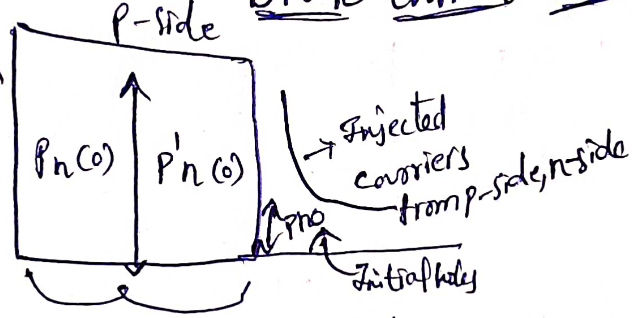
Diode Current Eq'n



$P_n(x) = P_{no} + P'_n(x) e^{-x/L}$ — (1)

L_P = diffusion length

Where $x = 0$

$P_n(0) = P_{no} + P'_n(0) e^{-0}$

$\boxed{P'_n(0) = P_{no} - P_n(0)}$ — (2)

→ Boltzmey eqn $P_P = P_n e^{V_0/V_T}$ — (3)

→ Under reverse bias condition $P_P = P_{PO}$, $P_n = P_{no}$

And Applied voltage $= V_B$ only $(V=0)$ since open circuit $\boxed{V_0 = V_B}$

$P_{PO} = P_n(0) e^{\frac{V_0 - V}{V_T}}$ — (5) $P_{PO} = P_n(0) e^{V_0/V_T}$ — (4)

~~from~~ 4 & 5

$P_{no} \cdot e^{V_0/V_T} = P_n(0) e^{\frac{V_0 - V}{V_T}}$

$P_n(0) = \dfrac{P_{no} e^{V_0/V_T}}{e^{\frac{V_0 - V}{V_T}}} = \dfrac{P_{no} e^{V_0/V_T}}{e^{V_0/V_T} \cdot e^{-V/V_T}}$

$P_n(0) = \dfrac{P_{no}}{e^{-V/V_T}} = P_{no} e^{V/V_T}$

$\boxed{P_n(0) = P_{no} e^{V/V_T}}$ — (6)

Substitute 6 in 2

$P'_n(0) = P_{no} e^{V/V_T} - P_{no}$

$\boxed{P'_n(0) = (e^{V/V_T} - 1) P_{no}}$ — (7)

Current density $J_P = I/A$

$I_{holes} = J_P A$

$I_{holes} = -q D_P \frac{dp}{dx} A$

$I_{holes} = -q D_P A \frac{d}{dx}(P_{no} + P_n(x) e^{-x/L_P})$

$= -q D_P A P'_n(x) e^{-x/L_P} \times \left(\frac{-1}{L_P}\right)$

$= Aq \frac{D_P}{L_P} P'_n(x) e^{-x/L_P}$

$x = 0$

$I_{holes} = Aq \frac{D_P}{L_P} P'_n(0) e^{-0/L_P}$

$I_{holes} = Aq \, D_P/L_P \, (e^{V/V_T} - 1) P_{no}$

$I_{electron} = Aq \, D_n/L_n \, (e^{V/V_T} - 1) N_{P_0}$

$I = I_{holes} + I_{electrons}$

$I = Aq \frac{D_P}{L_P} (\cancel{e^{V/V_T}} e^{V/V_T} - 1)$

$I = (e^{V/V_T} - 1)(Aq \frac{D_P}{L_P} P_{no} + Aq \frac{D_n}{L_n} \cdot N_{PO})$

$I = (e^{V/V_T} - 1) I_0$

$\boxed{I = I_0 (e^{V/V_T} - 1)}$

$I = I_0 (e^{V/\eta V_T} - 1)$

I = Diode Current

V = applied external voltage.

I_0 = diode reverse sat current.

η = constant for germanium $\eta = 1$
silicon $\eta = 2$

$V_T = \frac{KT}{q}$ where k = Boltzmey constant $= 1.38 \times 10^{-23} J/K$

q = charge of electron $= 1.6 \times 10^{-19} C$

T = Temperature $300^\circ K$.

Diffusion Capacitance

Under forward bias condition of P-N Junction diode capacitance called diffusion capacitance.

$$\boxed{C_D = \frac{dQ}{dV} = \frac{\tau I}{\eta V_T}}$$

$I = I_{pn}(x) + I_{np}(x)$

where, $I_{pn}(x)$ = The current with respect to electron from n-p side.

$I_{np}(x)$ = current with respect to holes from p-n side.

$I = I_{pn}(x) \quad (I_{np}(x) = 0)$

$J = \frac{I}{A}$

$\Rightarrow I = JA = J_p A$

$J_p = -q D_p \frac{dp}{dx}$

$I = -q D_p A \frac{dp}{dx}$ — (1)

$P_n(x) = P_{n0} + P_n'(x)^{-x/L_p}$

P_{n0} = Very small under forward bias

$\therefore P_n(x) = P_n'(x) e^{-x/L_p}$

Diff and w.r.t x

$\frac{dP_n(x)}{dx} = \frac{d}{dx} P_n'(x) e^{-x/L_p}$

$\frac{dP_n(x)}{dx} = P_n'(x) e^{-x/L_p} \times \left(\frac{-1}{L_p}\right)$ — (2)

(2) in (1)

$I = -q D_p A \, P_n'(x) e^{-x/L_p} (-1/L_p)$

$I = q \frac{D_p}{L_p} A \cdot P_n'(x) e^{-x/L_p}$

$x = 0$ in FB of P.N Diode

$\therefore I = \frac{q D_p}{L_p} A \cdot P_n'(0) e^0$

$I = \frac{q D_p}{L_p} A \cdot P_n'(0)$

$P_n'(0) = \frac{I L_p}{A q D_p}$ — (3)

$Q = \int_0^\infty A \cdot q \cdot P_n(x)\, dx$

$Q = \int_0^\infty A \cdot q \cdot P_n'(x) e^{-x/L_p} dx$

$Q = \left[A \cdot q \cdot P_n'(x) \frac{e^{-x/L_p}}{-1/L_p} \right]_0^\infty$

$Q = (-A \cdot q \cdot L_p P_n'(x) e^{-x} (L_p))_0^\infty$

$e^{-\infty} = 0, e^0 = 1$

$Q = -\left[A q \cdot L_p P_n'(\infty) e^{-\infty} - A q L_p P_n'(0) e^0\right]$

$Q = -(0 - A q L_p P_n'(0))$

$Q = A q L_p P_n'(0)$ — (4)

(3) in (4)

$Q = A \cdot q \cdot L_p \cdot \frac{I L_p}{A \cdot q \cdot D_p}$

$Q = \frac{L_p^2 I}{D_p} \qquad \frac{L_p^2}{D_p} = \tau$

$Q = \tau I$

$\frac{Q}{I} = \tau$

$\frac{dQ}{dI} = \tau$ — (5)

$C_D = \frac{dQ}{dV} = \frac{dQ}{dI} \times \frac{dI}{dV} \Rightarrow \frac{dI}{dV}$

$C_D = \tau \cdot \frac{I}{\eta V_T}$

$$\boxed{C_D = \frac{\tau I}{\eta V_T}}$$

⇒ Derivation of Transition Capacitance (C_T):-

consider PN-Junction, whose p-side is lightly doped. than n-side. so the depletion region penetrates more on lightly doped side. Hence the width is more on p-side.

→ Practically. it can be assumed concentration of acceptor impurity on p-side. (N_A) because entire depletion region. at p-side only.

→ The relation between voltage (v), and charge density (N_A) by using poison equation.

$$\frac{d^2v}{dx^2} = \frac{qN_A}{\varepsilon} \quad \text{——} ①$$

integrating on b.s with respect to 'x',

$$\int \frac{d^2v}{dx^2} = \int \frac{qN_A}{\varepsilon} dx.$$

$$\frac{dv}{dx} = \frac{qN_A}{\varepsilon} . \int dx.$$

$$\frac{dv}{dx} = \frac{qN_A x}{\varepsilon}$$

integrating w.r.t 'x' on b.s.

$$\int \frac{dv}{dx} = \int \frac{qN_A x}{\varepsilon} dx$$

$$V = \frac{qN_A}{\varepsilon} \int x \, dx.$$

$$V = \frac{qN_A}{\varepsilon} \times \frac{x^2}{2}.$$

$$V = \frac{qN_A x^2}{2\varepsilon}$$

here $\boxed{x = w}$

$$V = \frac{qN_A w^2}{2\varepsilon}. \quad \text{—— (2)}$$

differentiate w.r.to v.

$$\frac{dv}{dv} = \frac{d}{dv} \frac{q \cdot N_A}{2\varepsilon} w^2$$

$$1 = \frac{qN_A}{2\varepsilon} \cdot \frac{d}{dv} w^2$$

$$1 = \frac{qN_A}{\cancel{2}\varepsilon} \cdot \cancel{2} w \cdot \frac{dw}{dv}$$

$$1 = \frac{qN_A w}{\varepsilon} \cdot \frac{dw}{dv}$$

$$\frac{dw}{dv} = \frac{\varepsilon}{qN_A w} \quad \text{—— (3)}$$

$$Q = N_A \times \text{vol} \times q$$

$$Q = N_A \times Aw \times q.$$

Differentiate w.r.t. v.

$$\frac{dQ}{dV} = \frac{d}{dV}(N_A A w q)$$

$$\frac{dQ}{dV} = N_A \cdot A \cdot \frac{dw}{dV} \cdot q$$

$$\frac{dQ}{dV} = \cancel{N_A} \cdot A \cdot \frac{\varepsilon}{\cancel{q}\cancel{N_A} A w} \cdot \cancel{q} \quad [\because \text{From } Eq^n 3]$$

$$\frac{dQ}{dV} = \frac{A\varepsilon}{w} \quad (\text{or}) \quad \boxed{C_T = \frac{A\varepsilon}{w}}$$

$$\boxed{C_T = \frac{\varepsilon A}{w}}$$

Zener diode:- When the reverse voltage reaches breakdown voltage in normal pn Junction diode, the current through the juction and power dissipated at the junction will be high. such an operation destructive and the diode gets damaged. where as diodes can be designed with control the power dissipation capabilities to operate in the breakdown region. one such a diode is known as zener diode.

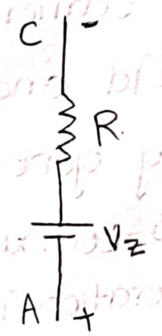
→ the zener diods are fabricated with precise breakdown voltages by controlling the doping level during manufacturing.

→ silicon is preffered than Germonium, it is always operated in the breakdown region.

→ these silicon zener diodes are designed for a specific reverse breakdown voltage.

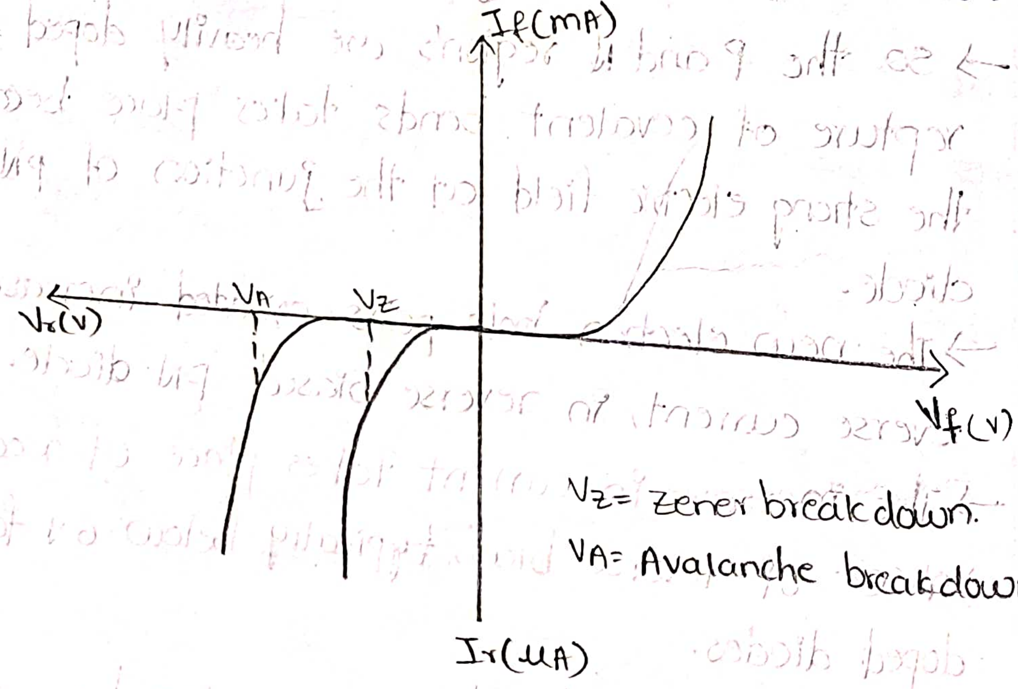
→ When reverse biased, if the reverse current of zener diode is limited using a series resistance. then the power dissipation at the junction is limited to such a level which will not damage the diode. under zener diode. continuous to operate safely in reverse breakdown region.

Zener diode symbol



Equivalent circuit

→ When reverse voltage is applied to zener diode initially current is small, which is it's reverse saturation current.
→ At a certain reverse voltage, the reverse breakdown occurs (V_Z) and current in the zener diode increases rapidly. This breakdown is called zener breakdown.
→ This value is carefully designed by controlling the doping level during manufacturing.
→ The sharp change in the zener current is called knee (or) zener knee of the reverse characteristics.
→ The zener breakdown occurs less than 6 V.
→ The characteristics of zener diode is shown in below figure.



Differentiate between ~~zener~~ Zener Breakdown and Avalanche breakdown.

