# Zener Diodes and Applications

## Zener Diodes:

Diodes which are designed with plate power-dissipation capabilities to operate in the breakdown region may be employed as voltage-reference or constant-voltage devices. Such are known as ***avalanche, breakdown,*** or ***zener diodes.*** The zener diode is made for operation in the breakdown region. By varying the doping level, a manufacturer can produce zener diodes with breakdown voltages from 2 to 250V.

When the applied reverse voltage reaches the breakdown value, minority carries in the depletion layer are accelerated and reach high enough velocities to dislodge valence electrons from outer orbits. The newly liberated electrons can then gain high enough velocities to free other valence electrons. In this way, we get an avalanche of free electrons. Avalanche occurs for reverse voltages greater than 6V or so.

The zener effect is different. When a diode is heavily doped, the depletion layer is very narrow. Because of this, the electric field across the depletion layer is very intense. When the field strength reaches approximately $3 \times 10^7$ V/m, the field is intense enough to pull electrons out of valence orbits. The creation of free electrons in this way is called zener breakdown (also known as high-field emission).

The zener effect is predominant for breakdown voltages less than 4V, the avalanche effect is predominant for breakdown voltages greater than 6V, and both effect are present between 4 and 6V. originally, people thought the zener effect was the only breakdown mechanism in diodes. For this reason, the name "zener diode" came into widespread use before the avalanche effect was discovered. All diodes optimized for operation in the breakdown region are therefore still called zener diodes.

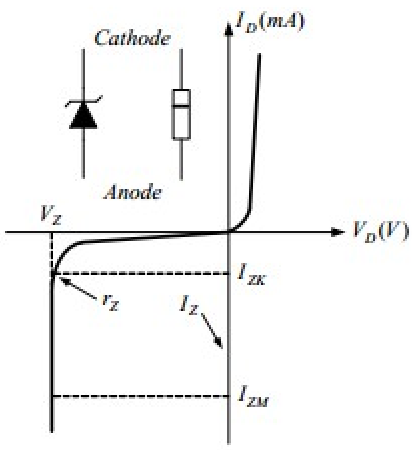



**Fig. 7-1**

Fig. 7-1 shows the schematic symbol and the current-voltage curve of a zener diode. Negligible reverse current flows until we reach the breakdown voltage $V_Z$ . In a zener diode, the breakdown has a very sharp knee, followed by an almost vertical increase in current. Note that the voltage is approximately constant, equal to $V_Z$ over most of breakdown region. Data sheets usually the value of $V_Z$ at a particular knee current $I_{ZK}$ which is beyond the knee (see Fig. 7-1).

The power dissipation of a zener diode equals the product of its voltage and current. In symbols,

$$P_Z = V_Z . I_Z$$

As long as $P_Z$ is less than the power rating $P_{Z(max)}$ , the zener diode will not be destroyed. Commercially available zener diodes have power ratings from 0.25W to more than 50W. Data sheets often specify the maximum current a zener diode can handle without exceeding its power rating. This maximum current is designed $I_{Z(max)}$ (see Fig.7-1).

The relation between $I_{Z(max)}$ and power rating is given by

$max$
$max$
$Z$
$P$
$Z$
$I$

When a zener diode is operating in the breakdown region, a small increase in voltage produces a large increase in current. This implies that a zener diode has a small dynamic resistance ( $r_Z$, see Fig. 7-1). We can calculate this zener resistance by

$$r_Z = \frac{\Delta v}{\Delta i}$$

The complete equivalent circuit of the zener diode in the zener region includes a small dynamic resistance $r_Z$ and dc battery equal to the zener potential $V_Z$, as shown in Fig. 7-2a. for all applications to follow, however, we shall assume as a first approximation that the external resistance are much larger in magnitude than the zener-equivelent resistor and that the equivalent circuit is simply the dc battery that equal to $V_Z$ as indicated in Fig. 7-2b.

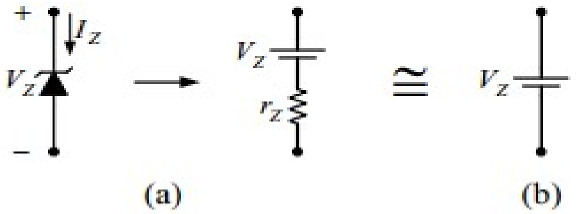



**Fig. 7-1**

## Zener Diode:

these diodes have adequate power dissipation capabilities to operate in the breakdown region. These are used as voltage reference, and constant voltage devices. These are called avalanche, breakdown or zener diodes.

Zener may have breakdown voltage 2 to 200V depending upon level of doping.

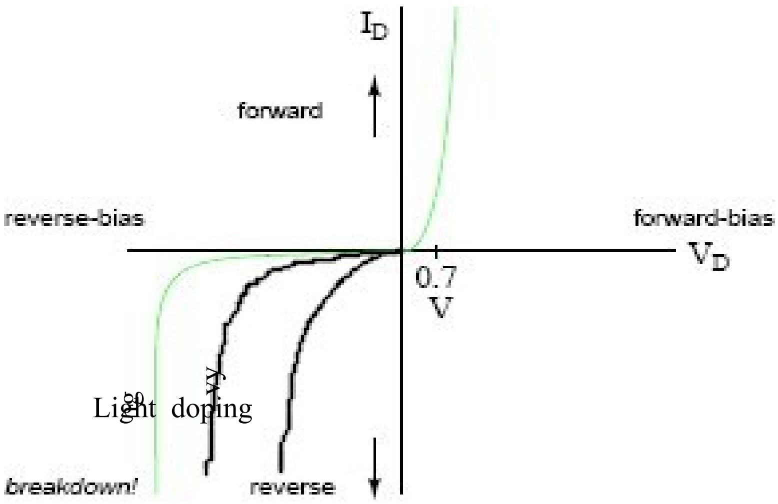



**Fig. 7-2: V-I characteristics**

## Avalanche Breakdown:

When the applied reverse voltage reaches the breakdown value, minority carriers in the depletion layer are accelerated and reach high enough velocity to dislodge valance electrons from outer orbits. These newly liberate electrons further free valence electrons. In this way avalanche of free electrons is obtained. Avalanche occurs for reverse voltage greater than 6V.

## Zener Breakdown:

With heavily doping the depletion layer becomes narrow and electric field intensity across the depletion layer is very intense of the order of 300KV/cm, enough to pull electrons out of valance orbits. The free electron creation of this way is called zener breakdown or high field emission.

This effect is prominent for breakdown voltages less than 4V.

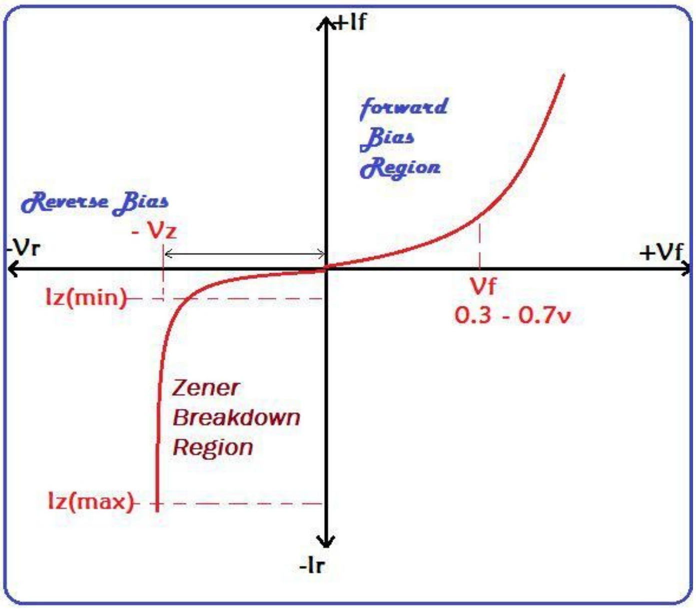
Both avalanche  and zener effect are present between 4V and 6V.

## Zener impedance:

$Z_Z = \frac{\Delta v}{\Delta i} \rightarrow$ called dynamic impedance

In breakdown region, zener diode has small impedance in voltage produces large chang in current. The change in zener voltage with temp.

$\Delta V_Z = T_C \times \Delta T \times V_Z$




Where

$T_C$ : *temperture coefficient*

$\Delta T$ : *change* $\in$ *temp.*

$V_Z$ : *zener voltage*

Then

$$T_C = \frac{\Delta V_Z / V_Z}{T_1 - T_o} \times 100\ C^\circ$$

Where

$T_1$: is the new temperature level

$T_o$: is room temperature in an enclosed cabinet ( $25\,C°$

**Fig. 7-3**

$T_C$: *is the temperture coefficient*

$V_Z$: is the nominal zener potential at $25\,C°$

## Example7-1:

Analyze the 10V zener diode if the zener diode if the temperature is increased to $100\,C°$ and typical temperature coefficient is 0. $0.072\,C°$ .

## Solution:

$$\Delta V_Z = \frac{T_C \times V_Z}{100}(T_1 - T_o) = \frac{(0.072\,\%C°)(10\,V)}{100}(100-25)\,C°$$

$$\Delta V_Z = 0.54\,V$$

The resulting potential zener is now

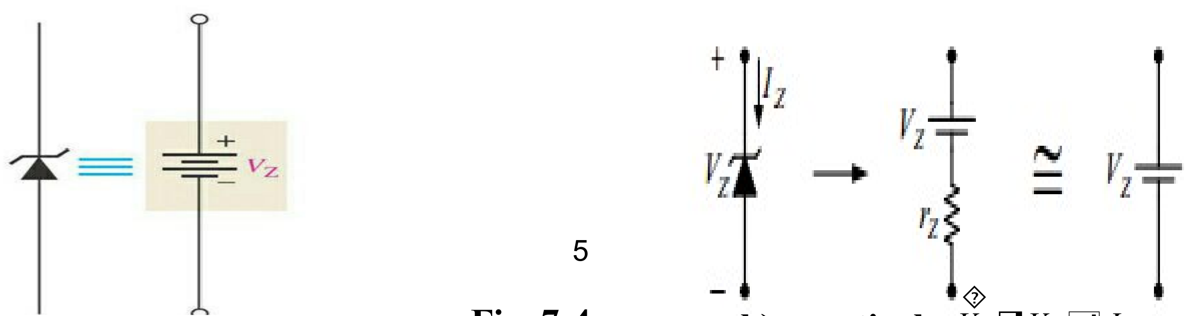
$$V_Z = V_Z + 0.54 = 10.54\,V$$

The power dissipation of zener diode $P_Z = V_Z . I_Z$

The maximum current in zener

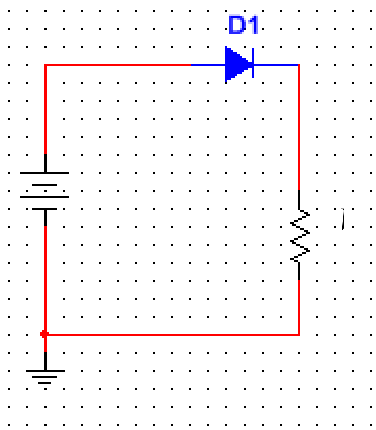
max
max
Z
P
Z
I

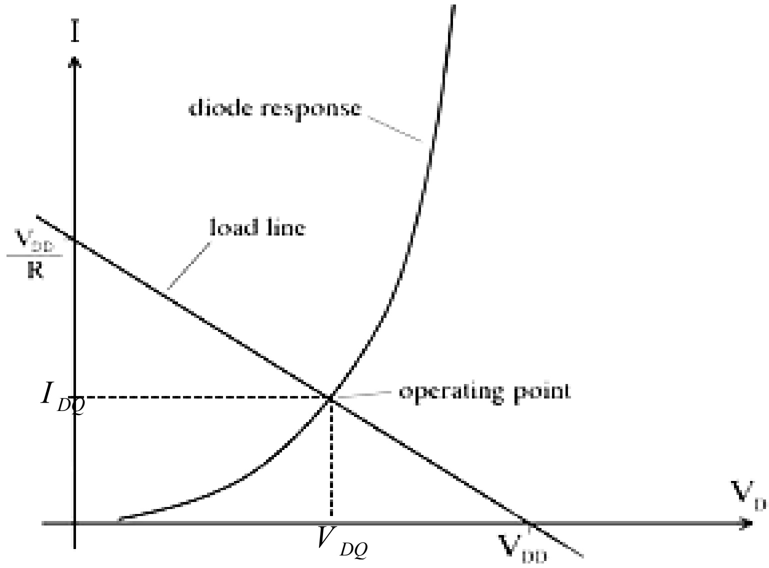
## Zener Approximation:



