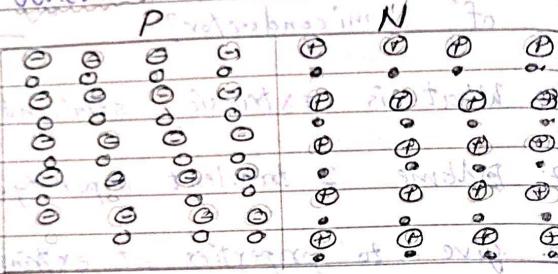


DIODES & THEIR APPLICATIONS

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(1) PN Junction with bias applied at reverse bias.



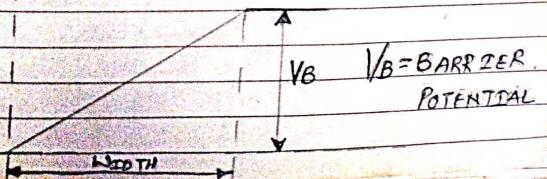
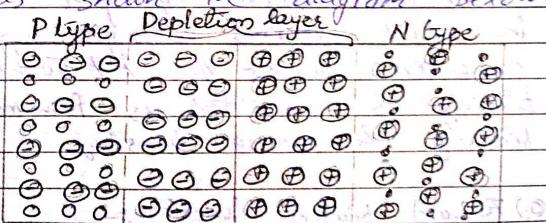
When P-type semiconductor & N-type semiconductors are joined a PN junction is formed. As soon as junction is formed due to internal repulsion & difference in concentration of e⁻ from N-region diffuse into P-region and combine into holes.

Similarly, holes from P-region diffuse into N-region and combine with the e⁻. Whenever a e⁻ combines with a hole in P-region, one positive immobile ion in the N-region is left uncovered.

Similarly, whenever a hole from P-region combines with the e⁻ of N-region, one -ve ion in P-region is left uncovered. Thus a layer of the immobile ions and -ve immobile ions is formed on the either sides of the junction.

Now the additional holes try to diffuse into the N-region are repelled by the charge of the immobile ions. Similarly, the additional e⁻ trying to diffuse into P-region are repelled by the charge of -ve immobile ions. As a result of this, further diffusion of e⁻ & holes across the junction is stopped.

The region containing immobile +ve and -ve ions is depleted of free e⁻ & free holes and hence is called depletion layer. This layer of ions acts as a barrier for further flow of e⁻ & holes across the junction as shown in diagram below.

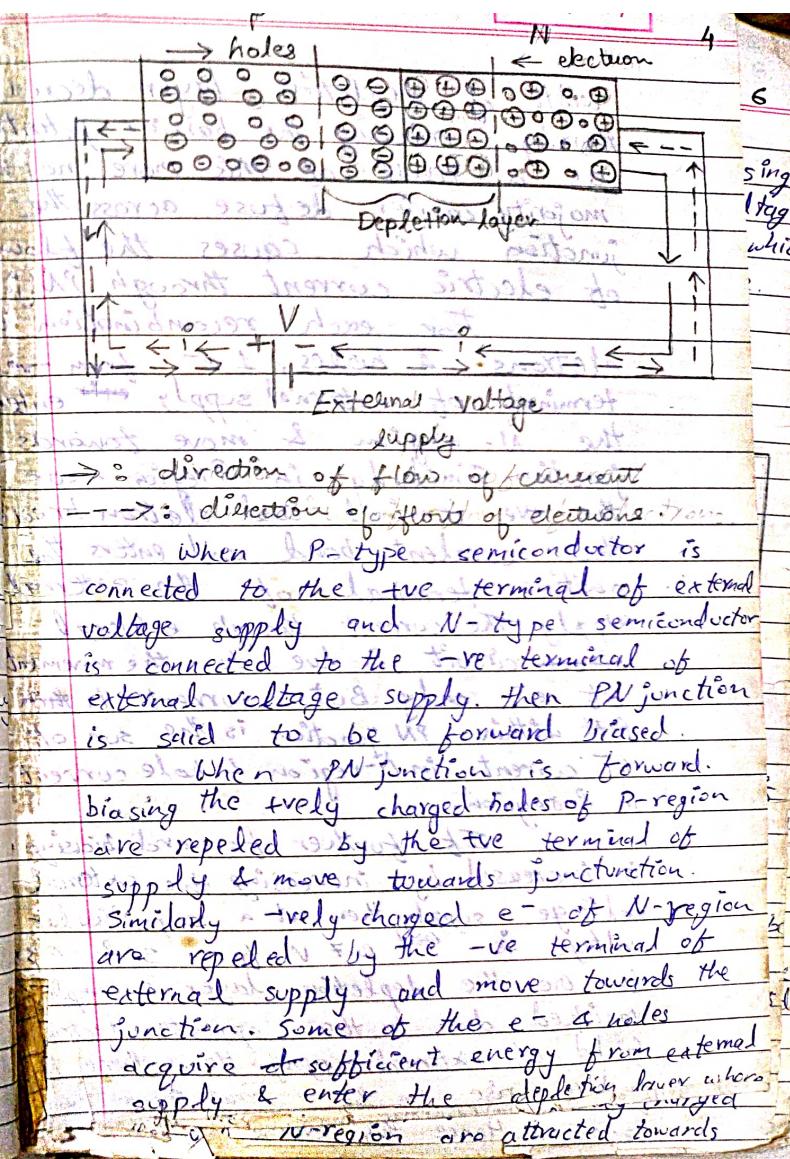


V_B = BARRIER POTENTIAL

Since the depletion layer has immobile ions which are electrically charged, they possess electric field between them called barrier potential (V_b). The difference of potential from one side of the barrier to the other side is called barrier potential difference. With no external voltage applied, the barrier potential for silicon PN junction is 0.7 V and for germanium PN junction it is 0.3 V .

(1.1) Biasing of PN Junction:
Whenever an external voltage supply is connected across PN junction it is called biased PN junction depending upon the way in which external voltage supply is connected across the PN junction biasing is classified as forward biasing & reverse biasing.

(a) Forward biased junction:-



width of depletion layer decreases thereby reducing the barrier potential as a result of this more no. majority carrier diffuse across the junction which causes the flow of electric current through PN.

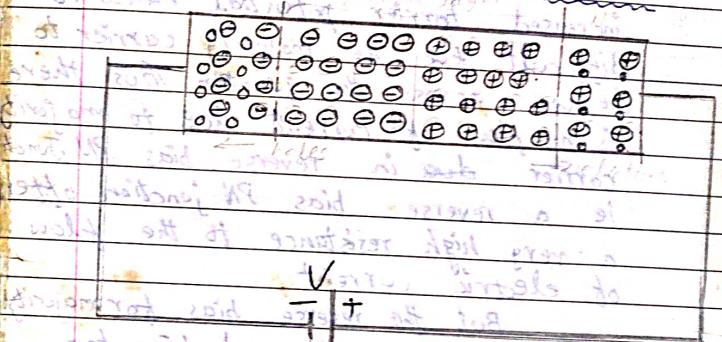
For each recombination electrons & holes, 1 e^- from - terminal of external supply enter the N-region & move toward junction. Similarly in P-region near the +ve terminal and electron breaks the covalent bond and enters the positive terminal of the external supply. The current through external circuit is due to the movement of e^- only. But current is the sum of current within PN junction is the sum of electron current in N-region & hole current in P-region.

If further forward bias is increased by increasing the external voltage supply then at a particular voltage i.e. ~~at~~ 0.7 V for Si &

for Ge the depletion layer is completely vanished due to the opposite electric field of external supply. Hence there sudden rise in the current. From now

onwards current goes on increasing with external supply but the voltage across junction remains constant which is 0.7 V for Si & 0.3 V for Ge.

(b) Reverse Biased PN junction:-



When a P-type semiconductor is connected to the -ve terminal of external voltage supply and N-type semiconductor is connected to the +ve terminal of PN Junction is said to be reversed bias.

When the PN Junction is in reversed bias the +ve charged holes of P-region are attracted towards the -ve terminal of voltage supply and -ve charged electrons of N-region are attracted towards

the +ve terminal of voltage supply. As a result of this the majority carriers are driven away from the junction, due to this the width of depletion layer increases which in turn increases the barriers potential. The increased barrier potential makes it difficult for the majority carrier to diffuse across the junction. Thus there is no flow of current due to majority carrier due in reverse bias PN Junction ie a reverse bias PN junction offers a very high resistance to the flow of electric current.

But the reverse bias for majority carrier acts as forward bias for minority carriers so as soon as minority carriers are generated, they are drifted away across the PN junction and hence a small amount of current flows through the reverse bias PN junction due to minority carriers. The generation of minority carriers depends upon the temperature and is independent of applied reverse voltage. Therefore the current due to movement of minority carrier remains fixed even if the reverse voltage is increased or decreased.

known as reverse saturated current. If the reverse bias is further increased to a larger value then at a particular voltage the crystal structure breaks down due to which large number of minority carriers are available and hence the current increases suddenly. The voltage at which there is a sudden rise in reverse current is known as breakdown voltage.

(i) Reverse breakdown.

There are two processes which cause the PN Junction to break down in reverse bias condition. They are :-

(A) Zener breakdown.

(A) Zener breakdown.

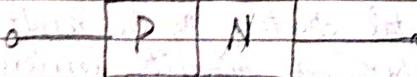
When reverse voltage is increased the depletion layer increases due to which the electric field across junction also increases. A strong electric field causes the covalent bonds to break from crystal structure. As a result of this large number of minority carriers are generated due to which a large amount of electric current flows through the junction.

(B) Avalanche breakdown

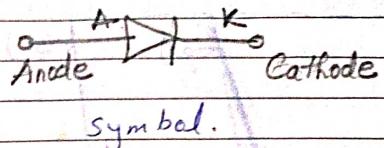
An increased reverse bias increases the amount of energy given to the minority carriers. If reverse bias is further increased, the minority carriers acquire a large amount of energy and start moving with high velocities. In the process, these carriers collide with semiconductor atoms and impart sufficient energy to bring a covalent bond. As a result of this additional minority carriers are generated. These newly generated carriers pick up the energy from applied reverse voltage and generate still more minority carriers. Due to which the reverse current increases rapidly. This cumulative process of carrier generation is known as avalanche breakdown.

(2) Diode

Construction



construction.