Zener Breakdown	Avalanche Breakdown.
Break down is due to intense Electric field across the junction.	1. Breakdown is due to the collision of accelerated charge carriers with the adjacent atoms and due to carrier multiplication

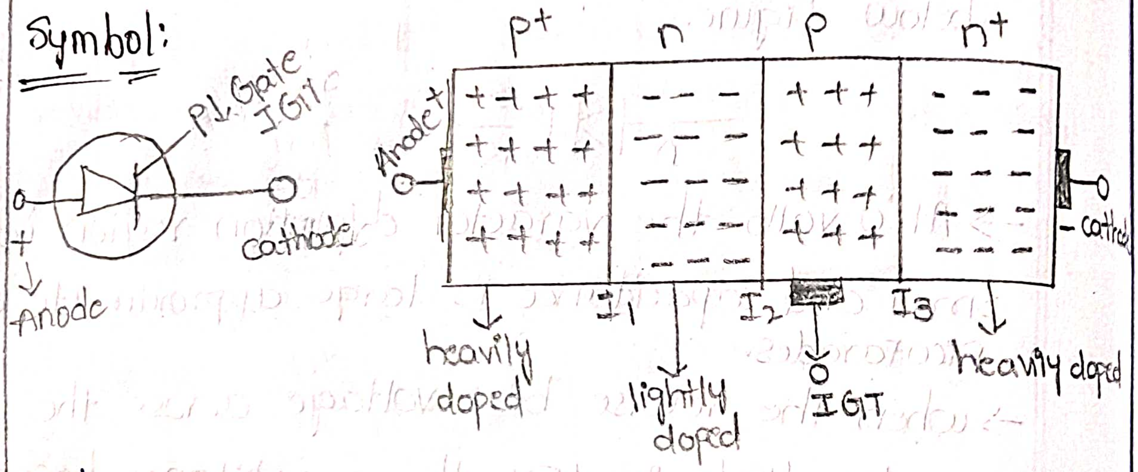
This breakdown occurs with zener voltage less than 6v.	2. This breakdown occurs with junction voltage morethan 6v
The Temperature coefficient is negative	3. The Temperature coefficient is positive.
The breakdown voltage decreases as Junction temperature increases	4. The breakdown voltage increases as Junction temperature increases
The V-I characteristics is very sharp in breakdown region.	5. The V-I characteristics is not as sharp as zener breakdown.

Silicon Controlled Rectifier (SCR): Invented in 1957.

SCR is one which is a controlled switch, which perform function of rectification, inversion & regulation.

→ It is termed as with different names as thyristors, thriode transistor.

Symbol:



→ When one PN Junction is added to a junction transistor, the resulting three PN junction device is called a "SCR".

→ An ordinary rectifier (PN) and a junction transistor (NPN) combined in one unit to form a PNPN device. three terminals are taken as shown in fig.

→ The SCR is a four layer p-n-p-n device where p and n layers are alternately arranged.

→ The outer layers are heavily doped while inner layers are lightly doped.

→ There are three p-n junctions called J_1, J_2 and J_3.

The outer 'p' layer is called anode while outer 'n' layer is called cathode. Middle 'p' layer is called gate.

→ The three terminals are taken out respectively. from these three layers, anode must be positive with respect to cathode to forward bias the SCR.

→ But this is not sufficient criterion to turn SCR ON. To make it ON, a current to be passed through the gate terminal denoted as I_{GT}.

→ thus it is a current operated device. the I_{GT} is the gate trigger current required to make the SCR ON. the basic material used for the SCR fabrication is silicon.

Working principle:- The operation of SCR is divided into 2 categories. i) when gate is open and ii) when gate is closed.

① **When gate is open:-** consider that the anode is positive with respect to cathode and gate is open. The junctions J_1 and J_3 are forward biased and junction J_2 is reverse biased.

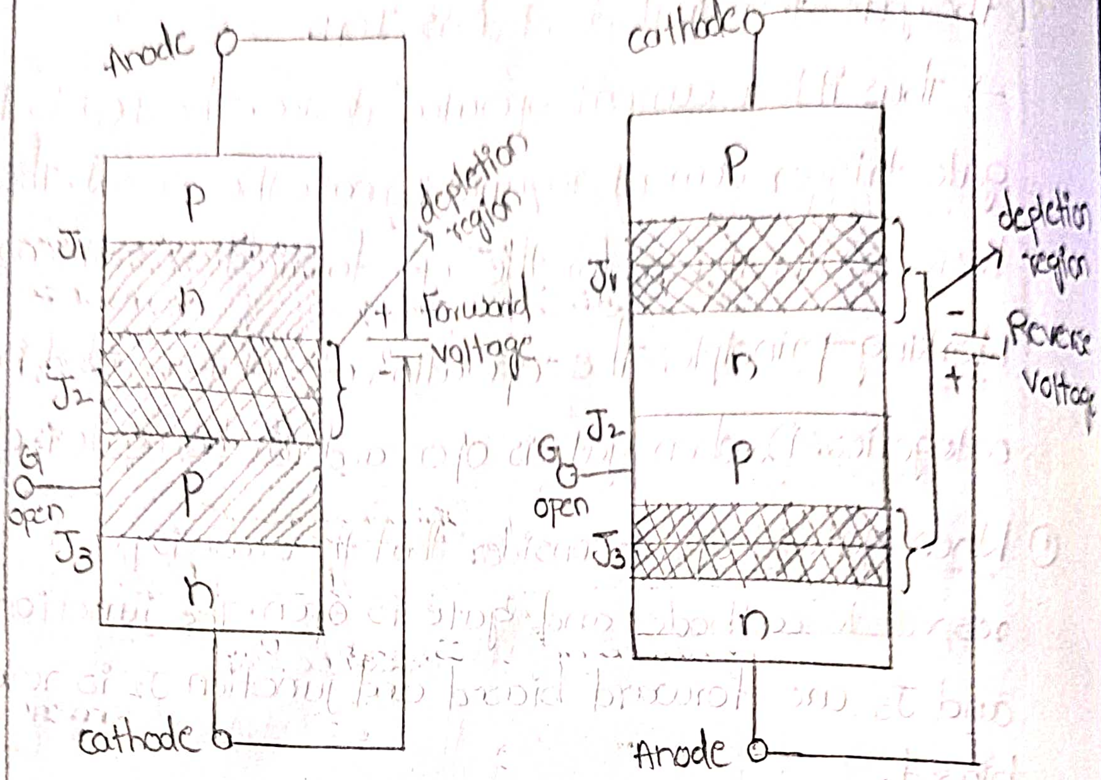
→ There is depletion region around J_2 & only leakage current flows which is negligibly small.

→ Practically the SCR is said to be OFF. this is called Forward blocking state of SCR & voltage applied to anode & cathode with anode positive is called Forward voltage. with gate open, if cathode is made positive with respect to anode, the junctions J_1, J_3 become reverse biased & J_2 forward biased still the current flowing is leakage current, which can be neglected as it is very small.

→ The voltage applied to make cathode positive is called reverse voltage & SCR is said to be in reverse blocking state.

→ In Forward blocking state, if the forward voltage is increased & made sufficiently large, the reverse biased Junction J_2 breaks down & SCR conducts heavily.

→ This voltage is called forward breakover voltage V_{BO} of SCR. In such condition, SCR is said to be ON or triggered.



J_1, J_3 forward biased
J_2 reverse biased

J_1, J_3 reverse biased
J_2 forward biased

Operation of SCR when gate is open.

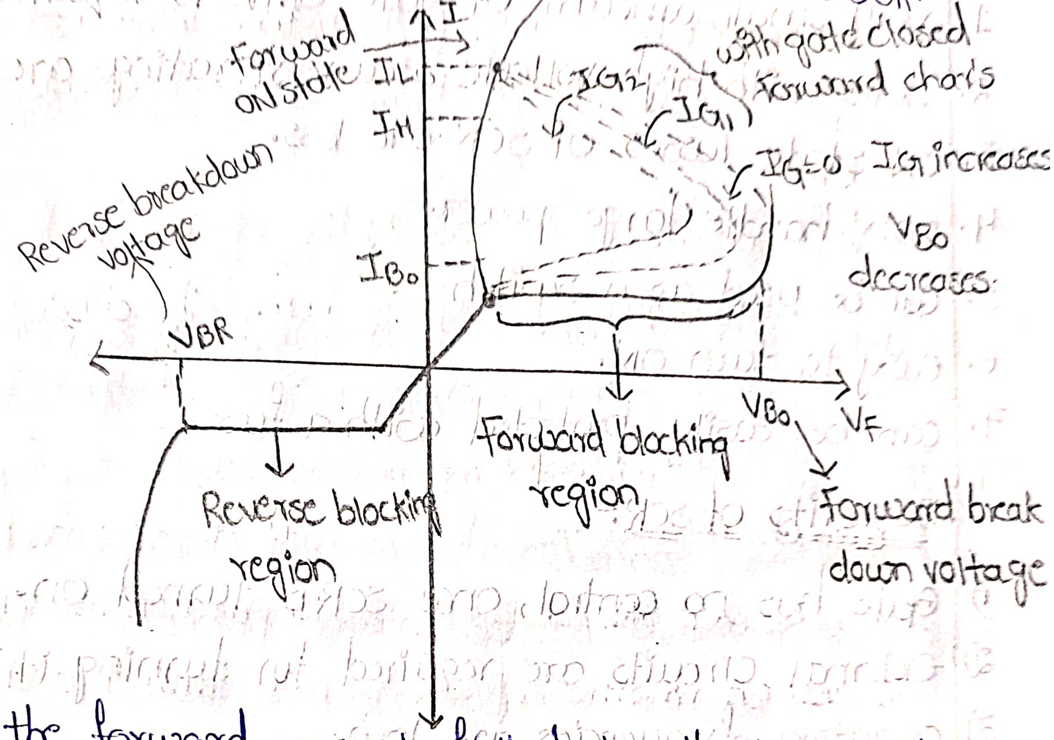
When gate is closed:- consider that the voltage is applied between gate & cathode when the SCR is in forward blocking state. The gate is made +ve with respect to the cathode.
→ The electrons from n-type cathode which are majority in number, cross the junction J_3 to reach to +ve of battery. while holes from P-type move towards the -ve of battery this constitutes the gate current.

Characteristics of SCR:

1) **Forward characteristics:-** It shows a forward blocking region, when $I_G = 0$. It also shows that when forward voltage increases upto V_{BO}, the SCR turns ON & high current results.

→ The drop across SCR reduces suddenly which is now the ohmic drop in the four layers. The current must be limited only by the external resistance in series with the device.

→ It also shows that, if gate bias is used then as gate current increases, less voltage is required to turn ON the SCR.



→ If the forward current falls below the level of the holding current I_H, then depletion region begins to develop around J_2 & device goes into the forward blocking region.

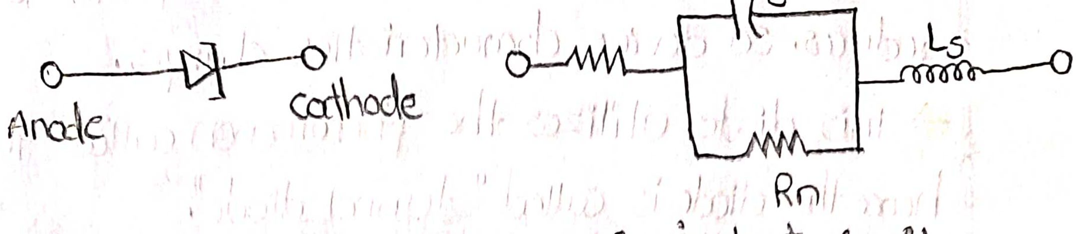
→ When SCR is turned ON from OFF state, the resulting forward current is called latching current I_L. The latching current is slightly higher than the holding current.

2) Reverse characteristics :- If the anode to cathode voltage is reversed then the device enters into the reverse blocking region.

→ The current is negligibly small & practically neglected. If the reverse voltage is increased, similar to the diode, at a particular value avalanche breakdown occurs & a large current flows through the device.

Tunnel diode: / Esaki diode

symbol:-

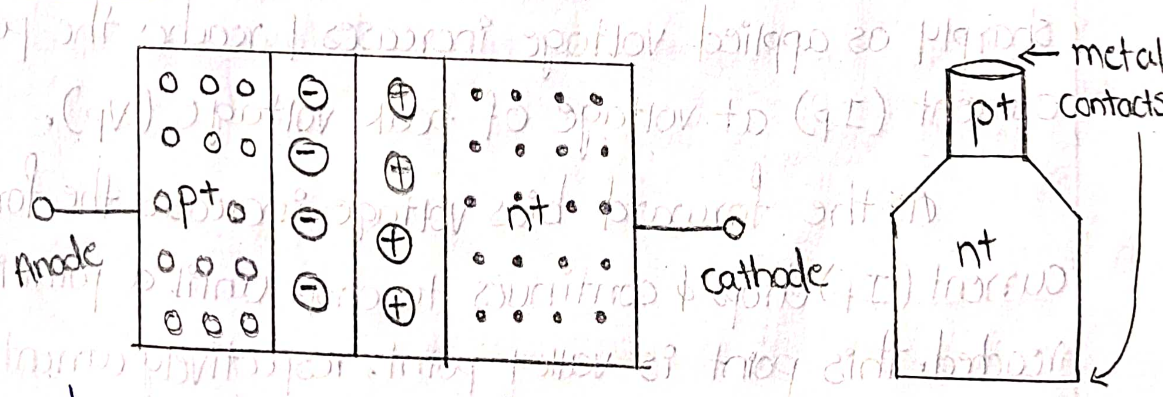


Equivalent circuit

Basics:- It is invented by Leo Esaki in 1957 & he got noble prize in 1960 for his contribution. First manufacture of sony electronics in 1957. other electronics companies are started manufacturing. 1960 onwards.

→ Tunnel diode has fast switching characteristics. so it is used microwave applications. It's working based on theory of quantum mechanical tunneling, Highest frequency, room temperature, solid state oscillations based on (RTD). resonant tunnelling diode. Metal insulator metal [MIM] mostly it is used in research based applications.

Structure:-



→ The tunnel diode is a thin junction diode, under forward bias condition it exhibits -ve resistance. this makes the tunnel diode useful for oscillations (or) amplification.

→ In conventional PN diode is doped to have impurity atoms in the concentration of 1 part in 10^8. then the width of the depletion layer is of the order of a micron.