a) ideal **Fig. 7-4** **b) practical** $V_Z = V_Z + I_Z r_Z$

## Load-Line Analysis:

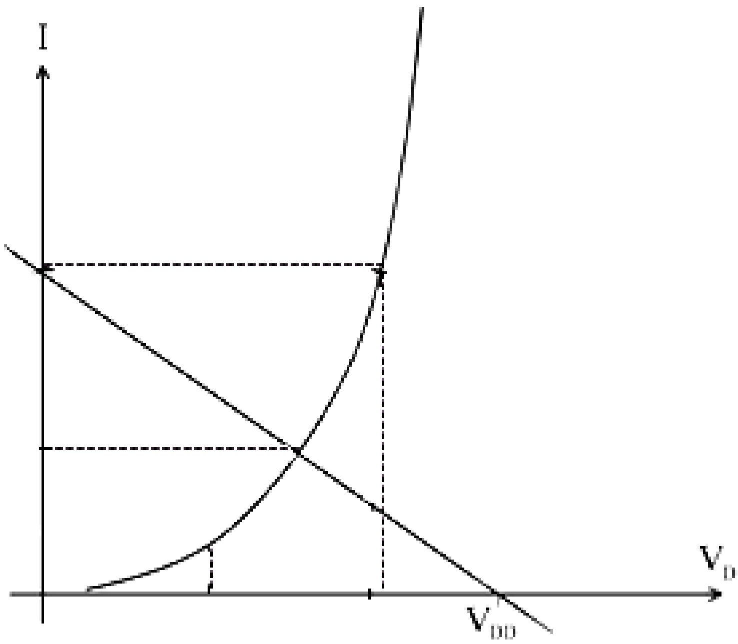



$$E - V_D - V_R = 0 \quad (KVL)$$

$$E = V_D - I_D R$$

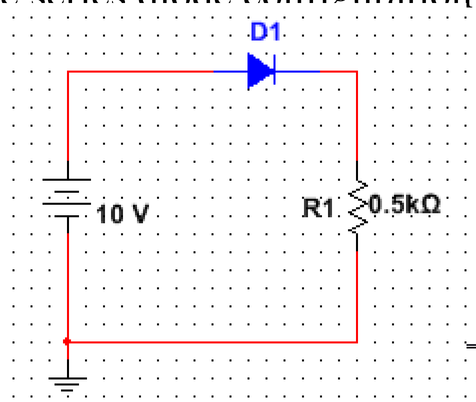
$$when\ V_D = 0 \Longrightarrow I_D = \frac{E}{R} \wedge I_D = I_S \left( e^{V_D / \eta V_T} - 1 \right)$$




## Example7-1:

For the series diode configuration e

Deter



20

18.5mA

0.5 0.8

a) $I_D = \frac{E}{R}$, at $V_D = 0 \Longrightarrow I_D = \frac{10\,V}{0.5\,k\Omega} = 20\,mA$

$V_D = E$ at $I_D = 0 \Longrightarrow V_D = 10\,V$

$V_{DQ} = 0.78\,V$

$I_{DQ} = 18.5\,mA$

b) $V_R = I_R R = (18.5\,mA)(1\,k\Omega) = 18.5\,V$

## The DC Zener Regulator:

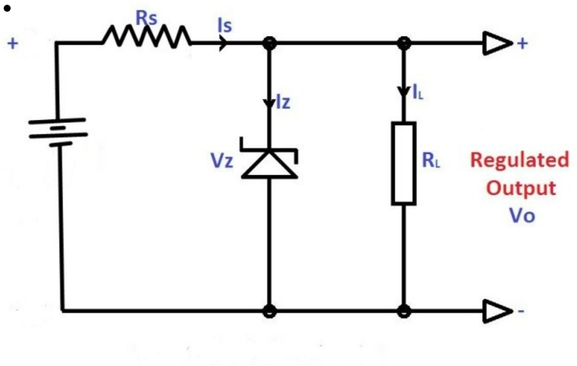
### Equation of load current across load:

$$R = \frac{V - V_Z}{I_L + I_Z}$$

$$I_{Z(min)} < I_Z < I_{Z(max)}$$

Q-point is chosen such that

$$I_Z = 20\,I_{Z(max)}$$



$$max$$
$$Z$$
$$I_L \approx 0.2 I$$
$$\therefore R = \frac{V - V_Z}{}$$

Fig. 7-5

And

$$r_Z = \frac{\Delta v}{\Delta i} \quad (\text{ideally } r_Z = 0)$$

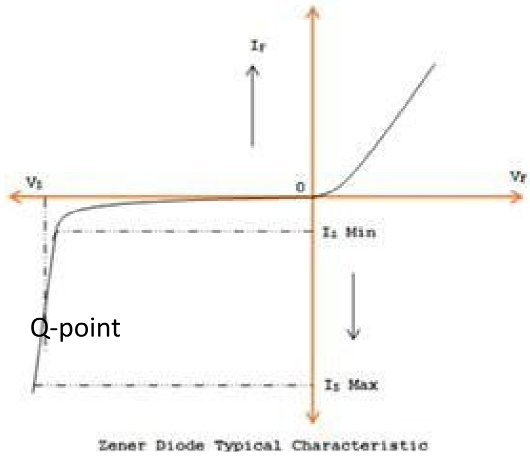



**Fig. 7-6**

## 1. $V_i, R_L$ Fixed

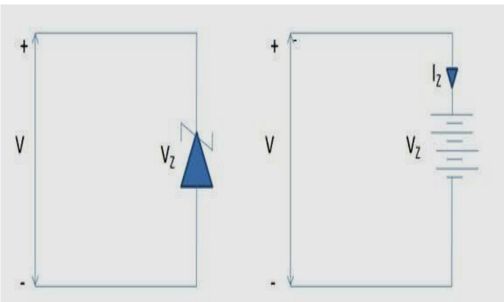



**Fig. 7-7a: "on state"**

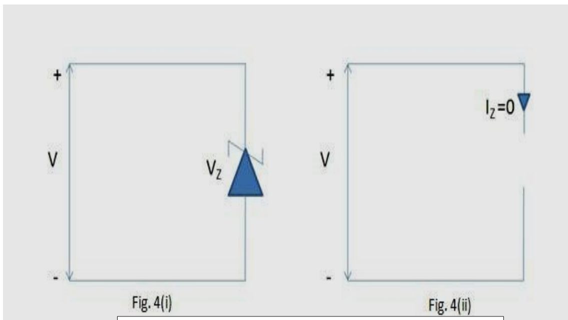



**Fig. 7-7b: "off state"**

The simplest of Zener diode regulator networks appears in Fig. 7-8 . The applied dc voltage is fixed, as is the load resistor.

If $V \geq V_Z$ the Zener diode is on.

If, $V < V_Z$ the Zener diode is off.

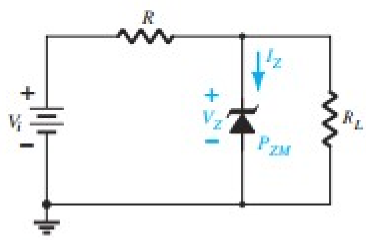
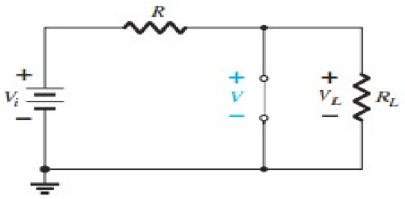



**Fig. 7-8**

**At off state:**

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

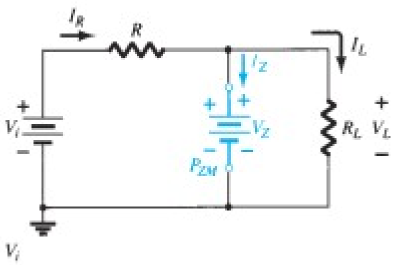



## At on state:

$$V_L = V_Z$$

$$I_R = I_Z + I_L$$

$$I_Z = I_R - I_L \quad , \quad I_L = \frac{V_L}{R_L} \quad \& \quad I_R = \frac{V_R}{R} = \frac{V_i - V_Z}{R}$$




## Example 7-2:

(a) For the Zener diode network of Fig.7-9, determine $V_L$ , $V_R$ , $I_Z$ , and $P_Z$

(b) Repeat part (a) with $R_L$ = 3 k

## Solution:

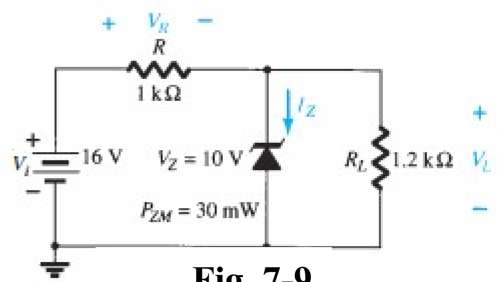
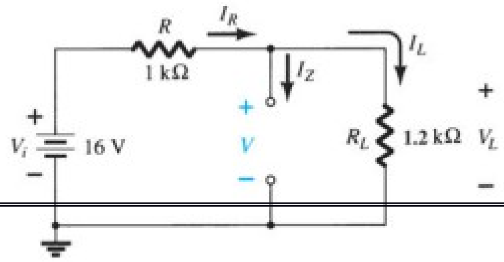



**Fig. 7-9**

(a)

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

$$V_L = \frac{16\,V \times 1.2\,K\Omega}{1\,k\Omega + 1.2\,K\Omega} = 8.73\,V$$



$V_L = V = 8.73\,V$

$I_Z = 0$

$V_R = V_i - V_L = 16 - 8.73 = 7.72\,V$

$P_Z = V_Z . I_Z = 0\,W$

(b)

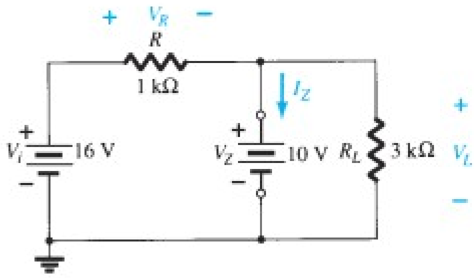
$$V = \frac{V_i R_l}{R_L + R} = \frac{16 \times 3}{1 + 3} = 12\,V$$

Since V=12V is greater than $V_Z = 10$, the diagram is in the "on state". Then :

$V_L = V_Z = 10\,V$

$V_R = V_i - V_Z = 16 - 10 = 6\,V$

$$I_L = \frac{V_Z}{R_L} = \frac{10}{3} = 3.33\,mA$$



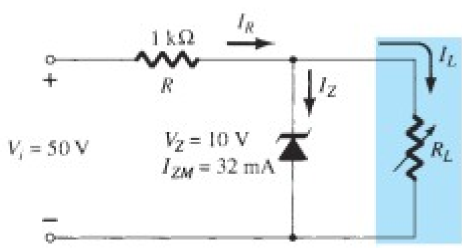

$$I_R = \frac{V_R}{R} = \frac{6}{1} = 6\,MA$$

$I_Z = I_R - I_L = 6\,mA - 3.33\,mA = 2.67\,mA$

$P_Z = V_Z . I_Z = 10 \times 2.67 = 26.7\,mW$

## 2. Fixed *Vi*, Variable *RL*

To determine the minimum load resistance of Fig. 7-10 that will turn the Zener diode on, simply calculate the value of $R_L$ that will result in a load voltage




$V_L = V_Z$

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

Then

$R_{L\,min}$

**Fig. 7-10**

Any load resistance value greater than the $R_{L\,min}$ that the Zener diode is in the “on” state and the diode can be replaced by its $V_Z$ source equivalent.