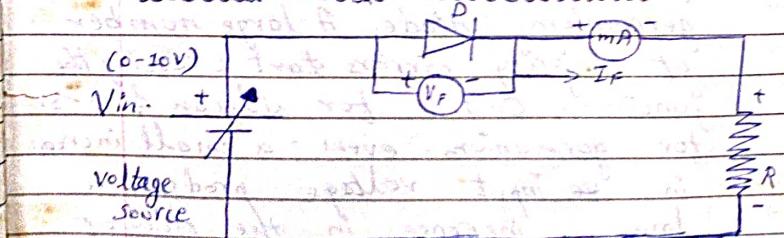


Symbol.

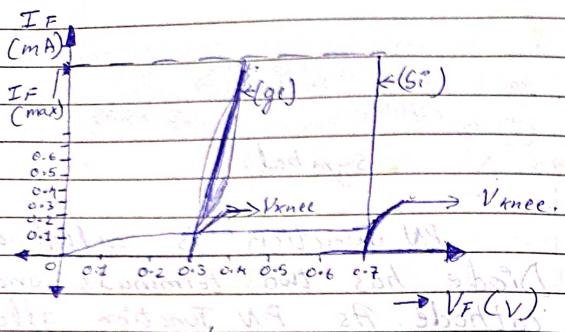
PN Junction is called as diode. Diode has two terminals anode and cathode. As PN Junction allows the current to flow only when it is forward biased. Hence the diode allows the current to flow only in one direction from anode to cathode. The arrow head in the symbol indicates direction of the flow of current.

V-I characteristics of PN junction diode

(a) Forward bias characteristics



Circuit diagram

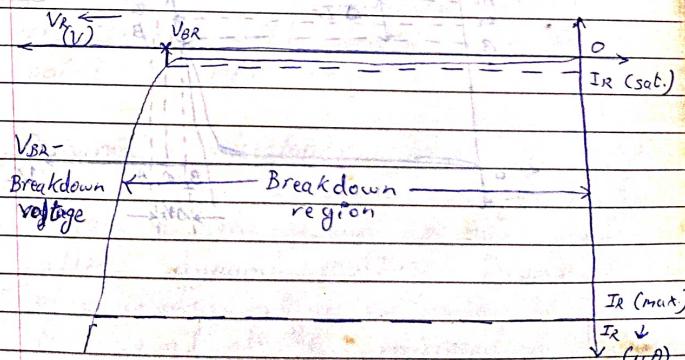
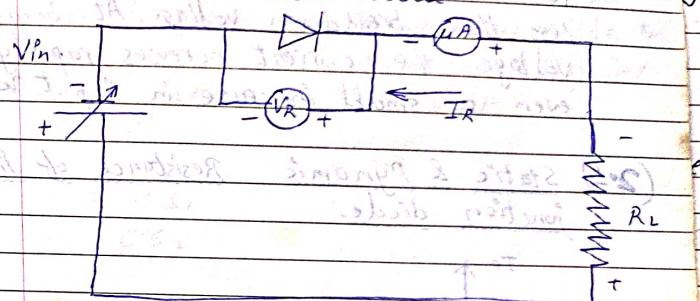


$V_{knee} \text{ for Ge} = 0.3 \text{ V}$
 $\text{for Si} = 0.7 \text{ V}$

When forward bias is applied across a diode then for first few volts diode does not conduct a large current until the external voltage overcomes potential barrier. As the external voltage approaches 0.7V for silicon diode and 0.3V for germanium diode. A large number of majority carriers start crossing the junction. 0.7V for silicon & 0.3V for germanium even a small increase in input voltage produces a large increase in the flow of current through the diode. But across voltage diode remains constant. The voltage at which the current starts increasing rapidly is called knee voltage or cutting voltage.

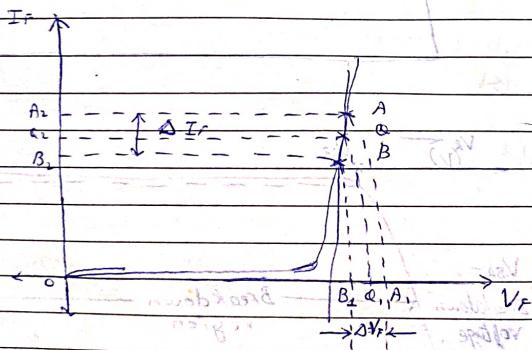
increasing rapidly when diode is formed biasing is called knee voltage or cutting voltage.

(b) Reverse bias characteristics.



In reverse bias condition, the diode current is very small. It is in μAmp . for Germanium diode and nAmp for silicon diode. It remains small and constant almost for reverse bias voltages less than breakdown voltage. At breakdown voltage the current increases rapidly for even a small increase in input voltage.

(201) Static & Dynamic Resistance of PNP junction diode:



When forward bias diode offers a definite resistance to the flow of current. This resistance is known as static resistance. It is the ratio of DC voltage across the diode to DC current flowing through the diode. From the graph static resistance at point A is given by $R = V/I$

$$R = \frac{V}{I}$$

$$= \frac{\Delta V}{\Delta I}$$

$$= \frac{\Delta V_F}{\Delta I_F}$$

Since the curve is non-linear the ratio $\Delta V_F/\Delta I_F$ or static resistance will vary with the point of measurement.

Dynamic resistance.

The resistance offered by diode in favor of the flow of AC signal is called dynamic resistance. Dynamic resistance of a diode at a particular DC voltage is equal to the reciprocal of the slope of characteristic of a given point. Dynamic resistance is the ratio of change in voltage across diode to the change in current flowing through

diode. From the graph it is given by:-

$$r_d = \frac{\Delta V}{\Delta I}$$

$$r_d = OA_2 - OB_2$$

$$\text{Now, } r_d = \frac{OA_2 - OB_2}{Y_2 - Y_1}$$

$$\text{Slope of curve} = Y_2 - Y_1$$

$$\therefore s = \frac{\Delta I}{\Delta V}$$

$$\therefore r_d = \frac{\Delta V}{\Delta I}$$

$$r_d = \frac{\Delta I}{\Delta V}$$

$$r_d = \frac{I_2 - I_1}{V_2 - V_1}$$

2.2 Specification of diodes.

- (1) PIV/PRV
- (2) Average forward current.
- (3) Forward surge current.
- (4) Maximum forward voltage.
- (5) Reverse current.
- (6) Power dissipation (liberation).
- (7) Reverse Recovery time.

(1) PIV/PRV [Peak inverse voltage].

[Peak reverse voltage].

It is defined as the max. reverse voltage that can be applied to the diode without destruction.

(2) Average forward current.

It is defined as the forward current which a diode can pass continuously at room temperature.

(3) Forward surge current.

It is defined as large forward current which a diode can safely pass for a very short time (say 1 sec.).

(4) Maximum forward voltage.

It is defined as the max. voltage that can be applied to the diode without destruction when diode is forward biased.

(5) Reverse current.

It is defined as the max. reverse saturation current at a max. reverse voltage at given temperature.

(6) Power dissipation
It is defined as the max. power that a diode can dissipate continuously without destruction at room temperature which is 5W .

(7) Reverse Recovery time, t_{rr}
It is defined as the time taken by the diode to switch from low ON-state to OFF state. It is in nanosecond range which is diodes turn-on time constant more than microseconds.

(2.3) Applications etc. Diode.

(a) Electronic switch.

(b) Rectifier circuit.

(c) Voltage Multiplier.

(d) Clipping circuit.

(3) Diode as a Rectifier.

Rectifier is an electronic circuit which converts AC signal into DC signal.

(3.1) Classification of Rectifiers.

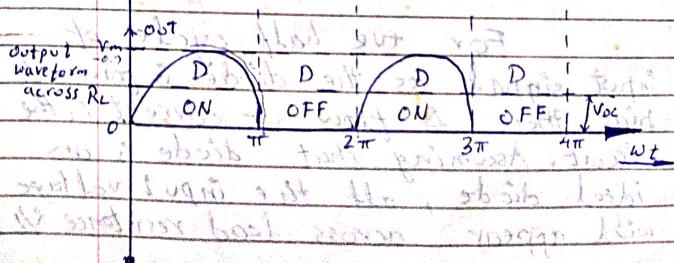
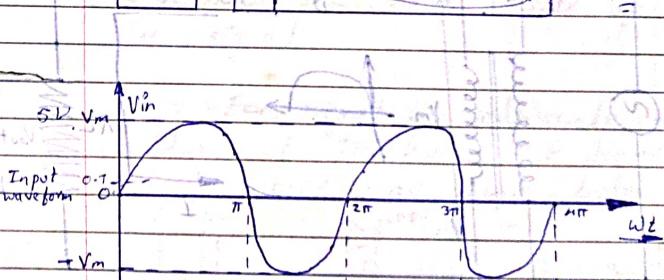
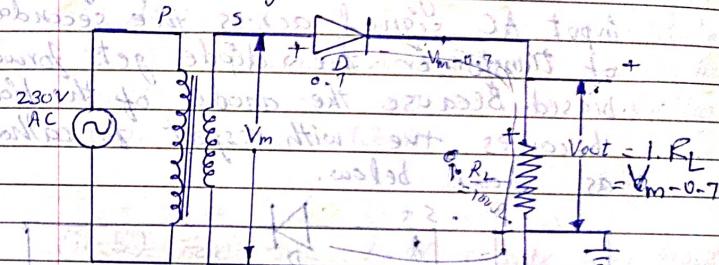
(a) Half wave rectifier (HWR).

(b) Full wave rectifier (FWR).

(i) Center tap FWR.
(ii) Bridge FWR.

[3.1] Half wave rectifier.

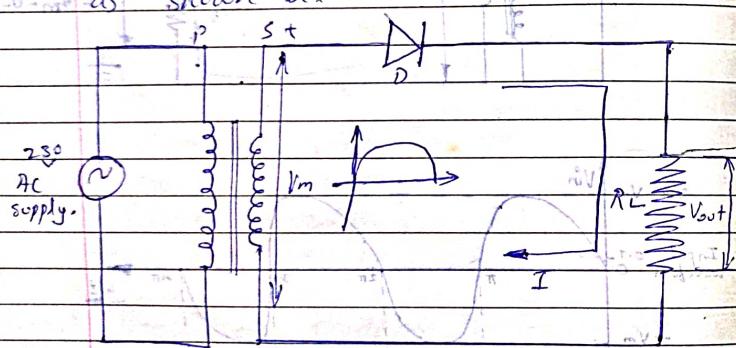
(i) Circuit diagram:



(ii) Working of half wave rectifier.