→ But in tunnel diode the impurity concentration is greatly increased to 1 part in 10^3. then the depletion layer width reduces. so device characteristics changes.

→ this diode utilizes the phenomenon called "tunnelling" & hence the diode is called "tunnel diode".

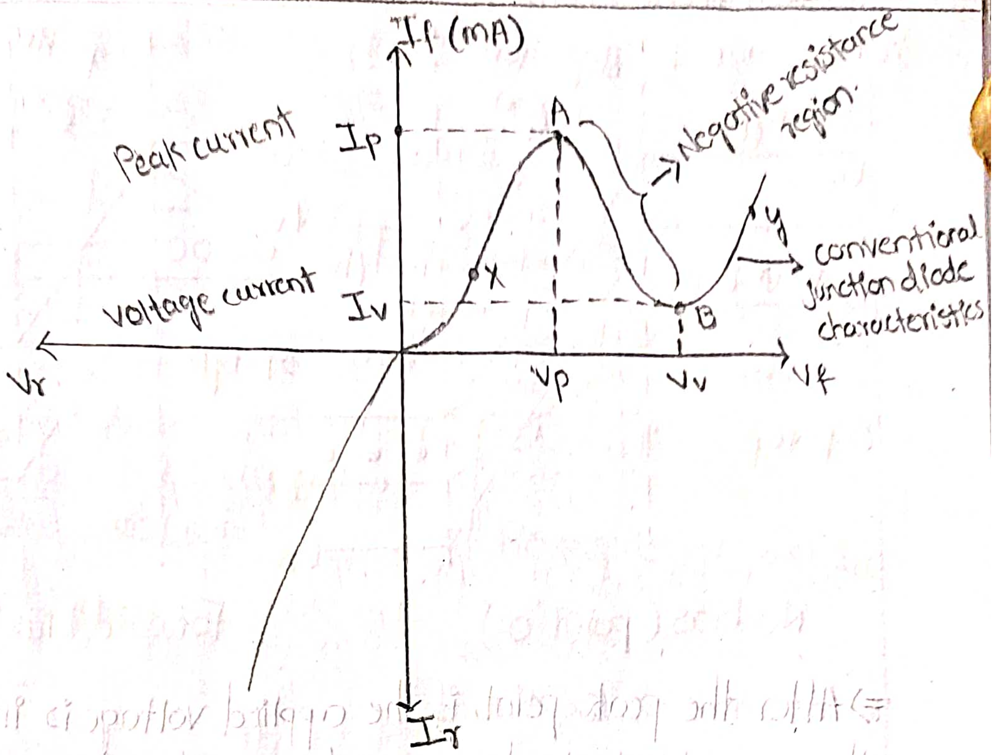
→ the barrier is extremly thin, then instead of crossing over the junction barrier the electron may penetrate through the barrier

→ This behaviour exhibited by the electron to the applied potential is called "tunnelling" hence the diode is called "tunnel diode". This tunnelling effect happens at very low forward bias voltage.

→ V-I characteristics:- The heavily doped tunnel diode results in a thin depletion region so as to permit tunnelling to occur. The VI char's of a typical germanium tunnel diode is shown in the below fig. It is seen at first current rises sharply as applied voltage increases & reaches the peak current (I_P) at voltage of peak voltage (V_P).

As the forward bias voltage increased the forward current (I_F) drops & continues to drop until a point is a reached. this point is valley point, respectively current is valley current (I_V) & Voltage is Valley voltage (V_V).

After the valley point is reached further increase in input voltage increases the current very rapidly as PN junction diode. the tunnel diode exhibits "-ve resistance" characteristics seen between the peak current (I_P) & (I_V). The peak current I_P depends on the impurity.



VI characteristics on the basis of energy band diagram of tunnel diode.

→ The tunnelling phenomenon is explained in terms of the energy band diagram. In p-type material, due to heavy doping there is increased concentrations of holes in the valence band & n-type is high concentrations of electrons in the conduction band.

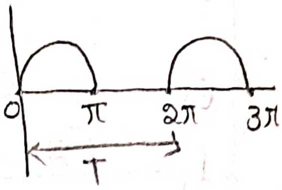
→ Till no, forward bias is applied, the energy levels of holes in "p" region as slightly out of alignment. so no current flows across the junction.

→ When a small forward voltage is applied, the energy bands become move upward, due to this the motion of energy levels of "n" region relative to those of "p" region, the e^- in the conduction band on 'N' side just cross the barrier in the valence band of 'p' side because the two are in exact alignment. At this stage, electrons tunnels the depletion layer with the velocity of light & gives rise to large current. this tunnelling current reaches a maximum value Ip at "Vp".

3. RECTIFIERS

1) Half wave Rectifier :-

3A. **Average DC current (I_{dc}) :-**



$$I_{dc} = \frac{1}{T}\int i\,dt$$

$$I_{dc} = \frac{1}{T}\int I_{in}(t)\,dt$$

$$I_{dc} = \frac{1}{T}\int_0^{2\pi} I_m \sin\omega t . dt$$

$$I_{dc} = \frac{1}{2\pi}\left[\int_0^{\pi} I_m \sin\omega t\,dt + \int_{\pi}^{2\pi} 0\,dt\right]$$

$$I_{dc} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin\omega t\,dt + 0$$

$$I_{dc} = \frac{I_m}{2\pi}\int_0^{\pi} \sin\omega t\,dt$$

$$I_{dc} = \frac{I_m}{2\pi}\left(-\cos\omega t\right)_0^{\pi}$$

$$I_{dc} = \frac{I_m}{2\pi}\left[-\cos(\pi) + \cos(0)\right]$$

$$I_{dc} = \frac{I_m}{2\pi}\left(-(-1)+1\right)$$

$$I_{dc} = \frac{I_m}{2\pi}(1+1)$$

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

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

Average DC voltage $V_{dc} = I_{dc} . R_L$

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

$$V_{dc} = \frac{V_m}{(R_f + R_s + R_L)\pi} \times R_L \qquad \left[\because I_m = \frac{V_m}{R_f + R_s + R_L}\right.$$

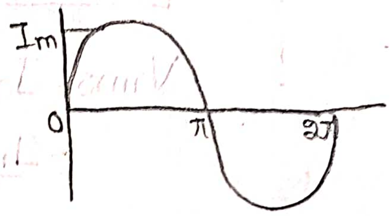
$$V_{dc} = \frac{V_m}{\cancel{R_L} \times \pi} \times \cancel{R_L} \qquad \left[\because R_f + R_s << R_L\right]$$

$$\boxed{V_{dc} = \frac{V_m}{\pi}}$$

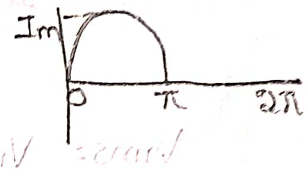
$$I_{dc} = \frac{I_m}{\pi}, \quad V_{dc} = \frac{V_m}{\pi}$$

I_{rms} of out put current:-

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T i^2 dt}$$



$$\boxed{I_{rms}^2 = \frac{1}{T}\int_0^T i^2 dt}$$



$$I_{rms}^2 = \frac{1}{2\pi}\int_0^{2\pi} (i_m(t))^2 dt$$

$$= \frac{1}{2\pi}\int_0^{2\pi} (i_m \sin\omega t)^2 dt$$

$$= \frac{1}{2\pi}\left[\int_0^{2\pi} (I_m \sin\omega t)^2 dt + \int_\pi^{2\pi} 0\, dt\right]$$

$$= \frac{1}{2\pi}\int_0^{2\pi} I_m^2 \sin^2\omega t . dt$$

$$= \frac{I_m^2}{2\pi}\int_0^{\pi} \sin^2\omega t\, dt$$

$$I_{rms}^2 = \frac{I_m^2}{2\pi}\int_0^{\pi} \frac{1-\cos 2\omega t}{2} dt \qquad \left[\because \cos 2\theta = 1-2\sin^2\theta \quad 2\sin^2\theta = 1-\cos 2\theta \quad \sin^2\theta = \frac{1-\cos 2\theta}{2}\right]$$

$$= \frac{I_m^2}{4\pi}\left[\int_0^{\pi} 1 dt - \int_0^{\pi} \cos 2\omega t dt\right]$$

$$= \frac{I_m^2}{4\pi}\left[(t)_0^{\pi} - \left(\frac{\sin 2\omega t}{2}\right)_0^{\pi}\right] \qquad \left[\because \int \cos 2x = \frac{\sin 2x}{2}\right]$$

$$= \frac{I_m^2}{4\pi}\left[\pi - 0 - \left(\frac{\sin 2\pi}{2} - \frac{\sin 0}{2}\right)\right]$$

$$= \frac{I_m^2}{4\pi}\left[\pi - (0-0)\right] \qquad [\because \sin 0 = \sin\pi = \sin 2\pi = 0]$$

$$= \frac{I_m^2}{4\cancel{\pi}} \times \cancel{\pi} = \frac{I_m^2}{4}$$

$$I_{rms}^2 = \frac{I_m^2}{4}$$

$$I_{rms} = \sqrt{\frac{I_m^2}{4}} \Rightarrow \sqrt{\left(\frac{I_m}{2}\right)^{\cancel{2}}}$$

$$\boxed{I_{rms} = \frac{I_m}{2}} \quad \boxed{I_{dc} = \frac{I_m}{\pi}}$$

$$V_{rms} = I_{rms} \cdot R_L$$

$$= \frac{I_m}{2} \cdot R_L$$

$$= \frac{V_m}{2(R_s+R_f+R_L)} \times R_L \qquad \left[\because I_m = \frac{V_m}{R_s+R_f+R_L}\right]$$

$$V_{rms} = \frac{V_m}{2\cancel{R_L}} \times \cancel{R_L} \qquad [\because R_s+R_f << R_L]$$

$$\boxed{V_{rms} = \frac{V_m}{2}}$$

2) Ripple Factor (RF):-

$$\tau = \frac{I_{ac}}{I_{dc}}$$

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

$$\tau = \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}} = \frac{\sqrt{I_{dc}^2\left[\frac{I_{rms}^2}{I_{dc}^2} - 1\right]}}{I_{dc}}$$

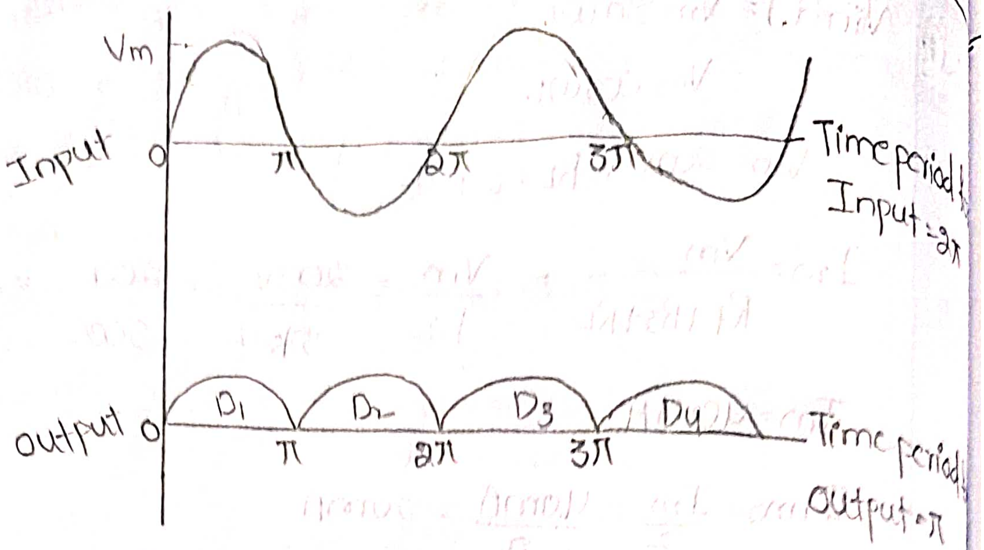
$$\tau = \frac{\cancel{I_{dc}}\sqrt{\frac{I_{rms}^2}{I_{dc}^2} - 1}}{\cancel{I_{dc}}} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

$$\tau \text{ for HWR} = \sqrt{\left(\frac{\cancel{I_m}/2}{\cancel{I_m}/\pi}\right)^2 - 1}$$

$$= \sqrt{\left(\frac{\pi}{2}\right)^2 - 1}$$

$$= \sqrt{1.4624} = 1.21$$

$$\boxed{\tau = 1.21}$$



$\boxed{I_{in}(t) = I_m \sin \omega t}$

Parameters OF FWR.