$I_{L\,max}$ $R_{L\,min}$

The diode is in the "on state & $V_R$ is fixed ( $V_R = V_i - V_Z$ ) and $I_R$ remains fixed at $I_R = \frac{V_R}{R}$ .

Then

$I_Z = I_R - I_L$

Minimum $I_Z$ when $I_L$ maximum , $I_R$ constant .

Maximum $I_Z$ when $I_L$ minimum , $I_R$ constant .

$I_{L(min)} = I_R - I_{Z(max)}$

$R_{L(min)} = \frac{V_Z}{I_{L(min)}}$

## Example 7-3:

(a) For the network of Fig. 7-11, determine the range of $R_L$ and $I_L$ that will result in $V_{RL}$ being maintained at 10 V.

(b) Determine the maximum wattage rating of the diode.

**solution:**

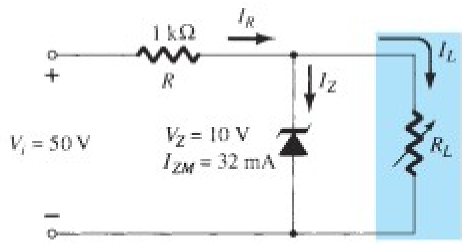



**Fig. 7-11**

a) $$R_{L(min)} = \frac{V_Z R}{V_i - V_Z} = \frac{10 \times 1}{(50 - 10)} = 250\,\Omega$$

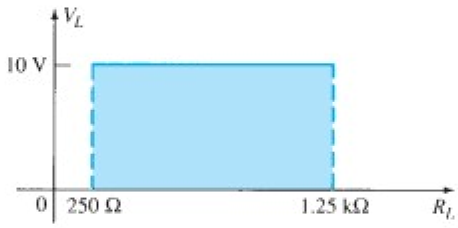
$$V_R = V_i - V_Z = 50 - 10 = 40\,V$$

$$I_R = \frac{V_R}{R} = \frac{40}{1} = 40\,mA$$ .

$$I_{L(min)} = I_R - I_{Z(max)} = 40 - 32 = 8\,mA$$

$$R_{L(max)} = \frac{V_Z}{I_{L(min)}} = \frac{10}{8} = 1.25\,K\Omega$$

A plot of $V_L$ versus $R_L$ appears in Fig.7-12



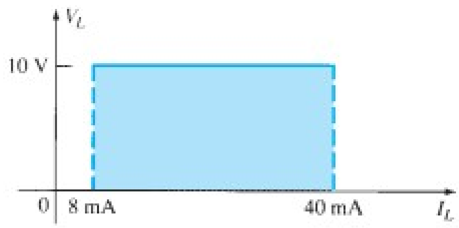




**Fig. 7-12**

b)

$$P_{Z(max)} = V_Z . I_{Z(max)} = 10\,V \times 32\,mA = 320\,mW.$$

## 3. Fixed *RL*, Variable *Vi*

For fixed values of $R_L$ in Fig. 7-13 , the voltage $V_i$ must be sufficiently large to turn the
Zener diode on. The minimum turn-on voltage $V_i = V_i$

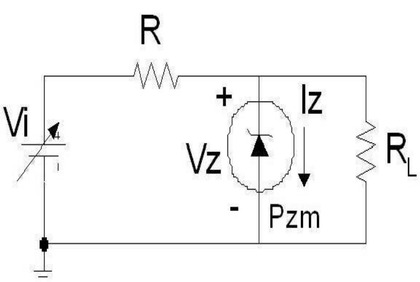



Fig. 7-13

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

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

The maximum value of $V_i$ is limited by the maximum Zener current $I_{Z(max)}$ . Since $I_{Z(max)} = I_R - I_L$

$$I_{R(max)} = I_{Z(max)} + I_L$$

Since $I_L$ is fixed at $\frac{V_Z}{R_L}$ and $I_{Z(max)}$ is the maximum value of $I_Z$ , the maximum $V_i$ is
defined by:

$$V_{i(max)} = V_{R(max)} + V_Z$$

$$V_{i(max)} = I_{R(max)} * R + V_Z$$

## Example7-4:

Determine the range of values of $V_i$ that will maintain the Zener diode of Fig. 7-14 in the "on" state.

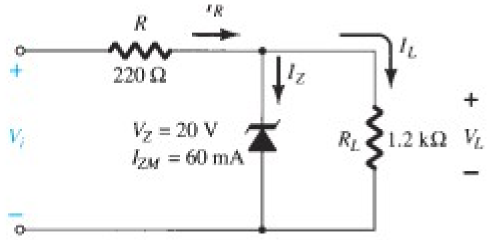



**Fig. 7-14**

**Solution:**

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

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

$$I_{R(max)} = I_{Z(max)} + I_L = 6\,mA + 16.67\,mA$$

$$I_{R(max)} = 76.67\,mA$$

$$V_{i(max)} = I_{R(max)} R + V_Z$$

$$V_{i(max)} = (76.67\,mA)(0.22\,K\Omega) + 20\,V$$

$$V_{i(max)} = 36.87\,V$$

A plot of $V_L$ versus $V_i$ is provided in Fig. 7-15 .

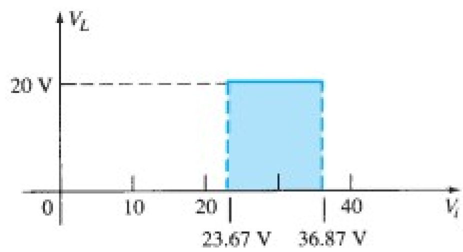



**Fig. 7-15**

# Rectifiers

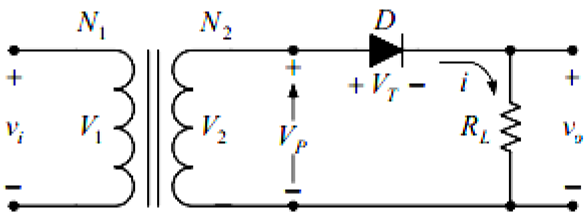
It has convert ac waveform to dc signal. The process of conversion is called rectification.

Types:

1. Half-Wave Rectifier.
2. Full-Wave Rectifier.
   a. Full-Wave Bridge Rectifier.
   b. Center-Tapped Transformer.

Half Wave Rectifier:

It provides rectification for half wave




If $V_i \gg V_r$ (diode offset voltage), then linear approximation of diode characteristics is used.

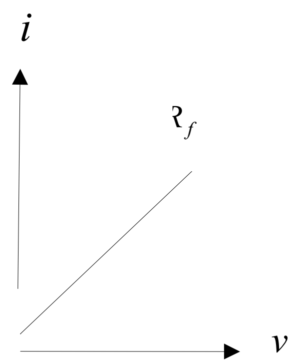
$V_i = V_m \sin \omega t = V_m sin\alpha$

$i = I_m sin\omega t = I_m sin\alpha$

$i = I_m sin\alpha$ , $when\ 0 \le \alpha \le \pi$

$i = 0$, $when\ \pi \le \alpha \le 2\pi$

$$I_m = \frac{V_m}{R_f + R_L}$$




$I_{dc} = average\ value$

=area under the curve

=average current passing through $R_L$

$P_o = average\ output\ power$

$$P_o = V_{dc} = \frac{I_m}{\pi} R_L . \frac{I_m}{\pi} = \left(\frac{I_m}{\pi}\right)^2 . R_L$$

Efficiency of rectification $\eta = \frac{P_o}{P_i} = \frac{\left(\frac{I_m}{\pi}\right)^2 . R_L}{I_{rms}}$

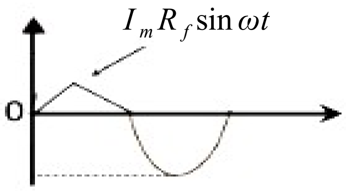
$$\eta = \frac{\left(\frac{I_m}{\pi}\right)^2 . R_L}{\frac{I_m}{2}}$$

For $R_L \gg R_f, \; R_f = 0, \eta = \frac{4}{\pi^2} \Rightarrow \eta_{percent} = \frac{4}{\pi^2} \times 100 = 40.6$

Peak inverse voltage (PIV):

For every diode, these is a maximum voltage to which it can be subjected. It called peak inverse voltage (PIV).

$PIV \geq V_m$



## Regulation:

The regulator is defined in percentage.

$$Regulation = \frac{V_{No\,load} - V_{Full\,load}}{V_{Full\,load}} \times 100$$

- At no load $V_{dc} = \frac{V_m}{\pi}$ .
- At full load $V_{dc} = -I_{dc}.R_f + \frac{V_m}{\pi} = \frac{V_m}{\pi} - I_{dc}.R_f$

## Example 7-5 :

Find the regulation for the following circuit $V_{No\,load} = 12\,V$ .

**Solution:**

$V_{Full\,load} = 12 - 0.1 * 20$

$= V_{dc} - I_{dc}.R_f$

= 12-2

=10V

$$\%Req = \frac{12-10}{10} \times 100 = 20$$

## Ripple factor (r) :

It is a measure of fluctu ability component (ac component) and is definded as:

$$r = \frac{rms\ value\ of\ ac\ wave}{average\ value\ of\ wave} = \frac{I_{rms}}{I_{dc}} = \frac{V_{rms}}{V_{dc}}$$

Where $I_{rms}$ and $V_{rms}$ denote the rms value of ac component in current and voltage respectively.