(ii-a) For positive half cycle of input ac signal.

During the +ve half cycle of input AC signal across the secondary of transformer the diode gets forward biased. Because the anode of the diode becomes +ve with respect to cathode as shown below.

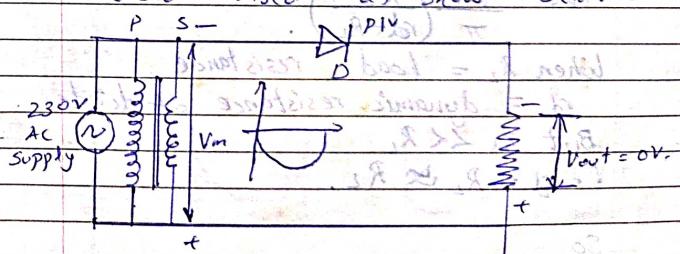


For the half cycle of input signal as the diode is forward bias there is flow of current in the circuit. Assuming that diode is an ideal diode, all the input voltage will appear across load resistance R_L .

On ideal basis $V_{out} \approx V_m$. But practically no diode is an ideal diode i.e. it offers some resistance when forward biased. So a small amount of voltage is dropped across the diode which is 0.7V for Si diode & 0.3V for Ge diode. The output voltage is given by $V_{out} = V_m - V_F$ where V_F is voltage drop across diode.

(ii-b) For -ve half cycle of input ac signal.

For negative half cycle across secondary of transformer, the diode gets reversed biased as shown below.



During -ve half cycle as the diode is reversed biased ideally no current flow into the circuit because a reversed bias diode offers high resistance to the flow of current so all the input voltage drops across diode and there is no voltage at the output across R_L . The output waveform across R_L indicate that that output signal is unidirectional but its magnitude keeps on changing and hence the output is called pulsating DC output. For half wave rectifier $\bar{V}_D = V_m$.

Output DC voltage of HWR.

$$V_{DC} = \frac{V_m}{\pi} \left(\frac{R_L}{r_d + R_L} \right)$$

When R_L = load resistance

r_d = dynamic resistance of diode.

But $r_d \ll R_L$

$$\therefore r_d + R_L \approx R_L$$

So,

$$V_{DC} = \frac{V_m}{\pi} \left(\frac{R_L}{R_L} \right)$$

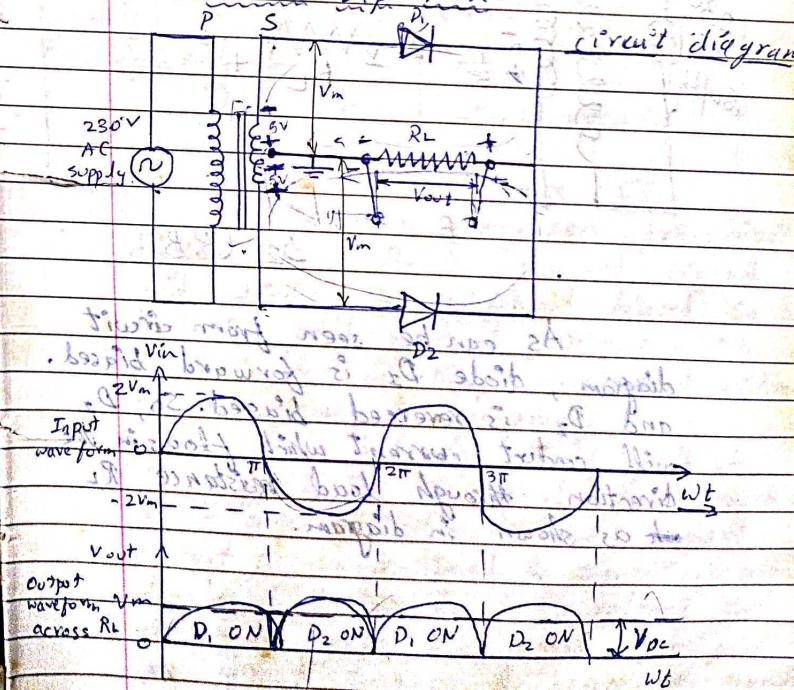
$$\therefore V_{DC} = \frac{V_m}{\pi}$$

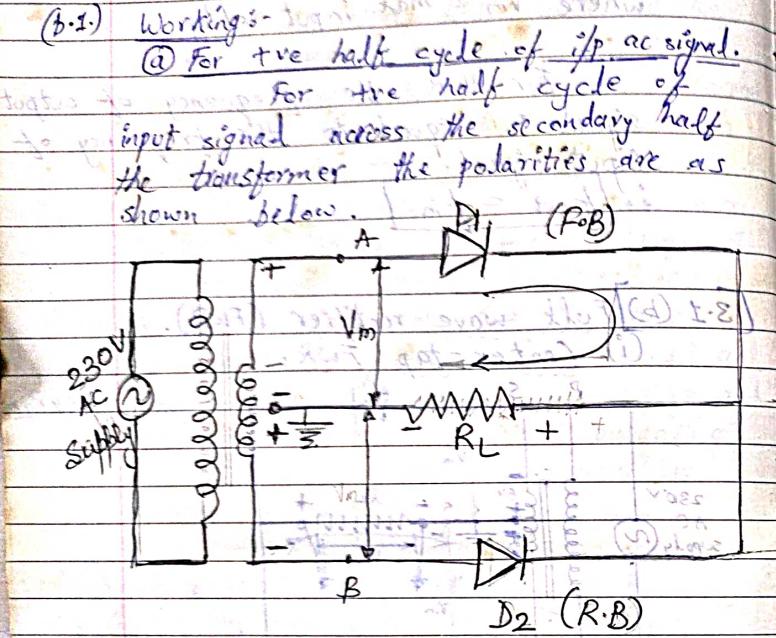
where V_m = max. input voltage.

For HWR, the frequency of output signal is equal to the frequency of input signal.
 $\therefore f_{out} = f_{in}$

[3.1 (b)] Full wave rectifier (FWR).

(i) Center-tap FWR.

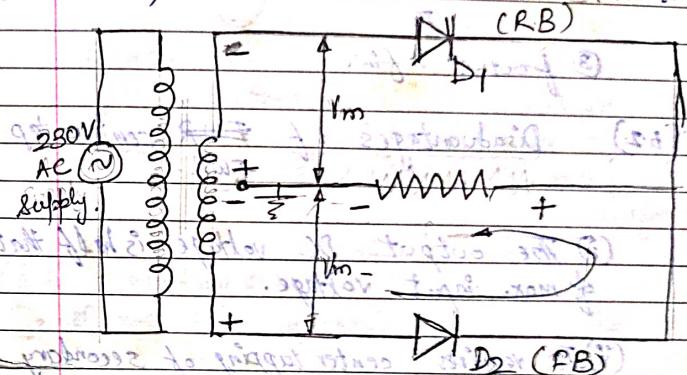




As can be seen from circuit diagram, diode D_1 is forward biased and D_2 is reversed biased. So, D_1 will conduct current which flows in the direction through load resistance R_L as shown in diagram.

② For -ve half cycle of i/p ac signal

For -ve half cycle of input signal across the secondary of transformer the polarities are as shown below:-



As can be seen from circuit diagram, diode D_1 is reversed biased and diode D_2 is forward biased. So, diode D_2 will conduct current which flows in the direction through load resistance R_L as shown in diagram.

From both the half cycle of input signal the current flows through R_L in same direction hence the output current is unidirectional & the output voltage developed across R_L is DC voltage. Both the half cycle of input signal gives the output across R_L hence the name

full wave rectification. $v = \frac{V_m}{\pi}$ (a)

* For center tap F.W.R.

$$\textcircled{1} \quad \frac{1}{2} V = \frac{1}{2} V_m \quad \text{at } t = \frac{\pi}{2}$$

$$\textcircled{2} \quad V_{dc} = \frac{2}{\pi} V_m \quad \text{at max. VP voltage}$$

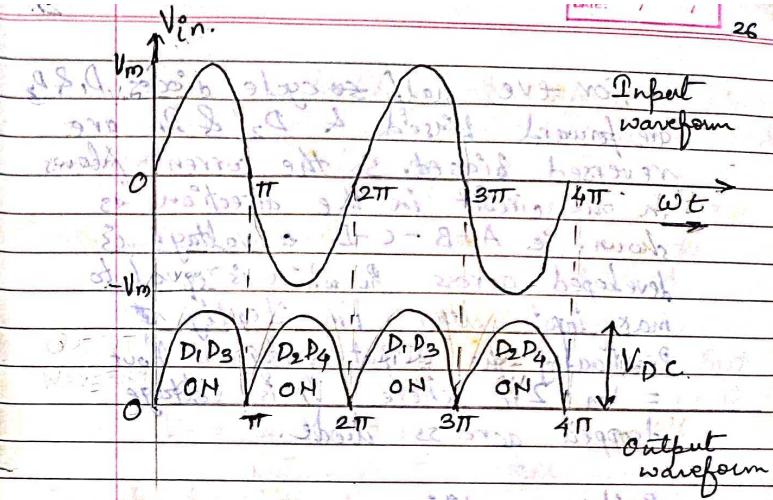
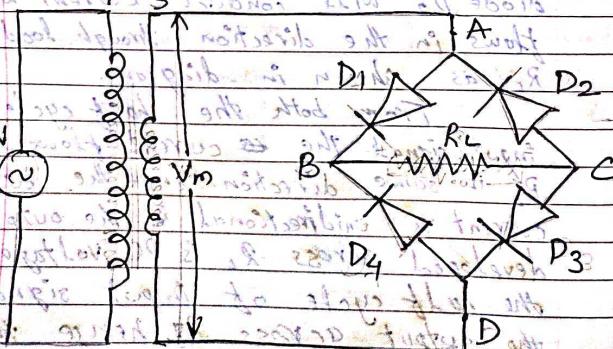
$$\textcircled{3} \quad f_{out} = 2 f_{in.}$$

(b) Disadvantages of ~~FWR~~ center tap FWR.

(i) The output DC voltage is half that of max. input voltage.

(ii) It requires center tapping of secondary winding of transformer which is not easy.