1) Average DC current :-

w.r.to (π)

$$I_{DC} = \frac{1}{T}\int_0^T i(t)\,dt$$

$$= \frac{1}{\pi}\int_0^{\pi} I_m \sin\omega t\,dt$$

$$= \frac{I_m}{\pi}\int_0^{\pi} \sin\omega t\,dt = \frac{I_m}{\pi}\left[-\cos\omega t\right]_0^{\pi}$$

$$= -\frac{I_m}{\pi}\left[\cos\pi - \cos 0\right]$$

$$= -\frac{I_m}{\pi}\left[-1-1\right] = -\frac{I_m}{\pi}(-2) = \frac{2I_m}{\pi}$$

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

(or)

w.r.to (2π)

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i(t)\,dt = \frac{1}{2\pi}\int_0^{2\pi} I_m \sin\omega t\,dt$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} I_m \sin\omega t\,dt + \int_{\pi}^{2\pi} I_m \sin\omega t\,dt\right]$$

$$= \frac{1}{2\pi}\left[I_m[-\cos\omega t]_0^{\pi} + I_m[-\cos\omega t]_{\pi}^{2\pi}\right]$$

$$= \frac{1}{2\pi}\left[I_m(-\cos\pi - \cos 0) + I_m[-\cos\pi - \cos 2\pi)\right]$$

$$= \frac{1}{2\pi}\left[I_m(-(-1-1) + I_m(-(1+1))\right]$$

$$= \frac{1}{2\pi}\left[I_m(2) - I_m(-2)\right]$$

$$= \frac{1}{2\pi}\left[2I_m + 2I_m\right]$$

$$= \frac{1}{2\pi}[4I_m] \Rightarrow \frac{4I_m}{2\pi} = \frac{2I_m}{\pi}$$

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

Average DC voltage:-

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

$$= \frac{2}{\pi} \frac{V_m}{(R_f + R_s + R_L)} \cdot R_L \quad [\because R_f + R_s << R_L]$$

$$= \frac{2}{\pi} \frac{V_m}{\cancel{R_L}} \cdot \cancel{R_L}$$

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

Irms current:- $I_{rms} = \sqrt{\frac{1}{T}\int_0^T i^2(t)\,dt}$

$$I_{rms}^2 = \frac{1}{T}\int_0^T i(t)^2\,dt$$

$$I_{rms}^2 = \frac{1}{2\pi}\int_0^{2\pi} i(t)^2\,dt$$

$$I_{rms}^2 = \frac{1}{\pi}\int_0^{\pi} i(t)^2\,dt$$

$$I_{rms}^2 = \frac{1}{\pi}\int_0^{\pi} (I_m \sin(\omega t))^2\,dt$$

$$I_{rms}^2 = \frac{I_m^2}{\pi}\int_0^{\pi} \sin^2\omega t\,dt$$

$$I_{rms}^2 = \frac{I_m^2}{\pi}\int_0^{\pi} \frac{1-\cos 2\omega t}{2}\,dt \quad \left[\because \sin^2\theta = \frac{1-\cos 2\theta}{2}\right]$$

$$I_{rms}^2 = \frac{I_m^2}{\pi}\left[\int_0^{\pi}\frac{1}{2}\,dt - \int_0^{\pi}\frac{\cos 2\omega t}{2}\,dt\right]$$

$$I_{rms}^2 = \frac{I_m^2}{\pi}\left[\frac{1}{2}(t)_0^{\pi} - \frac{1}{2}\left(\frac{\sin 2\omega t}{2}\right)_0^{\pi}\right]$$

$$I_{rms}^2 = \frac{I_m^2}{\pi}\left[\frac{\pi}{2} - \frac{1}{4}(\sin 2\pi - \sin 0)\right]$$

$$I_{rms}^2 = \frac{I_m^2}{\pi}\left[\frac{\pi}{2} - \frac{1}{4}(0)\right]$$

$$I_{rms}^2 = \frac{I_m^2}{\pi}\left[\frac{\pi}{2}\right] = \frac{I_m^2}{2}$$

$$I_{rms}^2 = \frac{I_m^2}{2} \Rightarrow I_{rms} = \sqrt{\frac{I_m^2}{2}} = \sqrt{\left(\frac{I_m}{\sqrt{2}}\right)^2}$$

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

$$\Rightarrow V_{rms} = I_{rms} \cdot R_L$$

$$V_{rms} = \frac{I_m}{\sqrt{2}} \times R_L$$

$$V_{rms} = \frac{V_m}{\sqrt{2}(R_f + R_s + R_L)} \cdot R_L \quad (\because R_s + R_f \ll R_L)$$

$$V_{rms} = \frac{V_m}{\sqrt{2}\cdot \cancel{R_L}} \times \cancel{R_L}$$

$$\boxed{V_{rms} = \frac{V_m}{\sqrt{2}}}$$

Ripple Factor :-

$$\Upsilon = \frac{I_{ac}}{I_{dc}} = \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}}$$

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

$$\Upsilon = \sqrt{\left(\frac{I_m/\sqrt{2}}{\frac{2I_m}{\pi}}\right)^2 - 1} = \sqrt{\frac{I_m^2}{2} \times \frac{\pi^2}{4I_m^2} - 1}$$

$$\tau = \sqrt{\frac{\pi^2}{8} - 1} = 0.48$$

$$\boxed{\tau = 0.48}$$

Efficiency (η):- $\frac{P_{dc}}{P_{ac}}$

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

$$P_{dc} = \frac{4I_m^2}{\pi^2} \times R_L$$

$$P_{ac} = I_{rms}^2 (R_f + R_s + R_L)$$

$$P_{ac} = \left(\frac{I_m}{\sqrt{2}}\right)^2 (R_f + R_s + R_L)$$

$$P_{ac} = \frac{I_m^2}{2} (R_f + R_s + R_L)$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{\frac{4I_m^2}{\pi^2} \cdot R_L}{\frac{I_m^2}{2} (R_f + R_s + R_L)}$$

$$\eta = \frac{4\cancel{I_m^2} \cdot R_L}{\pi^2} \times \frac{2}{\cancel{I_m^2} (R_f + R_s + R_L)}$$

$$\eta = \frac{8R_L}{\pi^2 (R_f + R_s + R_L)}$$

$$\eta = \frac{8R_L}{\pi^2 (R_L)}$$

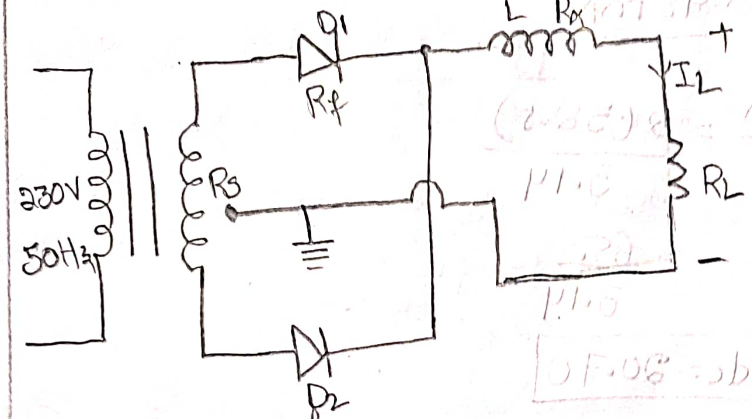
$$\eta = \frac{8}{\pi^2} = \frac{8}{9.8596}$$

$$\eta = 0.8113$$

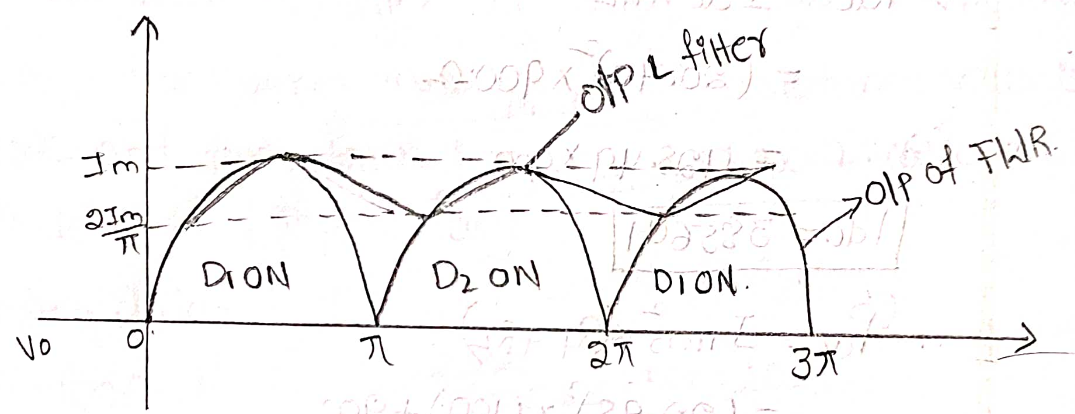
$$\% \eta = 0.8113 \times 100$$

$$\boxed{\% \eta = 81.13\%}$$

L Section Filter:- It consists of centre tapped type rectifier (or) Bridge type rectifier, an inductor and load Resistance (R_L) which is shown in below fig.



Output wave form:-



→ The impedance of inductor varies with frequency ($X_L = 2\pi f L$). Hence the inductor will remove all the high frequency components and leaves DC and low frequency ripple components.

→ This filter is also called choke filter.

Derivation of 'L' Filter:-

From the output wave form of inductive filter the load current can be expressed as

$$I_L = \frac{2I_m}{\pi} - \frac{4I_m}{3\pi}\cos 2\theta - \frac{4}{15\pi}\cos 4\theta - \text{[}\because \text{From Fourier series]}$$

In terms of frequency it can be expressed as

$$I_L = \frac{2I_m}{\pi} - \frac{4I_m}{3\pi}\cos 2\omega t - \frac{4}{15\pi}\cos 4\omega t$$

The above expressions can also be expressed in output voltage

$$V_0 = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi}\cos 2\theta - \frac{4}{15\pi}\cos 4\theta -$$

$$V_0 = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi}\cos 2\omega t - \frac{4}{15\pi}\cos 4\omega t -$$

neglecting higher order AC ripples (or) harmonic terms

then $I_L = \frac{2I_m}{\pi} - \frac{4I_m}{3\pi}\cos 2\omega t.$

$$V_0 = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi}\cos 2\omega t$$

here $\frac{2V_m}{\pi}$ is called DC term. remaining $\frac{4V_m}{3\pi}\cos 2\omega t$ term is called AC term.

→ We know that $V_{dc} = \frac{2V_m}{\pi}$ [∵ FWR]

$$I_{dc} = \frac{V_{dc}}{(R_f + R_x + R_s + R_L)}$$

if $R_f + R_x + R_s << R_L$

$$I_{dc} = \frac{V_{dc}}{R_L}$$ [here R_x = reactance of inductor]

$$I_{dc} = \frac{\frac{2V_m}{\pi}}{R_L}$$

$$\boxed{I_{dc} = \frac{2V_m}{\pi R_L}}$$

⇒ The second harmonic component represents AC component is given by.

$$I_m = \frac{V_m}{Z}$$

but here V_m has magnitude $\frac{4V_m}{3\pi}$

$$\therefore I_m = \frac{4V_m}{3\pi Z}$$

Here $Z = R_L + jX_L \Rightarrow |Z| = \sqrt{R_L^2 + X_L^2}$

$$\therefore I_m = \frac{4V_m}{3\pi\sqrt{R_L^2+X_L^2}}$$

we know that I_{rms} of Full wave Rectifier is given by

$$I_{rms} = \frac{I_m}{\sqrt{2}} \Rightarrow \frac{\frac{4V_m}{3\pi\sqrt{R_L^2+X_L^2}}}{\sqrt{2}}$$

$$I_{rms} = \frac{4V_m}{3\sqrt{2}\pi\sqrt{R_L^2+X_L^2}}$$

Ripple Factor $(\gamma) = \frac{I_{rms}}{I_{dc}}$

$$\gamma = \frac{\frac{4V_m}{3\sqrt{2}\pi\sqrt{R_L^2+X_L^2}}}{\frac{2V_m}{\pi R_L}}$$

$$\gamma = \frac{\cancel{4}^{2}\cancel{V_m}}{3\sqrt{2}\cancel{\pi}\sqrt{R_L^2+X_L^2}} \times \frac{\cancel{\pi}R_L}{\cancel{2}\cancel{V_m}}$$

$$\gamma = \frac{2R_L}{3\sqrt{2}\sqrt{R_L^2+X_L^2}}$$

$$\gamma = \frac{\cancel{\sqrt{2}}\times\sqrt{2}R_L}{3\cancel{\sqrt{2}}\sqrt{R_L^2+X_L^2}} = \frac{\sqrt{2}R_L}{3\sqrt{R_L^2+X_L^2}}$$

$$\gamma = \frac{\sqrt{2}R_L}{3\sqrt{R_L^2\left(1+\frac{X_L^2}{R_L^2}\right)}} = \frac{\sqrt{2}\cancel{R_L}}{3\cancel{R_L}\sqrt{\left(1+\left(\frac{X_L}{R_L}\right)^2\right)}}$$

$$\boxed{\gamma = \frac{\sqrt{2}}{3\sqrt{\left[1+\left(\frac{X_L}{R_L}\right)^2\right]}}}$$

case(i):- If $\frac{X_L}{R_L} << 1$ then neglect $\frac{X_L}{R_L}$ in above expression

$$\therefore \gamma = \frac{\sqrt{2}}{3\sqrt{1}} = \frac{\sqrt{2}}{3}$$

$$\gamma = \frac{\sqrt{2}}{3} \times \frac{\sqrt{2}}{\sqrt{2}}$$

$$\boxed{\gamma = \frac{2}{3\sqrt{2}}}$$

case(ii):- If $\frac{X_L}{R_L} >> 1$ then neglect 1 in above expression.