$i' = i - I_{dc}$

$i - I_{dc}$

$\frac{1}{2\pi}\int_0^{2\pi}$

$\therefore I_{rms}$

$(i^2 - 2I_{dc}\,i + I_{dc}^2)\,d\alpha$

$\frac{1}{2\pi}\int_0^{2\pi}$

$= (I_{rms}^2 - I_{dc}^2)^{\frac{1}{2}}$

$$\therefore r = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

For half wave rectifier (HWR)

$$\frac{I_{rms}}{I_{dc}} = \frac{I_m/2}{I_m/\pi} = \frac{\pi}{2} = 1.57$$

$$\therefore r = \sqrt{(1.57)^2 - 1} = 1.21$$

The result indicates that the rms ripple factor voltage exceeds the dc output voltage in HWR. It is poor circuit for converting ac to dc

Note:

$min$

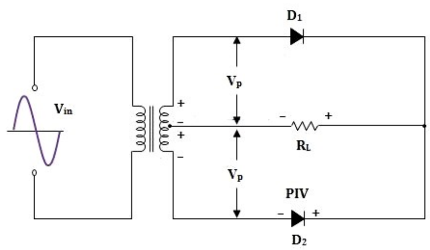
$L$

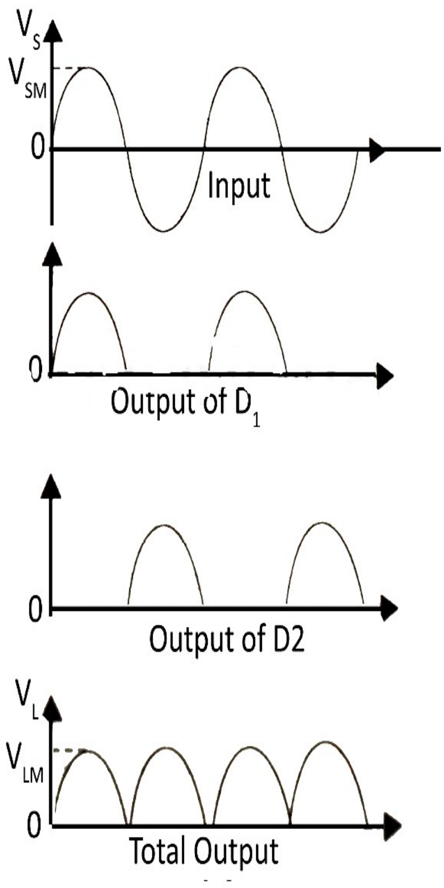
$R$

$V_R = 0 \Rightarrow V_{NL} - V_{FL} \approx 0$

## Full Wave Rectifier (FWR):

With center-tap transformer




single-phase center-tap output wave

$$I_{dc} = \frac{2I_m}{\pi}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

$$V_{dc} = \frac{2I_m}{\pi}.R_L = I_{dc}.R_L$$

$$P_o = I_{dc}^2.R_L = \left(\frac{2I_m}{\pi}\right)^2.R_L$$

$$P_i = I_{rms}^2.\left(R_f + R_L\right)$$

$$\eta = \frac{P_o}{P_i} = 81.2$$ twice that for HWR

Current ratio

$$\frac{I_{rms}}{I_{dc}} = \frac{I_m/\sqrt{2}}{2I_m/\pi} = 1.11$$

Ripple factor $r = \sqrt{(1.11)^2 - 1} = 0.482$

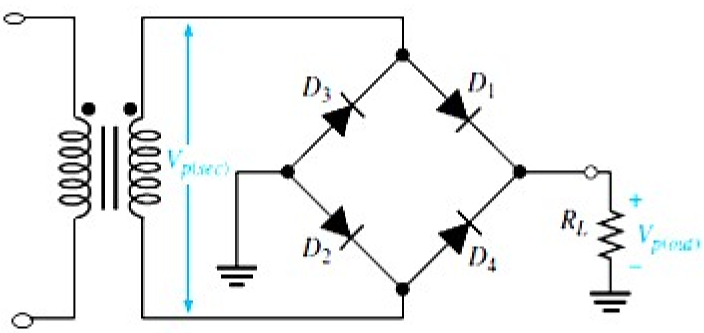
So ripple factor has dropped from 1.21 in HWR to 0.482 in FWR.

## PIV for FWR

As it is clear from the circuit that when diode is conducting, the voltage across the other is $2V_m$ , $PIV \geq 2V_m$ .

FWR with two diodes needs a center tapped transformer.

## Bridge Rectifier (Full-Wave):




$$V_D = \frac{2V_P}{\pi}$$

$$f_{out} = 2f_{in}$$

$$PIV = V$$

### Advantages:

1- It needs no center tapped transformer.
2- All four diodes are mounted on a single package.
3- $PIV \geq 2V_m$ for each diode.
4- This circuit is very commonly used.

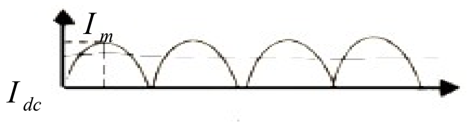
### Operation:

- For positive half, $D_1$ & $D_3$ conduct
- For negative half , $D_2$ & $D_4$ conduct

Current in $R_L$ is in the same direction during both positive and negative half cycles.

$$I_{dc} = \frac{2I_m}{\pi}$$

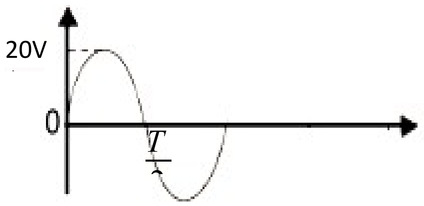
$$V_{dc} = \frac{2V_m}{\pi} = 0.636V_m$$

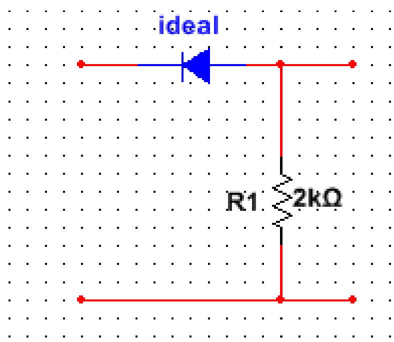



## Example 7-6:

a- Sketch the output $V_o$ and determine the dc level of the output for the network of Fig.

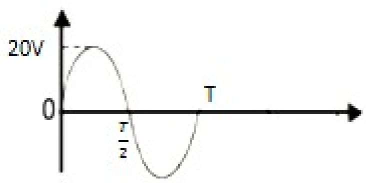
b- Repeat part(a) if the diode is replaced by a silicon diode.

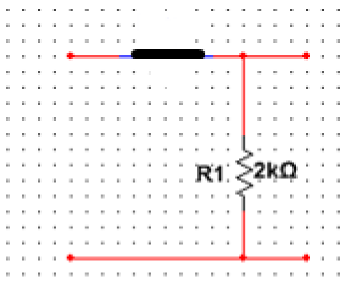


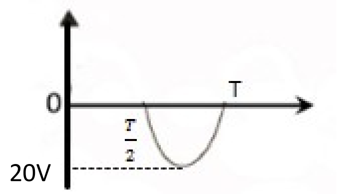




**Solution:**

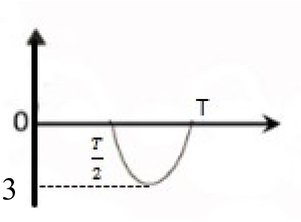
a- $$V_{dc} = \frac{I_m R_l}{\pi} = -0.318V_m = -0.318(20) = -6.36V$$



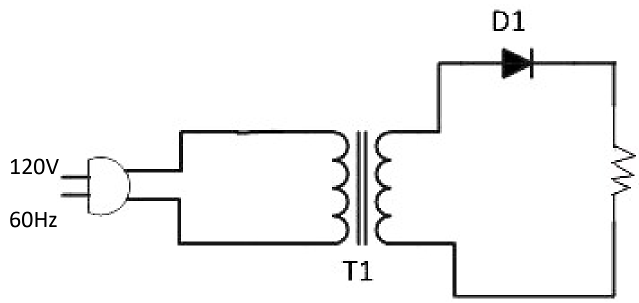

b- $$V_{dc} = -0.318(V_m - 0.7) = -0.318(19.3) = -6.14V$$




$20 - 0.7 = 19.3$

## Example7-7:

For the circuit shown below find $V_{dc}$ & PIV.




**Solution:**

$$V_P = \sqrt{2}\,V_{rms} = \sqrt{2} \times 120 = 170\,V$$

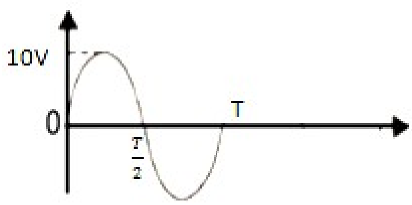
$$V_m = \frac{N_1}{N_2} V_P = \frac{1}{4} * 170 = 42.5\,V$$

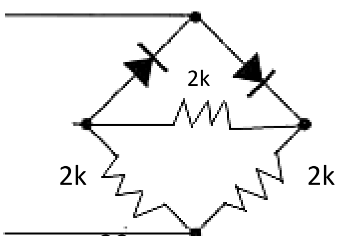
$$V_{dc} = \frac{V_m}{\pi} = \frac{42.5}{\pi} = 13.5\,V$$

$$PIV = V_m = 42.5\,V$$

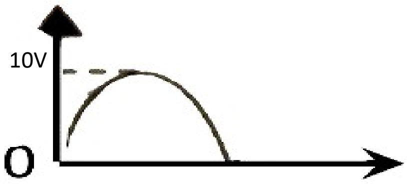
## Example 7-8:

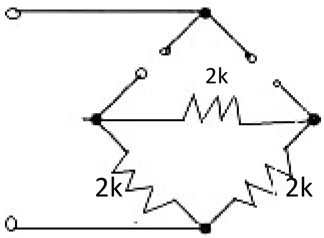
Determine the output waveform for the network of Fig.7- . and calculate the output dc level and the required PIV of each ideal diode.

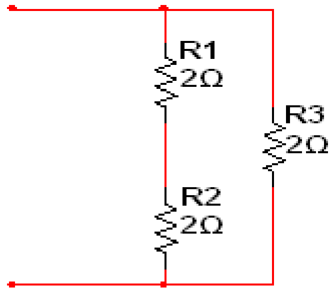


## Solution:



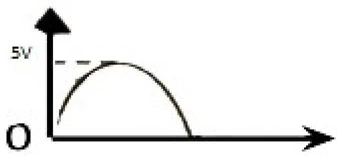



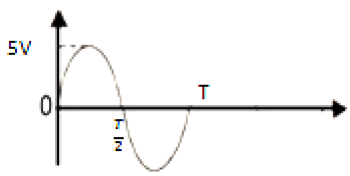




*max*
*max*
*i*
*o*
*V*

$$V_{dc} = \frac{2V_m}{\pi} = 0.636(5) = 3.18\,V$$

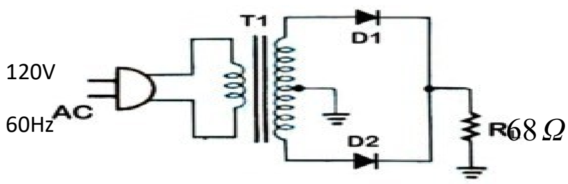
$$PIV = V_o = 5\,V$$



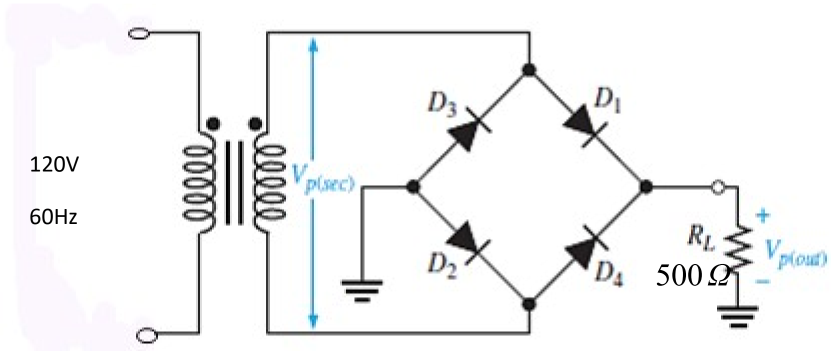

## Home Work:

1-For the circuit shown in Fig. . find $V_{dc}$ ,PIV.



