Intro. to Semi-Conductors

→ Difference between Metals, Semi-Conductors and Insulators

	Metals	Semi-Conductors	Insulators
1.	Free e's	e's becomes free at room temp.	No free e's
2.	Conductivity ↓ with ↑ in temperature	Conductivity ↑ with ↑ in temperature.	No effect of temp. on conductivity.
3.	They have almost zero band gap.	Band gap is greater than metals but less than insulators	Very high band gap.
eg.	Cu, Fe, Ag, Al, Au etc.	Si, Ge, GaAs, etc.	wood, plastic, paper etc.

→ Energy bands : Every material is composed of atoms. Each atom has certain discrete energy levels. When the atoms come close to each other, these energy levels split and gives rise to ~~ov~~ overlapping energy levels which contains a range of energies. These are known as energy bands.
The completely filled band is known as Valence band and the partially filled band is known as Conduction band. Sometimes, there is gap between the conduction band and valence band which is known as Band Gap of that particular material.

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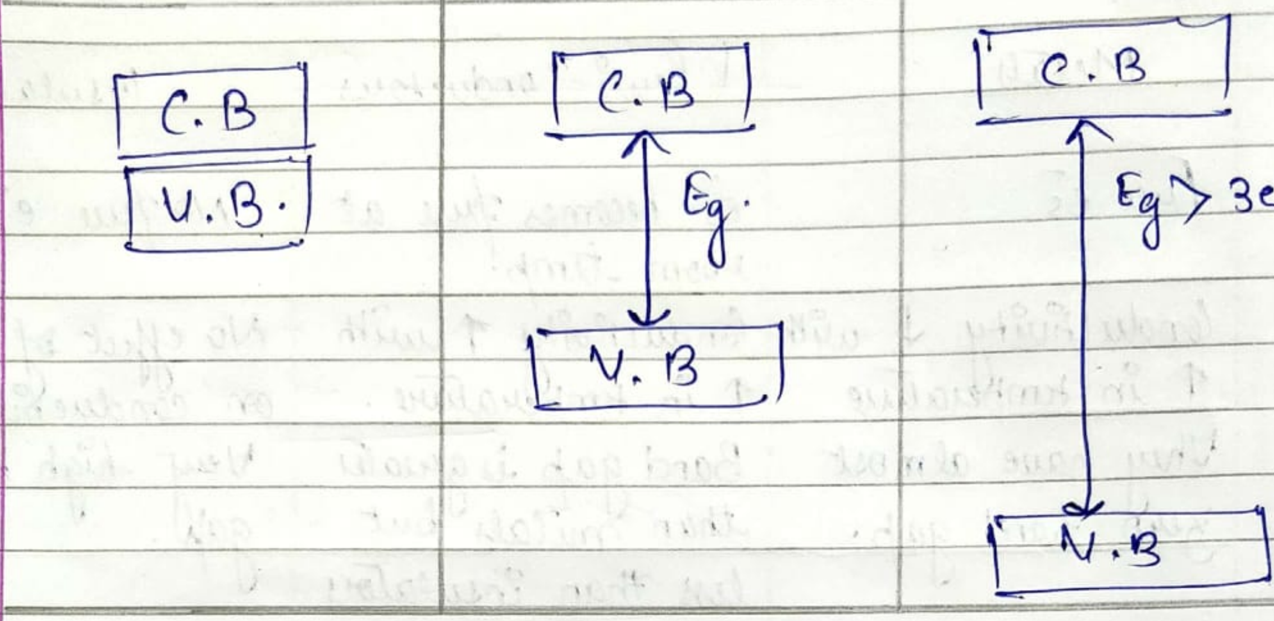
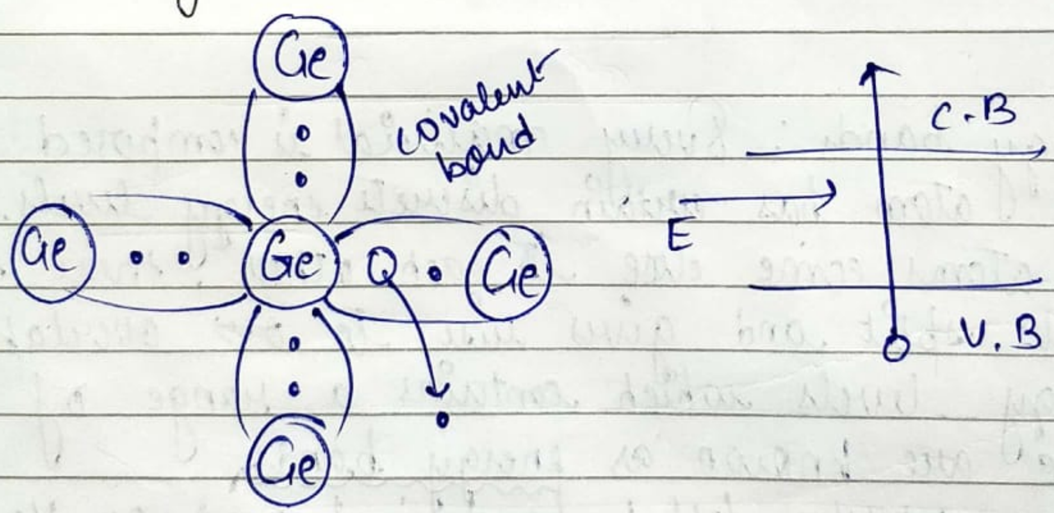
Difference between Metals, Semi-conductors and insulators w. r. to. energy bands.

METALS	SEMI-CONDUCTORS	INSULATORS.



Concept of electrons and holes.

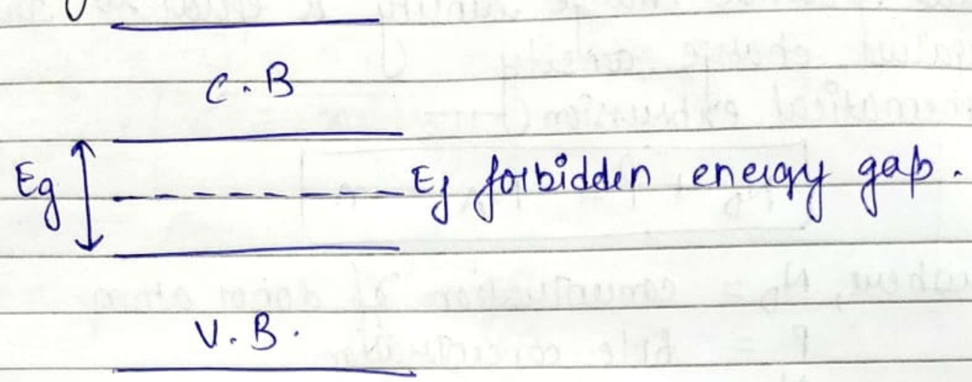


~~Doping~~ FERMI-ENERGY fermi energy is the quantum mechanical concept & usually refer to the energy of the highest occupied quantum state in a system of fermi-~~ohms~~ ions at absolute temp.

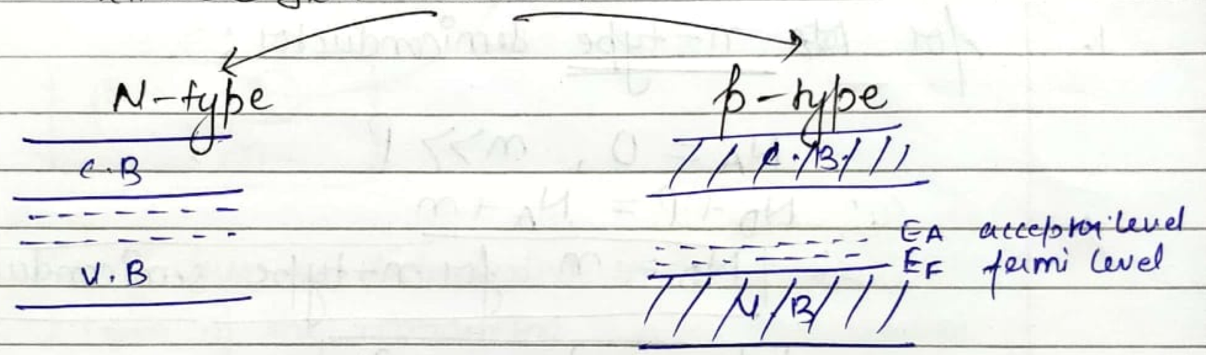
Fermi level is the max. energy which can be occupied by an electron at absolute 0K.

FERMI-ENERGY DIAGRAM

~~Law of Mass Action~~: (for Intrinsic Semiconductor):



for extrinsic semiconductor:



→ LAW OF MASS ACTION:

Under thermal equilibrium for any semiconductor, product of no. of holes and no. of e's is constant and is independant of amount of doping. This relation is known as Mass-action law.

mathematical expression —

$$\boxed{nP = n_i^2}$$

$n \longrightarrow \bar{e}$ concentration

$p \longrightarrow$ hole concentration

$n_i \longrightarrow$ Intrinsic concentration

→ LAW OF ELECTRICAL NEUTRALITY

Total positive charge density is equal to the total negative charge density

mathematical expression ←

$$\boxed{N_D + P = N_A + n}$$

where, N_D = concentration of donor atom

P = hole concentration

N_A = concentration of acceptor atom

n = electron concentration.

1. for ~~NA~~ n-type semiconductor;

$$N_A = 0, \quad n \gg P$$

$$\therefore N_D + P = N_A + n$$

$$\therefore \boxed{N_D = n \text{ for n-type semiconductor}}$$

Also, $\boxed{p = \frac{n_i^2}{n} = \frac{n_i^2}{N_D}}$

2. for p-type semiconductor;

$$N_D = 0 \quad p \gg n$$

$$\therefore N_D + P = N_A + n$$

$$\therefore \boxed{N_A = P \text{ for p-type semiconductor}}$$

$$\boxed{n = \frac{n_i^2}{P} = \frac{n_i^2}{N_A}}$$

NOTE : $J = \frac{I}{A} = neV_d$

$V_d = \underbrace{\mu}_{\text{mobility}} E \quad \therefore \boxed{J = ne\mu E}$

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$J_e + J_p \rightarrow p e \mu_p E$

current density $\leftarrow J = \sigma E$ microscopic form of ohm's law

conductivity $\leftarrow \boxed{\sigma = ne\mu}$

$F = qE \quad \therefore a = \frac{F}{m} = \frac{qE}{m}$

$\because v = at = \frac{qE}{m}(t) \rightarrow$ relaxation time

$= \mu E$

$$\boxed{\mu = \frac{q t}{m}}$$

N = No. of free e's distributed in the conductor
L = length of the conductor
A = cross-section of the conductor

$$I = q.\frac{N}{T}$$

$$\therefore I = q.\frac{N}{T} \frac{\times L}{\times L}$$

$$\therefore \frac{I}{A} = \frac{q\, N.v}{L.A} = J$$

$$\therefore \frac{I}{A} = \frac{q.\, N v}{V} = J \qquad \because n = \frac{N}{V}$$

$\boxed{J = q n v} \rightarrow$ drift velocity
$V \rightarrow$ volume

$$\therefore \boxed{J = q n \mu E}$$

$\therefore J_p = qp\mu_p E$ $\qquad J_n = -qn(-\mu_n E)$

intrinsic semi-conductor

$J_{total} = J_p + J_n$

$J_{total} = qE(p\mu_p + n\mu_n)$

$\therefore \sigma_{total} = q(p\mu_p + n\mu_n)$

n-type $\rightarrow \sigma = qn\mu_n$; $n >> p$

p-type $\rightarrow \sigma = qp\mu_p$; $p >> n$

Q/ A Cu wire of 2mm. diameter with conductivity $5.8 \times 10^7 \Omega m$ and e^- mobility $0.0032 m^2/V\text{-}s$. is subjected to electric field 20 mV/m. Find —

(i) Density of free e^- (n)
(ii) Current density (J)
(iii) Current flow in the wire (I)
(iv) Drift velocity. (V_d)

$d = 2mm$

$\sigma = 5.8 \times 10^7 \Omega m$

$\mu = 0.0032 \ m^2/V.s.$

$E = 20 \ mV/m.$

$\sigma = ne\mu.$

$5.8 \times 10^7 \Omega m = n \times 1.6 \times 10^{-19} C \times 0.0032 m^2/V.s.$

$\dfrac{5.8 \times 10^7 \times 10^4}{1.6 \times 10^{-19} \times 32} = n$

$n = \dfrac{58}{16 \times 32} \times 10^{30}$

TRANSPORT PHENOMENON

$$J = J_{drift} + J_{diffusion}$$

$$J_{drift} = neV$$

$$v = \mu E$$

$$J_{drift} = J_{n,drift} + J_{p,drift}$$
$$= ne\mu_n E + pe\mu_p E$$
$$= eE(n\mu_n + p\mu_p)$$

$$J = \sigma E$$

$$\sigma_{drift} = e(n\mu_n + p\mu_p)$$

$$\boxed{\sigma = ne\mu}$$

Temperature variation of Conductivity.

T < 200K impurity scattering
T > 400K lattice scattering.

$\boxed{J_{diffusion}}$: flow of charge carriers due to concentration gradient.

$$-\frac{dn}{dx}$$

$J_{n,diffusion}$ = diffusion current due to electrons

$J_{n,diffusion} = eD_n \cdot \frac{dn}{dx}$ → diffusion coefficient

$$J_{p,diffusion} = -eD_p \cdot \frac{dp}{dx}$$

$$J_{diffusion} = J_{n,diff.} + J_{p,diff.}$$
$$= eD_n \cdot \frac{dn}{dx} - eD_p \cdot \frac{dp}{dx}$$

PN Junction Diode

NOTE: Points to remember:- formation of depletion, Built in potential, potential barrier, forward bias, Reverse bias, Reverse saturation current, Breakdown voltage.

Q/ How depletion layer is formed?

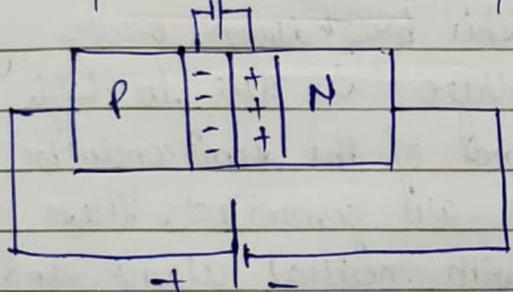
When PN Junction diode is formed, a concentration gradient exists across the junction as e's are majority charge carriers on n-side but minority charge carriers on p-side, similarly, holes are majority charge carriers on p-side but minority charge carriers on n-side. Due to this concentration gradient, diffusion of charge carriers occurs across the junction. Due to diffusion, e's on n-side leave the donor atoms and these donor atoms forms positive donor ions, similarly, on p-side when holes leave the acceptor impurities, acceptor impurities forms negative ions. Due to this process near the junction, a layer is formed which has positive immobile ions on n-side and negative immobile ions on p-side. This layer is depleted of mobile charge carriers and is known as Depletion layer.

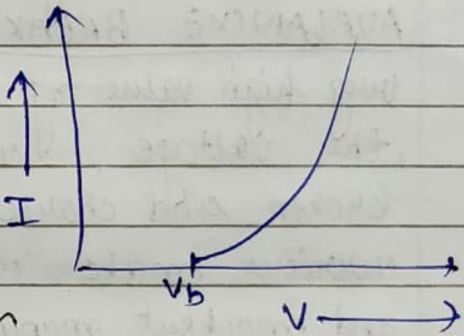
Q/ What is potential barrier?

Inside the depletion layer, due to formation of positive charges on n-side and negative charges on p-side, a potential difference originates which is known as potential barrier. This potential barrier stops the further diffusion of charge carriers.

FORWARD BIASING

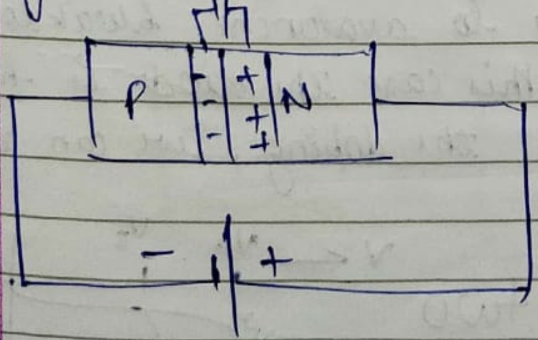
In p-n junction diode, the potential barrier stops the diffusion of carriers across the junction. In order to achieve conduction in a diode, it is necessary that charge carriers are able to cross the junction. This can only be done if we apply an external voltage to counter the potential barrier. This biasing of the diode is known as forward bias. Here, we connect p-side with positive terminal and n-side with negative terminal of the battery. Due to forward bias, the depletion layer becomes thinner and finally vanishes when the external voltage exceeds the potential barrier.

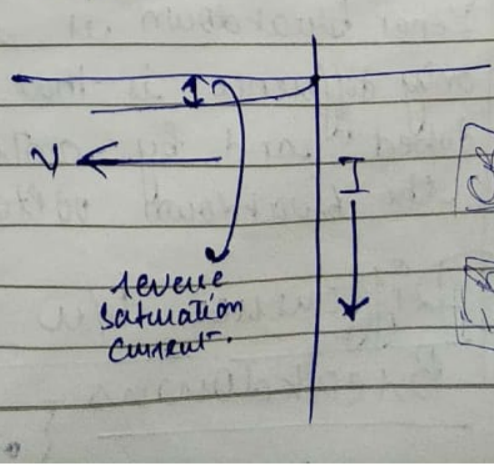




REVERSE BIASING

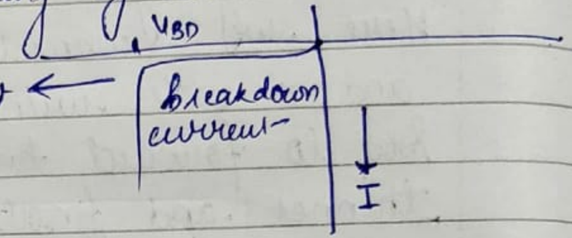
In reverse bias, p is connected to negative terminal and n is connected to positive terminal. This biasing adds to the potential barrier and depletion layer expands. In this case, minority charge carriers are able to cross the junction and we get a very small value of current which is known as reverse saturation current.





BREAK DOWN

Under reverse bias, we get a small value of current due to minority charge carriers but when the reverse voltage is increased beyond a threshold value, the current suddenly increases. This particular value of reverse voltage is known as Breakdown voltage and the phenomenon of sudden increase of reverse current is known as Breakdown.
Breakdown occurs due to breaking of covalent bonds and creation of new charge carriers.

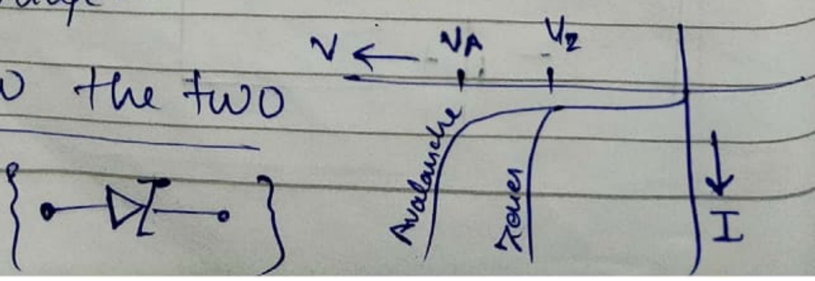


Breakdown is of two types :-

1. AVALANCHE BREAKDOWN: This breakdown occurs for a very high value of reverse voltage. So due to high value of the voltage, covalent bonds of the semiconductor are broken and charge carriers are generated. These charge carriers make collisions with neutral atoms and molecules and knockout many more charge carriers and this process continues till the diode completely burns. This is an uncontrolled process.

2. ZENER BREAKDOWN: Zener Breakdown occurs at sufficiently small values of reverse voltage because in this case, the diode is highly doped and it takes a small value of reverse voltage to break the covalent bonds.
Zener breakdown is similar to avalanche breakdown, the only difference is that in this case the diode is highly doped and by controlling the doping, we can control the breakdown voltage.

Difference b/w the two Breakdowns



Diode Equation

Diode current ; $I = I_S\left(e^{qV/nKT} - 1\right)$

where, V = applied voltage

q = electronic charge

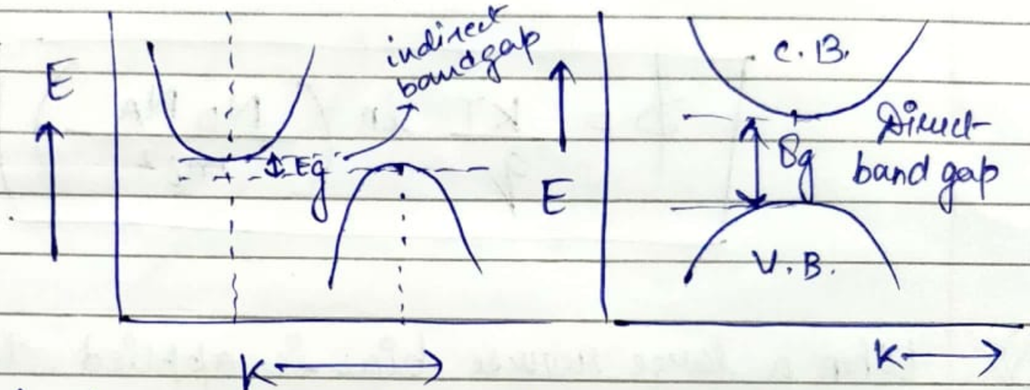
n = ideality factor

K = Boltzmann constant

T = temperature

$n=1$ for indirect band gap semiconductors (Ge, Si)

$n=2$ for direct band gap semiconductors (GaAs, InP)



$\frac{KT}{q}$ is known as thermal voltage, V_{TH}

for 300K, $V_{TH} = 25.9\,mV$

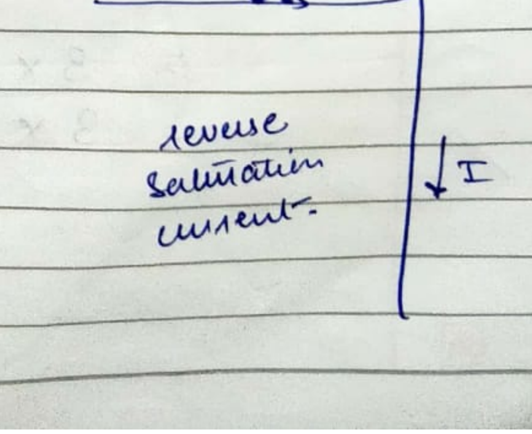
$$I = I_S\left(e^{V/nV_{TH}} - 1\right)$$

(1) for reverse bias, V is negative

$$I = I_S\left(e^{-V/nV_{TH}} - 1\right)$$

$$I = I_S\left(\frac{1}{e^{V/nV_{TH}}} - 1\right)$$

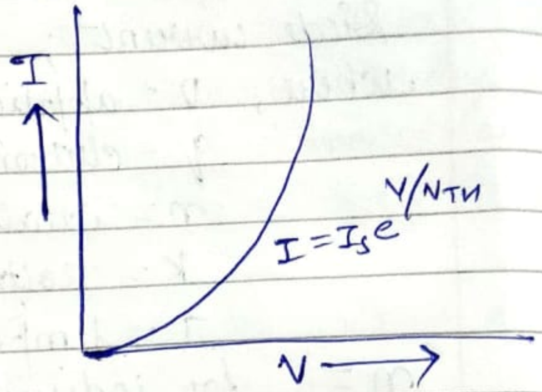
$$\therefore \boxed{I \sim -I_S}$$



(2) for forward bias, V is positive

$$I = I_S\left(e^{V/nV_{TH}} - 1\right)$$

$$\boxed{I = I_S e^{V/nV_{TH}}}$$



Built in potential.

$$\boxed{\phi = \frac{KT}{q} \ln\left(\frac{N_D N_A}{n_i^2}\right)}$$

Q/ When a large reverse bias is applied, the current flowing through a diode at room temperature is 3×10^{-7} A. Calculate the current flowing the diode when 200mV forward bias is applied.