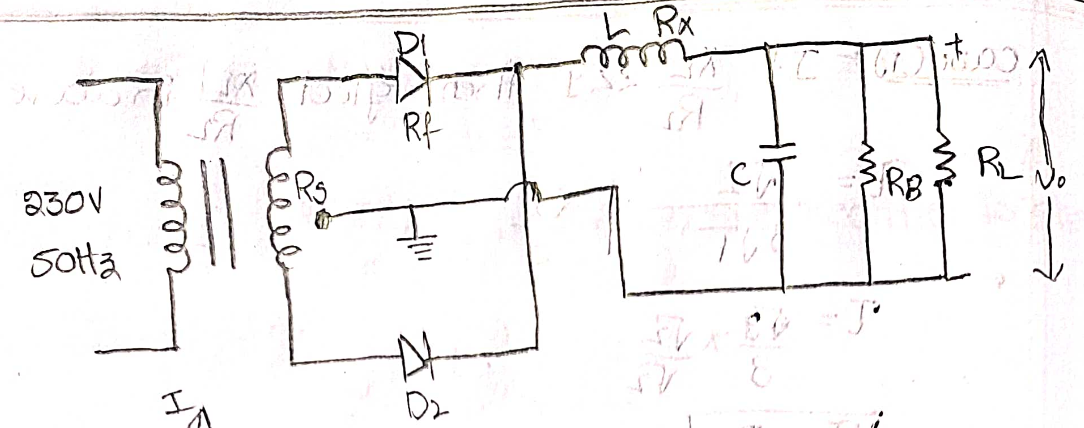
$$\therefore \gamma = \frac{\sqrt{2}}{3\sqrt{\left(\frac{X_L}{R_L}\right)^2}} = \frac{\sqrt{2}}{3\frac{X_L}{R_L}} = \frac{\sqrt{2}R_L}{3X_L}$$

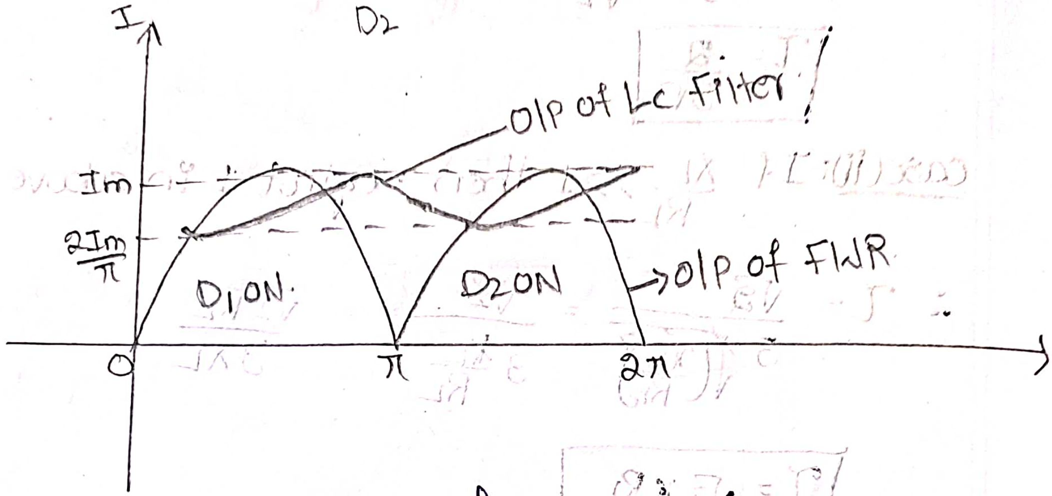
$$\boxed{\gamma = \frac{\sqrt{2} \times R_L}{3\omega L}}$$

From above expression the ripple factor of inductive filter is inversely proportional to inductance and proportional to Road Resistance R_L.

LC Filter:- It consists of centre tapped type rectifier or Bridge type rectifier, an inductor which is connected in series with parallel combination of capacitance 'C', Bleeder resistance (R_B) and Road Resistance (R_L).

We know that the impedance of inductor varies with frequency. Hence inductor will remove all the high frequency components and leavs DC and low frequency components. The circuit diagram of LC filter with R_B is shown in below figure.





From the output wave form,

$$I_L = \frac{2I_m}{\pi} - \frac{4I_m}{3\pi}\cos 2\omega t - \frac{4}{15\pi}\cos 4\omega t - -$$

The output voltage can be expressed as

$$V_o = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi}\cos 2\omega t - \frac{4}{15\pi}\cos 4\omega t - - -$$

neglecting higher order harmonics,

$$I_L = \frac{2I_m}{\pi} - \frac{4I_m}{3\pi}\cos 2\omega t$$

$$V_o = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi}\cos 2\omega t$$

here, $\frac{2I_m}{\pi}$ (or) $\frac{2V_m}{\pi}$ is called DC term.

$\frac{4I_m}{3\pi}\cos 2\omega t$, $\frac{4V_m}{3\pi}\cos 2\omega t$ is called AC term.

neglecting diode Forward Resistance and Transformer secondary winding Resistance. we can write the DC Component of Current as $I_{dc} = \dfrac{\frac{2V_m}{\pi}}{R_x + R}$

where $R = R_B || R_L = \frac{R_B \times R_L}{R_B + R_L}$

$$V_{dc} = I_{dc} \times R$$

$$V_{dc} = \frac{\frac{2V_m}{\pi}}{R_x + R} \times R.$$

$$V_{dc} = \frac{2V_m/\pi}{R\left(1 + \frac{R_x}{R}\right)} \times R$$

$$V_{dc} = \frac{2V_m/\pi}{1 + \frac{R_x}{R}}$$

$$\boxed{V_{dc} = \frac{2V_m}{\pi\left(1 + \frac{R_x}{R}\right)}}$$

$$V_{dc} = \frac{2V_m}{\pi} \quad \left[\because \text{if } \frac{R_x}{R} << 1\right]$$

From the circuit impedence value is the parallel combination of capacitance and Resistance (R) [$R = R_B || R_L$] and series with impedence of inductor

$$\therefore Z = R_x + j2\omega L + \frac{1}{j2\omega c} || R.$$

Assume that $\frac{1}{2\omega c} << R$ and $2\omega L >> R_x$ then.

$$Z = j2\omega L + 0.$$

$$Z = j2\omega L$$

magnitue of $Z = |Z| = 2\omega L$.

Second harmonic component of the current is given by

$$I_{2m} = \frac{V_m}{|Z|} = \frac{\frac{4V_m}{3\pi}}{|Z|} = \frac{4V_m}{3\pi|Z|}$$

$$V_{2m} = I_{2m} \times \left(\frac{1}{2\omega c} || R\right)$$

$$V_{2m} = I_{2m} \times \frac{1}{2\omega c}$$

$$V_{2m} = \frac{4V_m}{3\pi|Z|} \times \frac{1}{2\omega C}$$

$$V_{2m} = \frac{4V_m}{3\pi(\cancel{2}\omega L)(\cancel{2}\omega C)}$$

$$V_{2m} = \frac{V_m}{3\pi\omega^2 LC}$$

$$V_{rms} = \frac{V_{2m}}{\sqrt{2}} = \frac{V_m}{3\pi\omega^2 LC \times \sqrt{2}}$$

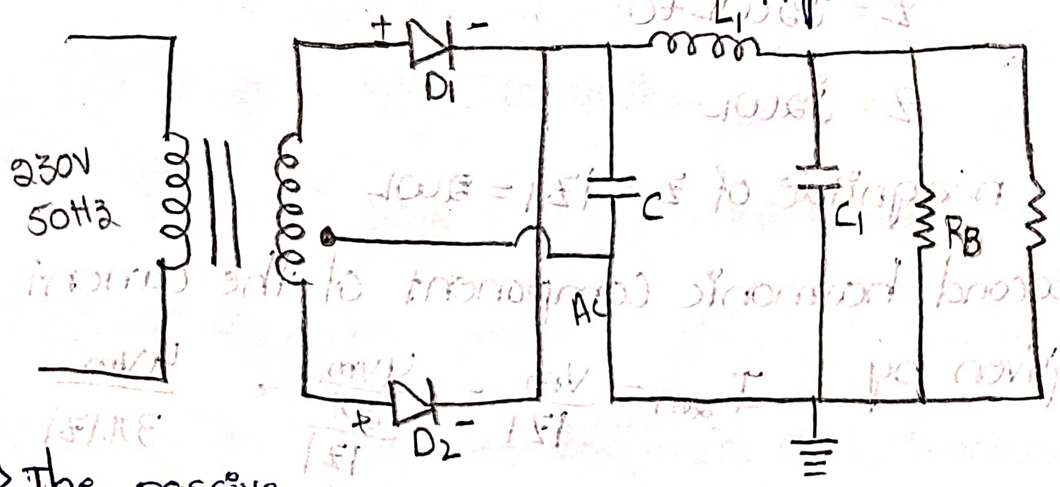
$$\text{Ripple Factor} = \frac{V_{rms}}{V_{dc}} = \frac{\frac{V_m}{3\pi\omega^2 LC \times \sqrt{2}}}{\frac{2V_m}{\pi\left(1+\frac{R_x}{R}\right)}}$$

$$\gamma = \frac{V_m}{3\pi\omega^2 LC \times \sqrt{2}} \times \frac{\pi}{2V_m}\left(1+\frac{R_x}{R}\right)$$

$$\boxed{\gamma = \frac{1}{6\sqrt{2}\,\omega^2 LC}\left(1+\frac{R_x}{R}\right)}$$

$$\gamma = \frac{1}{6\sqrt{2}\,\omega^2 LC} \quad \left[\because \text{if } \left[\left(1+\frac{R_x}{R}\right) \simeq 1\right]\right]$$

CLC or π section filter:- The circuit diagram of CLC filter is shown in below figure.



→ The passive components C, L1, C1 forms a π-structure hence it is also called π-section filter.

We know that the output wave form of capacitive Filter is in the form of triangular waves.

→ According to Fourier series the out put voltage across the capacitor is given by.

$$V_c = V_{dc} - \frac{V_m}{\pi}\left[\sin 2\omega t - \frac{\sin 4\omega t}{2} + \frac{\sin 6\omega t}{3} + \cdots\right]$$

$$V_c = V_{dc} - \frac{V_m}{\pi}\sin 2\omega t + \frac{V_m}{2\pi}\sin 4\omega t - \frac{V_m}{3\pi}\sin 6\omega t \cdots]$$

From above expression.

dc component $= V_{dc}$

Ac component $= \frac{V_m}{\pi}\sin 2\omega t$

→ Hence magnitude is given by $\frac{V_m}{\pi}$ [neglecting higher order terms].

we know that $I_m = \frac{V_m}{X_{L1}}$

$$I_m = \frac{V_m}{\pi X_{L1}}$$

From the capacitive Filter Vm is given by.

$$V_m = \frac{I_{dc}}{2fc}$$

Now $I_m = \frac{I_{dc}}{2\pi fc X_{L1}}$

we know that Irms of FWR is

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

$$I_{rms} = \frac{I_{dc}}{2\sqrt{2}\pi fc X_{L1}}$$

voltage across capacitor C1,

$$V_{rms} = I_{rms} \times X_{C1}$$

$$V_{rms} = \frac{I_{dc}}{2\sqrt{2}\pi f C} \times \frac{X_{C1}}{X_{L1}}$$

We know that ripple factor of Filter is given by

$$r = \frac{V_{rms}}{V_{dc}}$$

Now

$$V_{rms} = \frac{V_{dc}}{2\sqrt{2}\pi f C R} \times \frac{X_{C1}}{X_{L1}} \quad [\because R = R_B \| R_L]$$

Now $$r = \frac{\frac{V_{dc}}{2\sqrt{2}\pi f C R} \times \frac{X_{C1}}{X_{L1}}}{V_{dc}}$$

$$r = \frac{1}{2\sqrt{2}\pi f C R} \times \frac{X_{C1}}{X_{L1}}$$

$$r = \frac{1}{2\sqrt{2}\pi f C R} \times \frac{1}{2\omega C_1} \times \frac{1}{2\omega L_1} \quad \left[\because X_C = \frac{1}{2\pi f C}\right] \left[= \frac{1}{2\omega C}\right]$$

$$r = \frac{1}{8\sqrt{2}\pi f C R \omega^2 C_1 L_1}$$

$$r = \frac{1}{8\sqrt{2}\pi f C R (2\pi f)^2 C_1 L_1} \quad [\because \omega = 2\pi f]$$

$$r = \frac{1}{32\sqrt{2}\pi f C R \pi^2 f^2 C_1 L_1}$$

$$r = \frac{1}{32\sqrt{2}\pi^3 f^3 C R C_1 L_1}$$

$$r = \frac{1}{4\sqrt{2}(2\pi f)^3 C R C_1 L_1}$$

$$r = \frac{1}{4\sqrt{2}(\omega)^3 C R C_1 L_1}$$

$$\boxed{r = \frac{\sqrt{2}}{8(\omega)^3 C R C_1 L_1}}$$

relationship between α, β, γ :-

we know that from three configurations of BJT amplification factors can be represented as follows.

$$\alpha = \frac{I_C}{I_E}, \quad \beta = \frac{I_C}{I_B} \text{ and } \gamma = \frac{I_E}{I_B}$$

$$I_C = \alpha I_E \quad I_B = \beta I_B, \quad I_E = \gamma I_B.$$

Relationship between α, β.

$$I_E = I_B + I_C. \quad [\because \text{Transistor current eq}^n]$$

$$\alpha \cancel{I_E} = \frac{I_C}{I_E} = \frac{I_C}{I_B + I_C}$$

$$\alpha = \frac{\beta I_B}{I_B + \beta I_B}$$

$$\alpha = \frac{\beta \cancel{I_B}}{\cancel{I_B}(1+\beta)}$$

$$\boxed{\alpha = \frac{\beta}{1+\beta}}$$

Relationship between β and α.

$$I_E = I_B + I_C$$

$$I_E = I_B + \beta I_B.$$

$$I_E = I_B(1+\beta)$$

$$\beta = \frac{I_C}{I_B} = \frac{\alpha I_E}{I_B}$$

$$\beta = \frac{\alpha \cancel{I_B}(1+\beta)}{\cancel{I_B}}$$

$$\beta = \alpha(1+\beta)$$

$$\beta = \alpha + \alpha\beta$$

$$\alpha = \beta - \alpha\beta$$

$$\beta(1-\alpha) = \alpha$$

$$\boxed{\beta = \frac{\alpha}{1-\alpha}}$$

(or)

$$\alpha = \frac{\beta}{1+\beta}$$

$$1-\alpha = \frac{1}{1} - \frac{\beta}{1+\beta} = \frac{1+\beta-\beta}{1+\beta} = \frac{1}{1+\beta}$$

$$1-\alpha = \frac{1}{1+\beta}$$

$$\frac{1}{1-\alpha} = 1+\beta$$

$$\beta = \frac{1}{1-\alpha} - 1$$

$$\beta = \frac{1-(1-\alpha)}{1-\alpha}$$

$$\beta = \frac{1-1+\alpha}{1-\alpha}$$

$$\boxed{\beta = \frac{\alpha}{1-\alpha}}$$

Relationship b/w γ and β.

$$\gamma = \frac{I_E}{I_B}$$

$$\gamma = \frac{\cancel{I_B}(1+\beta)}{\cancel{I_B}}$$

$$\boxed{\gamma = 1+\beta}$$

Relationship b/w γ & α

$$\gamma = \frac{I_E}{I_B}$$

$$\gamma = \frac{\cancel{I_B}(1+\beta)}{\cancel{I_B}}$$

$$\gamma = 1+\beta$$

$$\gamma = 1+\beta \quad \text{—— (1)}$$

$$= 1 + \frac{\alpha}{1-\alpha}$$

$$= \frac{1-\alpha+\alpha}{1-\alpha}$$

$$\boxed{\gamma = \frac{1}{1-\alpha}} \quad \text{—— (2)}$$

Relationship b/w α, β, γ from (1) & (2)

$$\boxed{\gamma = 1+\beta = \frac{1}{1-\alpha}.}$$

Stability factor (S') is the rate of change of collector current (I_C) w.r.to Base Emitter Voltage (V_{BE}) by keeping I_{CO} and β are constant.