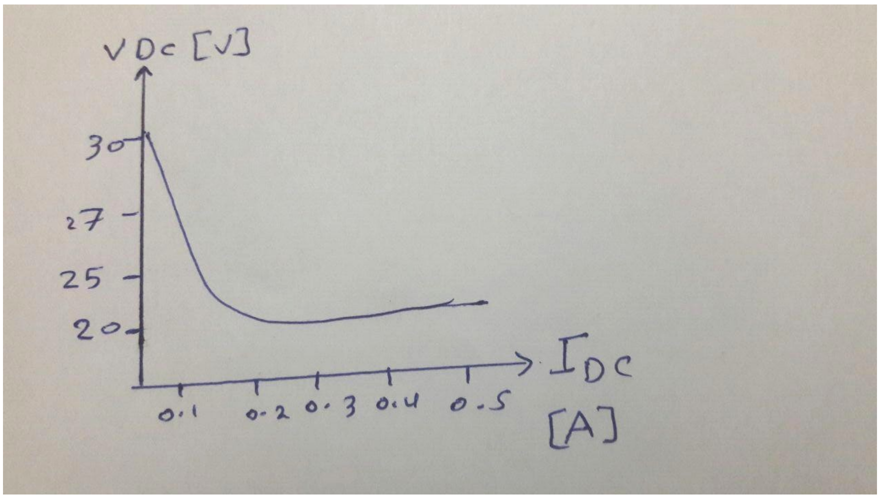

2- a- For the circuit shown in Fig. ,find $V_{dc}$ , $f_o$ , PIV

b-Repeat part (a) if the ideal diodes is replaced by silicon diodes.




**Example 7-9:**

For the power supply shown in Fig. $I_{FL} = 0.5\,A$ . find voltage regulation and minimum load resistance.



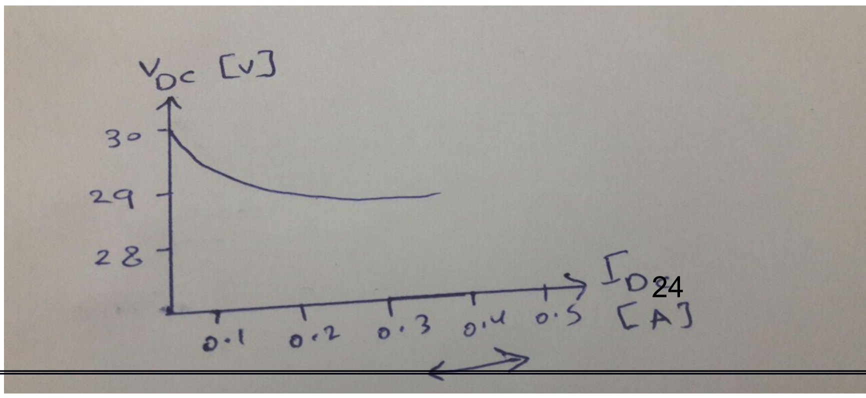

Solution:

$$V_R = \frac{30-20}{20} \times 100 = 50$$

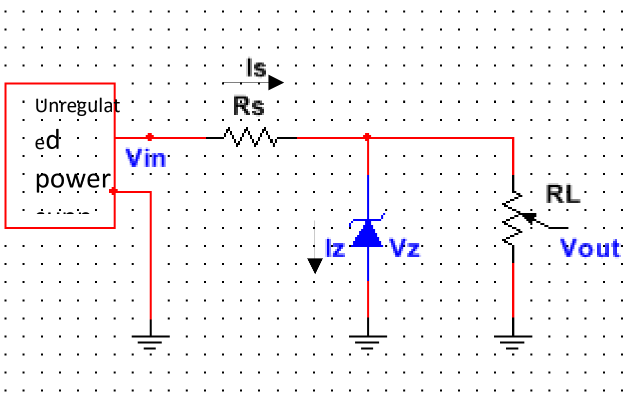
$R_{L\,min}$

**Home work**:

For the following figure. Find $V_R$, $R_{L\,min}$



## Zener Regulator:




$V_o = V_Z + I_Z . Z_Z$

$max$
$min$
$- V_o$
$max$
$L$
$i$
$V$
$s$
$R$

$max$
$s$
$R$

$R_s$: *limited resistance*

$$I_S = \frac{V_i - V_o}{R_s}$$

$$I_Z = I_S - I_L$$

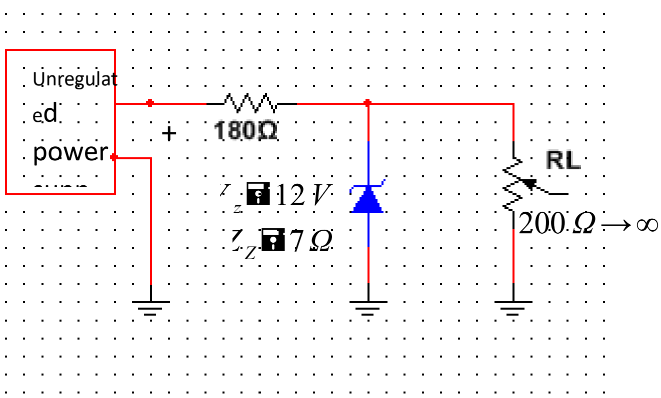
$V_o = V_Z$

$I_L = \frac{V_o}{R_l}$

Open CCT. max L
$I_Z = 0 , I_S = I_L = I$

## Example 7-10:

For the following circuit . find minimum and maximum current &




Solution:

$$I_S = \frac{V_i - V_o}{R_s} = \frac{25 - 12}{180} = 72\,mA$$

*min*

*L*

*I*

*max*

*L*

*I*

Where is $V_o$, $I_S$ constant

*min*

*Z*

*I*

*max*

*Z*

*I*

## Home work:

Zener regulator have input voltage vary from 15V to 20V and load current vary from 20mA t0 100mA. Find the limited resistor to be connected in series if the voltage $V_Z = 10\,V$.

# Zener Diode Application:

## 1. AC Voltage Regulator [Limiters or Clippers]:

Two back-to-back zeners can be used as an as regulator or a simple square-wave generator as shown in Examples 7-1 and 7-2 respectively.

### Example 7-1:

Sinusoidal ac regulator, see Fig. 70-3.

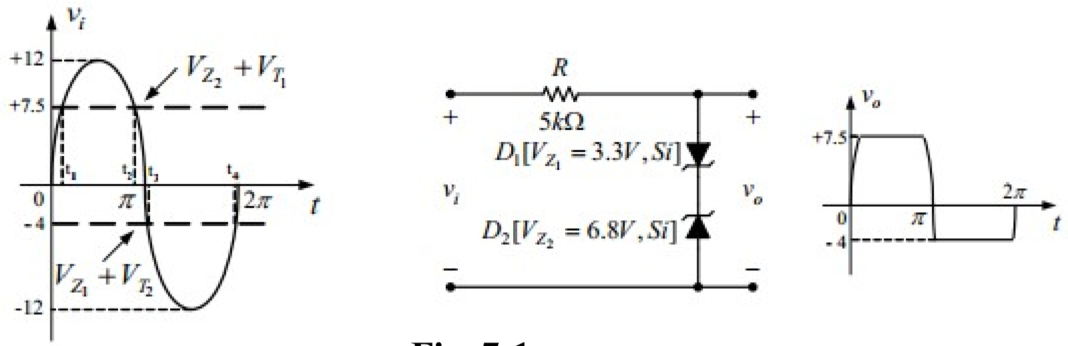



**Fig. 7-1**

For $t = 0 \rightarrow t_1 \;\&\; t_2 \rightarrow \pi : D_1 ON \;\&\; D_2 OFF \Rightarrow V_o = V_i$.

For $t = t_1 \rightarrow t_2 ; D_1 ON \;\&\; D_2 breakdown \Rightarrow V_o = V_{Z2} + V_{T1}$.

For $t = \pi \rightarrow t_3 \;\&\; t_4 \rightarrow 2\pi ; D_2 ON \;\&\; D_1 OFF \Rightarrow V_o = V_i$.

For $t = t_3 \rightarrow t_4 ; D_2 ON \;\&\; D_1 breakdown \Rightarrow V_o = V_{Z1} + V_{T2}$.

### Example 7-2:

Simple square-wave generator, see Fig. 7-4.

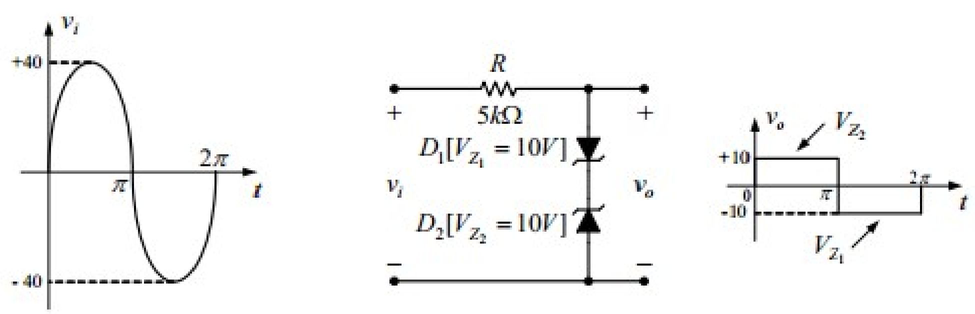



**Fig. 7-4**

## 2. DC Voltage Reference:

Two or more reference levels can be established by placing zener diodes in series as shown in Fig. 7-5. As long as $V_i$ is greater than the sum of $V_{Z1}$, $V_{Z2}$, both diodes will be in the breakdown state and the three reference voltages will be available.