$I_s = 3 \times 10^{-7}$ A $\quad n = 1$

~~$I = 3 \times 10^{-7}$ A~~

$$I = I_S\left(e^{V/nV_{TH}} - 1\right)$$

$$= 3 \times 10^{-7}\left(e^{200/25.9} \cancel{-1}\right)$$

$$= 3 \times 10^{-7} e^{7.78}$$

$$= 3 \times 10^{-7} \times$$

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Q) A Ge Diode displays a forward voltage of 0.25 V and 10 mA current at room temperature. Estimate the reverse saturation current I_s. Assume diode ideality factor to be 1. Calculate the bias voltage needed for the diode currents of 1 mA and 100 mA. Estimate the value of I_s & also forward current at 0.25 V and at 30°C above R.T.

$$\cancel{I = I_s\left(\frac{1}{e^{V/\eta V_{TH}}} - 1\right)}$$

$$\cancel{I = I_s\left(e^{V/\eta V_{TH}} - 1\right)}$$

$$\cancel{10 = I_s\left(\frac{1}{e^{0.25\times10^{3}/25.9}} - 1\right)}$$

$$\cancel{= I_s\left(\frac{1}{e^{5/6\times10^{-3}}} - 1\right)}$$

$$\cancel{= I}$$

(i)

$$I = I_s e^{V/\eta V_{TH}}$$

$$10\times10^{-3}\,A = I_s \times e^{\frac{0.25\times10^{+3}\,mV}{25.9}}$$

$$= I_s \times e^{\frac{250}{30}}$$

$$10^{-2}A = I_s \times e^{10.0}$$

$$I_s = \frac{10^{-2}}{e^{10}} \simeq 7\times10^{-7}\,A$$

(ii)

$$1\times10^{-3}A = 7\times10^{-7}\left(e^{V/25.9\times10^{-3}}\right)$$

~~taking log on both sides~~

$$1 = 7\times10^{-4}\left(e^{V/25.9\times10^{-3}}\right)$$

$$e^{\frac{V}{25.9\times10^{-3}}} = \frac{1}{7}\times10^{4}$$

$$\frac{V}{25.9\times10^{-3}} = \ln10^{4} - \ln 7$$

$$N = (25.9 \times 10^{-3})(4\ln 10 - \ln 7)$$

Q1) The following data is available for an intrinsic semi-conductor at 300k. $\mu_n = 0.39 \, m^2/V.s.$ and $\mu_p = 0.19 \, m^2/V.s$ and $n = 2.4 \times 10^{19} m^{-3}$. Calculate the resistivity of the material

$$\sigma = e(\mu_n n + p\mu_p)$$

$$n.p = n_i^2$$

$$n = p$$

$$n^2 = n_i^2$$

$$n = n_i$$

$$\sigma = 1.6 \times 10^{-19}(0.39 \times 2.4 \times 10^{19} + 0.19 \times 2.4 \times 10^{19})$$

$$= 1.6(0.39 + 0.19) \times 2.4$$

$$= 1.6 \times 2.4 \, (0.58)$$

$$\rho = \frac{1}{1.6 \times 2.4 \times 0.58} = 0.449 \, \Omega m$$

Q2) Calculate the no. of atoms for an n-type semi-conductor whose ~~resistivity~~ resistivity is $0.449 \, \Omega m$; $\mu_n = 0.6 \, m^2/V.s$

$$\frac{1}{0.449} = n \mu_n e$$

$$n = \frac{1}{0.449 \times 0.6 \times 1.6 \times 10^{-19}}$$

$$= 2.32 \times 10^{19}$$

$$N_D = 2.32 \times 10^{19}$$

Q3) A pure Ge at 300k having density of charge carriers ~~at~~ as $2.25 \times 10^{19} \, m^{-3}$ is doped with impurity P atoms at 1 in 10^6. $\mu_n = 0.4 \, m^2/V.s$. $\mu_p = 0.2 \, m^2/V.s$. The no. of intrinsic atoms is 4×10^{28} atoms$/m^3$. If all the impurity atoms are ionised ~~fixed~~. Find the

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Resistivity of n-type semi-conductor.

$$Total = 4 \times 10^{28}$$

$$N_D = \frac{4 \times 10^{28}}{10^6} = 4 \times 10^{22}$$

$$4 \times 10^{22} \times p = (2.25 \times 10^{19})^2$$

$$= 1.3 \times 10^{16}$$

$$\sigma = (4 \times 10^{22} \times 1.6 \times 10^{-19} \times 0.4) + (1.3 \times 10^{16} \times 1.6 \times 10^{-19} \times 0.2)$$

$$= 2560$$

$$\rho = 3.9 \times 10^{-4}\ \Omega m$$

(A)

(4) To an intrinsic Si crystal —

(i) Donor type impurity are added so as to have an n-type semi-conductor having $\rho = 10^{-4}\ \Omega m$.

(ii) Acceptor type impurities are added so as to have a p-type semiconductor having $\rho = 10^{-4}\ \Omega m$. Calculate the density of impurity atoms in each case give that $\mu_e = 0.36\ m^2/V_s$ and $\mu_p = 0.18\ m^2/V_s$

(i) $$10^4 = n \times 0.36 \times 1.6 \times 10^{-19}$$

$$n = 1.7 \times 10^{23}$$

(ii) $$10^4 = p \times 0.18 \times 1.6 \times 10^{-19}$$

$$p = \cancel{0.85 \times} \frac{1.7 \times 10^{23}}{2}$$

$$= 3.47 \times 10^{23}$$

Q5

At room temperature, the diode current is 0.5 mA at 0.45 V and 25 mA at 0.65 V. Determine n.

$$I = I_s (e^{V/nV_{TH}} - 1)$$

$$0.5\,mA = I_s (e^{0.45/n.25.9} - 1) \quad \text{--- (1)}$$

$$25\,mA = I_s (e^{0.65/n25.9} - 1) \quad \text{--- (2)}$$

dividing (2) by (1)

$$\frac{250}{0.5} = \frac{\cancel{I_s}}{\cancel{I_s}}\left\{\frac{e^{0.65/n \cdot 25.9\times10^{-3}} - 1}{e^{0.45/n \cdot 25.9\times10^{-3}} - 1}\right\}$$

neglecting 1 as it is a very small value

$$\therefore \quad 50 = \frac{e^{0.65/n \cdot 25.9\times10^{-3}}}{e^{0.45/n \cdot 25.9\times10^{-3}}}$$

$$50 = e^{0.2/n\times25.9\times10^{-3}}$$

$$\ln 50 = \frac{0.2}{n\times25.9\times10^{-3}}$$

$$\frac{1.69}{100} = \frac{0.2\times1000}{n\times25.9}\ \frac{0}{10}$$

$$\therefore n \simeq 1.9$$

Q6. A silicon diode has reverse saturation current of 0.1 μA at 27°C. Find reverse saturation current at 37°C and at 127°C

$$\frac{1.44}{n\times25.9\times10^{-3}}$$

$$\frac{747}{107268}$$

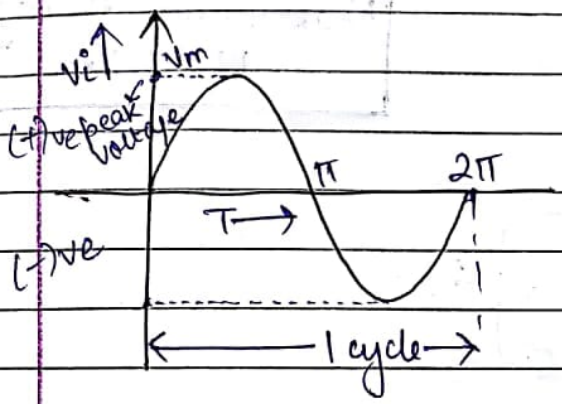
$$374\times10^{-3}$$

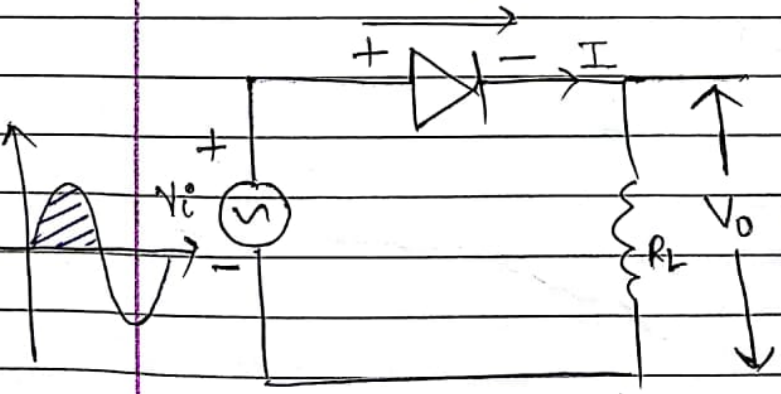
RECTIFIERS {minimizing the errors in a diode}

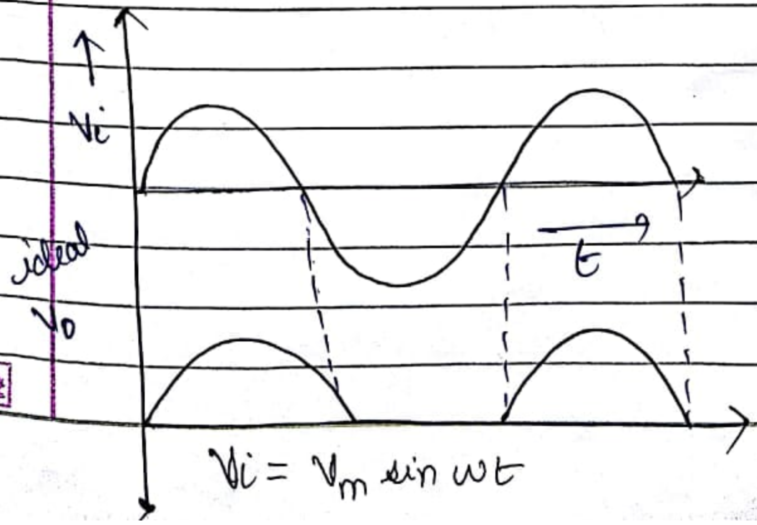
{An application of p-n junction diode. Use to convert from AC to DC.}

Half wave rectifier | Full wave rectifier

Only one half of the a.c voltage is rectified, for the other half we get zero voltage.







$V_i = V_m \sin \omega t$

FOR HALF-WAVE RECTIFIER

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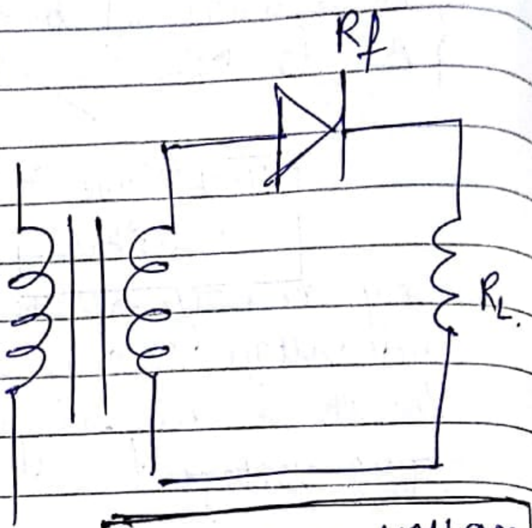
For average output (V_{av}) = V_{dc}

$$V_{avg.} = \int_0^{2\pi} V_0 \, d(\omega t) = \frac{1}{2\pi}\int_0^{2\pi} V_0 \, d(\omega t)$$



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

$\therefore V_i = V_0 = V_m \sin \omega t$
$(0 \leq \omega t \leq \pi)$

$V_0 = 0 \quad (\pi \leq \omega t \leq 2\pi)$

Peak inverse voltage
$PIV = V_m$

$$\therefore V_{avg.} = \frac{1}{2\pi}\int_0^{2\pi} V_m \sin \omega t \, d(\omega t)$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} V_m \sin \omega t + \cancel{\int_{\pi}^{2\pi} V_m \sin \omega t}\right] d(\omega t)$$

0

$$= \frac{1}{2\pi}\int_0^{\pi} V_m \sin \omega t \, d(\omega t)$$

$$= \frac{V_m}{2\pi}\int_0^{\pi} \sin \omega t \, d(\omega t)$$

$$= \frac{V_m}{2\pi}\left[-\cos \omega t\right]_0^{\pi}$$

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

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

$$\boxed{V_{avg.} = \frac{V_m}{\pi}}$$

$$\therefore V_{avg.} = \frac{V_m}{\pi}$$

$$\therefore I_{avg.} = \frac{V_{avg.}}{R_L} = \frac{V_m/\pi}{R_L}$$

$$= \frac{V_m}{R_L} \cdot \frac{1}{\pi}$$

$$= \frac{I_m}{\pi}$$

$$\therefore \boxed{I_{avg.} = \frac{I_m}{\pi}}$$

RMS load current and RMS load voltage.

↳ Root mean square current.

$\because I = I_m \sin\omega t$

$$\therefore I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi}\left(I^2 d(\omega t)\right)}$$

$$= \left[\frac{1}{2\pi}\int_0^{2\pi} I_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

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

$$= \left[\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{I_m^2}{2\pi}\int_0^{\pi} \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{I_m^2}{2\pi}\int_0^{\pi}\left(\frac{1-\cos 2\omega t}{2}\right) d(\omega t)\right]^{1/2}$$

$$= \left[\frac{I_m^2}{4\pi} \int_0^{\pi} (1-\cos 2\omega t)\, d(\omega t) \right]^{1/2}$$

$$= \left\{ \frac{I_m^2}{4\pi} \left[\omega t - \frac{\sin 2\omega t}{2} \right]_0^{\pi} \right\}^{1/2}$$

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

$$= \left[\frac{I_m^2}{4\cancel{\pi}} \cdot \cancel{\pi} \right]^{1/2}$$

$$= \left[\frac{I_m^2}{4} \right]^{1/2}$$

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

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

Form factor:

$$F = \frac{I_{rms}}{I_{DC}} = \frac{\pi}{2} = 1.57$$

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

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

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

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

$$I_{rms}^2 = I_{ac}^2 + I_{dc}^2$$

FOR HALF-WAVE RECTIFIER

$$\boxed{V_{avg.} = \frac{V_m}{\pi}}$$

$$\boxed{I_{avg.} = \frac{I_m}{\pi}}$$

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

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

Ripple factor $= \gamma$

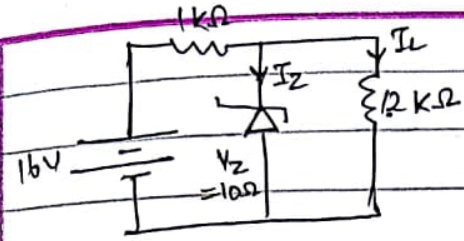
$$\gamma = \frac{I_{ac}}{I_{dc}} = \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}}$$

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

$$\gamma = \sqrt{F^2 - 1} = 1.22$$

Rectification efficiency $= \eta$

$$\eta = \frac{P_{dc}}{P_i} = \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_f + R_L)} = \frac{4}{\pi^2} \left(\frac{1}{\frac{R_f}{R_L} + 1} \right)$$



$$V = \frac{V_i R_L}{R+R_L} = \frac{16 \times 1.2}{1+1.2}$$

$$= \frac{16.12}{\cancel{10}} \Big/ \frac{2\cancel{2}2}{\cancel{10}} = \frac{\cancel{16}^{8}.12}{\cancel{22}_{11}} = \frac{96}{11}$$

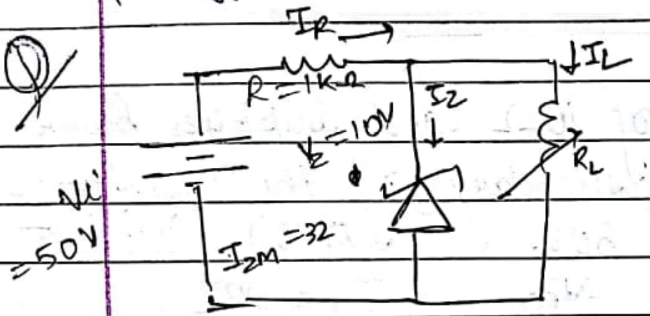
$$= 8.7$$

$I_Z = I_R - I_L$.

$\therefore$ OFF state

$\because$ $V < V_Z$

{In off state, power will be 0.}



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

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

$$= \frac{10 \times 1}{50 - 10} = \frac{1\cancel{0}}{4\cancel{0}} = \frac{1}{4}$$

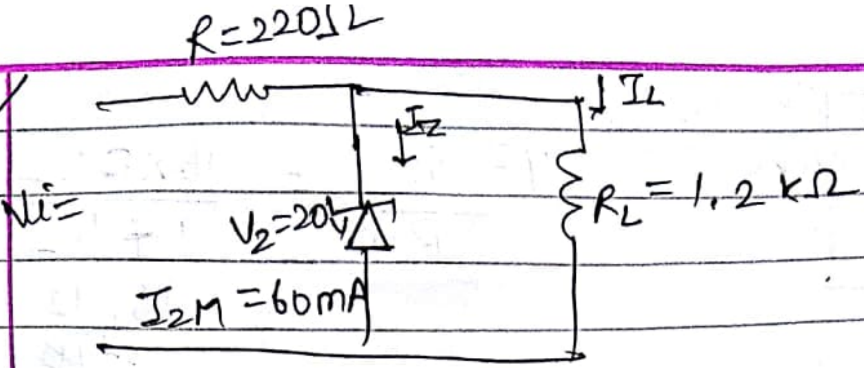
$$R_{Lmin} = \frac{1}{4} = 0.25$$

$$R_{Lmax} = \frac{V_Z}{I_{Lmin}} = \frac{V_Z}{I_R - I_{ZM}} = \frac{10}{40 - 32} = \frac{10}{8} = 1.2$$

$$I_{Lmax} = \frac{V_Z}{R_{Lmin}} = \frac{\cancel{1000}\ 40}{0.25} = 40$$

$$I_R = \frac{V_i - V_Z}{R} = \frac{50 - 10}{1} = 40.$$

1)



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

$$= \frac{20(220+1.2)}{1.2}$$

$$= 20\,($$

1) A diode has a resistance of 10Ω and supplies power to a load of 100Ω. The secondary of the Transformer supplies a voltage of 50V. (RMS). Calculate

1. The peak current — V_m — $I_m = \frac{V_m}{R_f+R_L}$
2. The DC load current
3. RMS current
4. DC voltage
5. The total AC input power.
6. Rectification efficiency.

$R_f = 10\,\Omega$

$R_L = 100\,\Omega$.

$V_{rms} = 50\,V$.

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

$$= \frac{70.7}{10+100}$$

$$= \frac{70.70}{1100}$$

$$= 0.64\,A.$$

1) $V_{rms} = \frac{V_m}{\sqrt{2}}$.

$50 \times \sqrt{2} = V_m$

(i) $V_m = 70.7\,V$.

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(ii) $\cancel{I_m = I_{rms} \times 2}$. $V_{DC} = I_{DC} \times R_L$

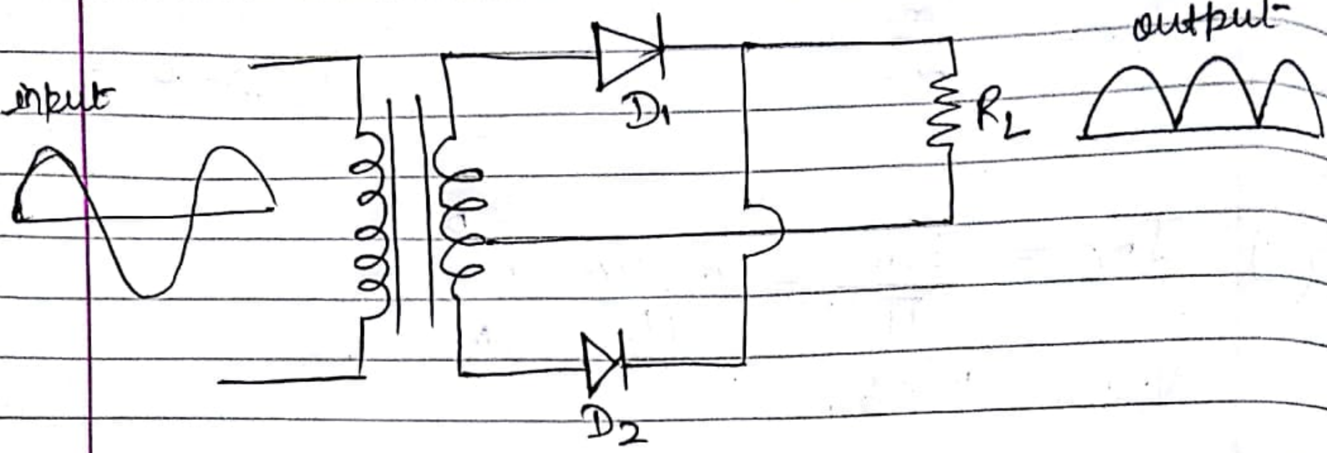
$$I_{rms} = \frac{I_m}{2}.$$ $=$

$=$ $I_{rms} = 0.32$

(iii) $I_{DC} = \frac{I_m}{\pi} = \frac{0.64A}{11} = 0.20.$

$V_{input} = 11.26$.