$$S' = \frac{\Delta I_C}{\Delta V_{BE}} = \frac{\partial I_C}{\partial V_{BE}} \Big| I_{CO}, \beta \text{ are constant.}$$

→ Stability factor (S'') is defined as the rate of change of collector current (I_C) w.r.to β by keeping I_{CO} and V_{BE} constant

$$S'' = \frac{\Delta I_C}{\Delta \beta} = \frac{\partial I_C}{\partial \beta} \Big| I_{CO}, V_{BE} \text{ constant.}$$

16/03/22 Stability Factor (S) :- For a common-Emitter configuration collector current is given by

$$I_C = \beta I_B + (1+\beta) I_{CBO}.$$

Derivate w.r.to I_C.

$$\frac{\partial I_C}{\partial I_C} = \frac{\partial}{\partial I_C}\left[\beta I_B + (1+\beta) I_{CBO}\right]$$

$$\frac{\partial I_C}{\partial I_C} = \frac{\partial}{\partial I_C}\beta I_B + \frac{\partial}{\partial I_C}(1+\beta) I_{CBO}$$

$$1 = \beta \cdot \frac{\partial I_B}{\partial I_C} + (1+\beta)\frac{\partial I_{CBO}}{\partial I_C}$$

$$1 - \beta \cdot \frac{\partial I_B}{\partial I_C} = (1+\beta)\frac{\partial I_{CBO}}{\partial I_C}$$

$$\frac{1-\beta \cdot \frac{\partial I_B}{\partial I_C}}{1+\beta} = \frac{\partial I_{CBO}}{\partial I_C}$$

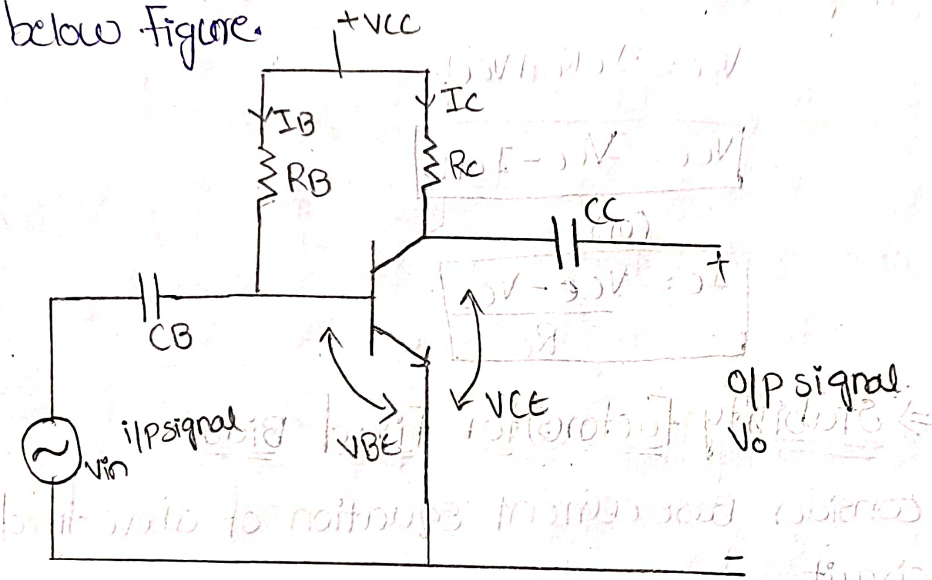
$$\frac{\partial I_{CBO}}{\partial I_C} = \frac{1-\beta \cdot \frac{\partial I_B}{\partial I_C}}{1+\beta}$$

$$\frac{\partial I_C}{\partial I_{CBO}} = \frac{1+\beta}{1-\beta\left(\frac{\partial I_B}{\partial I_C}\right)}$$

$$\boxed{S = \frac{\partial I_C}{\partial I_{CBO}} = \frac{\Delta I_C}{\Delta I_{CBO}} = \frac{1+\beta}{1-\beta\left(\frac{\partial I_B}{\partial I_C}\right)}}$$

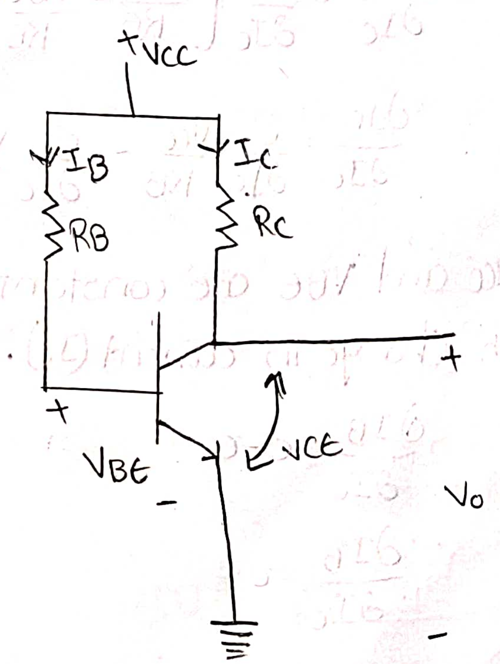
→ This is called standard equation of derivation of stability factor for other biasing circuits.

i) Fixed Bias :- It is also called base Resistor method. The amplifier circuit of fixed bias circuit is shown in below figure.



→ It is the simplest dc bias configuration. For DC analysis, we can replace capacitors with an open circuit because the reactance of capacitance is infinity for dc

→ The DC equivalent circuit of fixed bias is shown in below figure.



→ Apply KVL to the base circuit.

$\therefore V_{CC} = I_B R_B + V_{BE}$

$V_{CC} - V_{BE} = I_B R_B$

$$\boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B}}$$

apply KVL to the collector circuit.

$$V_{CC} = I_C R_C + V_{CE}.$$

$$\boxed{V_{CE} = V_{CC} - I_C R_C}$$

(or)

$$\boxed{I_C = \frac{V_{CE} - V_{CE}}{R_C}}$$

⇒ Stability Factor(s) for Fixed Bias :-

consider Base current equation of above fixed bias circuit

$$\therefore I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

$$I_B = \frac{V_{CC}}{R_B} - \frac{V_{BE}}{R_B}$$

derivate w.r.to I_C

$$\frac{\partial I_B}{\partial I_C} = \frac{\partial}{\partial I_C}\left[\frac{V_{CC}}{R_B} - \frac{V_{BE}}{R_B}\right]$$

$$\frac{\partial I_B}{\partial I_C} = \frac{\partial}{\partial I_C}\frac{V_{CC}}{R_B} - \frac{\partial}{\partial I_C}\frac{V_{BE}}{R_B}.$$

here both V_{CC} and V_{BE} are constant terms (or) doesn't changes with change in current (I_C).

$$\frac{\partial I_B}{\partial I_C} = 0 - 0$$

$$\frac{\partial I_B}{\partial I_C} = 0$$

we know that standard equation of stability factor for CE configuration is given by.

$$S = \frac{1+\beta}{1-\beta\left[\frac{\partial I_B}{\partial I_C}\right]}$$

here $\frac{\partial I_B}{\partial I_C} = 0$

$$S = \frac{1+\beta}{1-\beta(0)} = \frac{1+\beta}{1-0}$$

$$\boxed{S = 1+\beta}$$

stability Factor for Fixed Bias(S) $= 1+\beta$. It is more than 1. and it changes with β.

<u>Stability Factor (S') For Fixed Bias</u>:- We know that

$$S' = \frac{\partial I_C}{\partial V_{BE}} \Big|_{\beta, I_{CO} \text{ are constant}}$$

Consider collector current equation of CE configuration

$$I_C = \beta I_B + (1+\beta) I_{CO}$$

From Fixed bias circuit (or) base resistors circuit

$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

Now $I_C = \beta\left[\frac{V_{CC} - V_{BE}}{R_B}\right] + (1+\beta] I_{CO}$

$$I_C = \beta \frac{V_{CC}}{R_B} - \beta \frac{V_{BE}}{R_B} + [1+\beta] I_{CO}$$

derivate w.r.to V_{BE}

$$\frac{\partial I_C}{\partial V_{BE}} = \frac{\partial}{\partial V_{BE}} \beta \frac{V_{CC}}{R_B} - \frac{\partial}{\partial V_{BE}} \frac{\beta V_{BE}}{R_B} + \frac{\partial}{\partial V_{BE}} \cdot (1+\beta) I_{CO}$$

$$\frac{\partial I_C}{\partial V_{BE}} = 0 - (1)\frac{\beta}{R_B} + 0$$

$S' = 0 - \frac{\beta}{\ldots} + 0$ $\quad$ $\boxed{S' \ldots = \frac{-\beta}{R_B}}$

Relationship between S and S':-

$$S' = \frac{-\beta}{R_B}; \quad S = 1+\beta$$

$$S' = \frac{-\beta}{R_B} \cdot \frac{(1+\beta)}{(1+\beta)}$$

$$S' = \left[\frac{-\beta}{R_B} \cdot \frac{S}{(1+\beta)}\right]$$

Stability Factor (S'') For Fixed bias:- We know that collector current for common emitter configuration is given by $I_C = \beta I_B + (1+\beta) I_{CO}$

From fixed bias circuit $I_B = \frac{V_{CC} - V_{BE}}{R_B}$

Now $I_C = \beta \left[\frac{V_{CC} - V_{BE}}{R_B}\right] + (1+\beta) I_{CO}$

$$I_C = \beta \frac{V_{CC}}{R_B} - \beta \frac{V_{BE}}{R_B} + (1+\beta) I_{CO}$$

differentiate w.r.to β.

$$\frac{\partial I_C}{\partial \beta} = \frac{\partial \beta}{\partial \beta} \frac{V_{CC}}{R_B} - \frac{\partial \beta}{\partial \beta} \cdot \frac{V_{BE}}{R_B} + \frac{\partial}{\partial \beta} \cdot I_{CO} + \frac{\partial \beta I_{CO}}{\partial \beta}$$

$$\frac{\partial I_C}{\partial \beta} = \frac{V_{CC}}{R_B} - \frac{V_{BE}}{R_B} + 0 + I_{CO}$$

$$\frac{\partial I_C}{\partial \beta} = \frac{V_{CC} - V_{BE}}{R_B} + I_{CO}$$

$$\frac{\partial I_C}{\partial \beta} = S'' = I_B + I_{CO}$$

$$S'' = I_B + I_{CO}$$

$$\boxed{S'' = I_B} \quad [\because I_B \gg I_{CO}]$$

$$\boxed{S'' = \frac{I_C}{\beta}} \quad \left[\because \beta = \frac{I_C}{I_B}\right]$$

Relationship between S and S'':-

$$S = 1+\beta \; ; \; S'' = \frac{I_C}{\beta}$$

$$S'' = \frac{I_C}{\beta} \frac{(1+\beta)}{(1+\beta)}$$

$$S'' = \frac{I_C}{\beta} \frac{(S)}{(1+\beta)} \Rightarrow \boxed{S'' = \frac{I_C(S)}{\beta(1+\beta)}}$$

Advantages and disadvantages of Fixed bias circuit:-

Advantages:-

1) It is a simple circuit.
2) Maximum flexibility due to changes in operating point in the active region.

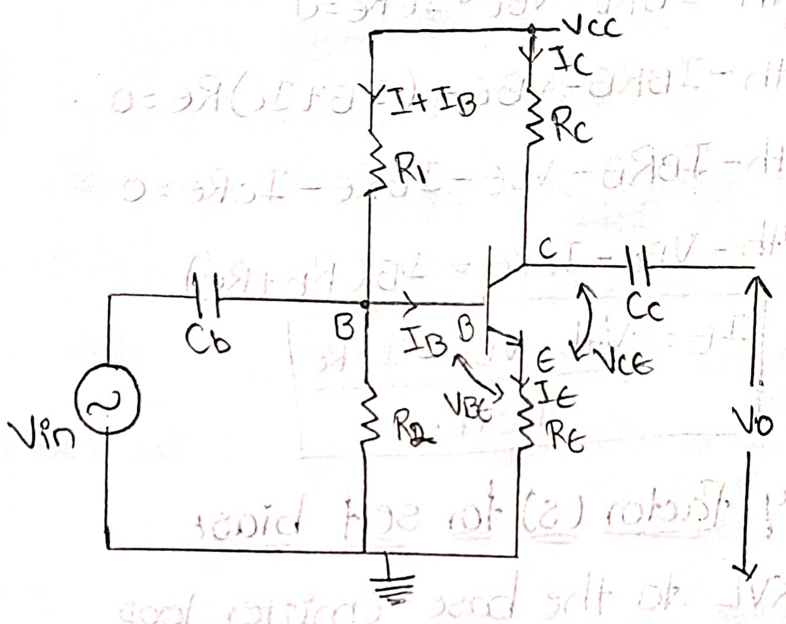
Disadvantages:-

1) Thermal stability is not provided by this circuit since $I_C = \beta I_B + (1+\beta) I_{CBO}$.
2) Stability factor depends on β. [since $S = 1+\beta$]
$\therefore$ β may change from one transistor to another transistor. and $I_C = \beta I_B$ $\therefore$ I_C changes. this will shift to the operating point. hence stabilization of fixed bias circuit is very poor.

Voltage Divider Bias (Self bias):- It is also called self bias. In this circuit, the biasing is provided by three resistors R_1, R_2 and R_E.

→ The R_1 and R_2 acts as potential divider by giving a fixed voltage to point B which is base.

→ The circuit diagram of voltage divider bias is shown in below figure.