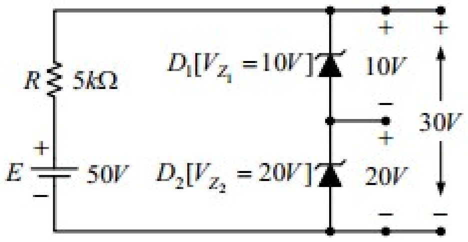



**Fig. 7-5**

## 3. DC Voltage Regulators:

a. **Fixed $R_L$ , Variable $V_i$ :**

For the regulator circuit shown in Fig.7-6;

$$I_L = \frac{V_Z}{R_L} = constant \quad (7-2a)$$

min
s
I
min
min
s
i
V

(7-2b)

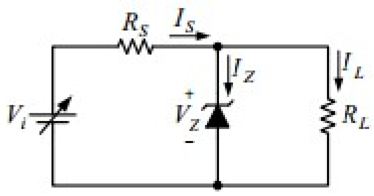



**Fig. 7-6**

$max$

$s$

$I$

$7 - 2c$

$max$

$max$

$s$

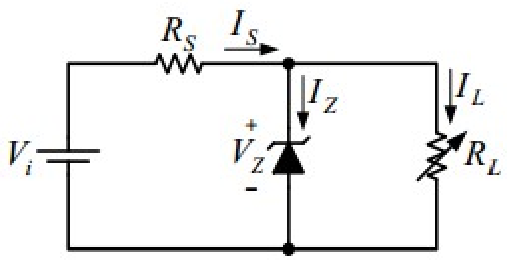
$i$

$V$

**b. Fixed** $V_i$, **Variable** $R_L$ **:**

For the regulator circuit shown in Fig. 7-7;

$$I_s = \frac{V_i - V_Z}{R_S} = constant$$




min
L
I

min
L
I

$$L\ max = \frac{V_Z}{\ }$$
R

max = $I_s - I_{ZK}$
L
I

max
L
I
$V_Z$

$R_{L\,min} =$

c. **Variable** $V_i$ **and** $R_L$:

For the regulator circuit shown in Fig.7- ;

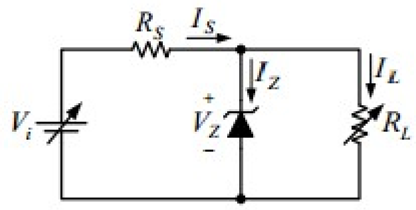
$min$

$max$
$L$
$s$
$I_{ZK}$ $I$

$min$

$min$

$-V_Z$
$i$
$V$
$s$
$I$




$max$

$L$
$I$

$max$

$min$
$L$
$s$
$I_{ZM}$ $I$

$max$

$max$

$-V_Z$
$i$
$V$
$s$
$I$

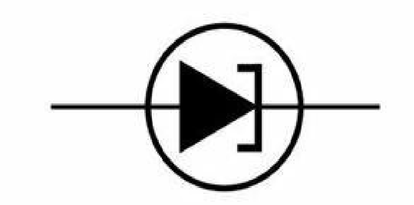
$min$

$L$
$I$

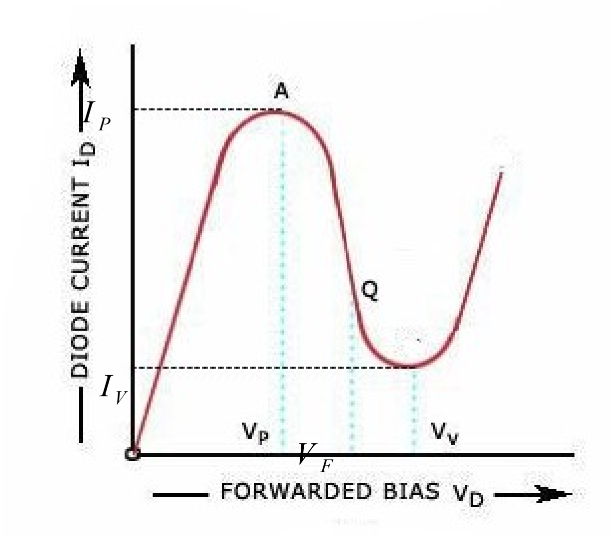
## Tunel Diode:

A p-n junction diode has an impurity concentration of about 1 part in $10^8$ , where the depletion layer width is of the order of 5micros ( $5 \times 10^{-4}$ cm).

If the connection of impurity atoms is greatly increased, say 1 part in $10^3$ , the device characteristics are completely changed as shown in Fig.7- .This kind of diode is called Tunel diode



symbol




**V-I characteristic**

$I_V -$ *valley current*

$V_V -$ *valley voltage*

$V_F -$ *peak forward voltage*

$I_P -$ *peak forward voltage*

$V_P -$ *voltage of* $I_P$

At this point

$\frac{dI}{dV}$ ■g■0

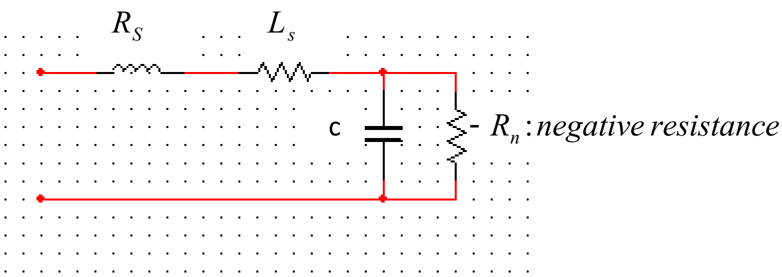
After $V_P$ ■ $\frac{dI}{dV}$, is negative

$0 < V_P \longrightarrow$ *controlled by zener breakdown.*

$V_P < V_V \longrightarrow$ *tuneling phenomenon.*

$V_V < V_P \longrightarrow$ *normal operation of p− n junction diode.*

Equivalent circuit:




$R_S$ : series ohmic resistance .

$L_S$ : series inductance.

C : junction capacitance.

$-R_n$ : has a minimum at the point of inflection between $I_P$ and $V_V$ .

Typical values at $I_P \approx 10\,mA$, $L_s \approx 5\,nH$, $-R_n \approx -30\,\Omega$, $c \approx 20\,PF$, $R_S \approx 1\,\Omega$.

Applications:

1- Negative resistance device.
2- High speed switch in logic circuit.
3- Low voltage rectifiers at reverse bias.
4- High frequency (micro wave) oscillator.

Advantage:

1- Low cost.
2- Low noise.
3- Simplicity
4- High speed.
5- Environmental immunity.
6- Low power.

Disadvantages:

1- Low output voltage swing.
2- No isolation between input and output.

Notes:

$I_P$ : determined by impurity concentration (the resistivity) & the junction area.

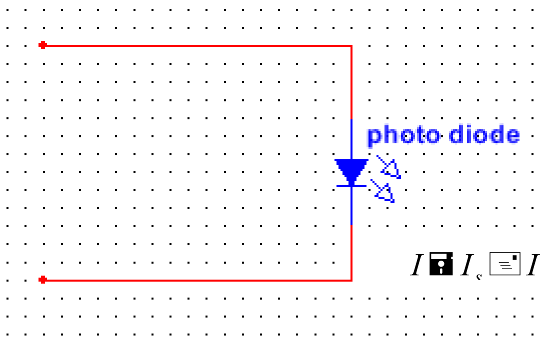
$V_P, I_P -$ not very temp sensitive.

Tunel diode – excellent conductor in reverse direction.

| | Ge | GaAs | si |
|---|---|---|---|
| $I_P / V_P$ | 8 | 15 | 3.5 |
| $V_P$, V | 0.055 | 0.15 | 0.065 |
| $V_V, V$ | 0.35 | 0.50 | 0.42 |
| $V_F, V$ | 0.50 | 1.10 | 0.70 |

Typical tunel diodes parameter.

## Photo Electric Semiconductor Diode:




$I = I_s - I_o$

Light sensors (photo diode)

$I = I_S - I_o(1 - e^{V/\eta V_T})$

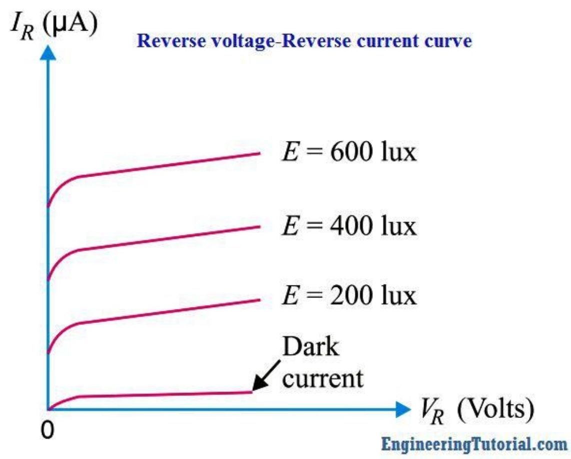
$I_o$ : reverse saturation current.

$I_S$ : short circuit current and is proportional to light intensity.

- It is a light sensitive diode.
- Light controls the operation of diode.
- It convert light into electric current.
- When light (photons) strike the semiconductor material, electrons and holes are generated.

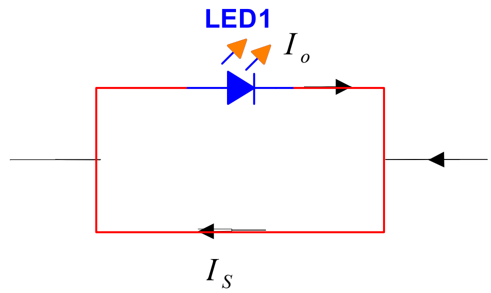
E: light illumination unit in foot-candle

- Curve except for dark current do not pass through the origin
- Slope of curves for voltage greater then few volts corresponding to dynamic

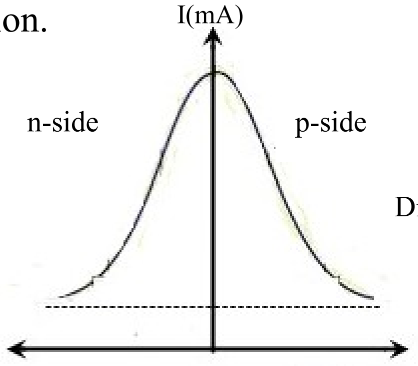


resistance of the order of few $\mu\Omega$ to hundreds of $\mu\Omega$ .

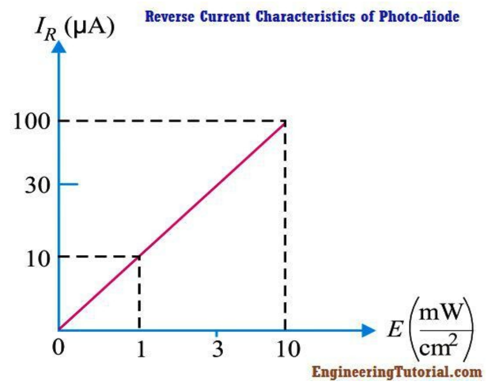
## Circuit Model:




(sensitivity of a semiconductor photodiode as a function of a the light spot from the junction.




Distance from junction in mm




Specification of a typical photo diode.

- Dark current= $2\ \mu A$ .
- Temp coefficient , $I_o$ double every $10\ ^\circ C$ .
- Small size (tenth of an inch).
- Characteristic of drift with age.
- Frequency response $\approx 1\ \mu Hz$ .

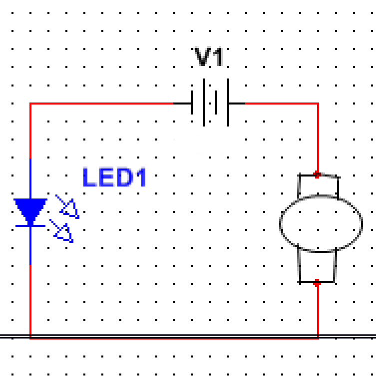
$I_R \propto mE$ , m=slope.

## Application:

1- Speed control of a very small motor.

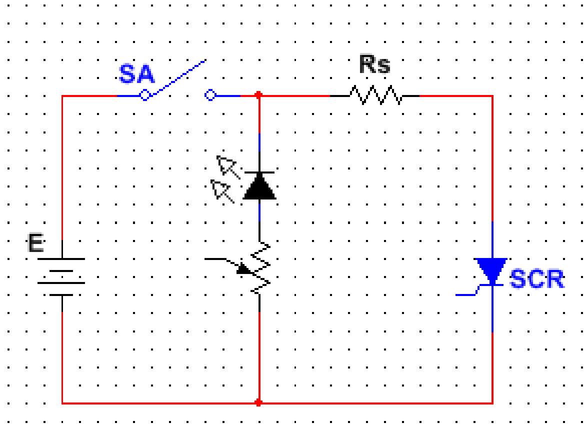
$I \propto f(light, V)$ , if V is constant.