Full wave Rectifier (CENTRE TAP)



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

$$\boxed{PIV = 2V_m}$$

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

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

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

Form factor $= F = \frac{I_{rms}}{I_{dc}} = \frac{I_m}{\sqrt{2}} \times \frac{\pi}{2I_m}$.

$$\therefore \boxed{F = \frac{\pi}{2\sqrt{2}}} = 1.11$$

Ripple factor $= \gamma = \frac{I_{ac}}{I_{dc}} = \sqrt{F^2 - 1}$

$$\boxed{\gamma = \sqrt{F^2 - 1}} = 0.48$$

Rectification efficiency $= \eta$

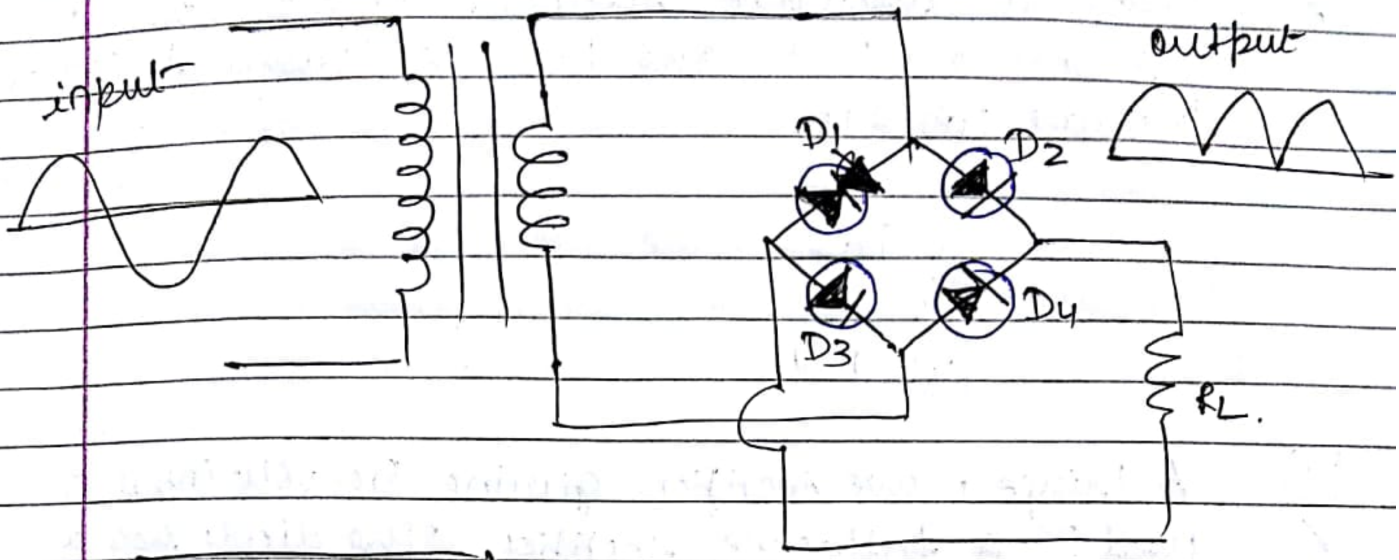
$$\eta = \frac{P_{dc}}{P_i}$$

$$P_{dc} = I^2_{dc} \cdot R_L$$

$$P_i = I^2_{rms}(R_f + R_L)$$

$$\therefore \boxed{\eta = \frac{8}{\pi^2 (R_f/R_L + 1)}}$$

Full wave Rectifier (BRIDGE RECTIFIER)



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

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

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

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

Form factor = F

$$F = \frac{I_{rms}}{I_{DC}} = \frac{I_m}{\sqrt{2}} \times \frac{\pi}{2I_m} = \frac{\pi}{2\sqrt{2}} = 1.11$$

$$\boxed{F = \frac{\pi}{2\sqrt{2}}}$$

Ripple factor = $\gamma = \frac{I_{ac}}{I_{dc}} = \sqrt{F^2 - 1} = 0.48$

$$\boxed{\gamma = \sqrt{F^2 - 1}}$$

Rectification efficiency = $\eta = \frac{P_{dc}}{P_i} = \frac{I_{dc}^2 R_L}{I_{rms}^2 (2R_f + R_L)}$

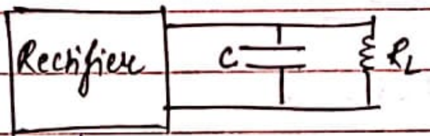
$$\boxed{\eta = \frac{8}{\pi^2}\left(\frac{1}{\frac{2R_f}{R_L} + 1}\right)}$$

Filter Circuits

The quality of rectification can be improved by smoothing the output wave forms from the rectifier. This is achieved by using filter circuits.

Filter circuits are such circuits which oppose the variations in a voltage. They are of different types—

(1.) **Shunt Capacitor filter**



The reactance of capacitor → X_C.

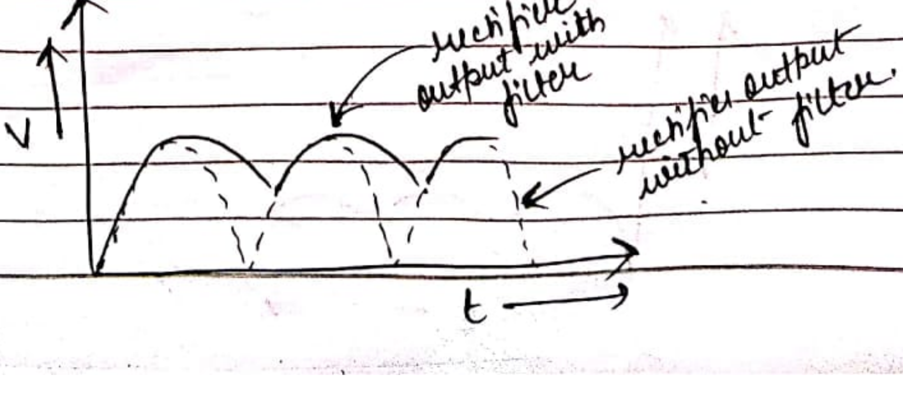
$$\therefore X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

$\therefore$ For DC, $X_C = \infty$

For AC, X_C is small.

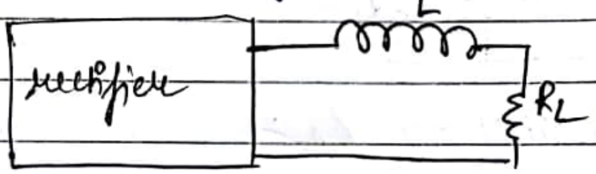
The capacitor offers infinite resistance to DC and very small resistance to AC. When it is connected in parallel with the load resistance, in the output circuit of a rectifier, it bypasses the AC and only DC appears across the load.

Alternatively;



When the voltage across R_L increases, the capacitor gets charged. When the voltage falls, the capacitor discharges sending an additional current through R_L and hence it tends to maintain a constant voltage across R_L and variations in the output voltage are reduced. For a given value of R_L, larger the capacitance C, smaller will be its impedence which will result in better bypassing of AC component. i.e; smaller ripple factor

2. Series Inductance filter



Inductance reactance = ωL

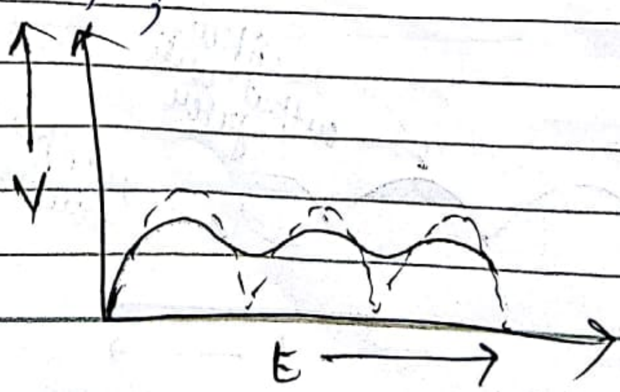
$\therefore \omega_L = 2\pi f L$

for DC, $X_L = 0$

for AC, X_L is high

The inductance offers a high resistance to AC and zero resistance to DC. It prevents AC to reach R_L and allows DC to appear across R_L. In this way Ripples are reduced in the rectifier output.

Alternatively,



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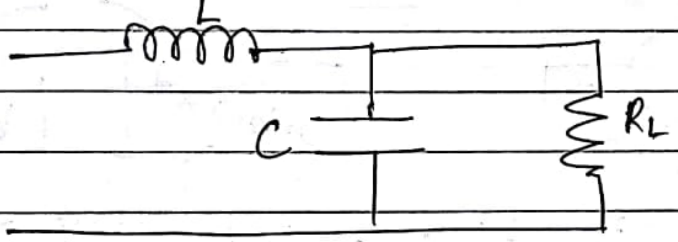
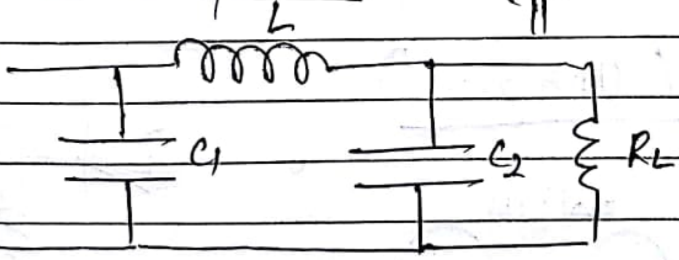
When the load current increases, the induced voltage across the inductor opposes the increase because its polarity is such that it sends an induced current in opposite direction. Similarly, when the load current decreases, the polarity of the induced voltage is reversed so that induced current flows in the same direction as the load current and boosts it up. The variations in the load current are thus minimized.

3. L-Section filter

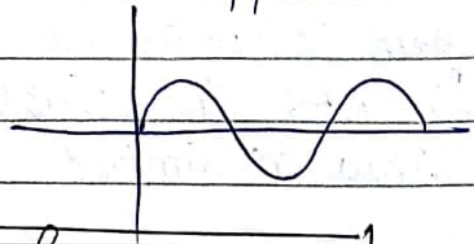


4. π-Section filter



CLIPPERS

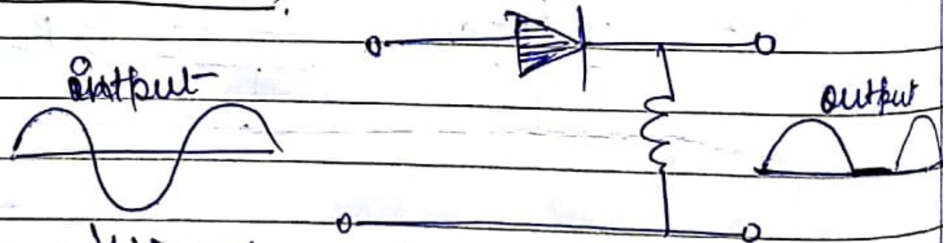
Diode networks that have ability to clip off a portion of input signal without distorting the remaining part of the alternating wave form are known as clippers.



- (I) SERIES CLIPPERS
  - unbiased
    - (+)ve
    - (−)ve
  - biased
    - (+)ve
    - (−)ve
- PARALLEL CLIPPERS
  - unbiased
    - (+)ve
    - (−)ve
  - biased
    - (+)ve
    - (−)ve

(I.) SERIES CLIPPERS (Unbiased)

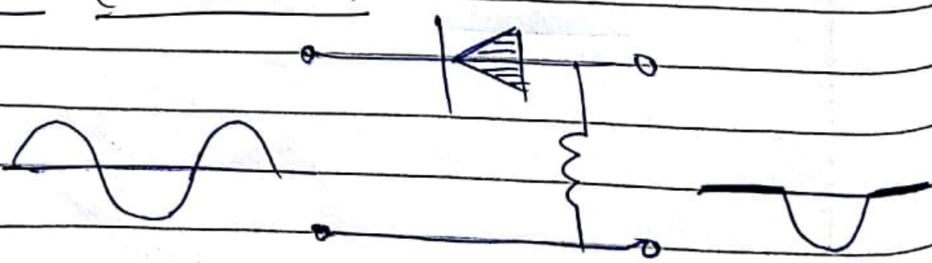
(−)ve



For half-wave rectifier, $V_i > 0V$, $V_0 = V_i$
$V_i < 0V$, $V_0 = 0$.

(II.) SERIES CLIPPERS (Unbiased)

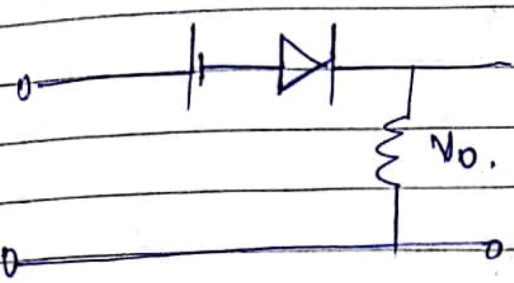
(+)ve.

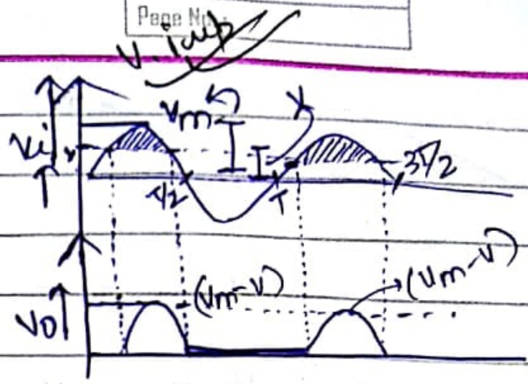


$V_i > 0V$, $V_0 = 0$
$V_i < 0V$, $V_0 = -V_i$

(III) SERIES CLIPPERS (Biased)

(−)ve





output waveform.

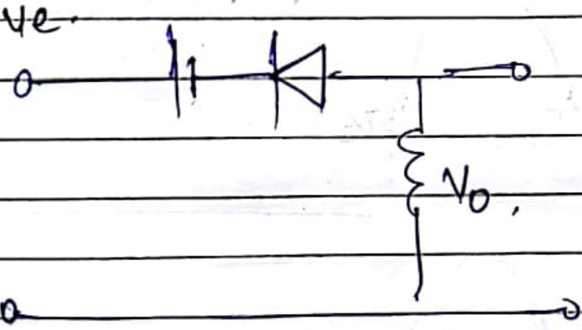
(just starts to conduct) $V_i = V$, $V_0 = 0$

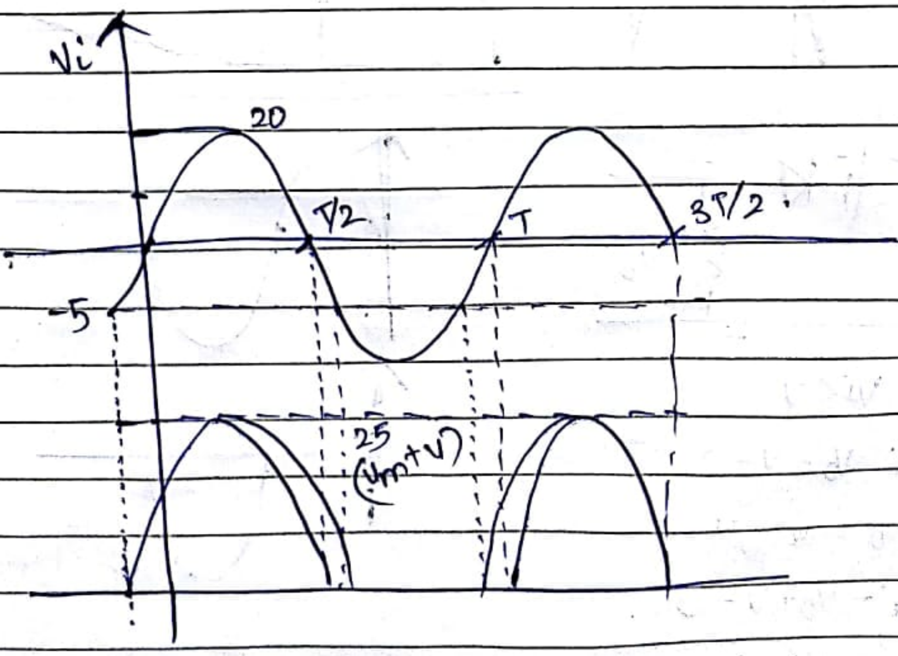
(~~starts~~ open circuit, reverse bias) $V_i > V$, $V_0 = V_i - V$ (forward bias)

$V_i < V$, $V_0 = 0$.

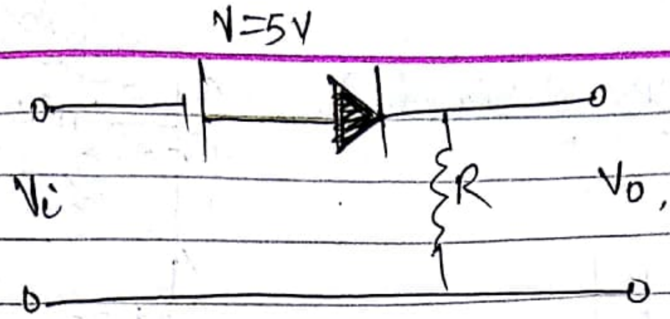
(IV) SERIES CLIPPERS (Biased)

(+)ve.





Eg,



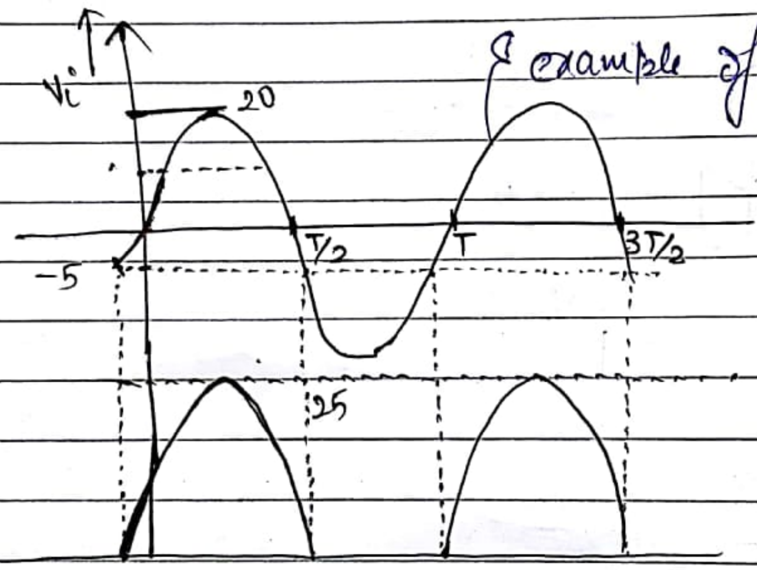
If $V_i = -5V$, $V_0 = 0$.

If $V_i < -5V$, $V_0 = 0$.

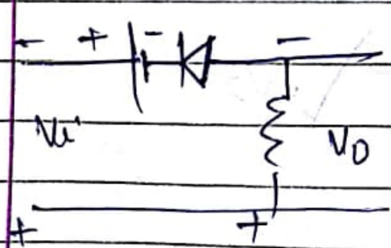
If $V_i > -5V$, $V_0 = V_i - (-5)$

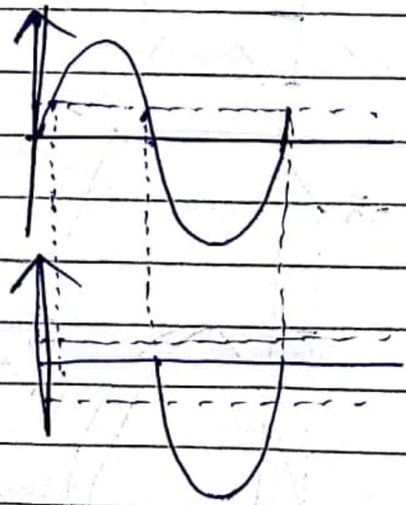
$= V_i + 5$.