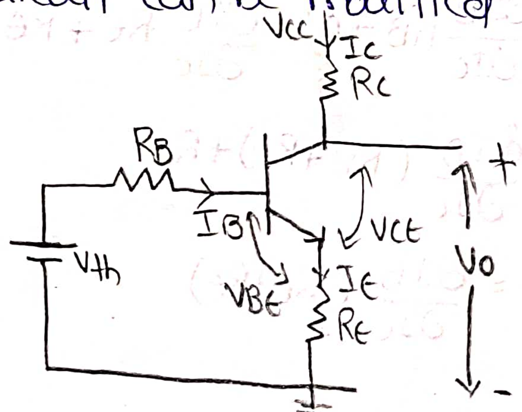
→ Apply KVL From above circuit base resistance R_B, is the parallel combination of R_1 and R_2

$$\therefore R_B = \frac{R_1 R_2}{R_1 + R_2}$$

→ The base voltage of the above circuit is equals to thebenins voltage.

$$\therefore V_{th} = \frac{R_2}{R_1 + R_2} V_{cc}$$

→ The above circuit can be modified as below.



→ apply KVL to collector to emitter terminal loop

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$V_{CC} - I_C R_C - V_{CE} - (I_B + I_C) R_E = 0$$

$$V_{CC} - I_C R_C - V_{CE} - I_B R_E - I_C R_E = 0$$

$$\boxed{V_{CC} - I_B R_E - I_C (R_C + R_E) = V_{CE}}$$

Apply KVL to the base-Emitter loop.

$$\therefore \quad V_{th} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_{th} - I_B R_B - V_{BE} - (I_B + I_C) R_E = 0$$

$$V_{th} - I_B R_B - V_{BE} - I_B R_E - I_C R_E = 0$$

$$V_{th} - V_{BE} - I_C R_E = I_B (R_B + R_E)$$

$$\boxed{I_B = \frac{V_{th} - V_{BE} - I_C R_E}{R_B + R_E}}$$

Stability Factor (S) for self bias

Apply KVL to the base Emitter loop

$$V_{th} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_{th} = I_B R_B + V_{BE} + I_E R_E$$

$$V_{th} = I_B R_B + V_{BE} + (I_B + I_C) R_E$$

$$V_{th} = I_B R_B + V_{BE} + I_B R_E + I_C R_E$$

differentiate w.r.to I_C

$$\frac{\partial}{\partial I_C} V_{th} = \frac{\partial}{\partial I_C} I_B R_B + \frac{\partial}{\partial I_C} V_{BE} + \frac{\partial}{\partial I_C} I_B R_E + \frac{\partial}{\partial I_C} I_C R_E$$

$$0 = \frac{\partial I_B}{\partial I_C} R_B + 0 + \frac{\partial I_B}{\partial I_C} R_E + R_E.$$

$$0 = \frac{\partial I_B}{\partial I_C} (R_B + R_E) + R_E.$$

$$-R_E = \frac{\partial I_B}{\partial I_C} (R_B + R_E)$$

$$\frac{\partial I_B}{\partial I_C} = \frac{-R_E}{R_B+R_E}$$

$$S = \frac{1+\beta}{1-\beta\left(\frac{\partial I_B}{\partial I_C}\right)} = \frac{1+\beta}{1-\beta\left(\frac{-R_E}{R_B+R_E}\right)}$$

$$S = \frac{1+\beta}{1+\beta\left(\frac{R_E}{R_B+R_E}\right)} = \frac{1+\beta}{1+\beta\left(\frac{R_E}{R_E\left(1+\frac{R_B}{R_E}\right)}\right)}$$

$$\boxed{S = \frac{1+\beta}{1+\beta\left(\frac{1}{1+\frac{R_B}{R_E}}\right)}}$$

From above stability factor expression $\frac{R_B}{R_E}$ controlls the stabilization of transistor.

$\therefore$ if $\frac{R_B}{R_E} << 1$ the stability factor becomes 1.

but practically $\frac{R_B}{R_E}$ not equal to zero.

$$S = \frac{1+\beta}{1+\beta}$$

$$S \simeq 1.$$

① If the various parameters of CE amplifier which uses self bias method (or) $V_{CC} = 12V$, $R_1 = 10k\Omega$, $R_2 = 5k\Omega$, $R_C = 1k\Omega$, $R_E = 2k\Omega$, $\beta = 100$. Find

i) The co-ordinates of operating point (V_{CE} and I_C)

ii) Stability factor (S).

iii) Assume $V_{BE} = 0.7$

Sol: $V_{CC} = 12V$, $R_1 = 10k\Omega$, $R_2 = 5k\Omega$, $R_C = 1k\Omega$, $R_E = 2k\Omega$, $\beta = 100$

$$V_{th} = \frac{R_2}{R_1+R_2} V_{CC} = \frac{5\times10^3}{10\times10^3+5\times10^3} \times 12$$

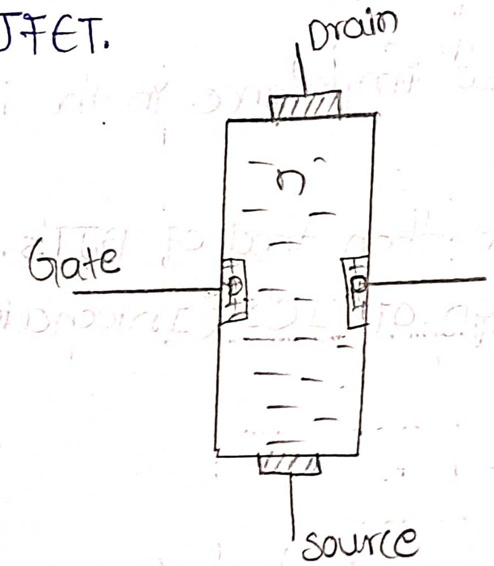
$$= \frac{5\times10^3}{15\times10^3} \times 12$$

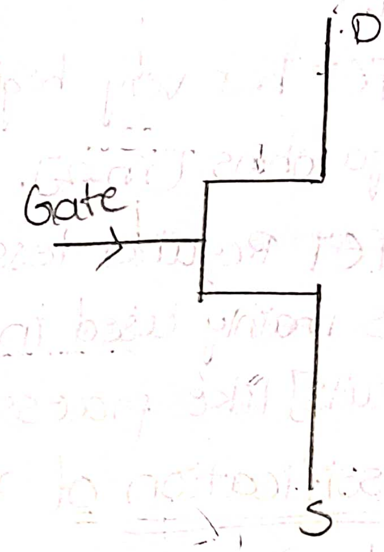
$$\boxed{V_{th} = 4V}$$

MOSFET is very high.

Construction and operation of N-channel JFET:-
p-channel

The below structure and symbol represents N-channel JFET.





⇒ Small bar of Extrensic semiconductor material, n-type is taken and two ohmic contacts are made which are Drain and source terminals of FET.

⇒ heavily doped electrodes of p-type material are placed at the middle of the bar, which forms gate of the FET.

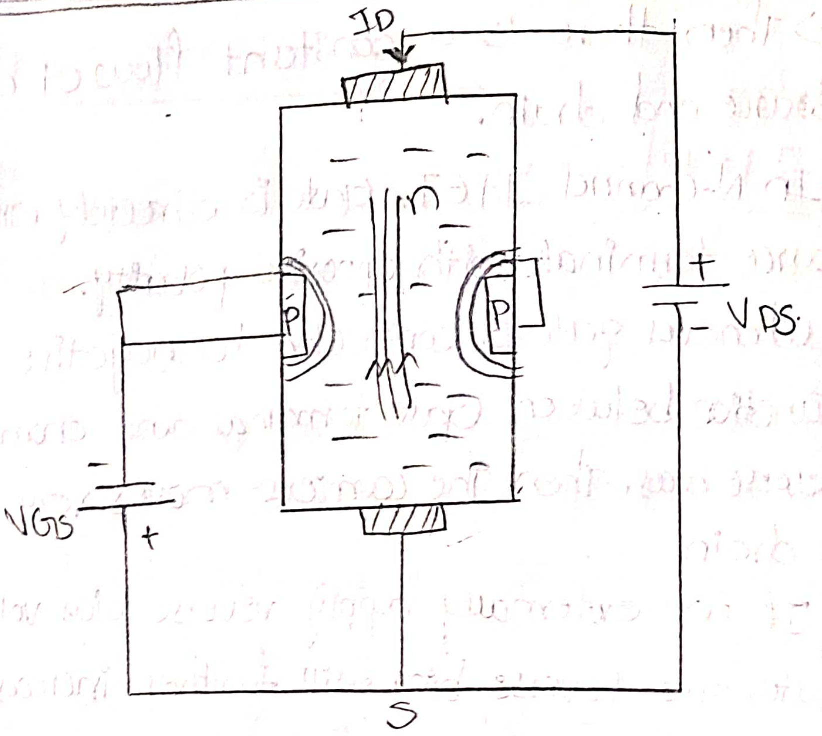
⇒ The region between the two p-gates (or) distance from the source to drain is called channel.

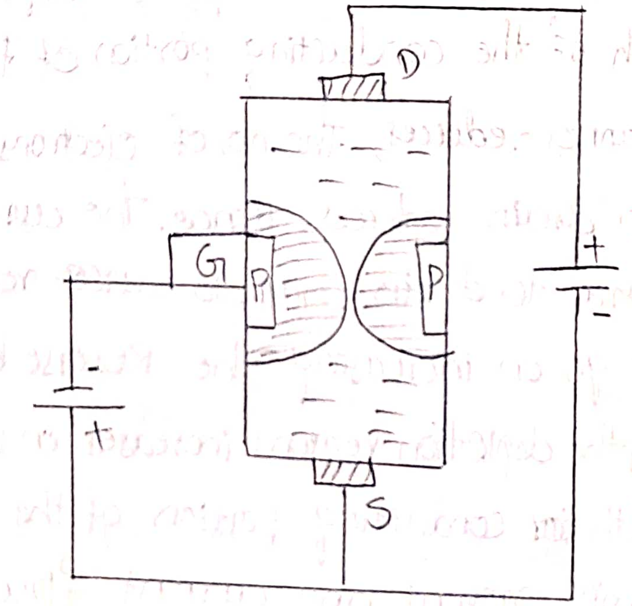
⇒ In above bar, the channel is formed with electrons.
∴ FET is called n-channel JFET.

Operation:-

⇒ In JFET, the PN Junction b/w Gate and Source is always kept in reverse bias. Since the current in reverse bias PN Junction Extremely small, The gate current in FET is often neglected, assumed to be zero.

⇒ The bias diagram of 'n' channel JFET at different gate voltages are shown in below figure.





→ let us consider when voltage VDS is applied b/w Drain and source, Gate terminal is kept open, due to this voltage, the majority carriers, i.e electrons in n-type (or) holes in P-type starts flowing from the Source to drain.

⇒ This flow of electrons makes the drain current ID. ~~the~~

⇒ when, drain voltage VDS is applied, the drain current ID flows in drain to source direction but electrons moves from source to drain.

=> Then there is a constant flow of current b/w source and drain.

=> In N-channel JFET, Gate is directely connected to the Source terminal with opposite polarity.

=> whenever gate is connected to negative voltage, the Junction between Gate terminal and channel goes to Reverse bias. then the carriers moves very less from source to drain.

=> If we externally apply reverse bias voltage to the Gate, the Reverse bias will further increase and hence, increase the penetration of depletion region, which reduces the width of the conducting portion of the channel

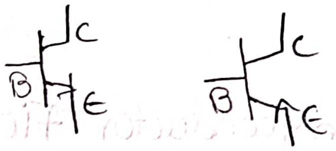
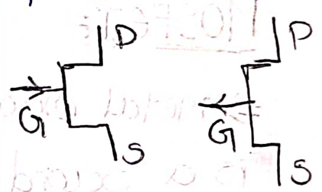
∴ The channel reduces, the no. of electrons flowing from Source to drain reduces. Hence, The current flowing from ~~source to drain~~ drain to source reduces.

=> If we go on increasing the Reverse bias voltage to the Gate, the depletion regions increases on both sides. leaving zero width ~~for~~ conducting portion of the channel.

=> This will prevent any current flow from drain to source. Hence cut off the drain current.

=> The Gate to source voltage that produces cutoff is known as cutoff voltage.

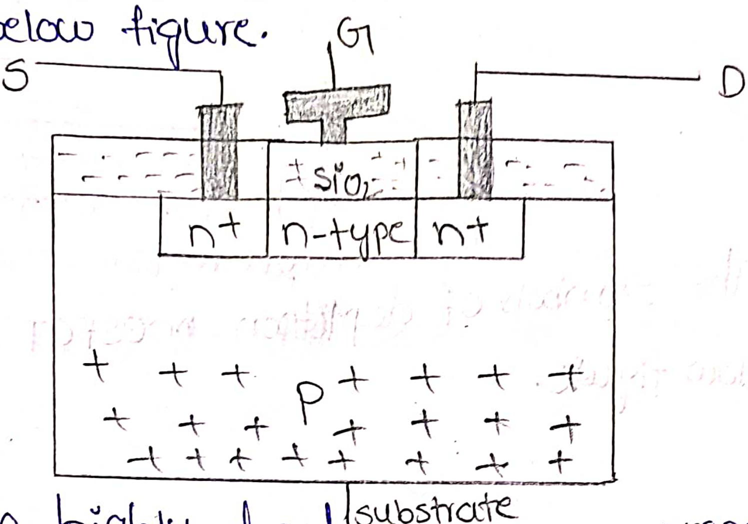
Difference between BJT and FET.

	Parameter	BJT	FET
1.	controll element	current controlled device. Input current I_B controls I_C.	It is a voltage controlled device. Input voltage V_{GS} controlls drain current I_D.
2.	Device type	Current flows due to both majority and minority carriers. so it is a bipolar device.	2. current flows only due to majority carriers either electrons or holes. Hence it is a unipolar device.
3.	Types	NPN, PNP	N-channel JFET P-channel JFET.
4.	symbols	 npn PNP	 n-channel P-channel
5.	configuration	CE, CB, CC	CS, CD, CG
6.	Input resistance	less, compared to JFET	high, compared to BJT.
7.	size	bigger than JFET	smaller than BJT, then it is used in IC's.
8.	sensitivity	higher sensitivity to changes in the applied signals	less sensitivity to changes in applied voltage.
9.	Thermal stability	less	more.
10.	ratio of output to input	$\beta = \frac{\Delta I_C}{\Delta I_B}$	$\frac{\Delta I_D}{\Delta V_{GS}} = g_m$. unit mhos Trance conductance.
11.	Thermal noise	more in BJT bcz of more junctions.	much lower in JFET, bcz few charge carriers cross the junction.