$I \propto f(photo\ light)$



M

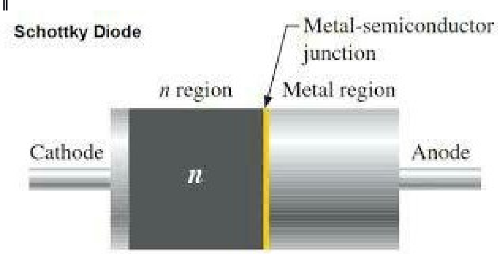
2- Photo diode as a control element .
R is for sensitivity adjustment



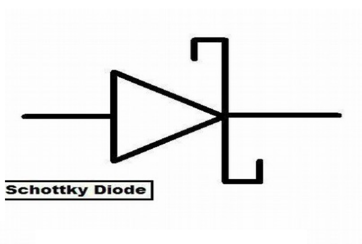

## Photo diode:

Is a reverse-biased silicon or germanium pn junction in which reverse current increase when the junction is exposed to light.

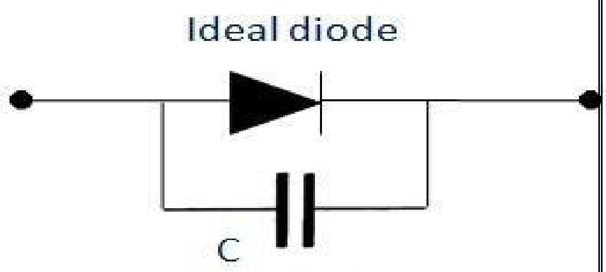
## Shottky Diodes:




schottky

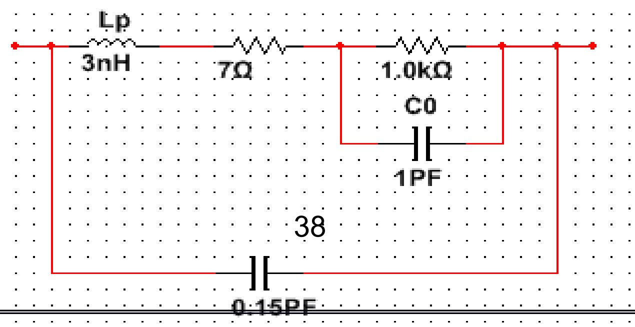



symbol




Approximate equivalent circuit

- This metal is cold or silver or platinum
- The equivalent circuit for the schottky diode with typical values appear in by below.



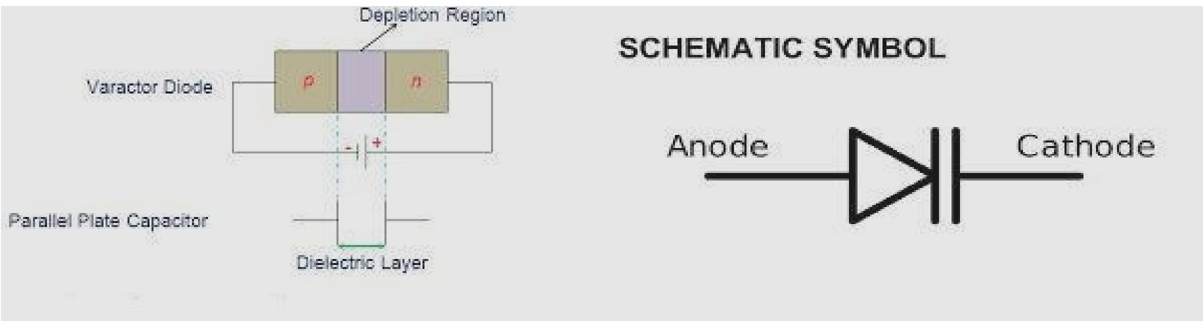
- Schottky diodes are effective at frequency approaching 20GHz.

Applications:

1. Digital electronics
2. Integral circuit (TTL schottky)

## Varactor Diode:

A junction diode which acts as variable capacitor under changing reverse bias is known a varactor diode .




For normal operation avaractor diode is always reverse biased. The capacitance of varactor diode is found as ,

$$C_T = \varepsilon \frac{A}{W_d}$$

Where :

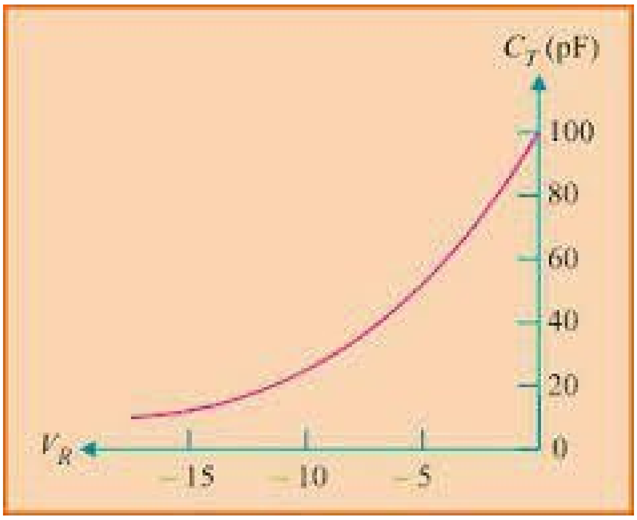
$C_T$ : *total capacitance of the junction .*

$\varepsilon$ : *ppermittivity of the semiconductor material .*

$A$ : cr osssectional area of the junction.

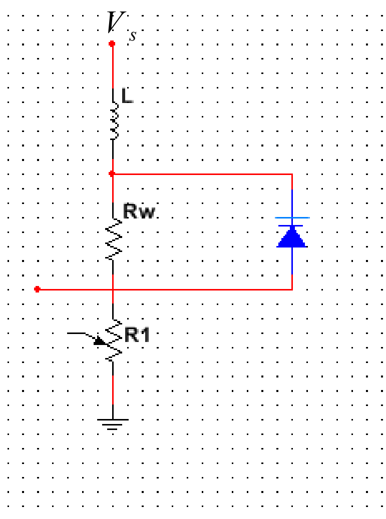
$W_d$ : width of the depletion layer.

When reverse voltage across a varactor diode is increased , the width $W_d$ of the depletion layer increases. Therefore, the total junction capacitance $C_T$ of the junction decreases.




## Application of Varactor Diode:

For normal operation, a varactor diode is always operated under reverse bias. In fact this condition is met in the circuit shown. The resistance $R_W$ in the circuit is the winding resistance of the inductor. This winding resistance is in series with the potentiometer $R_1$ . The $R_1$ and $R_W$ term a voltage divider that is used to determine the amount of reverse bias across the varactor diode $D_1$ and therefore its capacitance. By adjusting the setting of $R_1$ we can vary the diode capacitance. This in tune varies the resonant frequency of the LC circuit.



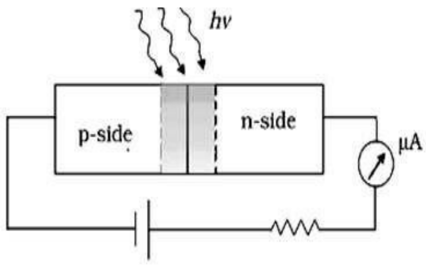

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

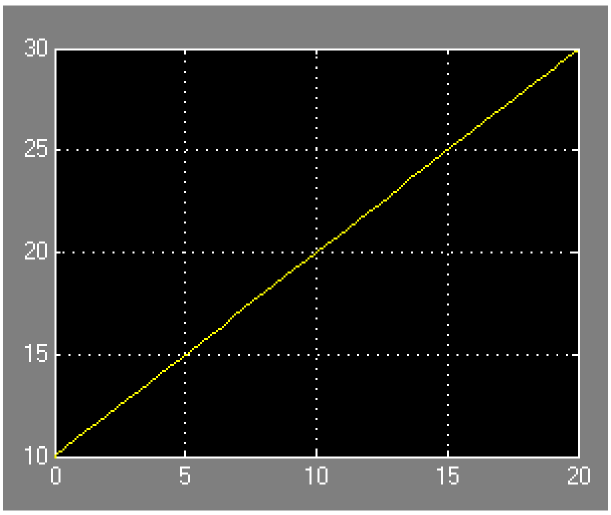
If the a mount of varactor reverse bias is decreased. The value of C of the varactor increases. The increases in C will cause the resonant frequency of the circuit to decrease and vice-versa.

## Light Emitting Diode (LED)

A light eitting diode is a diode that gives off visible light when forward biased.


LED is forward biased, the electrons from the n-type material cross the pn junction and recombine with holes in the p-type material. Recall that these electrons are in the conduction band and at a higher energy level than the holes in the valence band. When recombination takes place, the recombining electrons, release energy in the form of heat and light. In germanium and silicon diodes, almost the entire energy is given up in the form of heat and emitted light is insignificant. However in materials like gallium arsenide, the number of photons of light energy is sufficient to produce quite intense visible light.

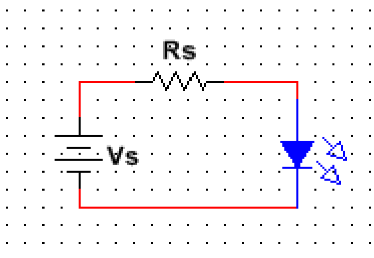



### LED voltage and current:

$$V_{R_s} = V_S - V_D$$

$$I_F = \frac{V_S - V_D}{R_s}$$



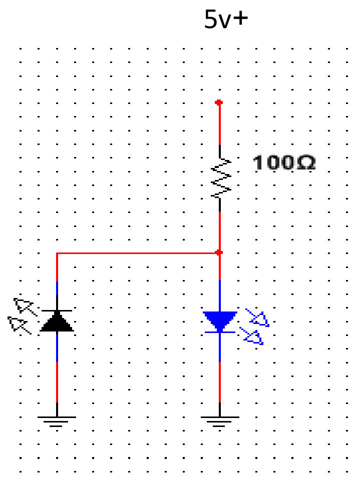
## Advantages of LED:

The light emitting diode(LED) is a soild-state light source

1- low voltage
2- longer life(more than 20 years)
3- fast ON-OFF switching

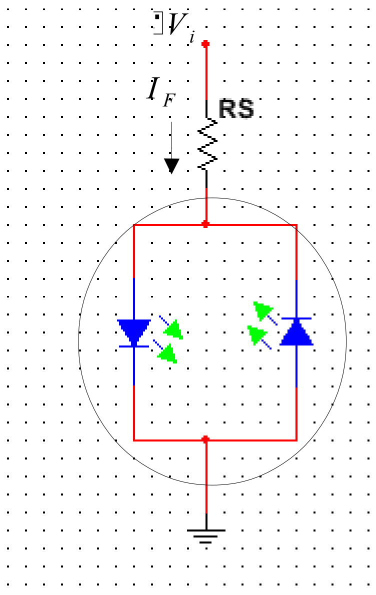
## protecting LED against reverse bias:

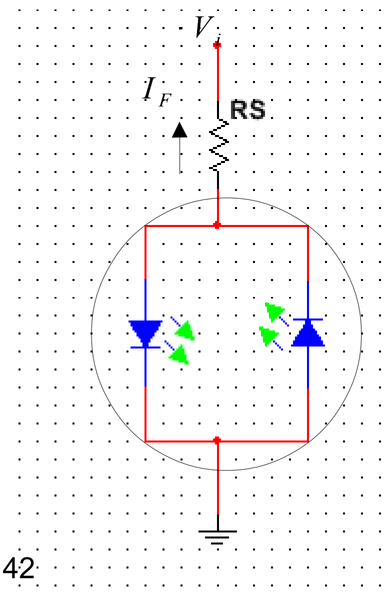
one way to protect a LED is to connect a rectifier diode in parallel with LED as shown. If reverse voltage greater than the reverse voltage greater than the reverse voltage rating of LED is a accidentally applied. The rectifier diode will be turned on. This protects the LED from damage.




