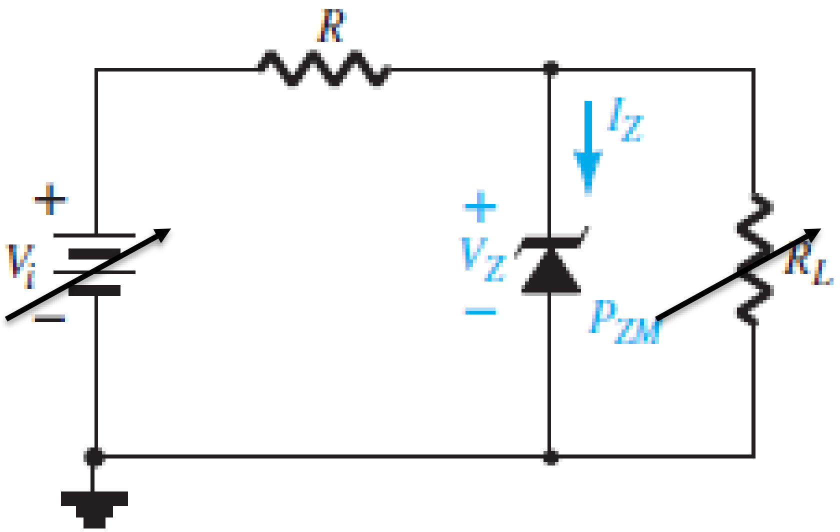




CASE-4: Variable supply voltage and a variable load

Worst case conditions for Zener Diode:

1. For the diode to enter into to the breakdown region, the necessary condition is $I_Z \geq I_{Zmin}$.



I_Z can become less than I_{Zmin} when

(i) I_L increases or R_L decreases.
(ii) R increases or I_R decreases.
(iii) Vin decreases.

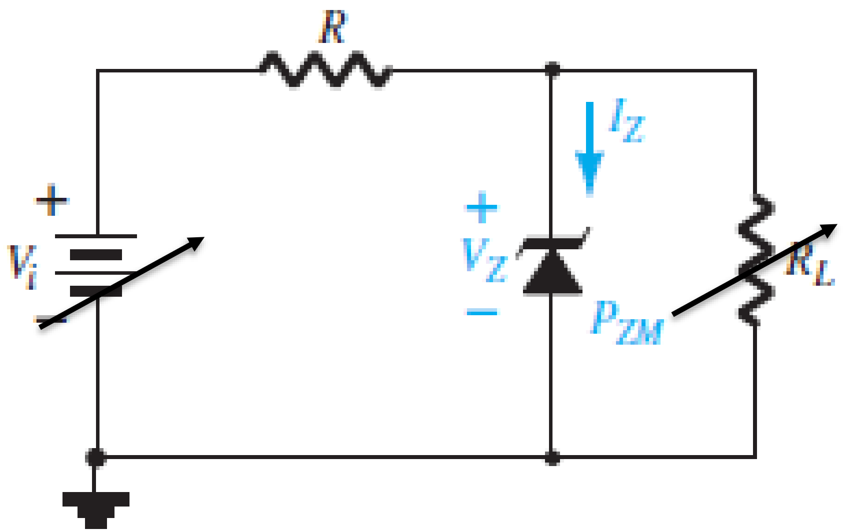
Hence the value for Rmax to ensure $I_Z \geq I_{Zmin}$ is

$$R_{max} = \frac{V_{imin} - V_Z}{I_{Zmin} + I_{Lmax}}$$

CASE-4: Variable supply voltage and a variable load

Worst case conditions for Zener Diode:

2. *The upper limit for the Zener current is* $\boldsymbol{I_Z < I_{Zmax}}$.



I_Z can become greater than I_{Zmax} when

(i) I_L decreases or R_L increases.
(ii) R decreases or I_R increases.
(iii) Vin increases.

Hence the value for Rmin is to ensure $I_Z < I_{Zmax}$ is

$$R_{min} = \frac{V_{imax} - V_Z}{I_{Zmax} + I_{Lmin}}$$

UNIT - II: Zener diode as Voltage Regulator

CASE-4: Variable supply voltage and a variable load

6. Design a Zener voltage regulator that maintains Vo at 10V for input voltage variation of 20V$\pm$10% and load current variation of 30mA $\pm$20%. Given $I_{Zmin} = 2mA\ and\ P_{Zmax} = 0.5W$

Vimin = 20 V - 2V = 18V

Vimax = 2V + 2V = 22 V

I_{Lmin} = 30mA – 6mA = 24mA

I_{Lmax} = 30mA + 6mA = 36mA

$$R_{max} = \frac{V_{imin} - V_Z}{I_{Zmin} + I_{Lmax}} = \frac{18 - 10}{2mA + 36mA} = 210.5\ \Omega$$

$$R_{min} = \frac{V_{imax} - V_Z}{I_{Zmax} + I_{Lmin}} = \frac{22 - 10}{50mA + 24mA} = 162.16\ \Omega$$

$$210.5\ \Omega \leq R \leq 162.16\ \Omega$$

THANK YOU

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