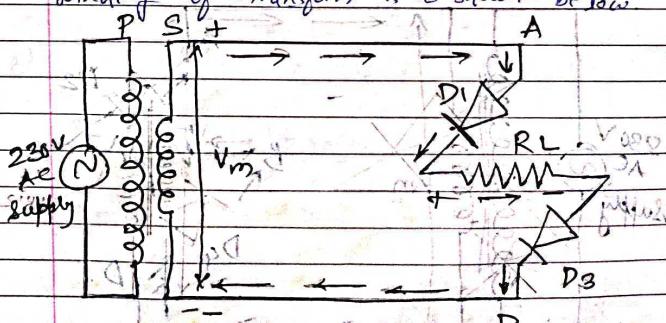
(iii) Bridge Rectifier.



(i) Working :-

At the start of AC cycle, D_1 & D_3 are ON.

For positive half cycle of input signal, the potential across polarities across secondary winding of transformer is as shown below.

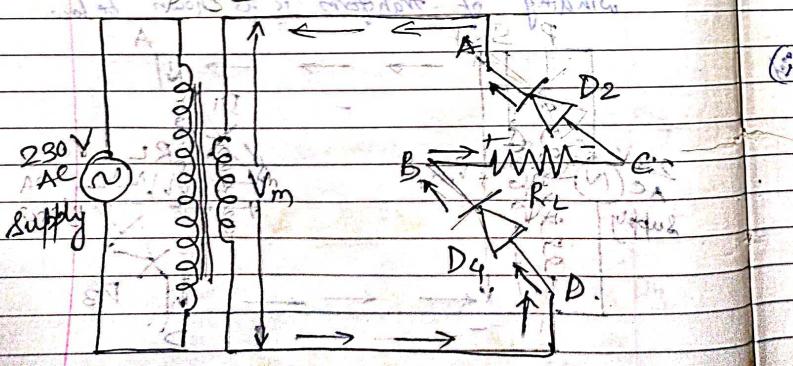


For +ve half cycle diodes D_1 & D_3 are forward biased & D_2 & D_4 are reverse biased. So the current flows in the circuit in the direction as shown. ie A-B-C-D a voltage is developed across R_L which is equal to max. input voltage V_m ideally. But practically the output voltage is $V_{out} = V_m - 2V_F$ where V_F is voltage dropped across diode.

~~Bridge rectifier.~~

(i) For -ve half cycle of i/p ac signal.

For -ve half cycle the magnetic polarities across secondary hot winding of transformer are as shown.



For -ve half cycle of input signal diodes D_{23} & D_4 are forward biased whereas diodes D_1 & D_3 are reversed biased. So the current flows through the circuit in the direction as shown. ie $D-B-C-A$ voltage is developed across R_L which is equal to $-V_m$ ideally. But practically the output voltage is $V_{out} = V_m - 2V_F$.

As for both the half cycles of input signal, the current flows through R_L in same direction. Hence the current is unidirectional & the output voltage across R_L is DC voltage.

- For (ii) ~~positive half cycle~~
- (ii) For Bridge Rectifier (a) $P_{IK} = V_m \times I_R$ using $I_R = \frac{V_m}{R_L}$
- (b) $V_{AC} = 2V_m$ using $\theta = 90^\circ$
- (c) $F_{out} = 2f_{in}$

(ii.3) Advantages of Bridge Rectifier.

- ① Center tapping of secondary winding of transformer is not required. The output voltage is twice as compared to output voltage of center tap rectifier for same amount of input voltage which is 20V
- ② PIV is less as compared to center tap rectifier. \Rightarrow $V_{Cmax} = 10V$

(ii.4) Disadvantages:

- ① It requires 4 diodes for its operation.

(ii.5) Specifications of Rectifier.

- (1) Rectifier Efficiency (η)
- (2) Ripple factor (r)

(1) Rectifier Efficiency (η)

It is defined as the ratio of output DC power to the applied input AC power. It is given as

$$\eta = \frac{\text{Output DC power}}{\text{Input AC power}}$$

i.e. $\eta = \frac{P_{dc}}{P_{ac}}$

Formulae.

$$P_{dc} = I^2 dc \times R_L$$

$$P_{ac} = I^2 rms \times (r_d + R_L)$$

$$\therefore \eta = \frac{P_{dc}}{P_{ac}}$$

\Rightarrow To find P_{dc} to $\approx 20V$, will not work

$$\therefore \eta = \frac{I^2 dc \times R_L}{I^2 rms \times (r_d + R_L)}$$

But ideally $r_d \ll R_L$ \Rightarrow ④

$$\therefore r_d + R_L \approx R_L$$

$$\therefore \eta = \frac{I^2 dc}{I^2 rms} \times \frac{R_L}{R_L}$$

$$\therefore \eta = \frac{I^2 dc}{I^2 rms} \quad \Rightarrow \quad \text{(A)}$$

④ For HWR

$$I_{dc} = \frac{I_m}{\pi} \quad \text{④} \quad \text{④} = \frac{I_m}{\pi}$$

$$I_{rms} = \frac{I_m}{2} \quad \text{⑤} \quad \text{⑤} = \frac{I_m}{2}$$

∴ substituting eqns ④ & ⑤ in eqn (A)

$$\therefore \eta = \frac{I^2 dc}{I^2 rms} = \frac{(\frac{I_m}{\pi})^2}{(\frac{I_m}{2})^2}$$

$$\therefore \eta = \frac{I_m^2}{4\pi^2} \times \frac{1}{4} \approx 0.025$$

$$\therefore \eta = \frac{I_m^2}{4\pi^2} \approx 0.025$$

$$\therefore \eta = \eta \times 100$$

$$\therefore \eta = 0.405 \times 100$$

$$\therefore \text{For HWR, } \eta = 40.5\%$$

$$\therefore \eta = 40.5\%$$

For HWR, 40.5% of input AC power is converted into DC supply.

$$(R+b) \times I_{avg}$$

(b) For FWR for efficiency

$$I_{dc} = 2 \frac{I_m}{\pi} R \rightarrow R \text{ is } b \text{ in eqn (A)}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}} \rightarrow \text{eqn (B)}$$

$$(B) \sqrt{2} \times I_{rms} = \frac{I_m}{\sqrt{2}}$$

Substituting eqn (B) & (B) in eqn (A).

$$\therefore \eta = \frac{4I^2 m}{\pi^2} / \frac{I^2 m}{2}$$

$$\therefore \eta = \frac{4I^2 m}{\pi^2} \times \frac{2}{I^2 m} = \frac{8}{\pi^2}$$

$$\therefore \eta = \frac{8}{\pi^2} = 0.811$$

$$(b) \therefore \eta = 0.811 \times 100$$

$$\therefore \eta = 81.1\%$$

For FWR 81.1% of input ac power is converted into output DC power. So FWR is more efficient than HWR.

(2) Ripple factor

The output of rectifier consists of dc components and ac components. These ac components cause the pulsation in the output of rectifier and are called ripples, so the smaller the ac components more pure is rectifier output.

Defn:- It is defined as the ratio of 'rms' value of AC components at the output to the average value of DC components at the output. It is given as

$r = \frac{\text{rms value of ac components at o/p}}{\text{avg. value of dc components at o/p.}}$

$$\text{ie. } r = \frac{I_{ac}}{I_{dc}}$$

$$I_{rms} = \sqrt{I^2_{ac} + I^2_{dc}}$$

where I_{rms} is rms value of ac signal.

I_{ac} = rms value of ac component at o/p

I_{dc} = avg. value of dc component at o/p.

$$I_{ac} = \sqrt{I^2_{rms} - I^2_{dc}}$$

$$I_{dc} = \sqrt{I_{rms}^2 - I^2_{dc} \alpha R(s)}$$

$$I_{dc} = I_{dc}$$

∴ $I_{dc} = \sqrt{I_{rms}^2 - I^2_{dc} \alpha R(s)}$
 Since $I_{dc} \propto \sqrt{I_{rms}^2 - I^2_{dc}}$
 Therefore $I_{dc} \propto \sqrt{I_{rms}^2 - I^2_{dc}}$ abt to
 stability abt mean changing in rate
 of current in future abt in
 future $I_{dc} = \sqrt{I_{rms}^2 - I^2_{dc}}$ will be
 future $I_{dc} = \sqrt{I_{rms}^2 - I^2_{dc}}$ changing in

case ie in changing in α will be
 $r = \sqrt{I_{rms}^2 - I^2_{dc}}$ \rightarrow (A)
 to reduce effect of I^2_{dc} of future abt to
 change in α due to the changing in

* Form HWR to the value of α
 $\therefore I_{rms} = \frac{I_m}{2}$ \rightarrow (1) $\text{for } r = \sqrt{\frac{\pi^2}{8}}$

$$I_{dc} = \frac{I_m}{\pi} \quad \text{--- (2)}$$

Substituting eqn. (1) & (2) in (A).

$$r = \sqrt{\frac{(I_m/2)^2}{(I_m/\pi)^2} - 1}$$

$$r = \sqrt{\frac{I_m^2 \times \pi^2}{I_m^2 \times 4} - 1}$$

$$r = 1.21 \quad \text{for HWR}$$

* For FWR,

$$I_{rms} = \frac{I_m}{\sqrt{2}} \quad \text{--- (1)}$$

$$I_{dc} = \frac{2I_m}{\pi} \quad \text{--- (2)}$$

Substituting eqn. (1) & (2) in (A), we get

$$r = \sqrt{\frac{(I_m/\sqrt{2})^2}{(2I_m/\pi)^2} - 1}$$

$$r = \sqrt{\frac{(I_m^2 \times \pi^2)}{2 \times 4I_m^2} - 1}$$

$$r = \sqrt{\frac{\pi^2}{8} - 1}$$

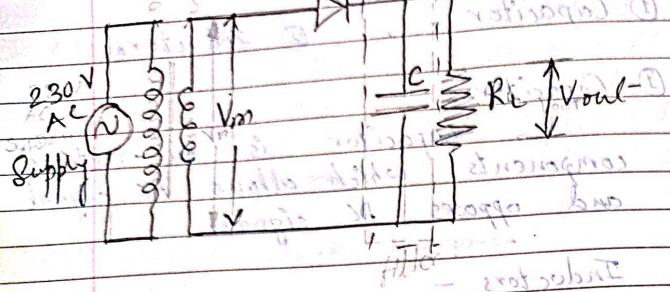
$$r = 0.48 \quad \text{for FWR}$$

Question Bank:-

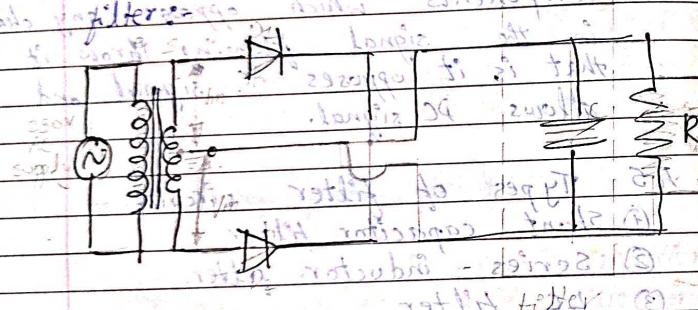
2 marks -

- 1.) Why conductivity of Ge is more than that of Si at room temperature?
- 2.) Define term - (a) Rectifier efficiency.
(b) Ripple factor.
- 3.) Define dynamic resistance of diode?
- 4.) State PIV rating of diode in center tap FWR?
- 5.) Name two pentavalent impurities?
- 6.) Give cutting / knee voltage in Si & Ge diode?
- 7.) Define PN rating of diode?
- 8.) Define Intrinsic semiconductor & give its two example?
- 9.) What is extrinsic semiconductor & give its 2 example?