Q/



{example of series clippers for biased (+)ve half cycle}





$V_i < V$

$V_i - V_0 - V = 0$

$V_0 = V_i - V$

$V_i - V_0 + V = 0$

$V_0 = V_i + V$

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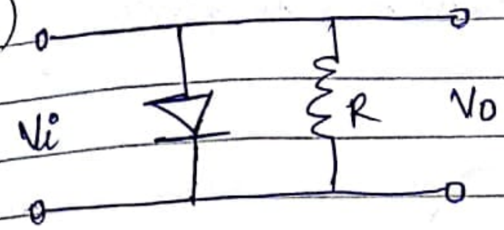
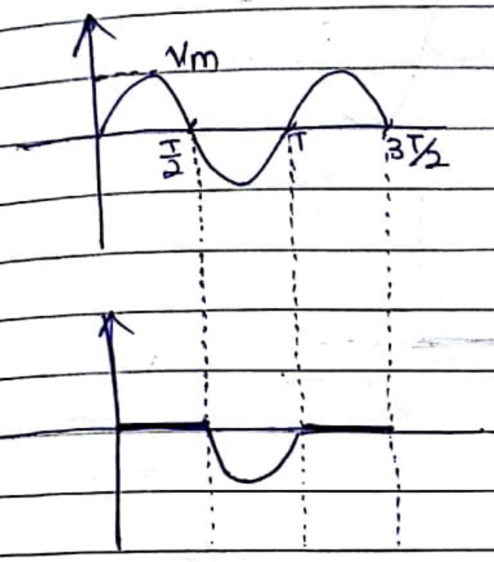
PARALLEL CLIPPERS (+)ve (diode in forward biased condition)

(Biased)





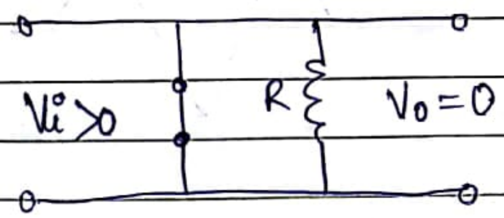
$V_i > 0$ V (diode in forward biased)

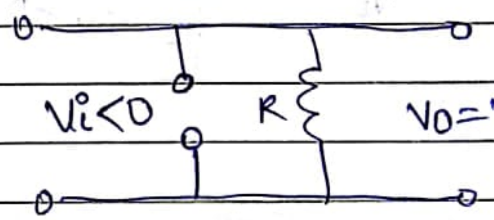
$V_o = 0$

$V_i < 0$ V

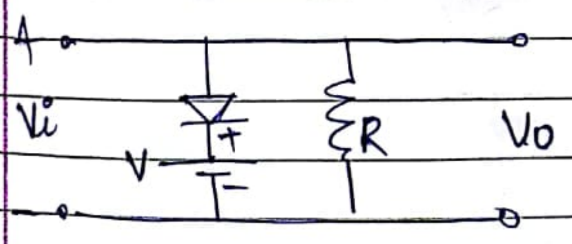
$V_o = V_i$

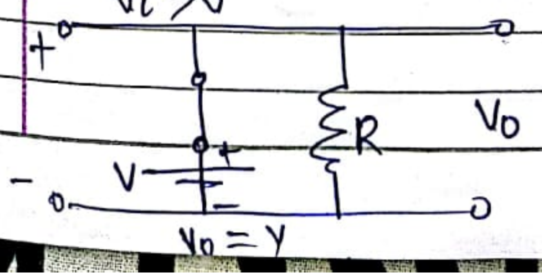
$\boxed{\text{OR}}$

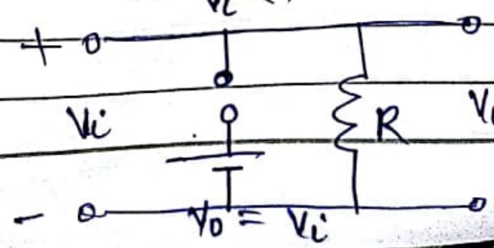




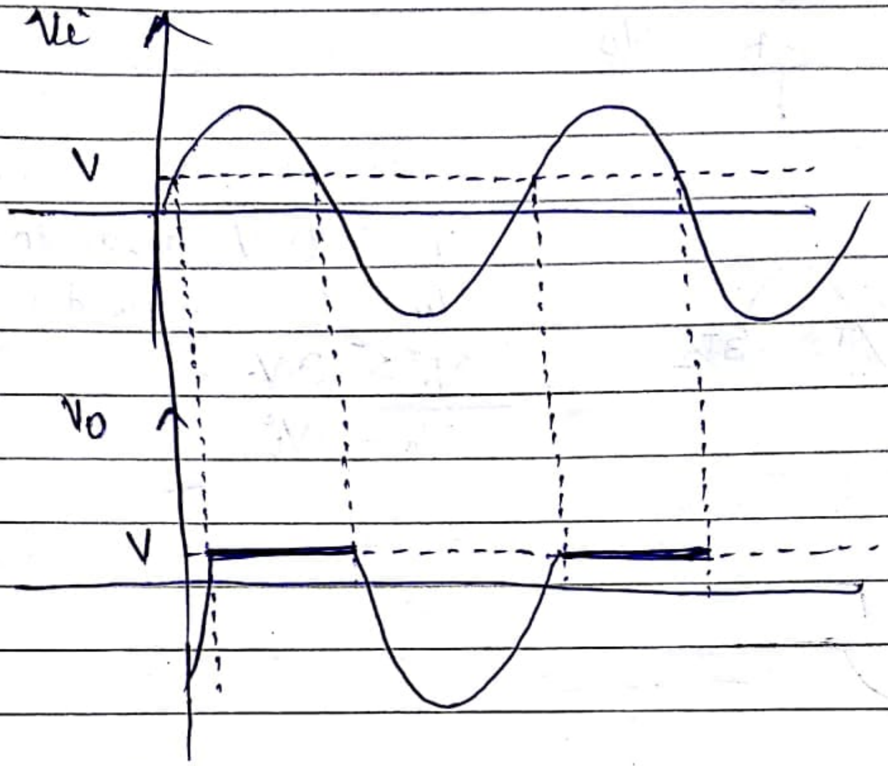
PARALLEL CLIPPERS







$V_i = V$
$V_0 = V$ } (Transition condition from reverse bias to forward bias.)



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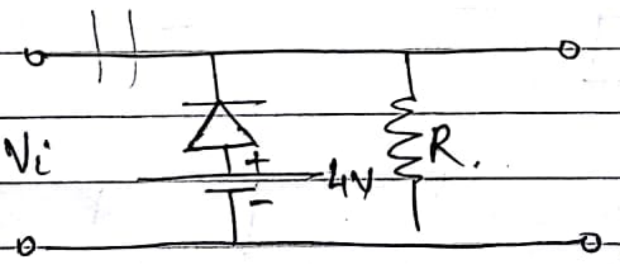
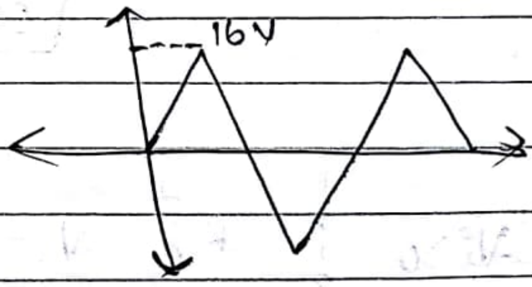
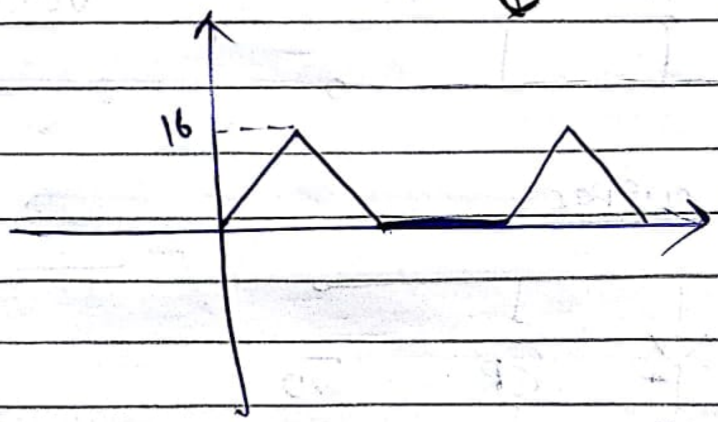
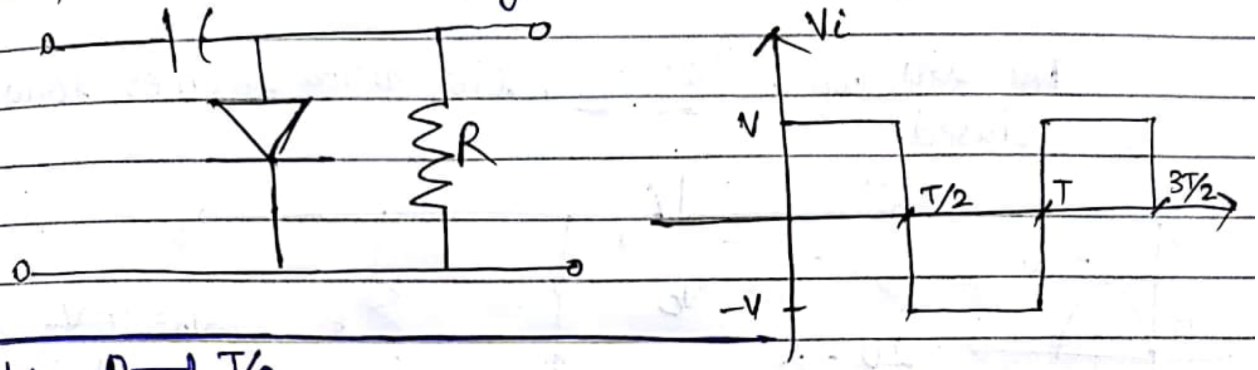




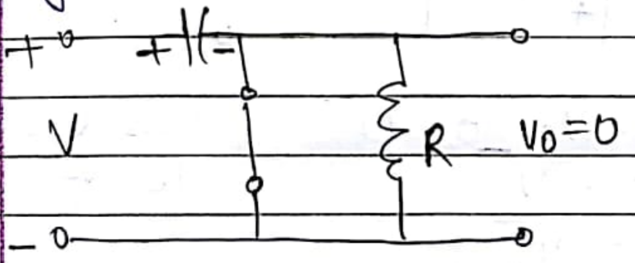


CLAMPERS

Clampers are those diode networks which clamp a signal to a different d.c. level. The network must have a capacitor, a diode and a resistive element. To introduce additional shift, sometimes it uses an independant d.c. supply.

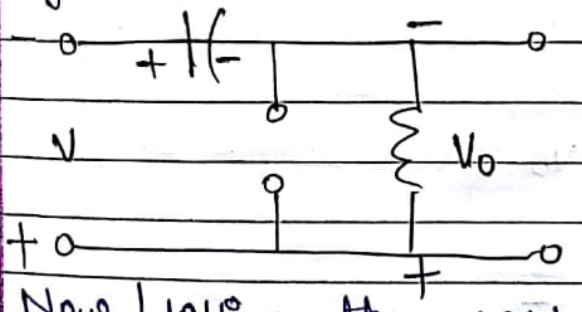


for 0 → T/2.



$$\boxed{V_0 = 0}$$

for T/2 → T



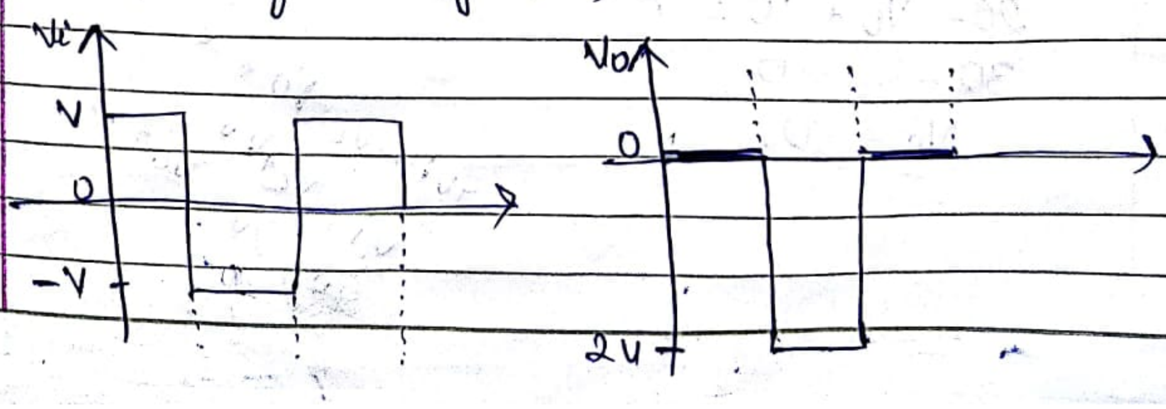
$V + V - V_0 = 0$

$2V = V_0$

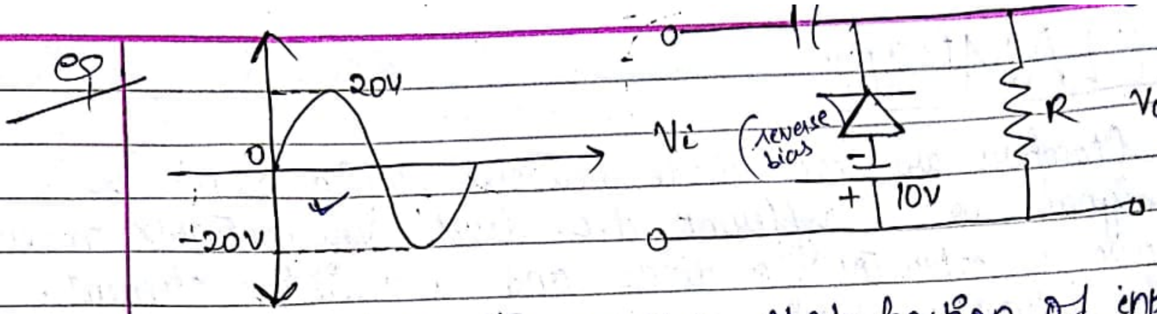
or

$$\boxed{V_0 = 2V}$$

Now plotting the graph;

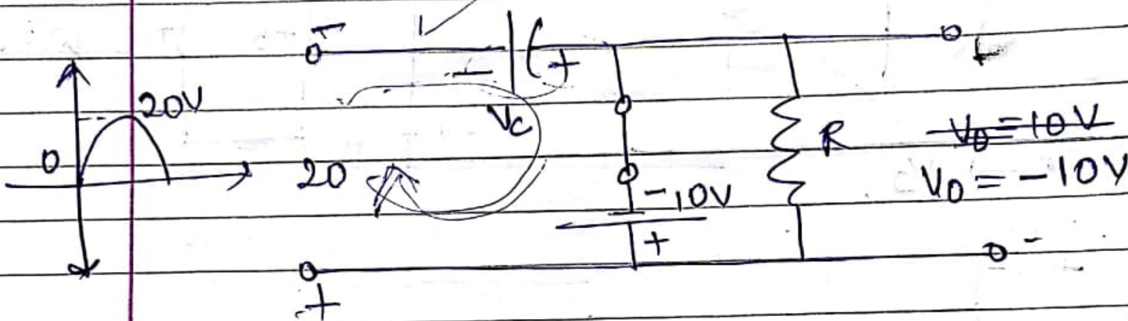


eg



first, we have to consider that portion of input signal for which the diode is in forward bias.

For the cycle $T/2 \rightarrow T$, the diode becomes forward biased.

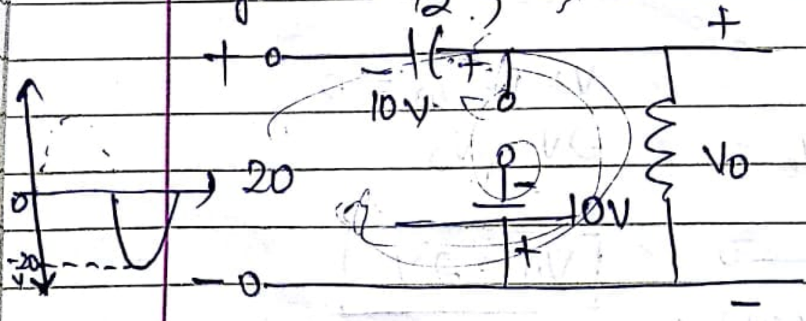


$$20 - V_c - 10 = 0$$
$$10 - V_c = 0$$
$$V_c = 10.$$

$20 = V_c + 10$

$10 = V_c$

for $0 \rightarrow T/2$, diode will be reverse biased.



$$20 - V_0 + 10 = 0$$
$$30 - V_0 = 0$$
$$V_0 = 30.$$

~~$+V_i - V_c - V_0 = 0$~~

~~$V_i = V_c + V_0$~~

~~$20 = V_c + V_0$~~

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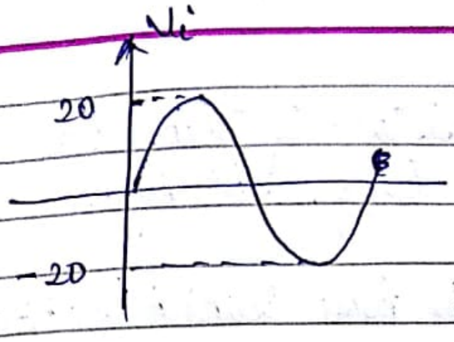
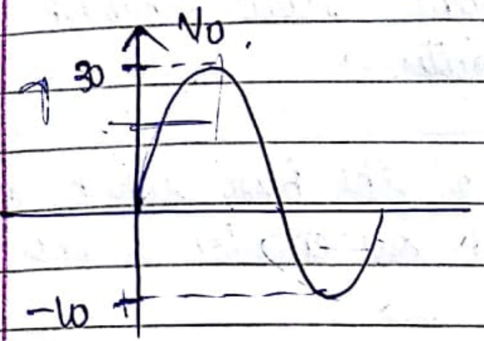




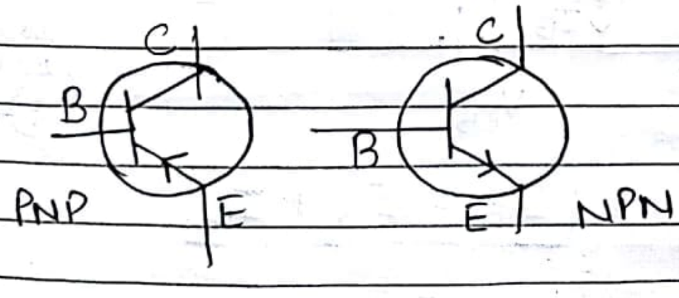
BIPOLAR JUNCTION TRANSISTORS

Invented in 1948 by Bardeen and Brattain. (BJTs)

Two junctions are joined either back to back or front to front.

$\boxed{P|N} + \boxed{N|P} \longrightarrow \boxed{P|N|P}$

$\boxed{N|P} + \boxed{P|N} \longrightarrow \boxed{N|P|N}$



- Base (B)
- emitter (E)
- Collector (C)

The central region of a transistor is thin and lightly doped. It is known as the base. ~~The region~~

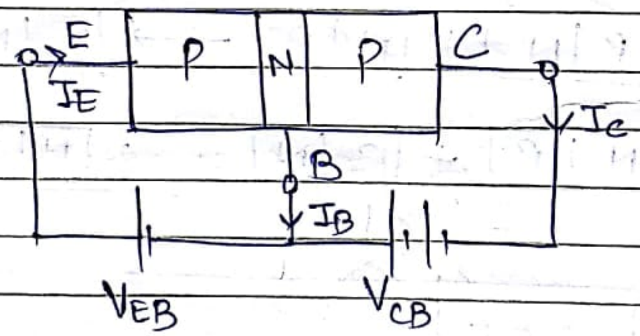
The region on one side of the base which supplies the charge carriers for the current flow through the transistor is known as Emitter.

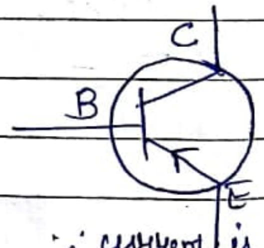
The region on the other side of the base which collects the charge carriers supplied by emitter is known as collector.

WORKING OF TRANSISTOR

For transistor operations;
EB junction should be forward biased.
CB junction should be reverse biased.

PNP

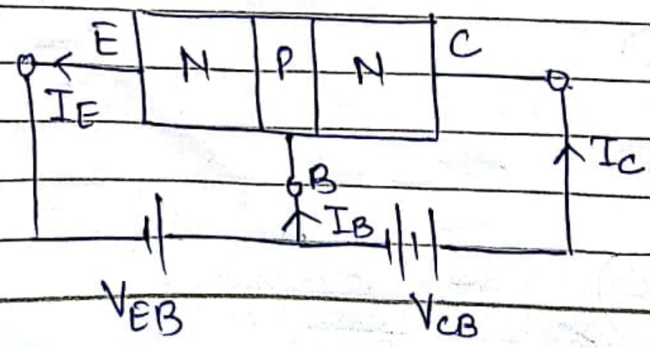


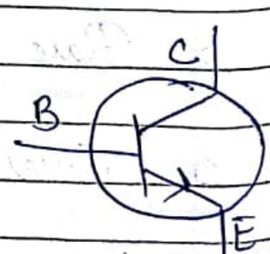


∵ current is flowing from (E) → (B) region

for every transistor ⟹ $\boxed{I_E = I_B + I_C}$

NPN





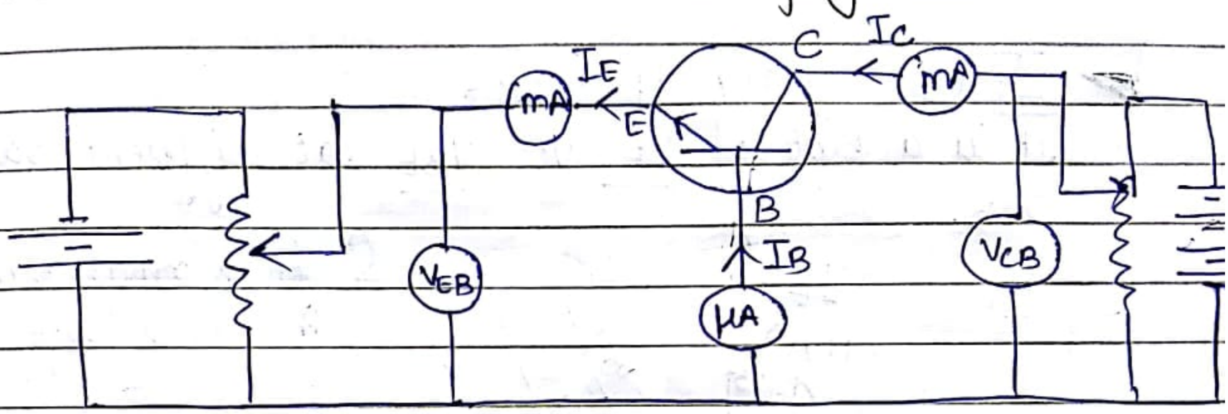
∵ current is flowing from (B) → (E) region.

I_B is very small because Base is lightly doped.

TRANSISTOR CONFIGURATIONS.