1) N-channel DMOSFET (and) P-channel.

⇒ Two highly doped n-regions are diffused into a lightly doped p-type substrait is called n-channel depletion MOSFET.

⇒ The Basic construction of N-channel DMOSFET is shown in below figure.



⇒ These two highly doped n-regions represents Source and drain. usually substrait is conneted. to source terminal internally.

⇒ The source and drain terminals are connected to matallic contacts.

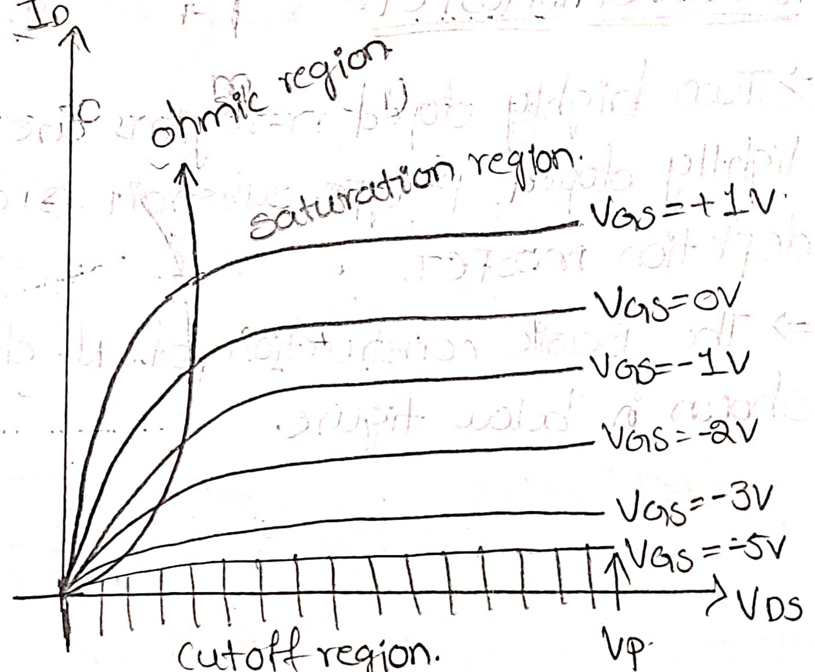
⇒ The Gate is also connected to a metal contact surface, But remains insulated from n-channel by a very thin layer of Dielectric material called SiO_2.

⇒ The depletion MOSFET is acts as an always on transistor.

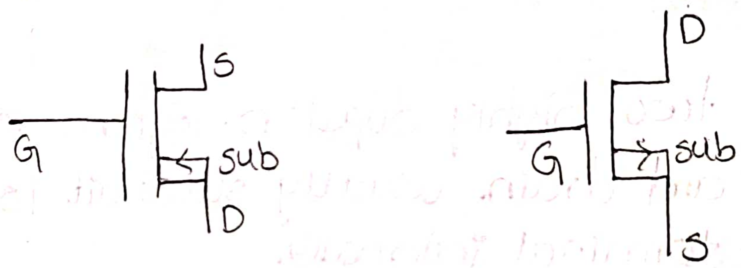
i.e. The channel is found during manufacturing.

⇒ If we apply negative gate voltage, the negative charges on the gate repel conduction, electrons from the channel and attracts holes from the p-type substrate.

⇒ In this process some of the electrons are recombined with holes which depends on negative voltage applied at the gate. The drain characteristics of N-channel Depletion MOSFET is shown in below figure.



⇒ The symbols of depletion MOSFET are shown in below figure.



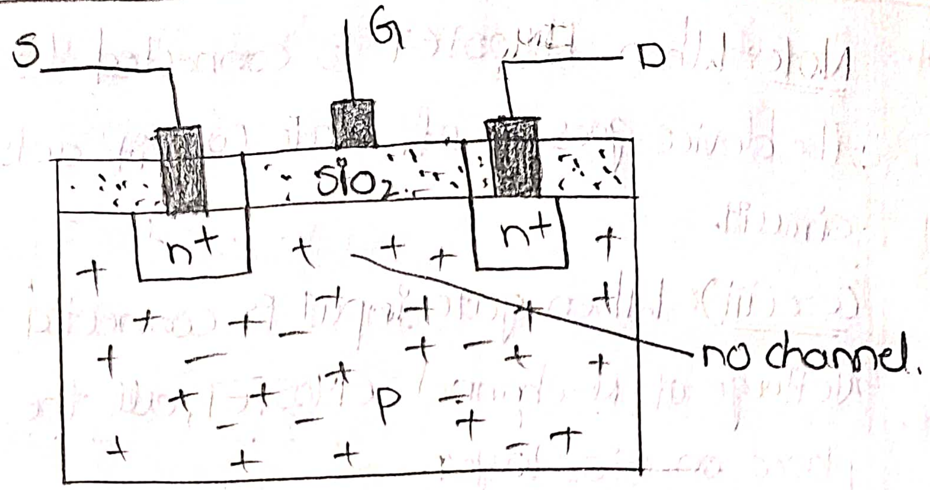
N-channel DMOSFET

P-channel DMOSFET.

~~N~~P-channel Enhancement MOSFET [N-EMOSFET]:

⇒ Like depletion MOSFET two highly doped n-regions are diffused into a lightly doped p-type substrate.

⇒ The source and Drain's are taken out to metallic contacts. The construction of N-channel Enhancement MOSFET is shown in below figure.



⇒ In N-channel enhancement MOSFET, There is no Proper channel b/w two n-regions.

⇒ The SiO_2 layer is still present to isolate the Gate metallic carriers between Drain and source. and it is [Gate] seperated by channel.

Operation:-

Case (i): when gate is open.

i.e. which is not connected to any source. then there is no flow of carriers between source and drian. Since different carriers are placed at channel.

⇒ Even the drain and source terminals are connected to different voltages. then also there is no flow of carriers in the channel.

∴ The device still in non-conducting mode.

Case (ii): when gate is connected to negative voltage (o), all the electrons are placed at SiO_2 layer. These electrons attracts holes from P-type substrate towards channel.

⇒ In this case also there is no change of carriers across the channel.

⇒ Again the device is in OFF state.

Note:- When EMOSFET is connected to negative voltage (V_{GS}) the device goes to off state (or) it acts as an open circuit.

Case (iii):- When gate input is connected to positive voltage of N-channel EMOSFET, all the ~~electrons~~ holes are placed on SiO_2 layer.

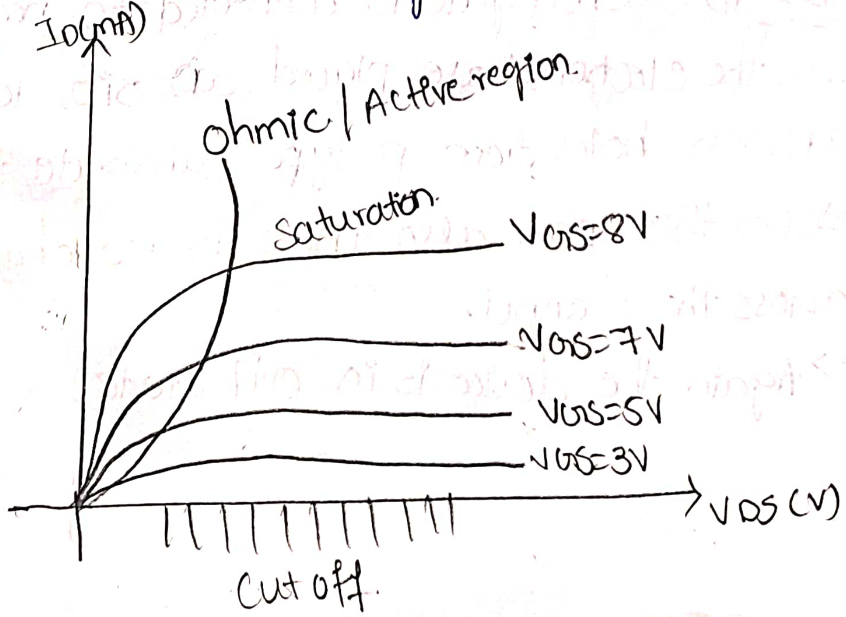
→ This holes attracts the minority carriers (e^-) of p-type substrate towards channel. and repulse majority carriers (holes) towards substrate.

→ Now the channel is replaced by opposite carriers (e^-) then a layer is formed which is called inversion layer.

*→ The minimum voltage which is applied to gate terminal to establish a proper channel between source and drain is called "Threshold voltage".

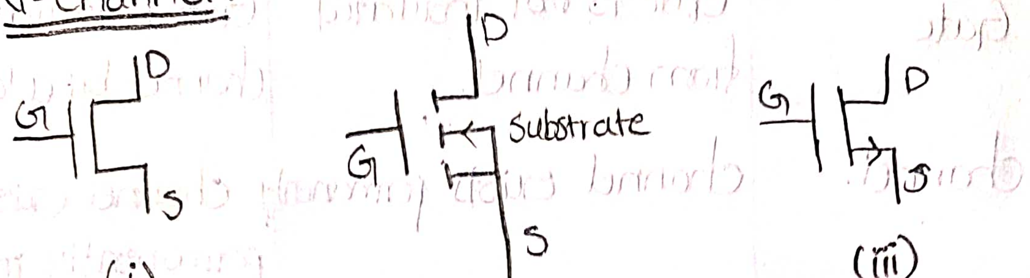
→ when proper channel is placed, based on applied voltage between drain and source, the carriers moves from either source to drain. (or) drain to source. then we can say that the device is in on state. (or) the device acts as an short circuit b/w source and drain.

→ The drain characteristics of n-channel Enhancement MOSFET is shown in below figure.



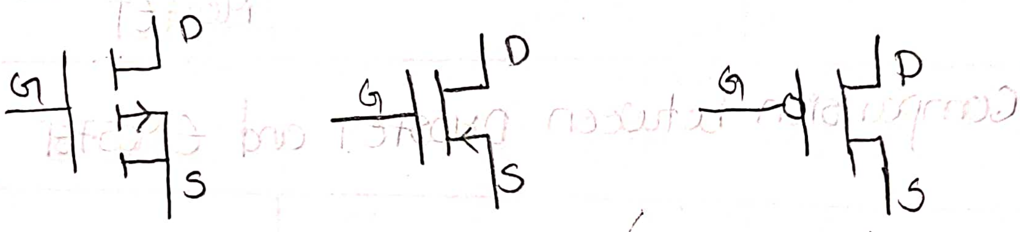
⇒ The symbols of N-channel and P-channel Enhancement MOSFET are shown in below figure.

N-channel :-



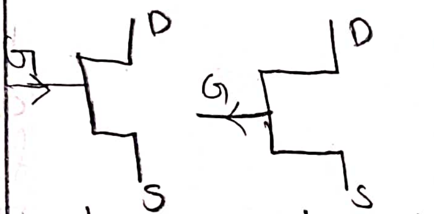
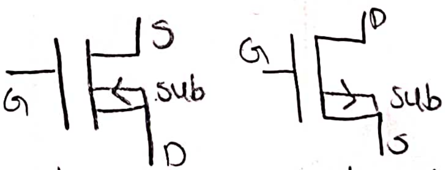
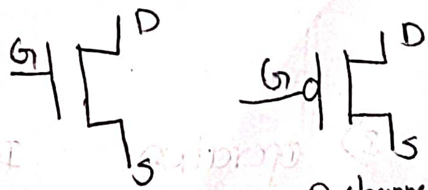
(i) (ii) (iii)

P-channel :-



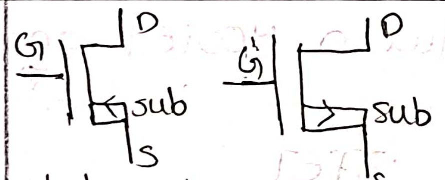
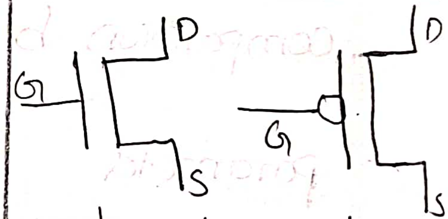
(i) (ii) (iii)

Comparision between MOSFET and JFET.

parameter	JFET	MOSFET.
Types	n-channel, p-channel	P-channel Depletion N-channel Depletion P-channel Enhancement N-channel Enhancement
symbols.	 n-channel P-channel	 n-channel DMOSFET p-channel DMOSFET  N-channel EMOSFET P-channel EMOSFET.
Operation Mode	~~The~~ operated in depletion Mode.	operated in depletion and Enhancement Mode.

4.	Input Impedence	High, Greater than 10 MΩ	very high, Greater than 10,000 MΩ
5.	Gate	Gate is not insulated from channel.	Gate is insulated from channel by a layer of SiO_2
6.	channel	channel exists permanently.	channel exists permanently in Deption type MOSFET but not in enhancement type MOSFET.

7. Comparision between DMOSFET and EMOSFET

	parameters	DMOSFET	EMOSFET.
1.	symbols	 N-channel P-channel	 n-channel P-channel
2.	Channel	Exists permanently	channel is physically absent. It is induced after application of Positive gate voltage above threshold voltage for n-channel EMOSFET, negative Gate voltage above threshold voltage for p-channel EMOSFET.
3)	operation	It can be operated in deption as well as enhancement	It is operated in Enhancement mode only.
4.	current flow.	Drain current flows b/w Drain and source even $V_{GS}=0$.	Practically no current flows b/w Drain and Source at $V_{GS}=0$. But current flows when V_{GS} > Threshold voltage.