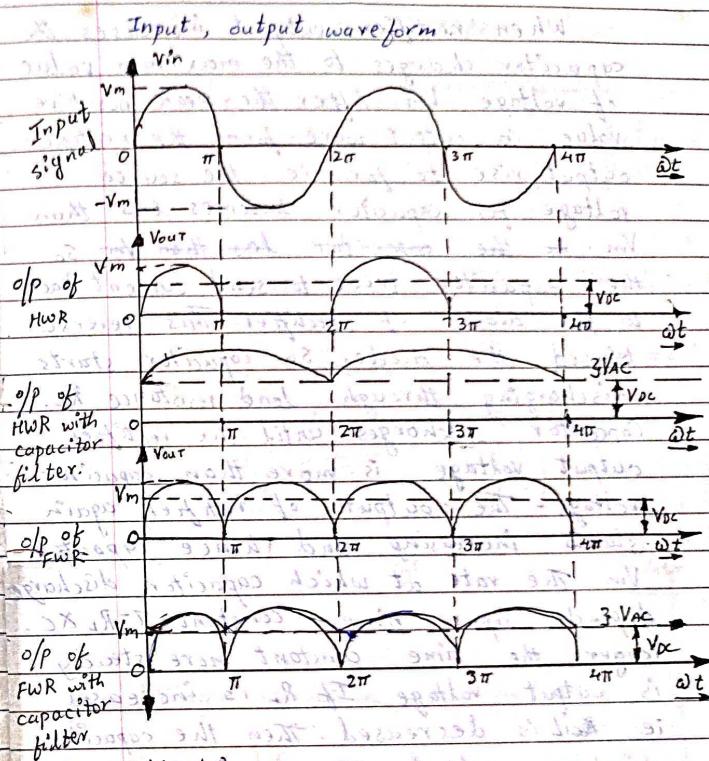
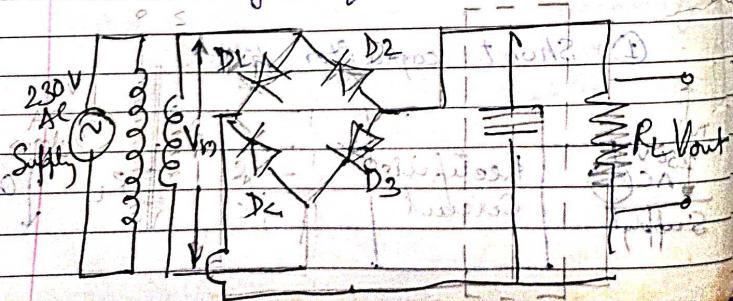
(a) HWR with shunt capacitor filter



(b) FWR with center tap with shunt capacitor filter



(c) Full Wave Bridge Rectifier with shunt capacitor filter



Working:-

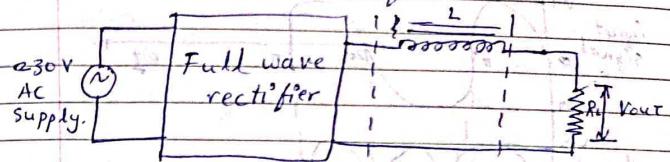
Whenever output of rectifier is given to the capacitor of the filter the AC components of rectifier output are bypassed through capacitor and DC components passed through load resistance R_L . thereby producing more improved out DC voltage.

When rectifier output increases the capacitor charges to the maximum value of voltage V_m . After the peak positive value, in output wave form the rectifier output rises to fall i.e. the source voltage for capacitor becomes less than V_m . So the capacitor tries to send current back to the diode of rectifier. This reverse biased the diode. So capacitor starts discharging through load resistance R_L . Capacitor discharges until the rectifier output voltage is more than capacitor voltage. The output of rectifier again starts increasing and hence capacitor voltage V_m . The rate at which capacitor discharge depends upon time constant $T = R_L \times C$. Longer the time constant more steady is output voltage. If R_L is increased i.e. R_L is decreased. Then the capacitor discharges slowly thereby reducing the ripples. But if R_L is decreased i.e. R_L is increased. Then the capacitor discharges rapidly thereby increasing the ripples.

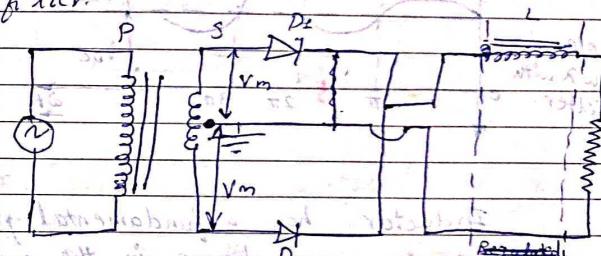
40

41

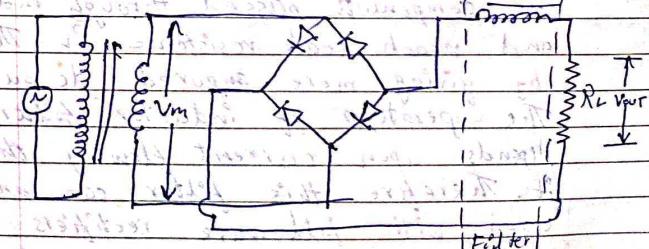
2. Series inductor filter.

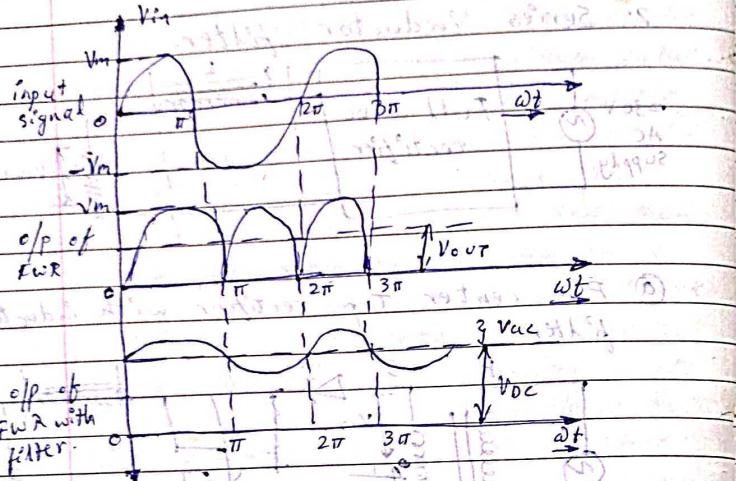


(a) FW center tap rectifier with inductor filter.



(b) Bridge rectifier with inductor filter



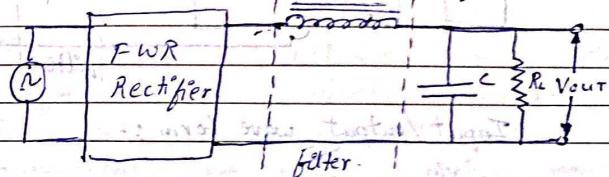


Inductor has a fundamental property of opposing any change in the current flowing through it. Therefore when pulsating DC output of rectifier is applied to inductor filter than only the DC components passed through inductor and reach load resistance, R_L . Thereby giving more ensured DC output.

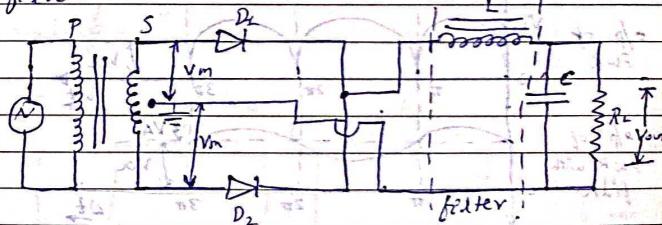
The operation of inductor filter depends upon current flowing through it. Therefore this filter can only be used with full-wave rectifiers because it requires a continuously flow of current. Higher the current

flowing through it better is the filtering action. Therefore increase in load current I_L , decreases ripples.

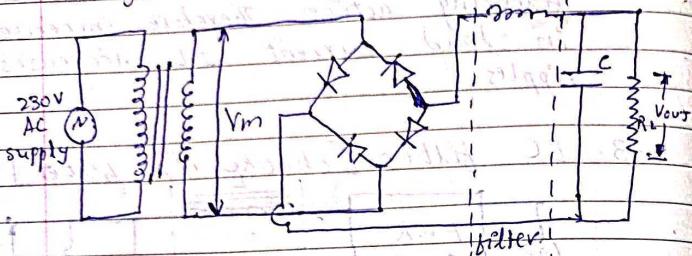
3. LC filter [choke i/p. filter].



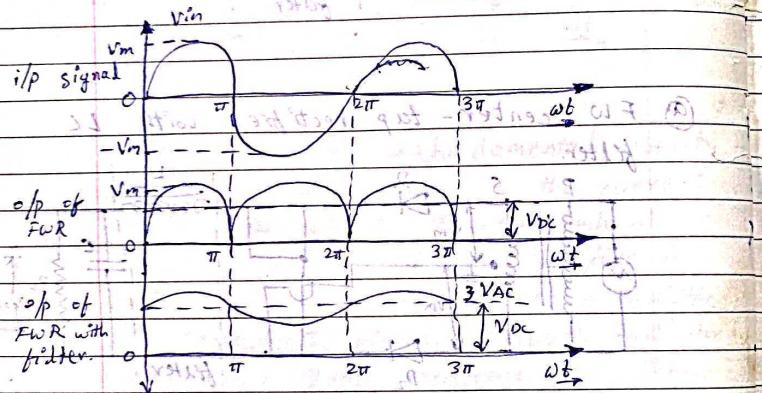
(a) FW center-tap rectifier with LC filter.