## Multicolor LEDS:

A LED that emits one color when forward biased and another color when reverse biased is called a Multicolor LED.

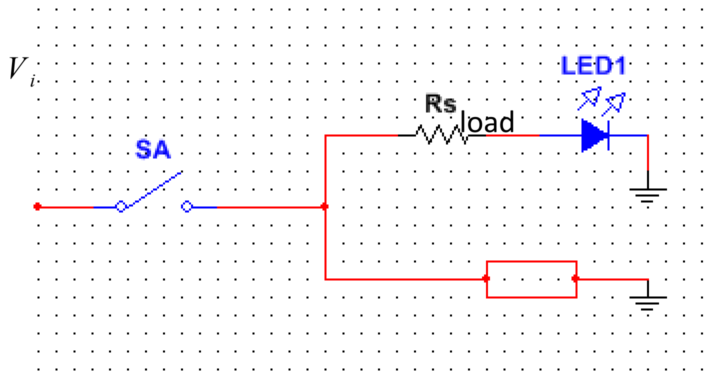


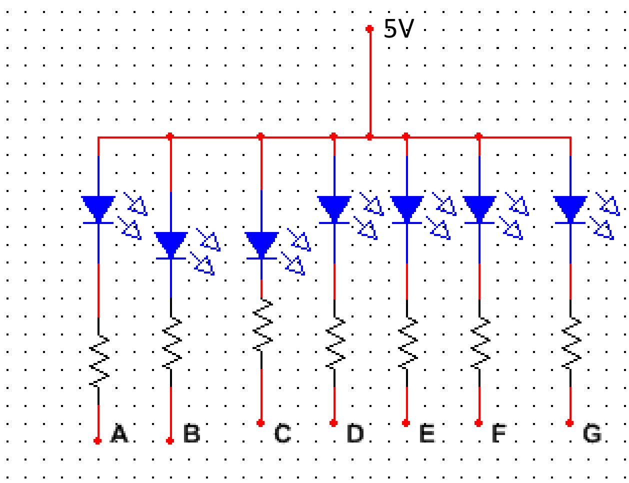



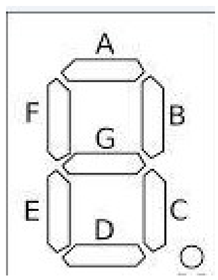
Multicolor LEDs are typically red when biased in one direction and green when biased in the other. If a multicolor LED is switched fast enough between two polarities, the LED will produce a third color. A red\ green will produce yellow.

## Applications of LEDs:

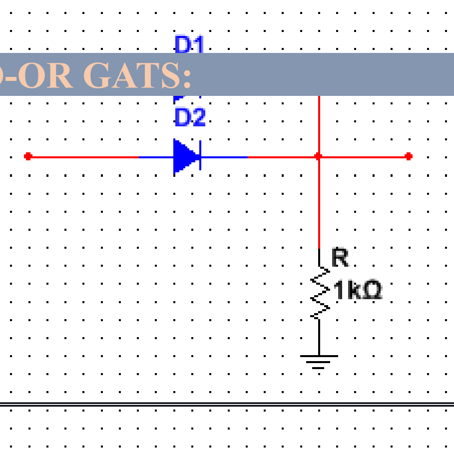
1- As a power indicator
2- Seven-segment display

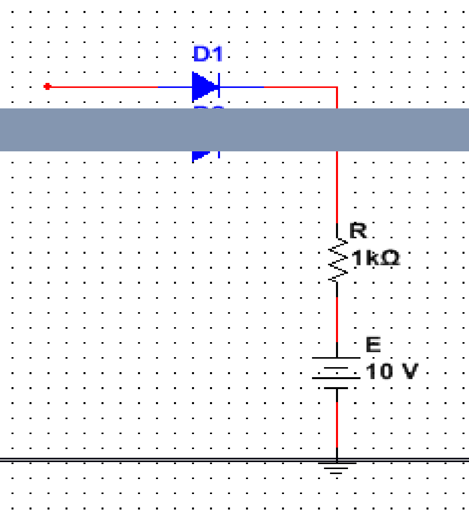


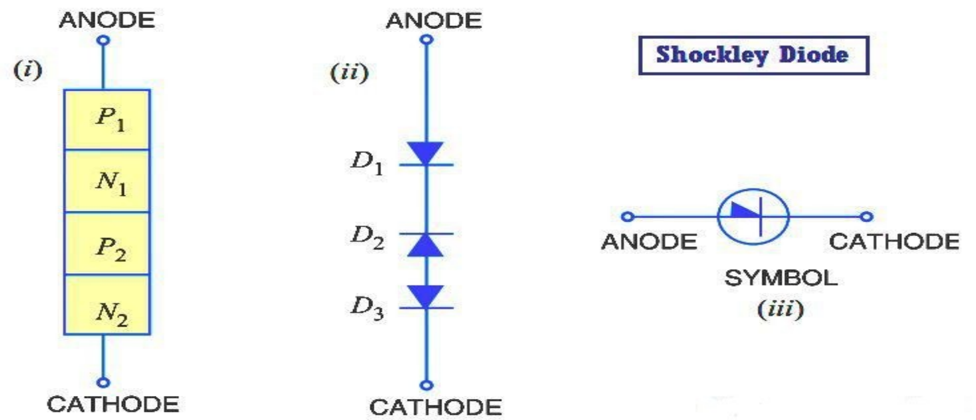

## AND-OR GATS:



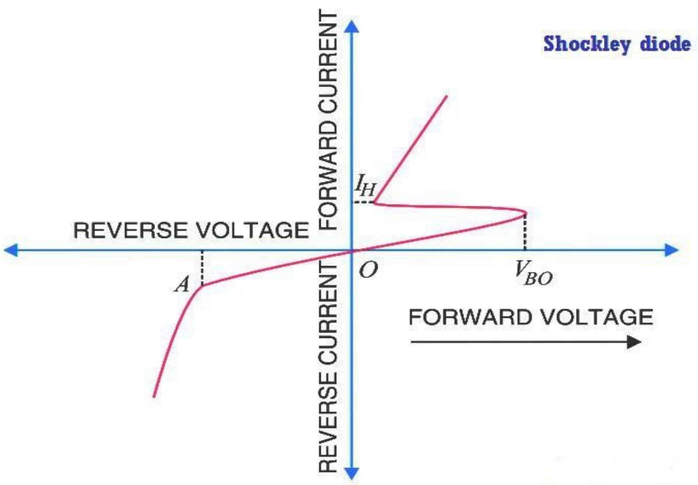



## Shockley diode:

Shockley diode is a PNPN device having two terminals as shown in Fig.



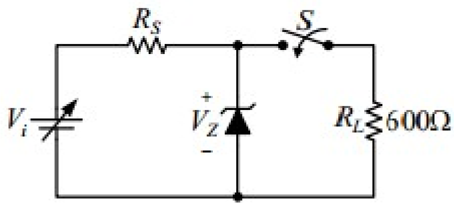

This device acts as a switch and consists of four alternate p-type and n-type layers in single crystal.



Forward $D_1 \& D_3$ but $D_2$ reverse biased to $V \geq V_{B0}$ then $D_2$ in reverse breakdown. From now onwards. The shockly diode behaves as a conventional forward biased diode. At reverse $D_1 \& D_3$ in reverse & $D_2$ forward to point A breakdown $D_1 \& D_3$ .

## Example 7-3:

The reverse current in a certain 12 V, 2.4 W zener diode must be at least 5 mA to ensure that the diode remains in breakdown. The diode is to be used in the regulator circuit shown in Fig. 7-9, where $V_i$ can vary from 18 V to 24 V. Find a suitable value for $R_S$ and the minimum rated power dissipation that $R_S$ should have.




**Solution:**

$$I_{ZK} = 5\,mA,\; I_{ZM} = \frac{P_Z}{V_Z} = \frac{2.4}{12} = 200\,mA.$$

$min$
$L$
$I$

$max$
$L$
$I$

$min$
$s$
$I_{ZK} = I$

$max$
$s$
$I_{ZM} = I$

$min$
$- V_Z$
$min$
$s$
$i$
$V$
$R_{s(max)} =$

$max$
$- V_Z$
$max$
$s$
$i$
$V$
$R_{s(min)} =$

Thus, we require $60\,\Omega \leq R_s \leq 240\,\Omega$ .

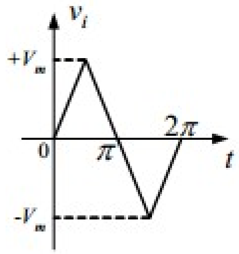
Choosing or calculating
$max$
$s$
$R_{s(min)} \cdot R$
$R_s = \sqrt{\ }$

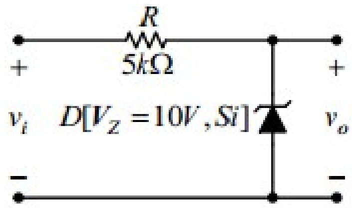
$max$
$- V_Z$
$i$
$V$
$I_{s(max)} =$

$P_{R_s} \geq I_{s(max)}^2 . R_s = (100 \times 10^{-3})^2 * 120 = 1.2\,W .$

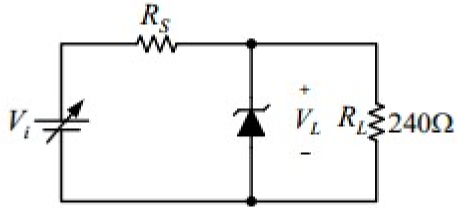
## Exercises:

1-Sketch the output ($v_o$) for the circuit of Fig. 7-10 for the input shown ($v_i$) when $|V_m|$ equal to (i) 5 V, and (ii) 15 V.

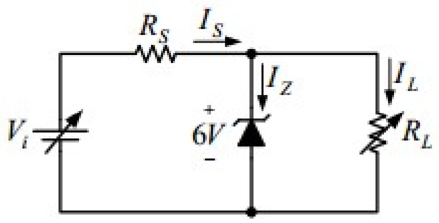



2-Design the voltage regulator circuit of Fig. 7-11 to maintain $V_L$ at 12 V across $R_L$ with $V_i$ that will vary between 16 and 20 V. That is, determine the proper value of $R_S$ and the power rating of the zener diode ($P_Z$).




3-The 6-V zener diode in Fig. 7-12 has a maximum rated power dissipated of 690 mW. Its reverse current must be at least 3 mA to keep it in breakdown. Find a suitable value for $R_S$ if $V_i$ can vary from 9 V to 12 V and $R_L$ can vary from 500 Ω to 1.2 kΩ.




4-If $R_S$ in Exercise 3 is set equal to its maximum permissible value, what is the maximum permissible value of $V_i$?

5-If $R_S$ in Exercise 3 is set equal to its minimum permissible value, what is the minimum permissible value of $R_L$?

6-If $R_S$ in Exercise 3 is set equal to 120 Ω, what is the minimum rated power dissipated that $R_S$ should have?