→ Common base (CB) configuration
→ Common emitter (CE) configuration
→ Common Collector (CC) configuration.

(1.) COMMON BASE Config.



Current gain : α

$$\therefore \alpha = \frac{\Delta I_C}{\Delta I_E} \quad (\text{for a.c.})$$

$$\therefore \alpha = \frac{I_C}{I_E}$$

I_{CBO}

Collector current (I_C)

It is due to two reason → (i) αI_E

(hence two parts of I_C) → (ii) Due to minority charge carriers under reverse bias of CB junction

$\boxed{\text{Leakage current}}$

$$\therefore I_C = \alpha I_E + I_{Leakage}$$

$$= \alpha (I_B + I_C) + I_{Leakage}$$

$$\therefore I_C (1-\alpha) = \alpha I_B + I_{CBO}$$

where $I_{CBO} = I_{Leakage}$

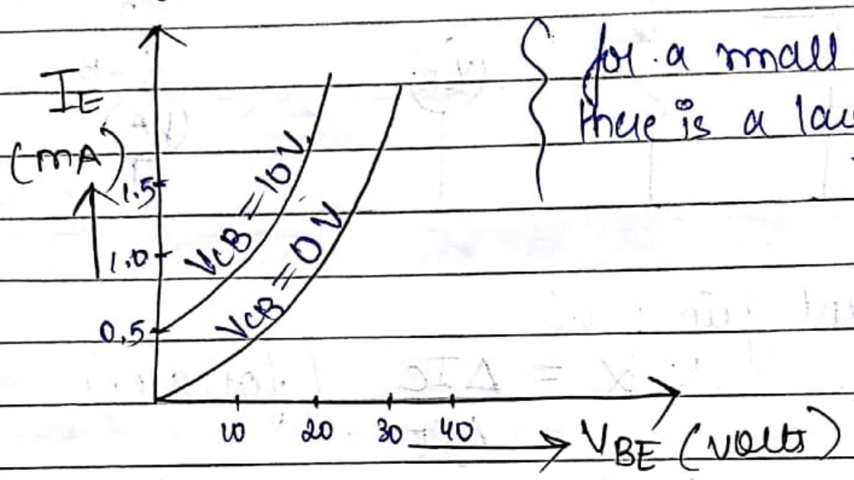
$$\therefore \boxed{I_C = \left(\frac{\alpha}{1-\alpha}\right) I_B + \frac{I_{CBO}}{(1-\alpha)}}$$

Expression for collector current (I_C) in CB configuration

{Current flows due to minority charge carriers under reverse bias}

INPUT CHARACTERISTICS

It is a plot of I_E Vs V_{BE} at different values of V_{CB}.



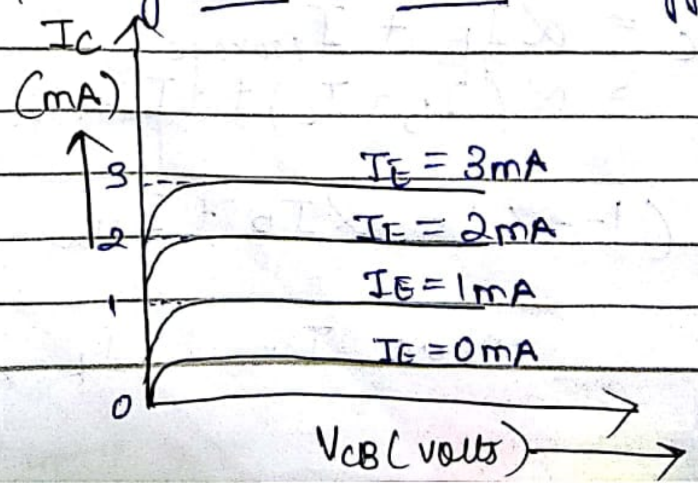
{for a small variation in V_{BE}, there is a large variation in I_E.}

Input resistance $= r_i = \left(\frac{\Delta V_{EB}}{\Delta I_E}\right)_{V_{CB}}$

(its value will be small)

OUTPUT CHARACTERISTICS.

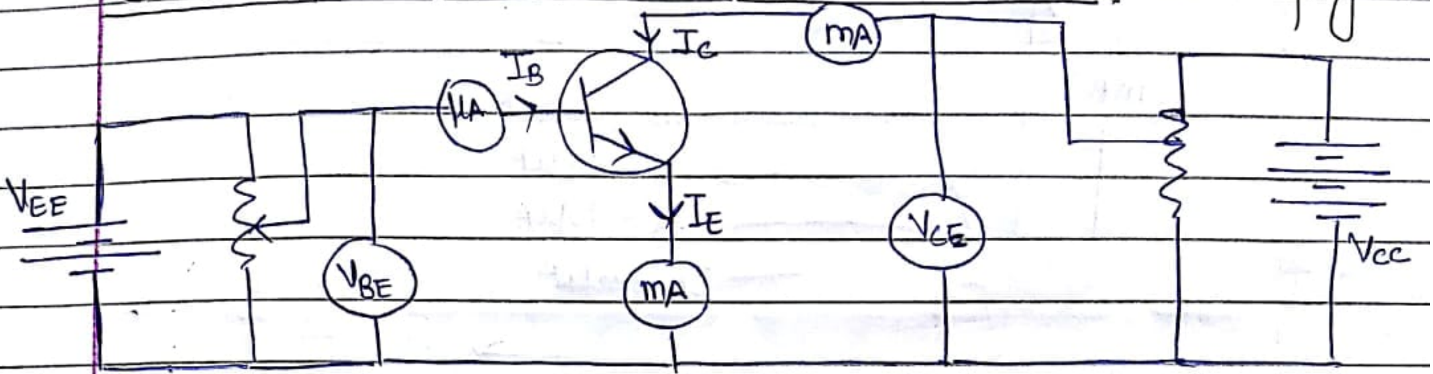
It is a plot of I_C Vs V_{CB} at different values of I_E



Output resistance = $r_o = \left(\frac{\Delta V_{CB}}{\Delta I_C}\right)_{I_E}$

(its value is very high)

COMMON EMITTER Config.



Relationship between α and β:

$\alpha = \frac{\Delta I_C}{\Delta I_E}$

$\alpha = \frac{\Delta I_C}{\Delta I_B + \Delta I_C}$

$= \frac{\Delta I_C / \Delta I_B}{1 + \frac{\Delta I_C}{\Delta I_B}}$

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

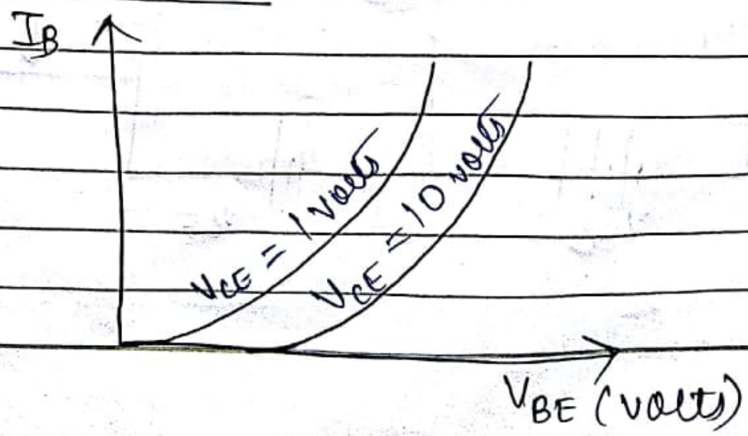
$\beta = \frac{\Delta I_C}{\Delta I_B}$

$\beta = \frac{\Delta I_C}{\Delta I_E - \Delta I_C}$

$= \frac{\Delta I_C / \Delta I_E}{1 - \frac{\Delta I_C}{\Delta I_E}}$

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

Input characteristics

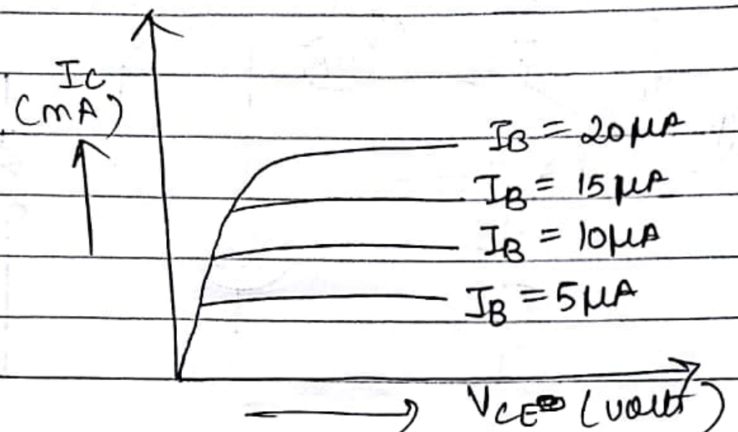


$$r_i = \frac{\Delta V_{BE}}{\Delta I_B}$$

(is small)

∴ for very low value of V_{BE}, there is a large value of I_B.

OUTPUT CHARACTERISTICS

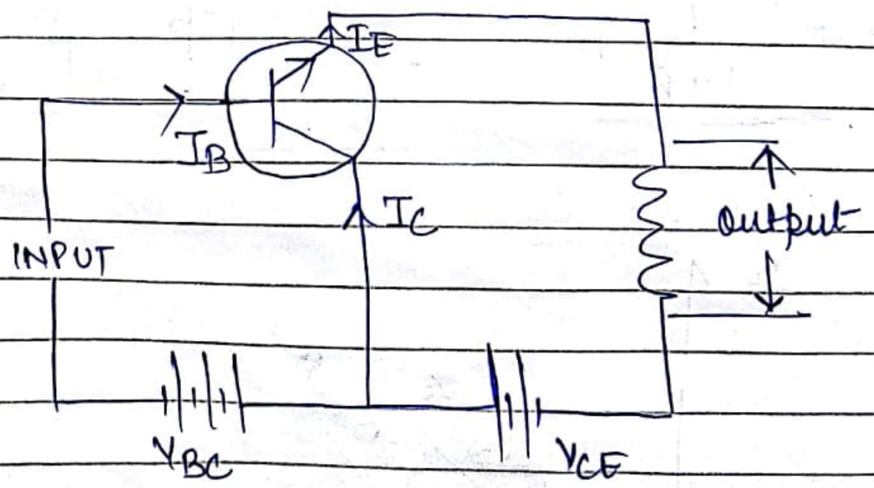


$$r_{output} = \left(\frac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B}$$

(is large)

The value of V_{CE} upto which I_C varies with V_{CE} is known as Knee voltage

COMMON COLLECTOR Config



Current gain ;

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

Relationship between α, β and γ.

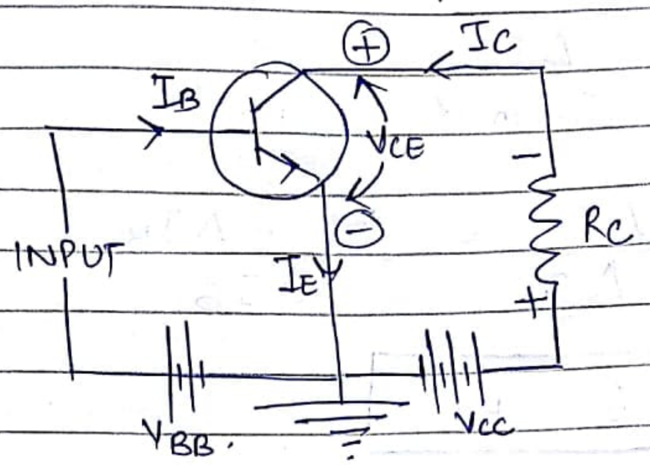
$$\gamma = \frac{\Delta I_C}{\Delta I_B} = \frac{\Delta I_C + \Delta I_B}{\Delta I_B}$$

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

COMPARISON b/w CB, CE & CC configurations

PROPERTIES	CB	CE	CC
Input resistance	Low (~100 Ω)	Low (~ 750 Ω)	Very high (~750 kΩ)
Output resistance	Very high (~ 450 kΩ)	high (~ 450 Ω)	Low (~ 50 Ω)
Voltage gain	~ 150	~ 500	Less than 1
Applications	High frequency	Audio frequency	Impedence matching.
Current gain	Less than 1 (α)	high (β)	Appreciable (γ)

Load line and operating point



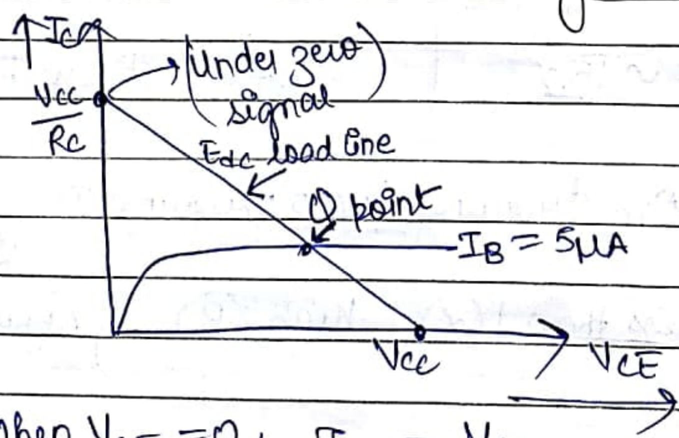
Apply kirchoff's voltage ~~low~~ law in output circuit:

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

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

$$I_C = \frac{V_{CC}}{R_C} - \frac{1}{R_C} V_{CE}$$

OUTPUT CHARACTERISTICS of CE configuration



When $V_{CE} = 0$; $I_C = \frac{V_{CC}}{R_C}$

when $I_C = 0$; $V_{CE} = V_{CC}$

Operating point / Quiescent point / Q-point

Under zero signal condition the intersection point of dc load line and output.

Page No.:

BJT	FET
→ Current controlled device	→ Controlled by input voltage
→ Bipolar device	→ Unipolar device
→ Input resistance is small	→ Input resistance is ↑ because input circuit is in reverse bias
→ Characterised by current gain	→ characterised by Trans conductance.
→ e's and holes both participate in conduction	→ Conduction due to one type of charge only.
→ Noise level is high	→ Noise level is low

The main drawback of JFET is that gate must be reverse biased for proper operation of the device. This means that we can only decrease the width of the channel. This type of operation is known as depletion mode operation. so a JFET can only be operated in depletion mode. ~~That~~

There is another type of FET known as MOSFET that can be operated to enhance the width of the channel. So MOSFET works in enhancement mode as well as in depletion mode

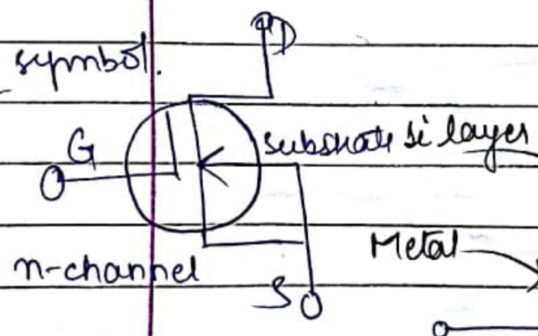
Types of MOSFET

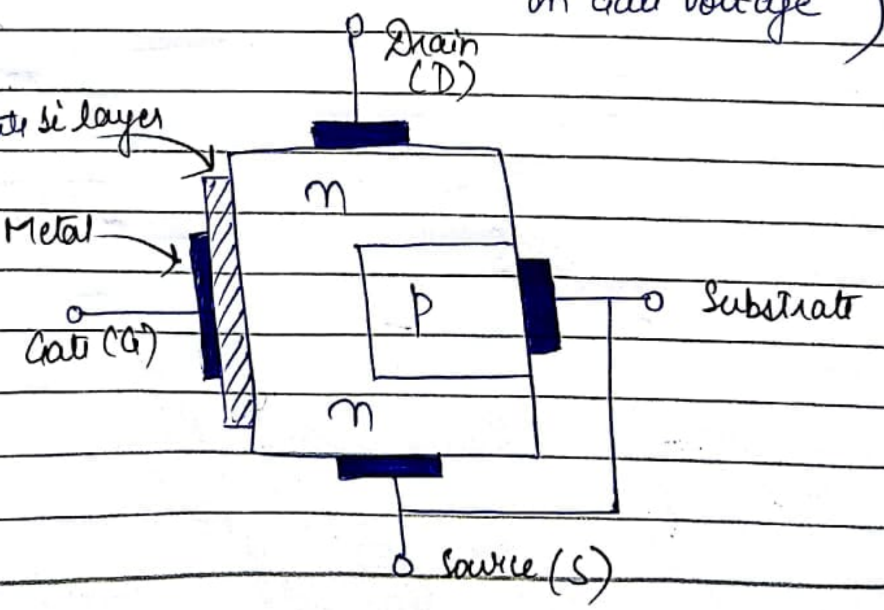
Depletion type MOSFET (D-type)	Enhancement type MOSFET (E-type)

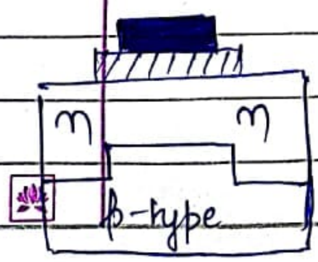
D-MOSFET

(works both in depletion mode and enhancement mode depending on Gate voltage)

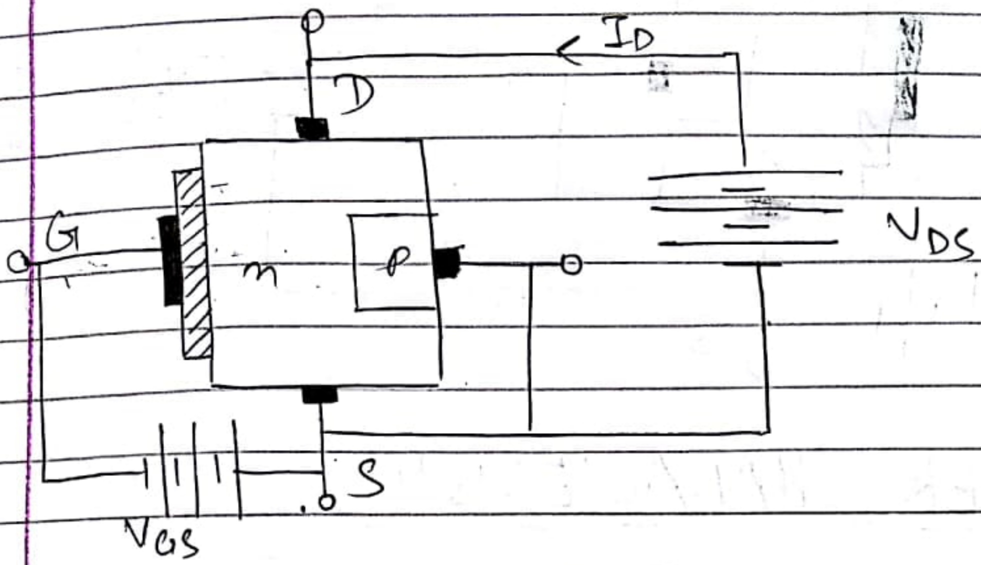
symbol

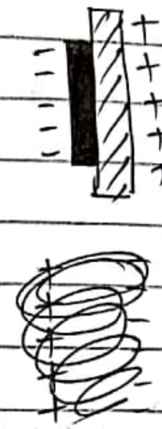






Depletion mode





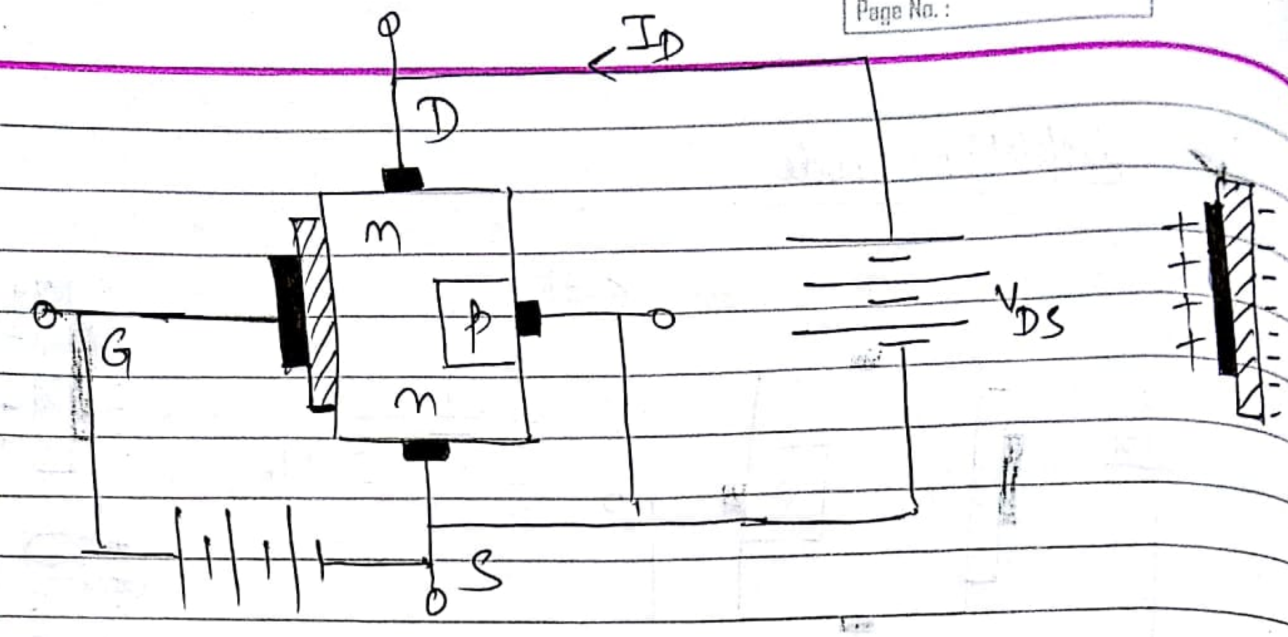
Since Gate is negative ; substrate is always connected to the source, free electrons of the n-channel are repelled leaving a layer of positive charge of the channel. Therefore less number of free electrons are available for conduction. Indirectly the channel width decreases. The greater the negative voltage of the gate less will be the current from source to drain.