⑥ Bridge rectifier with LC filter.



Input/output wave form :-

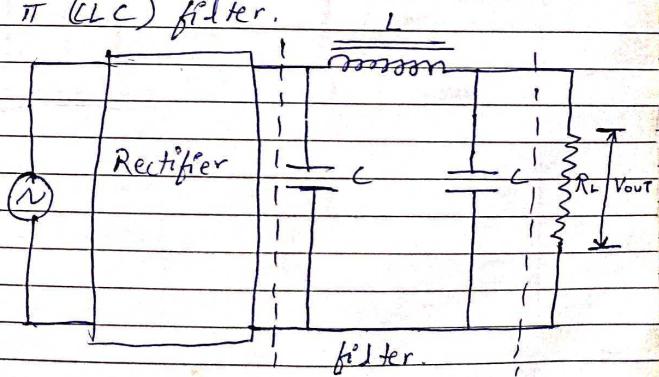


A series inductor filter has the property of decreasing ripple when load current IL increased. whereas shunt capacitor filter has the property of increasing ripples. when load current IL is

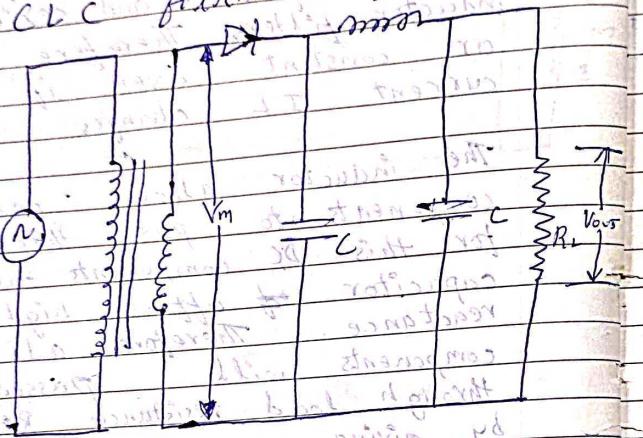
increased and LC filter combines the features of shunt capacitor filter and series inductor filter. Therefore ripples are constant even if load current IL changes.

The inductor allows only DC components to pass through it for this DC components the capacitor offers high reactance. Therefore all DC components will be passed through load resistance RL. thereby giving more purified DC out voltage.

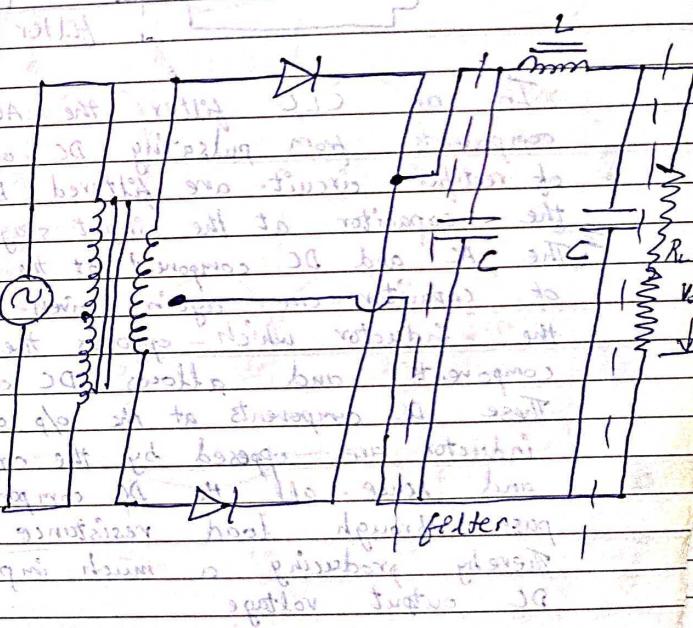
4. π (CLC) filter.



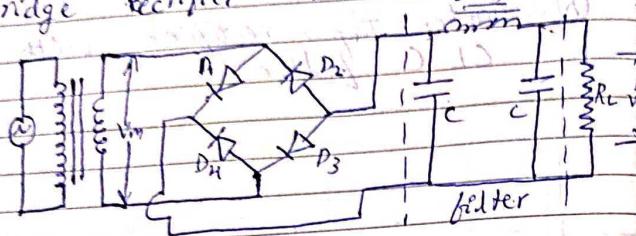
(a) Full Wave rectifier with CLC filter



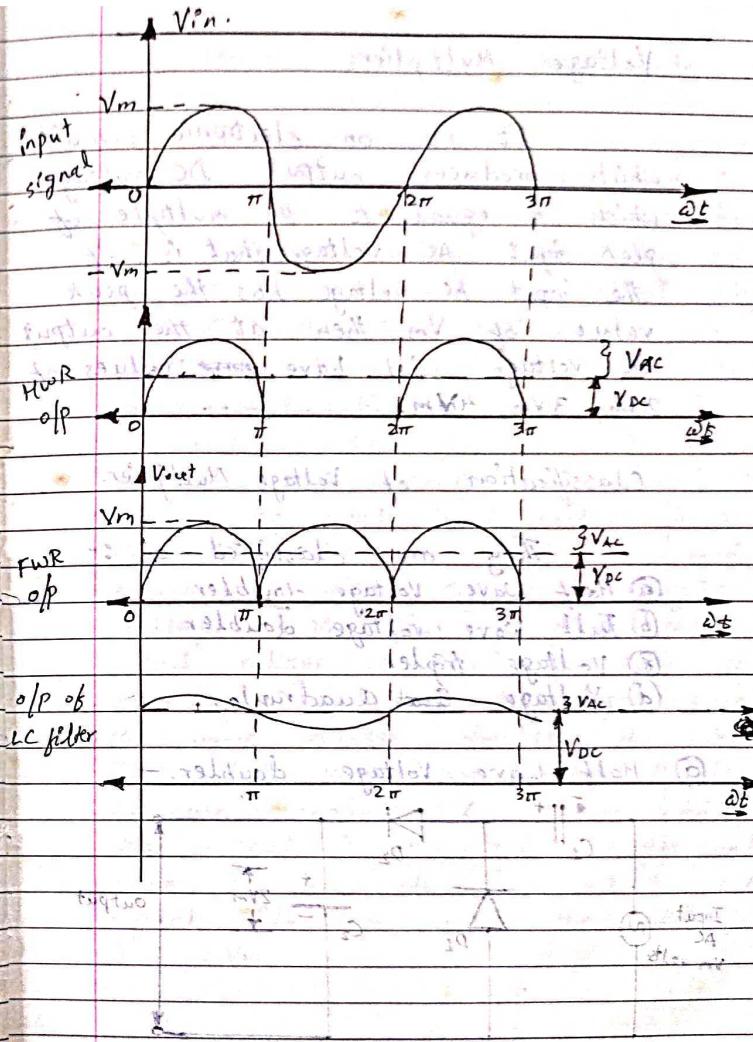
(b) Center-Tap rectifier with CLC filter



③ Bridge rectifier with CLC filter



In an CLC filter the AC components from pulsating DC output of rectifier circuit are filtered by the capacitor at the input stage. The AC and DC component at the output of capacitor are again given to the inductor which opposes the AC components and allows DC components. These DC components at the o/p of inductor are opposed by the capacitor and hence all the DC components pass through load resistance R_L thereby producing a much improved DC output voltage.



CHAPTER 5.

Zener diode & its applications.

[5.1] Definition of Zener diode

It is defined as the properly doped crystal diode which has ~~too~~ sharp breakdown voltage.

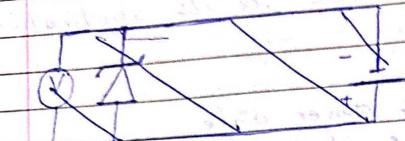
Symbol



Zener diode (Z)

Zener diodes are specially designed to operate in breakdown region without destruction. By changing the concentration of impurities it is possible to produce zener diode with breakdown voltage from 2V to 200V. In zener diode the current flowing through it in reverse biased condition is not destructive as its value is limited by controlling doping level.

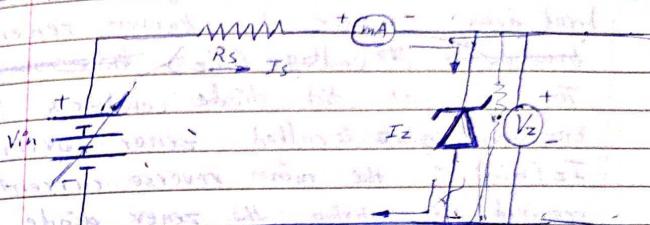
[5.2] V-I characteristics of zener diode.



(a) Forward biased characteristic.

When forward biased Zener diode operates as ordinary PN Junction diode. For first few volt. As the voltage increases the current also increases. After a particular voltage called cut off voltage the current increases suddenly keeping the voltage across diode constant.

(b) Reverse biased characteristics.



Intrinsic V_{ZB} remains constant and I_Z increases with V_Z .
 I_Z is zero until V_Z reaches V_{ZB} (Breakover voltage). At this point I_Z increases linearly with V_Z until it reaches $I_Z(\text{max})$. This current is called Breakover current. When I_Z reaches $I_Z(\text{max})$, the diode is said to be breakdown. The region where I_Z increases linearly with V_Z is called Breakdown region. The current I_Z is given by $I_Z = I_{Z0} e^{(V_Z - V_{ZB})/V_T}$.