Working of D-MOSFET in depletion mode is similar to JFET.

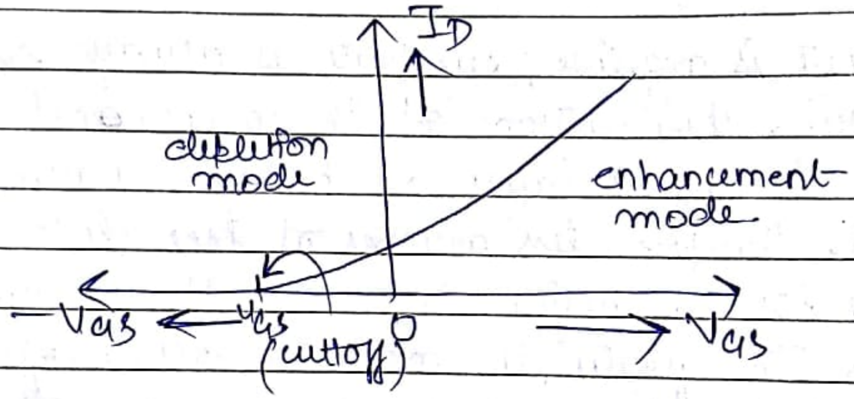
MOSFET → Insulated Gate Field Transistor (IGFET)

Enhancement mode

For enhancement mode operation, Gate is kept at positive potential so that negative charge is induced in the channel and the conductivity increases, the more the positive potential ~~on~~ Gate, the more will be the current from source to drain.

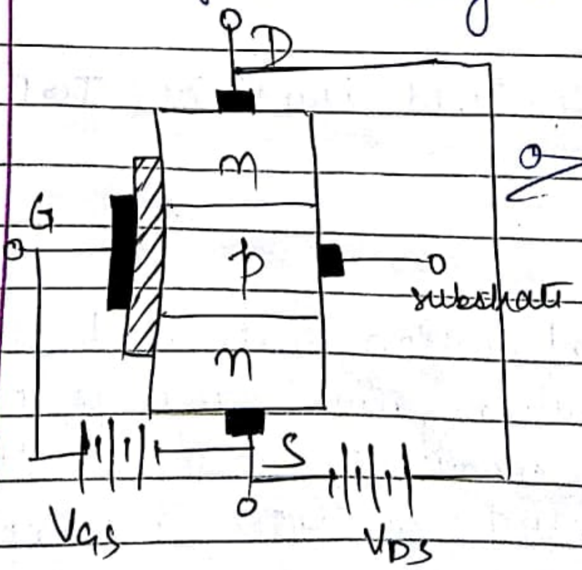


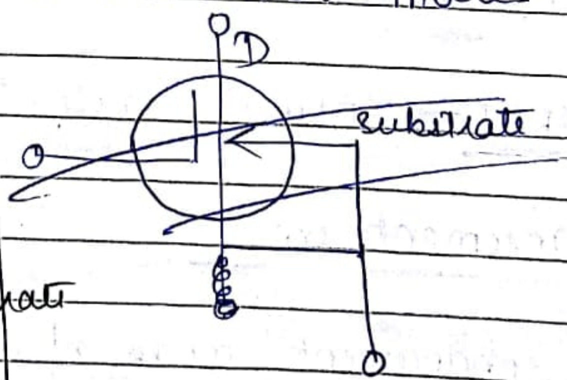
TRANSFER CHARACTERISTICS

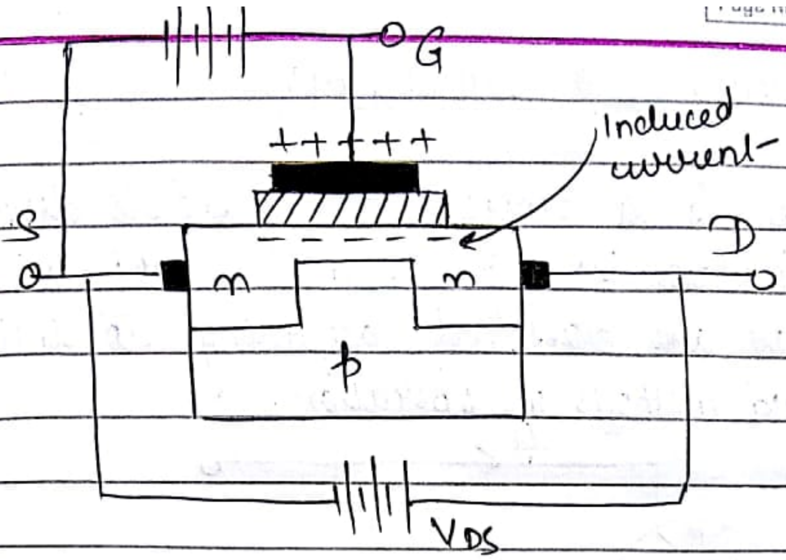


E-MOSFET

E-mosfet works only in enhancement mode.

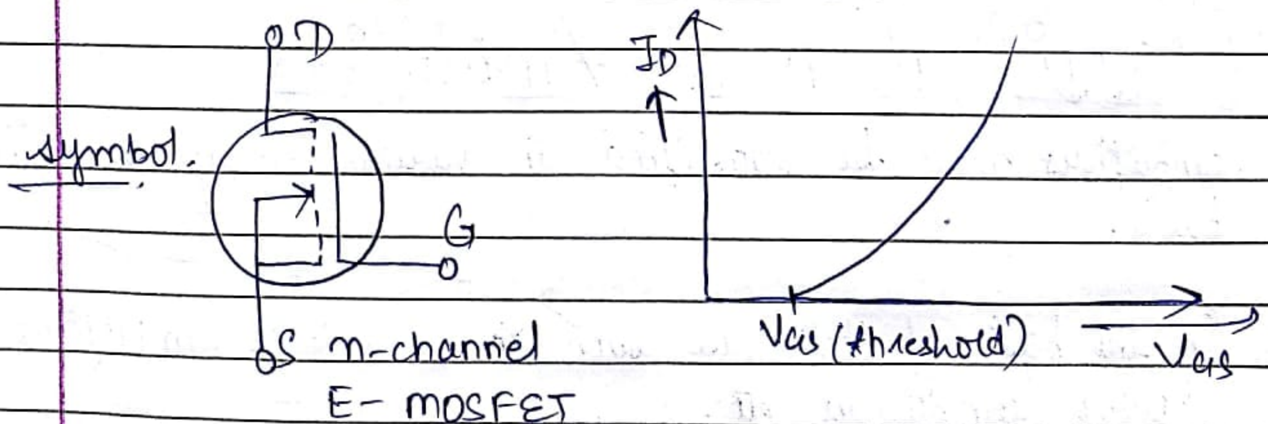


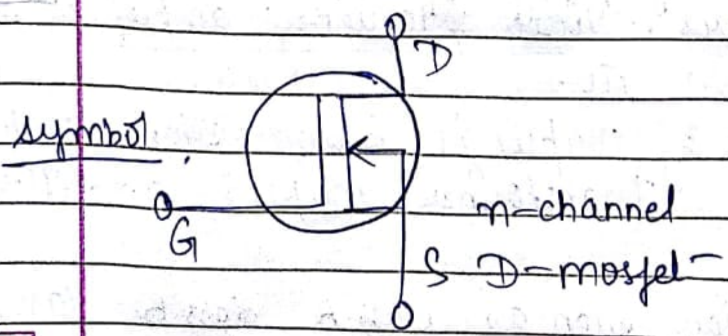




E-MOSFET has no channel, it requires a proper gate voltage to form a channel called induced channel. It works only in enhancement mode. As V_{GS} is increased, I_D increases, the minimum value of V_{GS} that turns the E-MOSFET on is known as Threshold voltage.

TRANSFER CHARACTERISTICS





UNIT → 4

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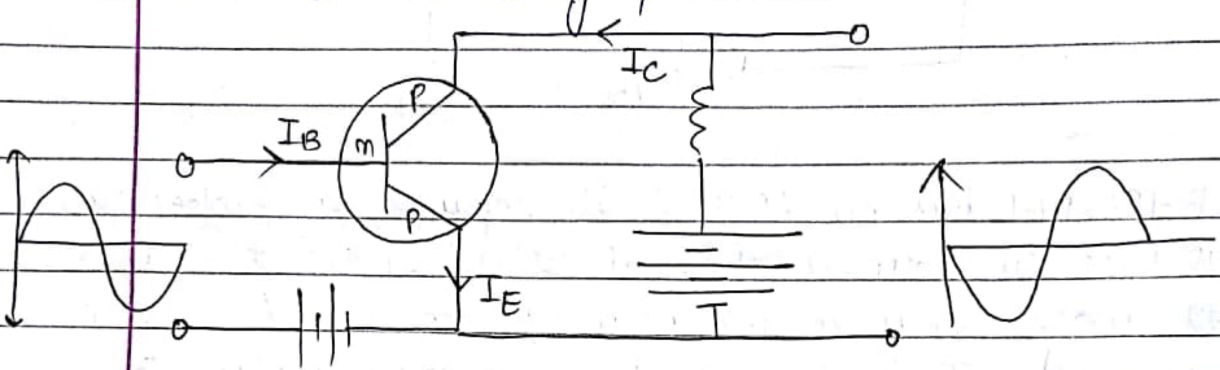
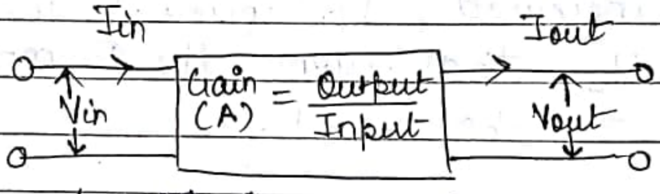
Introduction to Amplifiers

Amplifier is a general term used to describe a circuit which increase its input signal. Not all amplifiers are same. They are classified according to their circuit configur-ation and methods of operation.





Amplification stage ↑

Classification of Amplifiers

Amplifiers may be classified in various ways on different basis.

Ex.

(i) On the basis of their use such as voltage amplifiers, power amplifiers etc.

(ii) On the basis of frequency range of operation such as Audio frequency amplifiers, Video frequency amplifiers, Radio frequency amplifiers etc.

(iii) On the basis of types of coupling's between them such as RC coupled amplifiers, Transformer coupled amplifiers etc.

(iv) On the basis of operation such as class A, class B, class AB and class C amplifiers

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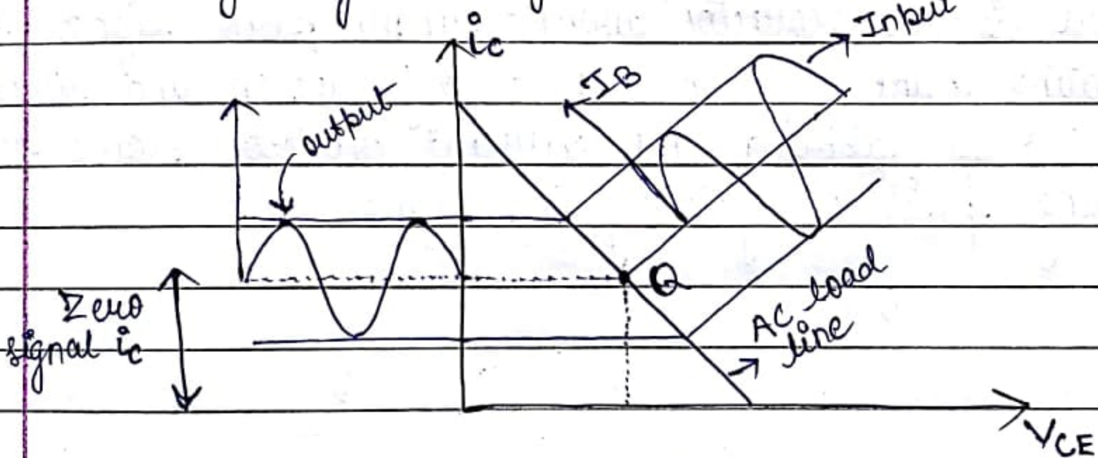
v.imp. **Classification on the basis of Mode of operation.**

This is the most important classification which is based on the portion of the input cycle during which the output collector current flows in the circuit.

On this basis, amplifiers are classified in four categories.

(1.) **Class A amplifiers:**

These are those in which the biasing circuit is so adjusted that there is a zero signal collector current and the operating point Q lies near the midpoint of the AC load line and when AC signal is applied, the collector current flows during the whole cycle of the signal.



CHARACTERISTICS

1. Since, the collector current flows during the whole cycle of the applied signal no part of the signal is cutt-off that is the output waveform is exactly similar to the input wave. Hence, Class A amplifier gives almost distortionless amplification.
2. Since, its operation is restricted to small central region of the load line. It is used for amplifying signals of small amplitude only. Large signals will shift the Q-point towards the saturation and cutt-off region causing distortion.
3. Due to the limitation of input signal amplitude,

the AC power output is low.

4. Collector efficiency is given by

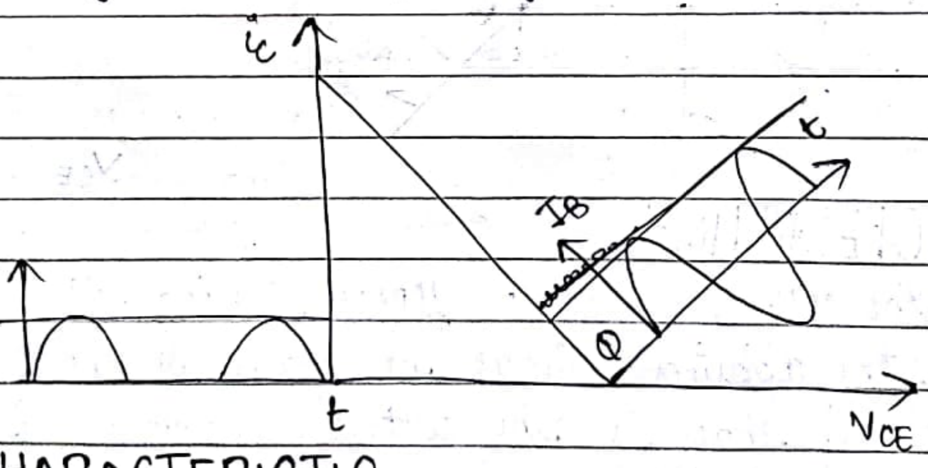
$$= \frac{\text{Average AC power output drawn across load}}{\text{Average DC power input drawn from DC supply}}$$

is less than 50 % ($\sim$35 %)

5. Voltage amplifiers are always class A amplifiers.

(2.) Class B Amplifiers

These are those amplifiers which are biased such that there is no collector current under zero signal condition. Operating point lies in the cutoff region and when AC signal is applied the current collector flows only during positive cycle of the signal.



CHARACTERISTIC

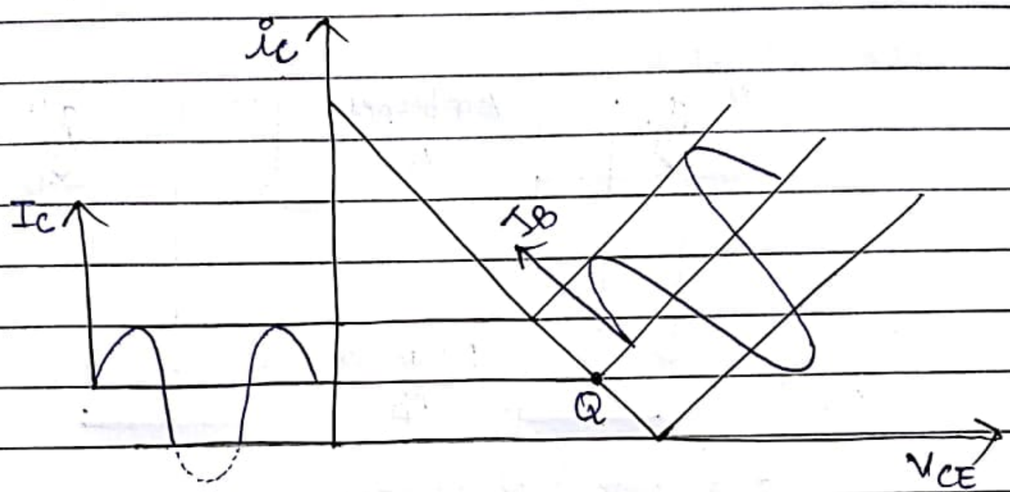
1. Class B amplifiers suffer from severe distortion because the negative half-cycle is completely absent.

ii. It provides medium power output and medium collector efficiency.

iii. Audio frequency power amplifier usually belongs to class B.

3. Class AB Amplifiers

These amplifiers is a compromised between less distortion of class A and high power output of class B where the collector current flows in the circuit for more than 1st half cycle and less than complete cycle of the input signal. The class AB amplifiers are used for power audio amplifiers.

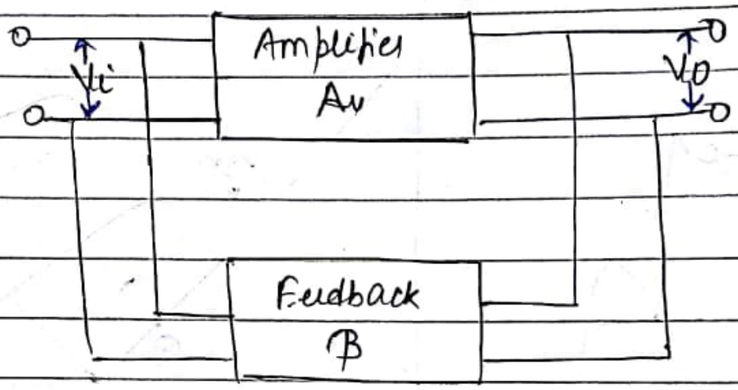


4. Class C

Class C amplifiers are those amplifiers which are biased so that the Q-point lies much beyond the cutt-off point of the load line so that there is no zero signal collector current. When a.c. signal is applied, the collector current flows only during some part of the positive half cycle.

Class C amplifiers are having high distortion, high power output and excellent collector efficiency (above 75%) because of high distortion, class C amplifiers are never used as audio amplifiers. They are mainly used in oscillators for radio frequency amplification where high efficiency is needed regardless of distortion.

FEEDBACK



$$\boxed{\text{Gain } A_v = \frac{V_0}{V_i}}$$

A feedback amplifier is that in which a fraction of the amplified output is fed back to the input circuit. There are two types of feedback.

I. POSITIVE FEEDBACK: When the feedback signal is in phase with the input signal.

II. NEGATIVE FEEDBACK: When the feedback signal is out of phase by 180° with the input signal.

Analysis

After feedback, the input becomes $V_i + \beta V_0'$

$A_v . V_i = V_0$.

Now, $A_v(V_i + \beta V_0') = V_0'$

$\therefore$ For positive feedback $\left\{ \begin{array}{l} A_v . V_i + \beta . A_v . V_0' = V_0' \\ A_v . V_i = V_0'(1 - \beta . A_v) \end{array} \right.$

Positive feedback

$$\boxed{\frac{V_o'}{V_i} = \frac{A_V}{1-\beta A_V}}$$

Gain with feedback } $\boxed{A_{Vf} = \frac{A_V}{1-\beta . A_V}}$ where, β = feedback factor

The denominator is less than 1, therefore, the gain with positive feedback is greater than gain without feedback. The product ($\beta . A_V$) is known as feedback factor where β is known as feedback ratio.

A_{Vf}. is also known as closed loop gain.

Although positive feedback increases the gain of the amplifier but it has disadvantage of increasing the distortion by the same factor.

if $\beta A_V = 1$

then gain becomes infinite and amplifier works as an oscillator.

Negative feedback

$$\boxed{A_{Vf} = \frac{A_V}{1+\beta . A_V}}$$

$\therefore$ $A_{Vf} < A_V$.

The greater the feedback factor $\beta . A_V$, the less will be the gain. But at the same time, the smaller will be the distortion.

The loss in gain maybe compensated by increasing the no. of stapes.

Advantages of NEGATIVE feedback

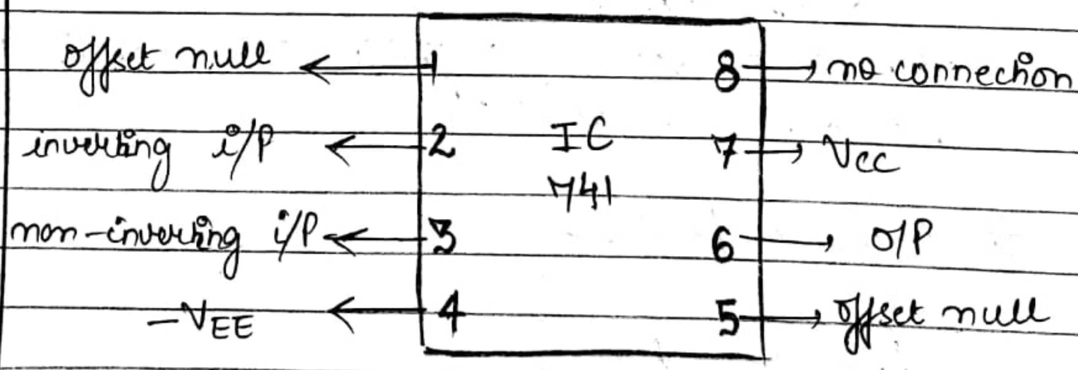
1. Negative feedback decreases amplitude distortion.
2. Negative feedback decreases frequency distortion.
3. Negative feedback makes the performance of the amplifiers more stable.

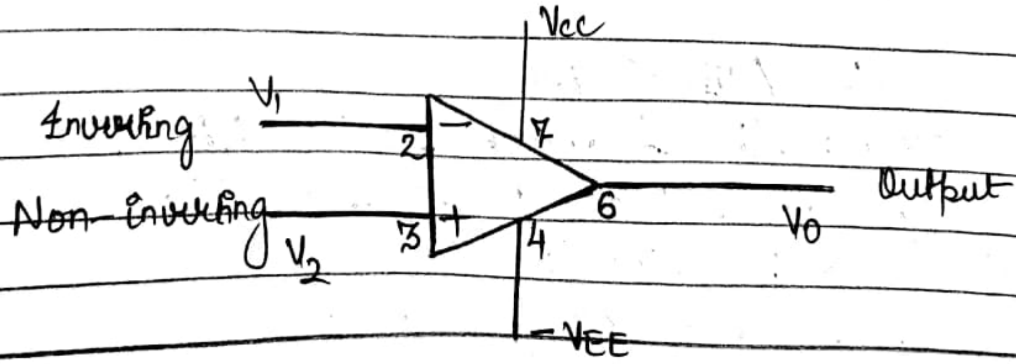
In view of the above advantages, negative feedback is a common feature of audio frequency amplifiers.