At $V_Z = V_{ZB}$, $I_Z = I_{Z0}$. At $V_Z = V_{ZB} + V_T$, $I_Z = 2I_{Z0}$. At $V_Z = V_{ZB} + 2V_T$, $I_Z = 4I_{Z0}$. At $V_Z = V_{ZB} + 3V_T$, $I_Z = 8I_{Z0}$. At $V_Z = V_{ZB} + 4V_T$, $I_Z = 16I_{Z0}$. At $V_Z = V_{ZB} + 5V_T$, $I_Z = 32I_{Z0}$. At $V_Z = V_{ZB} + 6V_T$, $I_Z = 64I_{Z0}$. At $V_Z = V_{ZB} + 7V_T$, $I_Z = 128I_{Z0}$. At $V_Z = V_{ZB} + 8V_T$, $I_Z = 256I_{Z0}$. At $V_Z = V_{ZB} + 9V_T$, $I_Z = 512I_{Z0}$. At $V_Z = V_{ZB} + 10V_T$, $I_Z = 1024I_{Z0}$. At $V_Z = V_{ZB} + 11V_T$, $I_Z = 2048I_{Z0}$. At $V_Z = V_{ZB} + 12V_T$, $I_Z = 4096I_{Z0}$. At $V_Z = V_{ZB} + 13V_T$, $I_Z = 8192I_{Z0}$. At $V_Z = V_{ZB} + 14V_T$, $I_Z = 16384I_{Z0}$. At $V_Z = V_{ZB} + 15V_T$, $I_Z = 32768I_{Z0}$. At $V_Z = V_{ZB} + 16V_T$, $I_Z = 65536I_{Z0}$. At $V_Z = V_{ZB} + 17V_T$, $I_Z = 131072I_{Z0}$. At $V_Z = V_{ZB} + 18V_T$, $I_Z = 262144I_{Z0}$. At $V_Z = V_{ZB} + 19V_T$, $I_Z = 524288I_{Z0}$. At $V_Z = V_{ZB} + 20V_T$, $I_Z = 1048576I_{Z0}$. At $V_Z = V_{ZB} + 21V_T$, $I_Z = 2097152I_{Z0}$. At $V_Z = V_{ZB} + 22V_T$, $I_Z = 4194304I_{Z0}$. At $V_Z = V_{ZB} + 23V_T$, $I_Z = 8388608I_{Z0}$. At $V_Z = V_{ZB} + 24V_T$, $I_Z = 16777216I_{Z0}$. At $V_Z = V_{ZB} + 25V_T$, $I_Z = 33554432I_{Z0}$. At $V_Z = V_{ZB} + 26V_T$, $I_Z = 67108864I_{Z0}$. At $V_Z = V_{ZB} + 27V_T$, $I_Z = 134217728I_{Z0}$. At $V_Z = V_{ZB} + 28V_T$, $I_Z = 268435456I_{Z0}$. At $V_Z = V_{ZB} + 29V_T$, $I_Z = 536870912I_{Z0}$. At $V_Z = V_{ZB} + 30V_T$, $I_Z = 1073741824I_{Z0}$. At $V_Z = V_{ZB} + 31V_T$, $I_Z = 2147483648I_{Z0}$. At $V_Z = V_{ZB} + 32V_T$, $I_Z = 4294967296I_{Z0}$. At $V_Z = V_{ZB} + 33V_T$, $I_Z = 8589934592I_{Z0}$. At $V_Z = V_{ZB} + 34V_T$, $I_Z = 17179869184I_{Z0}$. At $V_Z = V_{ZB} + 35V_T$, $I_Z = 34359738368I_{Z0}$. At $V_Z = V_{ZB} + 36V_T$, $I_Z = 68719476736I_{Z0}$. At $V_Z = V_{ZB} + 37V_T$, $I_Z = 137438953472I_{Z0}$. At $V_Z = V_{ZB} + 38V_T$, $I_Z = 274877906944I_{Z0}$. At $V_Z = V_{ZB} + 39V_T$, $I_Z = 549755813888I_{Z0}$. 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At $V_Z = V_{ZB} + 125V_T$, $I_Z = 42535295934910526443336033075953664I_{Z0}$. At $V_Z = V_{ZB} + 126V_T$, $I_Z = 8507059186982105288667206615188732I_{Z0}$. At $V_Z = V_{ZB} + 127V_T$, $I_Z = 17014118373964210577334413230377464I_{Z0}$. At $V_Z = V_{ZB} + 128V_T$, $I_Z = 34028236747928421154668826460754928I_{Z0}$. At $V_Z = V_{ZB} + 129V_T$, $I_Z = 68056473495856842309337652921509856I_{Z0}$. At $V_Z = V_{ZB} + 130V_T$, $I_Z = 136112946991713684618675305843019712I_{Z0}$. At $V_Z = V_{ZB} + 131V_T$, $I_Z = 272225893983427369237350611686039424I_{Z0}$. At $V_Z = V_{ZB} + 132V_T$, $I_Z = 544451787966854738474701223372078848I_{Z0}$. At $V_Z = V_{ZB} + 133V_T$, $I_Z = 1088903575933709476949402446744157696I_{Z0}$. At $V_Z = V_{ZB} + 134V_T$, $I_Z = 2177807151867418953898804893488315392I_{Z0}$. At $V_Z = V_{ZB} + 135V_T$, $I_Z = 4355614303734837907797609786976630784I_{Z0}$. At $V_Z = V_{ZB} + 136V_T$, $I_Z = 8711228607469675815595219573953261568I_{Z0}$. At $V_Z = V_{ZB} + 137V_T$, $I_Z = 17422457214939351631190439147866523136I_{Z0}$. At $V_Z = V_{ZB} + 138V_T$, $I_Z = 34844914429878703262380878295733046272I_{Z0}$. At $V_Z = V_{ZB} + 139V_T$, $I_Z = 69689828859757406524761756591466092544I_{Z0}$. At $V_Z = V_{ZB} + 140V_T$, $I_Z = 139379657719514813049523513182932180888I_{Z0}$. At $V_Z = V_{ZB} + 141V_T$, $I_Z = 278759315439029626098547026365864361776I_{Z0}$. At $V_Z = V_{ZB} + 142V_T$, $I_Z = 557518630878059252197094052731728723552I_{Z0}$. At $V_Z = V_{ZB} + 143V_T$, $I_Z = 111503726175611850439418810546345744704I_{Z0}$. At $V_Z = V_{ZB} + 144V_T$, $I_Z = 223007452351223700878837621092691488008I_{Z0}$. At $V_Z = V_{ZB} + 145V_T$, $I_Z = 446014904702447401757675242185382960016I_{Z0}$. At $V_Z = V_{ZB} + 146V_T$, $I_Z = 892029809404894803515350484370765920032I_{Z0}$. At $V_Z = V_{ZB} + 147V_T$, $I_Z = 178405961880978960703070096874153184064I_{Z0}$. At $V_Z = V_{ZB} + 148V_T$, $I_Z = 356811923761957921406140193748306368128I_{Z0}$. At $V_Z = V_{ZB} + 149V_T$, $I_Z = 713623847523915842812280387496612736256I_{Z0}$. At $V_Z = V_{ZB} + 150V_T$, $I_Z = 1427247695047831685624560774983225472512I_{Z0}$. At $V_Z = V_{ZB} + 151V_T$, $I_Z = 2854495390095663371249121549966450945024I_{Z0}$. At $V_Z = V_{ZB} + 152V_T$, $I_Z = 570898678019132674249824309993290188048I_{Z0}$. At $V_Z = V_{ZB} + 153V_T$, $I_Z = 1141797356038265348499648619986580376096I_{Z0}$. At $V_Z = V_{ZB} + 154V_T$, $I_Z = 2283594712076530696999297239973160752192I_{Z0}$. At $V_Z = V_{ZB} + 155V_T$, $I_Z = 4567189424153061393998594479946321504384I_{Z0}$. At $V_Z = V_{ZB} + 156V_T$, $I_Z = 9134378848306122787997188959892643008768I_{Z0}$. At $V_Z = V_{ZB} + 157V_T$, $I_Z = 18268757696612245575994377919785286017336I_{Z0}$. At $V_Z = V_{ZB} + 158V_T$, $I_Z = 36537515393224491151988755839570572034672I_{Z0}$. At $V_Z = V_{ZB} + 159V_T$, $I_Z = 73075030786448982303977511679141144069344I_{Z0}$. At $V_Z = V_{ZB} + 160V_T$, $I_Z = 14615006157289796460795522335828228138688I_{Z0}$. At $V_Z = V_{ZB} + 161V_T$, $I_Z = 29230012314579592921591044671656456277376I_{Z0}$. At $V_Z = V_{ZB} + 162V_T$, $I_Z = 58460024629159185843182089343312912554752I_{Z0}$. At $V_Z = V_{ZB} + 163V_T$, $I_Z = 11692004925831837168636417868662582509504I_{Z0}$. At $V_Z = V_{ZB} + 164V_T$, $I_Z = 23384009851663674337272835737325165019008I_{Z0}$. At $V_Z = V_{ZB} + 165V_T$, $I_Z = 46768019703327348674545671474650330038016I_{Z0}$. At $V_Z = V_{ZB} + 166V_T$, $I_Z = 93536039406654697349091342949300660076032I_{Z0}$. At $V_Z = V_{ZB} + 167V_T$, $I_Z = 18707207881330939469818268589860132015264I_{Z0}$. At $V_Z = V_{ZB} + 168V_T$, $I_Z = 37414415762661878939636537179720264030528I_{Z0}$. At $V_Z = V_{ZB} + 169V_T$, $I_Z = 74828831525323757879273074359440528061056I_{Z0}$. At $V_Z = V_{ZB} + 170V_T$, $I_Z = 149657663050647515758546148718801056122112I_{Z0}$. At $V_Z = V_{ZB} + 171V_T$, $I_Z = 29931532610129503151709229743760211144224I_{Z0}$. At $V_Z = V_{ZB} + 172V_T$, $I_Z = 59863065220259006303418459487520422288448I_{Z0}$. At $V_Z = V_{ZB} + 173V_T$, $I_Z = 119726130440518012606836918975040844576896I_{Z0}$. At $V_Z = V_{ZB} + 174V_T$, $I_Z = 239452260881036025213673837950081689153792I_{Z0}$. At $V_Z = V_{ZB} + 175V_T$, $I_Z = 478904521762072050427347675890163378307584I_{Z0}$. At $V_Z = V_{ZB} + 176V_T$, $I_Z = 957809043524144100854695351780326756615168I_{Z0}$. At $V_Z = V_{ZB} + 177V_T$, $I_Z = 1915618087048288201709390703560653513230336I_{Z0}$. At $V_Z = V_{ZB} + 178V_T$, $I_Z = 383123617409657640341878140712130702646072I_{Z0}$. At $V_Z = V_{ZB} + 179V_T$, $I_Z = 766247234819315280683756281424261405292144I_{Z0}$. At $V_Z = V_{ZB} + 180V_T$, $I_Z = 1532494469638630561367512562848522810584288I_{Z0}$. At $V_Z = V_{ZB} + 181V_T$, $I_Z = 3064988939277261122735025125697045621168576I_{Z0}$. At $V_Z = V_{ZB} + 182V_T$, $I_Z = 6129977878554522245470050251394091242337152I_{Z0}$. At $V_Z = V_{ZB} + 183V_T$, $I_Z = 1225995575710904449094010050278818248467424I_{Z0}$. At $V_Z = V_{ZB} + 184V_T$, $I_Z = 2451991151421808898188020100557636496934848I_{Z0}$. At $V_Z = V_{ZB} + 185V_T$, $I_Z = 4903982302843617796376040200515273933869696I_{Z0}$. At $V_Z = V_{ZB} + 186V_T$, $I_Z = 9807964605687235592752080400530547867739392I_{Z0}$. At $V_Z = V_{ZB} + 187V_T$, $I_Z = 19615929211374471185504160800560595755478784I_{Z0}$. At $V_Z = V_{ZB} + 188V_T$, $I_Z = 39231858422748942371008321600521191510957568I_{Z0}$. At $V_Z = V_{ZB} + 189V_T$, $I_Z = 78463716845497884742016643200542383021915136I_{Z0}$. At $V_Z = V_{ZB} + 190V_T$, $I_Z = 156927433690995769484033266400584766043830272I_{Z0}$. At $V_Z = V_{ZB} + 191V_T$, $I_Z = 31385486738199153896806653280056953208766544I_{Z0}$. At $V_Z = V_{ZB} + 192V_T$, $I_Z = 62770973476398307793613306560053906417533088I_{Z0}$. At $V_Z = V_{ZB} + 193V_T$, $I_Z = 125541946952796615587226613120057812835067776I_{Z0}$. At $V_Z = V_{ZB} + 194V_T$, $I_Z = 25108389390559323117445322624005562567013552I_{Z0}$. At $V_Z = V_{ZB} + 195V_T$, $I_Z = 50216778781118646234890645248005125134027104I_{Z0}$. At $V_Z = V_{ZB} + 196V_T$, $I_Z = 100433557562237292469781290496005050268054208I_{Z0}$. At $V_Z = V_{ZB} + 197V_T$, $I_Z = 200867115124474584939562580992005000536108416I_{Z0}$. At $V_Z = V_{ZB} + 198V_T$, $I_Z = 401734230248949169879125161984004999972216832I_{Z0}$. At $V_Z = V_{ZB} + 199V_T$, $I_Z = 803468460497898339758250323968004999944433664I_{Z0}$. At $V_Z = V_{ZB} + 200V_T$, $I_Z = 160693692099579667951650064793600499998886732I_{Z0}$. At $V_Z = V_{ZB} + 201V_T$, $I_Z = 32138738419915$