OPERATIONAL-AMPLIFIER (OP-AMP)

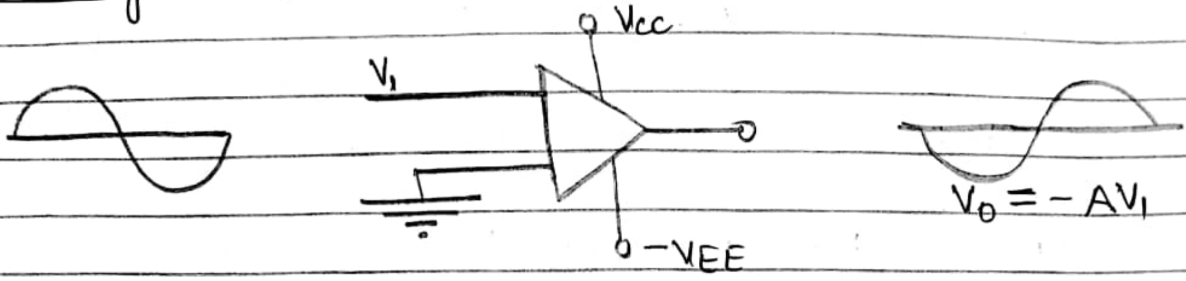
OP-AMP is a directly coupled multistage voltage amplifier with high gain it has very high input impedence and very low output impedence. OP-AMP are used for performing mathematical operation such as addition, subtraction, multiplication, differentiation and integration.

PIN Diagram and OP-AMP symbol.

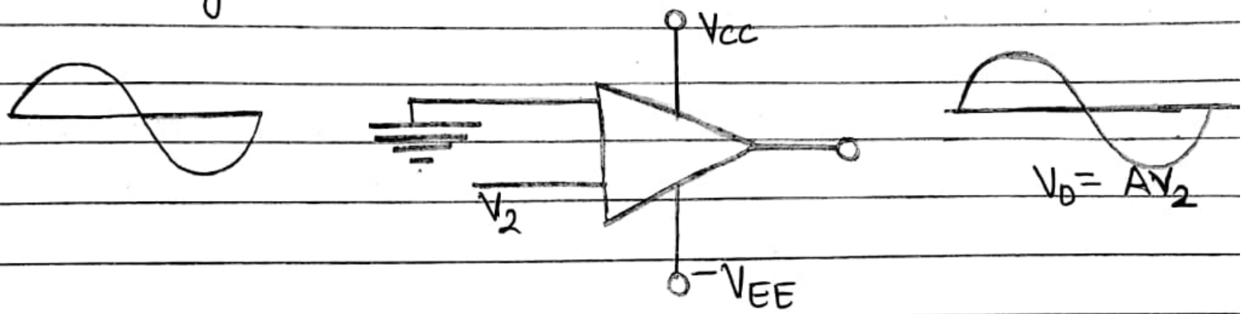




Inverting mode



Non- Inverting mode



Characteristics of an ideal OP-AMP :

1. Infinite Voltage gain

The open loop gain

$$A_{OL} = \infty$$

2. Infinite Input impedence

$$[\ R_i = \infty\ ]$$

An ideal OP-AMP doesnot draw any current from the voltage and source connected to its input terminals.

3. Zero Output Impedence.

$$[\ R_0 = 0\ ]$$

4. Infinite Bandwidth : An ideal OP-AMP amplifies signal of any frequency with a constant gain which implies that OP-AMP has infinite bandwidth.

5. Infinite CMRR (Common Mode Rejection Ratio) $\rho = \infty$

6. Infinite Slew Rate

$$SR = \infty$$

An ideal OP-AMP has infinite slew rate, this implies that the output voltage changes simultaneously with the input voltage.

7. The characteristics of ideal OP-AMP donot depend upon temperature.

8. Power supply Rejection Ratio

$$PSRR = 0$$

9. Zero offset voltage - The presence of small output voltage when $V_1 = V_2 = 0$ is called an offset voltage for and ideal OP-AMP offset voltage is zero.

Different parameters related to OP-AMP.

1. CMRR (common Mode Rejection Ratio)

Ratio of differential gain to common mode gain.

$$\boxed{\rho = \frac{A_d}{A_c}}$$

$$\boxed{\rho_{db} = 20 \log_{10} \frac{A_d}{A_c}}$$

2. Slew Rate It is defined as the maximum rate of change of output voltage with respect to time.

$$\boxed{S.R. = \left.\frac{dV_o}{dt}\right|_{max.}}$$

unit : $V/\mu sec$

3. Output offset voltage

When both the input terminals are connected to ground the output should be zero in ideal case but practically there exists a small value of output. which is known as Output offset voltage.

4. Input offset voltage

To make the output offset voltage zero, a small voltage is required to be given to the input. This voltage is known as Input offset voltage.

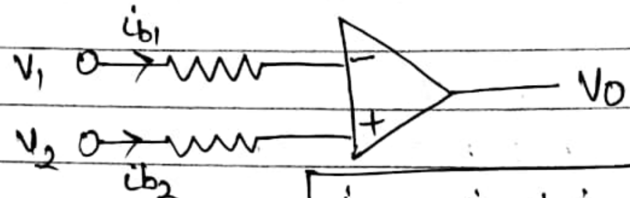
5. Power Supply Rejection Ratio (PSRR)

It is defined as the ratio of change in input offset voltage due to change in supply voltage producing it, keeping other supply voltage constant.

$$\boxed{PSRR = \frac{dV_{i_{offset}}}{dV_{EE}}\bigg/_{V_{CC}}}$$

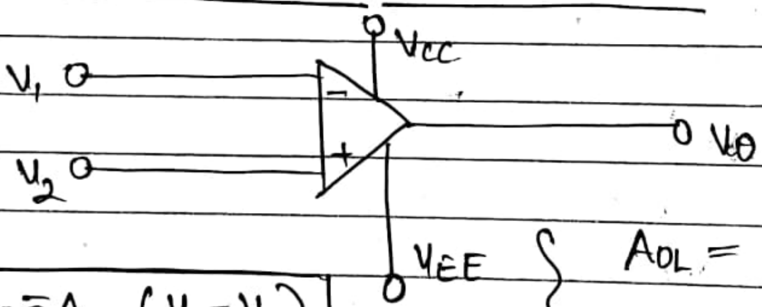
$$\boxed{PSRR = \frac{dV_{i_{offset}}}{dV_{CC}}\bigg/_{V_{EE}}}$$

6. Input biased current



$$\boxed{i_b = \frac{i_{b_1} + i_{b_2}}{2}}$$

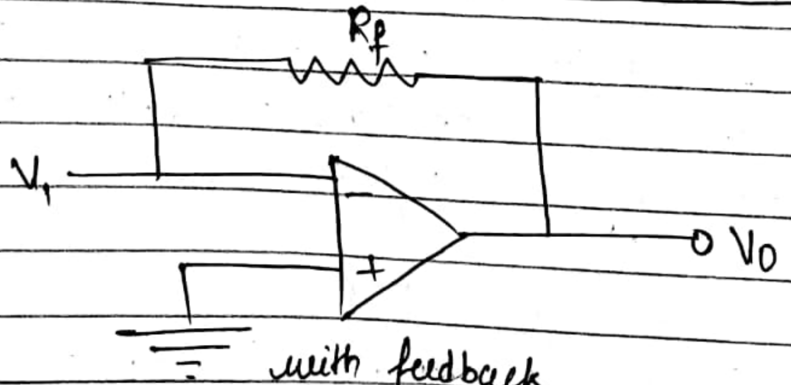
OPEN LOOP AMPLIFIER



$$\boxed{V_O = A_{OL}(V_1 - V_2)}$$

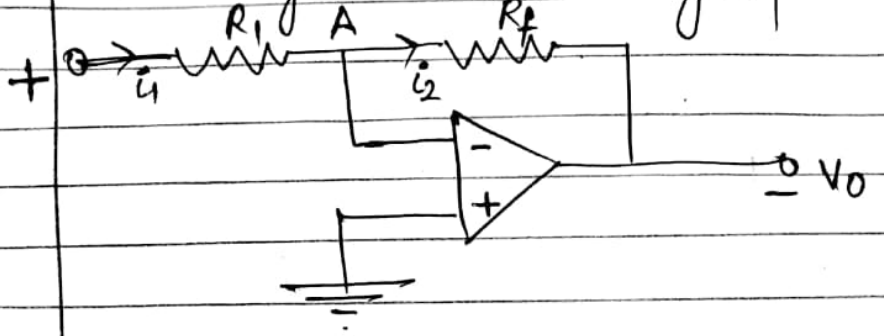
$$\left\{ \begin{aligned} & A_{OL} = \infty = \frac{V_O}{V_1 - V_2} . \\ & \therefore V_1 \sim V_2 . \end{aligned} \right\}$$

CLOSED LOOP AMPLIFIER



with feedback

Virtual ground or ~~Sunning~~ summing point

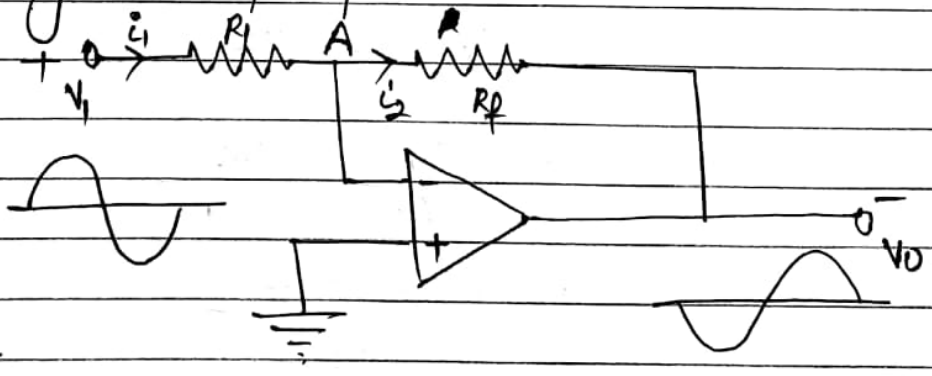


~~A is called suming point~~

point A is called summing point as input and feedback currents are algebraically added at point A.

The voltage at point A is forced to a very small value which can be used to be zero, hence, point A is referred to as virtual ground.

Inverting Amplifiers



$$i_1 = \frac{V_1}{R_1}$$

$$i_2 = \frac{0-(+V_0)}{R_f} = \frac{-V_0}{R_f}$$

Now, applying Kirchoff's current law at A;

$$\therefore \; i_1 = i_2$$

$$\frac{V_1}{R_1} = \frac{-V_0}{R_f} \qquad \therefore \; V_0 = -\frac{R_f}{R_1} V_1$$

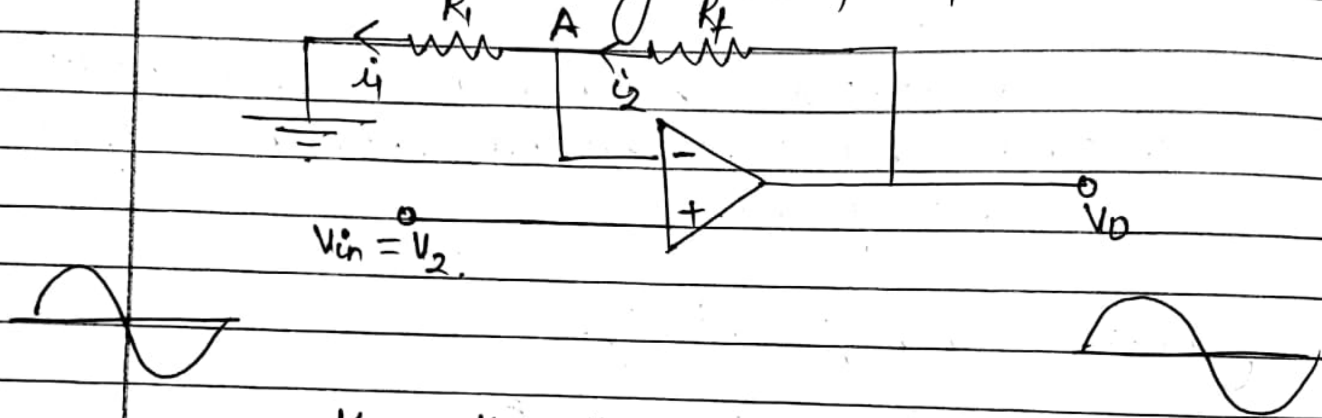
$$\boxed{V_0 = -\frac{R_f}{R_1} \cdot V_1}$$

OR

$$\boxed{V_0 = -\frac{R_f}{R_1} V_{in}}$$

$$\therefore \boxed{\text{Gain} = \frac{R_f}{R_1}}$$

Non Inverting Amplifier



Here, $V_A = V_2 = V_{in}$

$$i_1 = \frac{V_A}{R_1} = \frac{V_{in}}{R_1}$$

$$i_2 = \frac{V_0 - V_{in}}{R_f}$$

Again, by applying Kirchoff's current law;

$$i_1 = i_2$$

$$\frac{V_{in}}{R_1} = \frac{V_0 - V_{in}}{R_f}$$

$$\frac{V_{in}}{R_1} = \frac{V_0}{R_f} - \frac{V_{in}}{R_f}$$

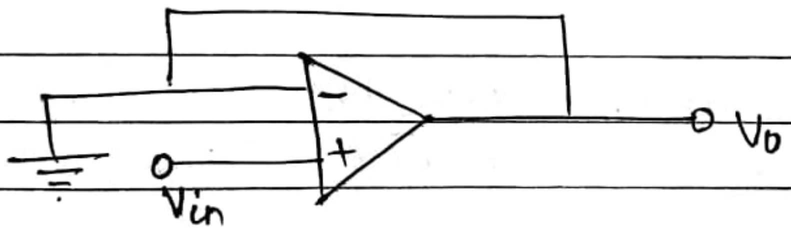
$$\therefore \frac{V_{in}}{R_1} + \frac{V_{in}}{R_f} = \frac{V_o}{R_f}.$$

$$\therefore V_{in}\left[\frac{1}{R_1} + \frac{1}{R_f}\right] = \frac{V_o}{R_f}$$

$$\therefore \boxed{V_o = V_{in}\left[\frac{R_f}{R_1} + 1\right]}$$

$$\therefore \boxed{\text{Gain} = 1 + \frac{R_f}{R_1}}$$

Voltage follower circuit (Unity follower circuit)



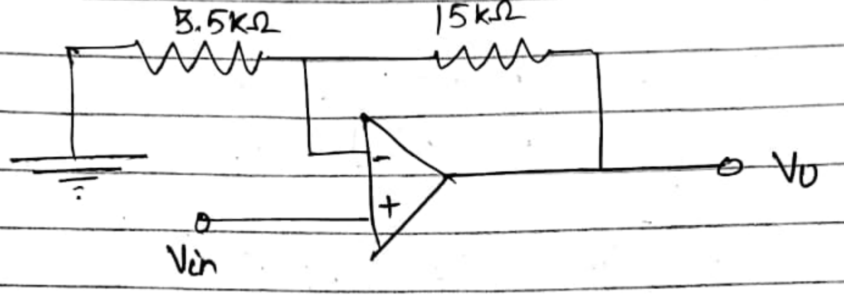
$$V_o = \left(1 + \frac{R_f}{R_1}\right) V_{in}$$

If $R_f = R_1 = 0$

$$\therefore \boxed{V_o = V_{in}}$$

{The circuit in which the output follows the input}

Q/ Calculate (i) input impedence (ii) voltage gain of the given OP AMP circuit.



Input impedence = ∞

Voltage gain: $1 + \frac{R_f}{R_1} = 1 + \frac{150}{3.5} = 1 + 4.2$

$= 5.2$

Q/ For an inverting amplifier, $R_1 = 1 k\Omega$ and $R_f = 1 M\Omega$ (mega) assuming, an ideal OP-AMP, determine the following circuit values.

(i) Voltage gain :

(ii) input resistance

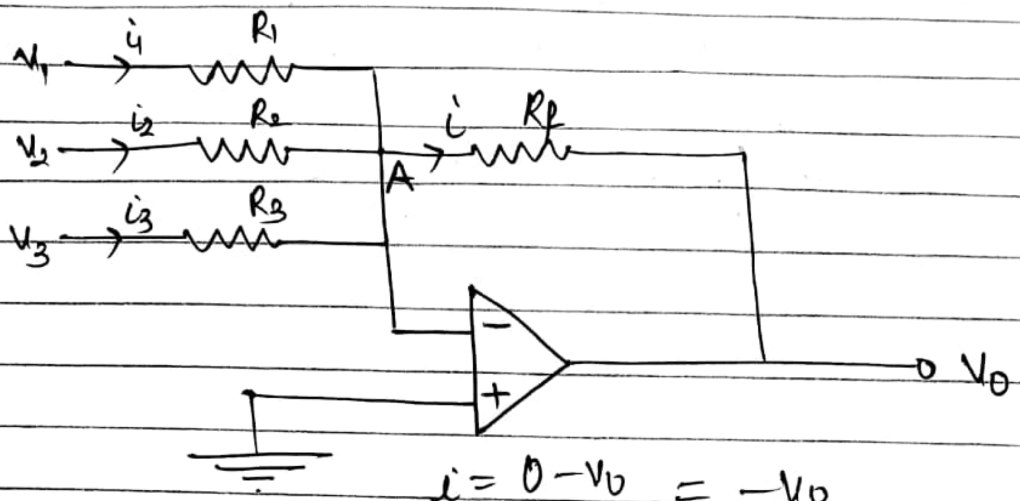
(iii) Output resistance = 0 (always)

voltage gain = $\frac{R_f}{R_1} = \frac{1 \, m\Omega}{1 \times 10^{-3} \, m\Omega} = 1000$

If input is grounded ∴ input impedence is infinite.

APPLICATIONS

Adder or Summer



$$i = \frac{0 - V_0}{R_f} = \frac{-V_0}{R_f}$$

$$i_1 = \frac{v_1}{R_1}$$

$$i_2 = \frac{v_2}{R_2}$$

$$i_3 = \frac{v_3}{R_3}$$

Applying kirchoff's current law at point A;

$$i = i_1 + i_2 + i_3$$

$$\therefore \frac{-V_0}{R_f} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}$$

$$V_0 = -\left(\frac{R_f}{R_1} \cdot V_1 + \frac{R_f}{R_2} \cdot V_2 + \frac{R_f}{R_3} \cdot V_3\right)$$

If $R_1 = R_2 = R_3 = R$

$$V_0 = -\frac{R_f}{R}\left(V_1 + V_2 + V_3\right)$$

Output voltage is proportional to the sum of input voltages.
(−)ve sign shows inverting output.