current increase. The voltage at which breakdown occurs is known zener breakdown voltage (V_Z). The current that diode conducts in breakdown region is called zener current. $I_Z(\text{min})$ is the min. reverse current required to bring the zener diode in the breakdown region. Zener diode cannot conduct any amount of zener current above $I_Z(\text{max})$. If it is forced to pass the current above $I_Z(\text{max})$ even the zener diode will burn out due to excessive heat.

Zener voltage depends upon the doping level if a diode is heavily doped then the depletion layer will be thinner and hence the breakdown will occur at smaller reverse voltage. If a diode is lightly doped then the depletion layer is wider and breakdown occurs at higher voltages. For breakdown voltages less than 1V, zener breakdown takes place. And for breakdown voltages greater than 6V, Avalanche breakdown occurs. For voltages between 4V and 6V both kinds of breakdown may occur.

[5.3] Specification of Zener diode :-

- (1) Break over Current - $I_Z(\text{min})$ -
- (2) Zener Voltage (V_Z) -
- (3) Power dissipation (P_Z) -
- (4) Dynamic resistance (r_d) -
- (5) Max. zener current $I_Z(\text{max})$ -

Definition :- It is defined as the min. reverse current required to bring zener diode in breakdown region.

(1) Breakover current $I_Z(\text{min})$:

It is defined as the min. reverse current required to bring zener diode in breakdown region.

(2) Zener voltage (V_Z):

It is defined as the voltage at which breakdown occurs in zener diode. At this voltage there is a sudden rise in zener current and the internal resistance of diode decreases from several k Ω to few ohms. The commercial value of V_Z for various zener diodes are available from 2V to 200V.

(3) Power dissipation (P_Z):

The max. amt. of power dissipated by zener diode safely is

called power dissipation. It is given by $P_Z = V_Z \times I_Z$. Its value ranges from 150 mWatt to 50Watt.

(4) Dynamic resistance (r_d) :- It is defined as the ratio of change in Zener voltage to change in Zener current. It is given by $r_d = \frac{\Delta V_Z}{\Delta I_Z}$.

(5) Max. Zener current $I_Z(\text{max})$:- It is defined as the max. amt. of current that can be allowed to flow through zener diode without destruction.

[5.5] Zener diode as Voltage Regulator :-

(a) Voltage regulation :-

Def:- It is the capability of an power supply to maintain constant output voltage inspite of fluctuation in i/p voltage and changes in load resistance. Mathematically voltage regulation is given by

$$V_{in} + I_S R_S + V_Z = \frac{P_{out}}{I_Z}$$

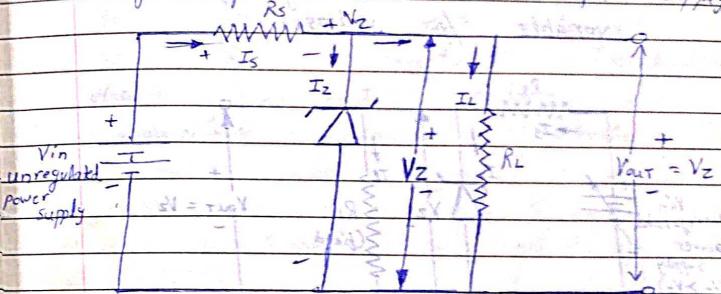
$$\therefore I_S = \frac{V_{in} - V_Z}{R_S}$$

% voltage regulation = $\frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$

where, V_{NL} = No load voltage

V_{FL} = Full load voltage

Smaller the value of percentage voltage regulation better is the power supply.



From circuit,

$$I_S = I_Z + I_L$$

$\therefore V_{in} - V_Z = I_S R_S + I_Z V_Z \rightarrow$ (Zener diode is in breakdown region $\Rightarrow R_L \gg R_S$ and $V_{out} = V_Z$).

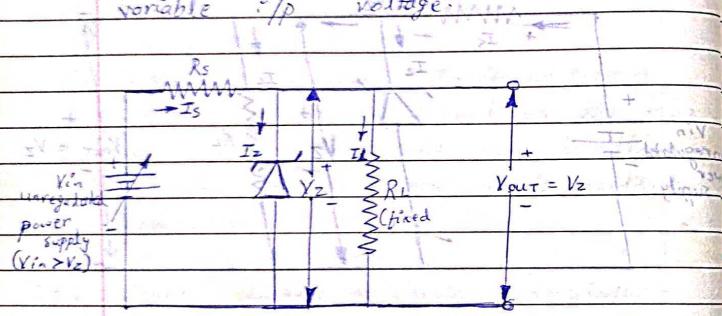
Substituting $I_S = I_Z + I_L$ in above equation we get

Zener diode can act as a voltage regulator to provide a constant

output voltage from unregulated power supply. Zener diode is connected in \parallel with

load resist. R_L or A series resist. R_S is connected in series to limit the zener current. The o/p voltage V_{out} is taken across load resist. R_L . Zener diode maintains a constant voltage V_Z across itself as long as i/p voltage does not fall below V_Z .

(a.1) Zener diode as voltage regulator with variable i/p voltage.



In this ckt., resistance R_L is kept fixed and i/p voltage & supply is variable. When the i/p voltage increases then i/p current I_S will increase due to this the current through zener diode will increase so as to keep current flowing through resistance R_L constant. i.e. if i/p current 'Is' increases zener diode will conduct extra current so that current flowing through load resistance R_L remains constant thereby keeping the voltage across R_L constant. If i/p voltage is decreased then the current through zener diode will decrease so as to keep the current flowing through load resistance R_L constant. Therefore the o/p voltage is constant.

current so that current flowing through load resistance R_L remains constant thereby keeping the voltage across R_L constant. If i/p voltage is decreased then the current through zener diode will decrease so as to keep the current flowing through load resistance R_L constant. Therefore the o/p voltage is constant.

Applications of zener diode.

- (1) As an voltage regulator
- (2) As a fixed reference source
- (3) In battery charges.

Limitations of zener diode.

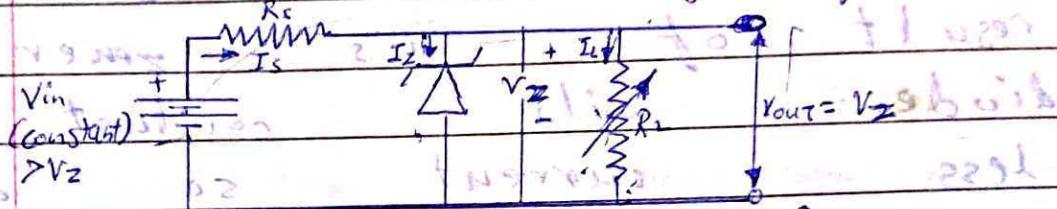
- (1) It is not a current regulator.
- (2) The max. load current I_L which can be supplied to load resistance R_L is limited to the value.

$$I_L = I_S - I_Z$$

which is few millamps only.

(3) It is not suitable for all values of R_L (i) If R_L is very small, then

(a.2) Zener diode as voltage regulator for load



In this circuit, i/p voltage is kept constant and load resist. R_L is variable. If R_L decreases, there will be increase in load current I_L so that voltage across R_L remains constant. The extra current which is required through R_L cannot come from supply as i/p voltage is constant. Hence zener diode will conduct less current so as to supply extra current through load resist. R_L . If R_L increases, it requires a decrease in load current I_L . In order to maintain constant voltage across R_L , the extra current is taken by diode so it will conduct more current than keeping the voltage across load resistance R_L constant.

Similarly the current through load resistor R_L is

$I_L = \frac{V_{out}}{R_L}$