If $R_f = R$

$$V_0 = -(V_1 + V_2 + V_3)$$

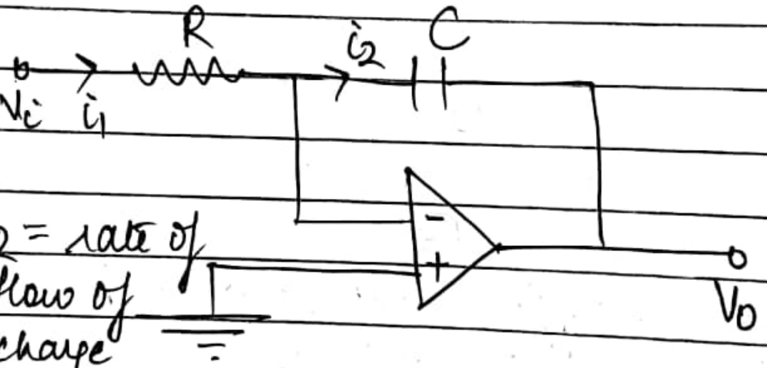
Q/ Find the output voltage of an OP-AMP inverting adder for the following sets of input voltages and resistances
$V_1 = -3V$, $V_2 = +3V$, $V_3 = +2V$, $R_1 = 250\,k\Omega$, $R_2 = 500\,k\Omega$, $R_3 = 1\,M\Omega$ and $R_f = 1\,M\Omega$

Using

$$V_0 = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)$$

$=$

Integrator



$i_1 = i_2 =$ rate of flow of charge

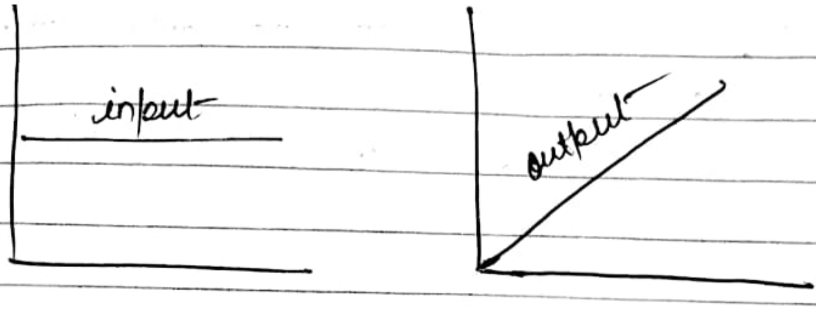
$$i_2 = \frac{dq}{dt} = \frac{C\,dV}{dt}$$

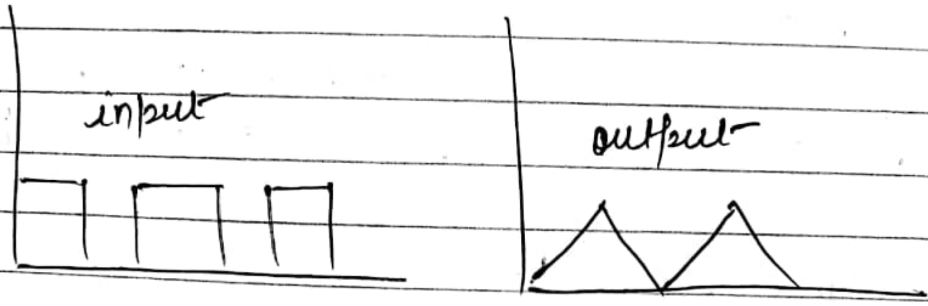
$$= -C\frac{dV_0}{dt}$$

$$i_1 = \frac{V_i}{R}.$$

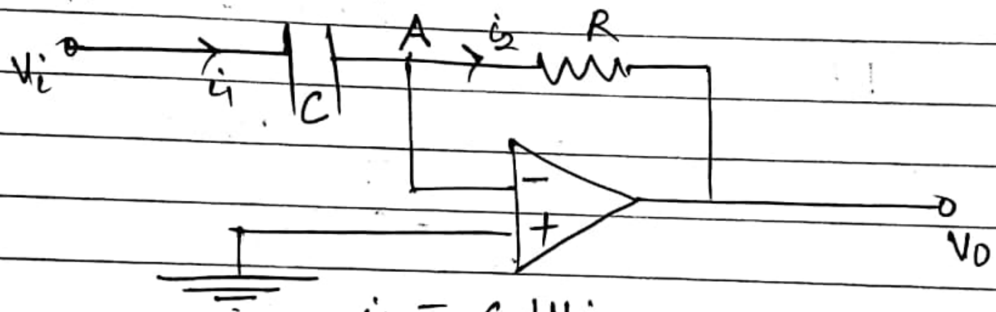
$$\frac{V_i}{R.} = -C\frac{dV_0}{dt}$$

$$\boxed{V_0 = \frac{-1}{RC}\int V_i\,dt}$$





Differentiator

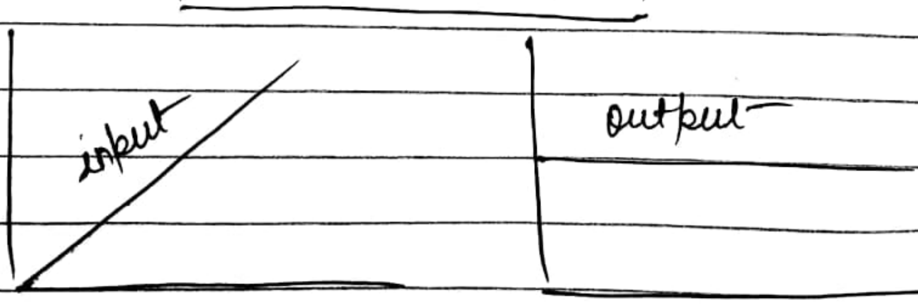


$$i_1 = C\frac{dV_i}{dt}$$

$$i_2 = -\frac{V_0}{R}$$

$$i_1 = i_2$$

$$\boxed{V_0 = -CR\cdot\frac{dV_i}{dt}}$$



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Q/ A 5mV, 1 KHertz sinosuidal signal is applied to the input of an OP-AMP integrator for which $R = 100\,k\Omega$ and $C = 1\,\mu F$ (micro). Find the output voltage.

Q/ The input to the differentiator circuit is a sinosuidal voltage of peek value 5 mV and frequency 1 KHertz. Find out the output if $R = 100\,k\Omega$ and $C = 1\,\mu F$.

$$V_0 = -\frac{1}{RC}\int V_i\,dt$$

input = 5 mV 1 KHz. $V_i = V_0 \sin\omega t$ where $\omega = 2\pi f$

$R = 100\,k\Omega$ $= V_0 \sin 2\pi f \times t$

$C = 1\,\mu F$ =

$V_0 = ?$ $V_0 = -\frac{1}{CR}\left[\int V_i\,dt\right]$

$= -CR\frac{dV_i}{dt}$

Q/ 5mV.

$f = 1\,KHz$.

$V_0 = ?$

$R = 100\,k\Omega$

$C = 1\,\mu F$.

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UNIT-5

Communication Systems

Modulation & Demodulation

In radio Transmission, audio signals are Transmitted over large distances. At audio frequencies, the signal power is less and therefore cannot be fed to the antenna for communication purposes. The high frequency signals on the other hand can be Transmitted over long distances. For proper Transmission, an audio signal is superimposed on a high frequency wave called the carrier wave. This process is known as Modulation.

After modulation, this wave can be fed to the antenna and can be Transmitted over a long distance.

Modulation: The process of changing some characteristics such as amplitude, frequency or phase of a carrier wave in accordance with the intensity of the signal is known as modulation.

Need for modulation :-

1. ~~the~~ Huge antenna requirement - The length of the antenna is inversely proportional to the frequency of the wave. For Transmitting an audio signal, the length of Transmitting antenna would be extremely large.
2. Short operating range - The energy of any wave depends upon its frequency. The audio signals having small frequency and consequently small power cannot be transmitted over large distances when radiated directly into space. However, modulated wave can be Transmitted over long distances.
3. Wireless Communication - One desirable feature of radio Transmission is that it should be carried without wires.

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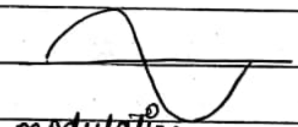
At audio frequencies, efficiency of radiation is poor, so it cannot be used directly for wireless communication. For this reason, modulation is always done in communication systems.

TYPES OF MODULATION:

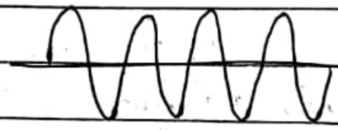
There are three types of modulation:

1. Amplitude Modulation
2. Frequency modulation
3. Phase modulation

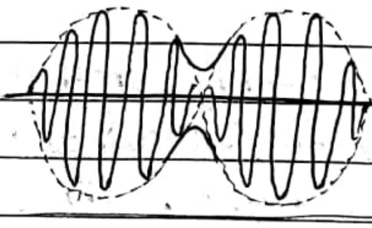
Amplitude Modulation: In amplitude modulation, amplitude of the carrier wave is varied in accordance with the modulating signal, keeping the frequency and phase of carrier wave unchanged.



modulating signal

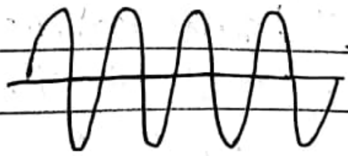


carrier wave

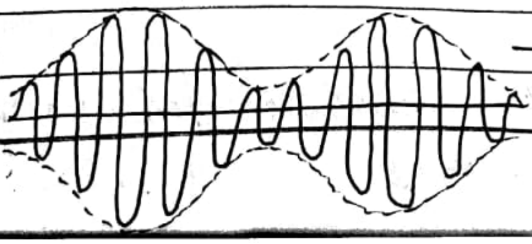


Resultant Modulated wave

→ Modulating signal

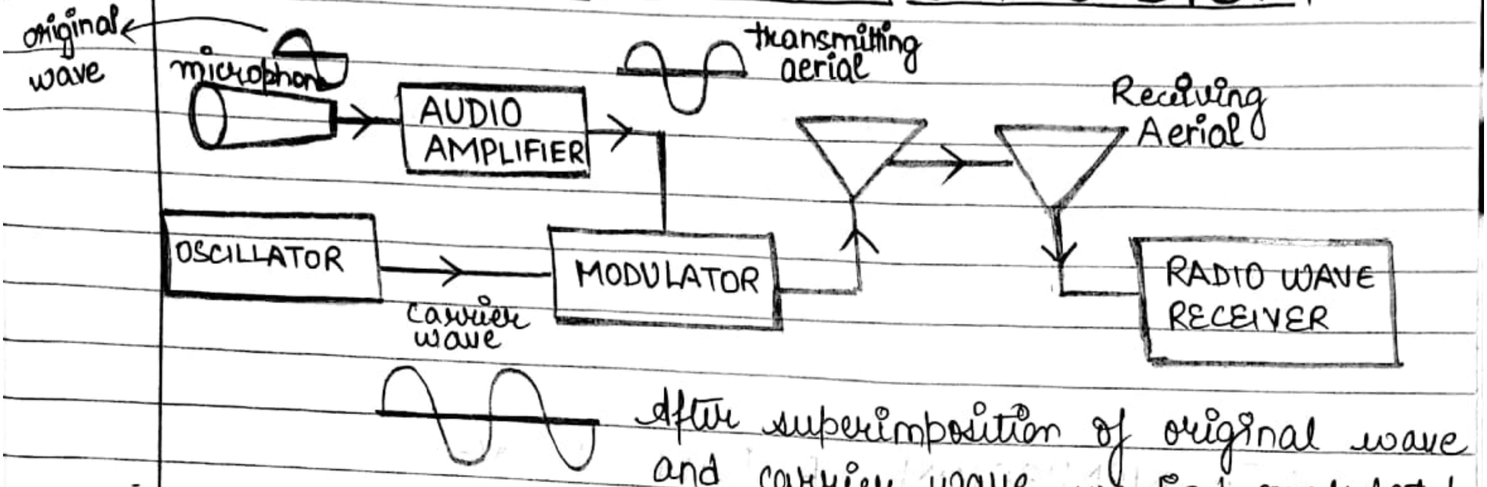


→ Carrier wave



→ Modulated wave

PARTS OF COMMUNICATION SYSTEM



after superimposition of original wave and carrier wave, we find modulated wave.

(A) **TRANSMITTER:** It is an extremely important equipment.

→ Its purpose is to produce radio wave for transmission into shape.

→ The components of a transmitter are described as follows:

I. **MICROPHONE:** A microphone is a device which converts sound waves into electrical waves.
The output of the microphone is fed to a multistage audio amplifier for raising the strength weak signal.

II. **AUDIO-AMPLIFIER:** The audio signal from microphone is quite weak and requires amplification which is done by the audio amplifier.
The amplified output is fed to the modulator.

III. **OSCILLATOR:** The function of oscillator is to produce high frequency signal known as a carrier wave.
The power level of carrier wave is increased to a sufficient value by using radio amplifiers so that the signal can be transferred to required distances.
The output of the oscillator is fed to the modulator.

IV. **MODULATOR:** Inside the modulator, the audio signal is superimposed on the carrier wave in a suitable manner. The resultant waves are called modulated wave or radio waves and the process is called modulation. As the carrier frequency is very high the audio signal can be transmitted to large distances.
The radio waves from the modulator are fed to the transmitting aerial which radiates them into space.

(B) TRANSMISSION OF RADIO WAVES:

The transmitting antenna radiates the radio waves in space. In all directions, these radio waves travel with the velocity of light. These radio waves are electromagnetic wave and possess the same properties.

(C) RADIO RECIEVER:

On ~~searching~~ reaching the recieving antenna, the radio waves induced tiny emf in it. This small voltage is fed to the radio reciever, where the radio waves are first amplified and then signal is extracted from them by the process of demodulation. The signal is amplified by audio amplifiers and then fed to the speaker for reproduction into sound waves.

Amplitude modulation

In amplitude modulation, there are a few important points as follows:

1. The amplitude of the carrier wave changes according to the intensity of the signal.
2. The amplitude variations of the carrier wave are at the signal frequency.
3. The frequency of the amplitude modulated wave remains the same as carrier frequency.

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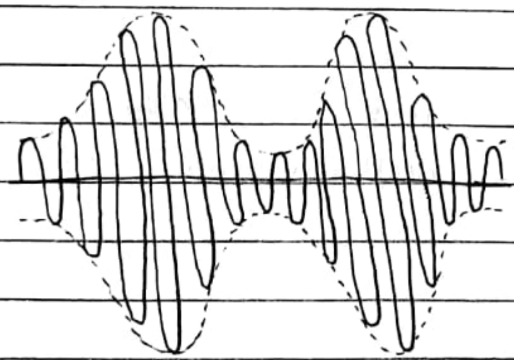
MODULATION FACTOR (M): It is defined by

$$M = \frac{\text{Amplitude change in carrier wave}}{\text{Original amplitude of carrier wave}}$$

Importance of Modulation factor:

It is very important since it determines the strength and quality of the transmitted signal. In a.m. (amplitude modulated) waves, the signal is contained in the variation of the carrier amplitude. When modulation factor is small, the amount of carrier amplitude variation will be small and the audio signal being transmitted will not be very strong. The greater the modulation factor, the stronger and clearer will be the audio signal.

Q/ If the maximum and minimum voltage of an A.M. wave are V_{max} and V_{min} respectively, then, show that the modulation factor is given by $m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$.



change in amplitude $= V_{max} - V_{min}$

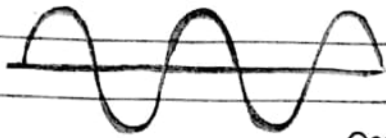
Let the amplitude of carrier wave is –

$$E_c = \frac{V_{max} + V_{min}}{2}$$

If E_s is the signal amplitude.

$$E_s = \frac{V_{max} - V_{min}}{2}$$

signal wave



carrier wave

$$m = \frac{\text{amplitude of S wave}}{\text{amplitude of C wave}}$$

$$m = \frac{\frac{V_{max} - V_{min}}{2}}{\frac{V_{max} + V_{min}}{2}}$$

$$\boxed{m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}}$$ Ans.

Q/ The max. peek to peek voltage of A.M. wave is 16mV and min. peek to peek voltage is 4mV. Calculate the modulation.

$$M = \frac{8-2}{8+2} = \frac{6}{10} = 0.6$$

Q/ Carrier wave of 100 volt and 1200 KHz is modulated by 50 volt 1000 Hz sine wave signal. Find the modulation factor.

$$M = \frac{50}{100} = 0.5$$

Limitation of amplitude Modulation

Although amplitude modulation is theoritically highly effective ~~still~~ till it suffers from following drawbacks:

I. **NOISY RECEPTION**: The radio reciever can't distinguish between amplitude variations that represent noise and those that contain the desired signal.

II. **LOW EFFICIENCY**: In amplitude modulation, useful power is in the side bands as they contain the signal, whereas, A.M. wave has low side band power hence, the efficiency of this type of modulation is low.

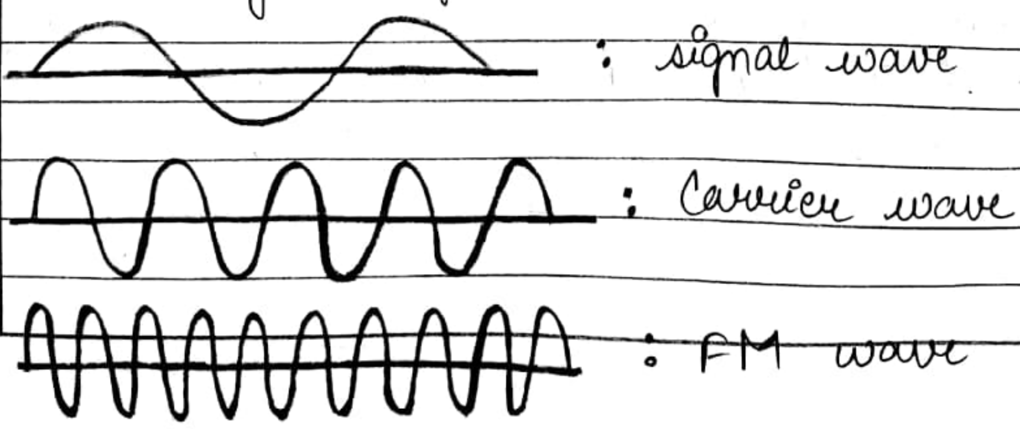
III. **SMALL OPERATING RANGE**: Due to low efficiency, of amplitude modulation, transmitters employing this method have a small operating range.

IV. **LACK OF AUDIO QUALITY**: In order to attain high quality reception, all audio frequencies upto 15 kHz must be reproduced. This requires bandwidth of 30 kHz but AM broad casting stations are assigned bandwidth of only 10 kHz to minimize the interference from nearby broadcasting stations.

Frequency Modulation (FM):

When the frequency of carrier wave is changed in accordance with the intensity of the signal. It is called frequency modulation.

In this case, amplitude of the modulated wave remains the same as the carrier wave. The frequency variations of carrier wave depends upon the instantaneous amplitude of the signal.



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Following points must be noted about frequency modu-
-lation:

1. The frequency deviations of FM signal depends on the amplitude of modulating signal.
2. The centre frequency is the frequency without modulation.
3. The frequency of modulating signal doesnot determine the frequency deviation.

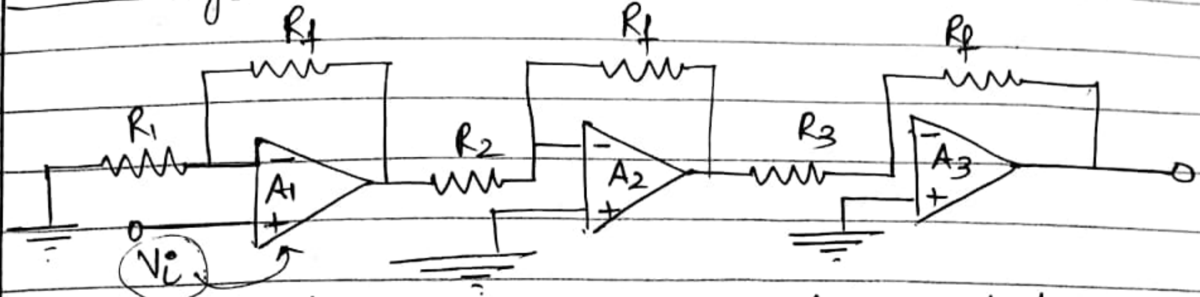
Advantages of F.M. over A.M.

→ It gives noiseless reception.
→ Operating range is large
→ It gives high quality reception.
→ The efficiency of Transmission is very high.

Comparison of FM & AM.

	FM	AM
1.	The amplitude of carrier wave remains constant.	The amplitude of carrier wave charges with modulation.
2.	The carrier frequency change with modulation.	The carrier frequency remains constant.
3.	The value of modulation ~~index~~ factor (m_f) can be more 1	The value of modulation factor can't be more than 1.

Multistage OP-AMP numericals.



1st amplifier: Non-inverting because input is being provided to the (+)ve.

gain; $A_1 = 1 + \frac{R_f}{R_1}$

$$V_{O_1} = \left(1 + \frac{R_f}{R_1}\right) V_i$$

IInd amplifier: Inverting;

gain; $A_2 = -\frac{R_f}{R_2}$

$$V_{O_2} = -\frac{R_f}{R_2} V_{O_1}$$

$$= -\frac{R_f}{R_2}\left[\left(1 + \frac{R_f}{R_1}\right)V_i\right]$$

$$= V_i\left(-\frac{R_f}{R_2}\right)\left(1 + \frac{R_f}{R_1}\right)$$

IIIrd amplifier:

Inverting;

gain; $A_3 = -\frac{R_f}{R_3}$

$$\therefore V_{O_3} = -\frac{R_f}{R_3} V_{O_2}$$

$$\therefore V_O = V_{O_3} = \left(\frac{R_f}{R_3}\right)\left(\frac{R_f}{R_2}\right)\left(1 + \frac{R_f}{R_1}\right) V_i$$

Total output

Total gain : $A = A_1 \cdot A_2 \cdot A_3$.

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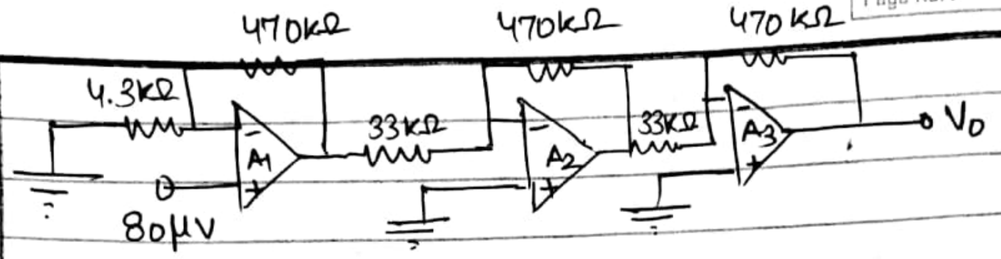
Q/



∴ for 1st amplifier which is non-inverting

$$= 1 + \frac{R_f}{R_1} = 1 + \frac{470}{4.3}$$

∴ for IInd amplifier which is inverting

$$= -\frac{R_f}{R_2} = \frac{470}{33}$$

for IIIrd amplifier which is inverting

$$= -\frac{R_f}{R_3} = \frac{470}{33}.$$

$$\therefore A = A_1 . A_2 . A_3 = \left(1 + \frac{470}{4.3}\right)\left(\frac{470}{33}\right)^2 \cdot V = 1.78\,V$$

Q/ A three stage OP-AMP circuit is required to produce voltage gains of +10, -18 and -27. Design the OP-AMP circuit. Use a 270 kΩ feedback resistor for all three circuits. What output voltage will result for an input of 150μV

For 1st amplifier, which is non-inverting;

$$\therefore A_1 = 1 + \frac{R_f}{R_1}$$

$$10 = 1 + \frac{270}{R_1}.$$

$$\cancel{9} = \frac{\cancel{270}\,30}{R_1}$$

$$R_1 = 30\ k\Omega.$$

For IInd amplifier, which is inverting

$$A_2 = -\frac{R_f}{R_2}$$

$$\cancel{18}\,{}^{2} = -\frac{\cancel{270}.\cancel{30}\ 15.}{R_2}.$$

$$\therefore R_2 = 15\ k\Omega$$

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(II)nd amplifier, which is inverting

$$A_3 = -\frac{R_f}{R_3}$$

$$\cancel{27} = -\frac{\cancel{270} \cdot 10}{R_3}$$

$$R_3 = 10\,k\Omega.$$

$$V_0 = \left(\frac{R_f}{R_3}\right)\left(\frac{R_f}{R_2}\right)\left(1+\frac{R_f}{R_1}\right)V_i$$

$$= \left(\frac{270}{10}\right)\left(\frac{270}{15}\right)\left(1+\frac{270}{30}\right) \times 150$$

$$= \frac{(270)^2}{10 \times 15} \times \frac{300}{30} \times 150 \qquad = 0.729\ V.$$

DEMODULATION

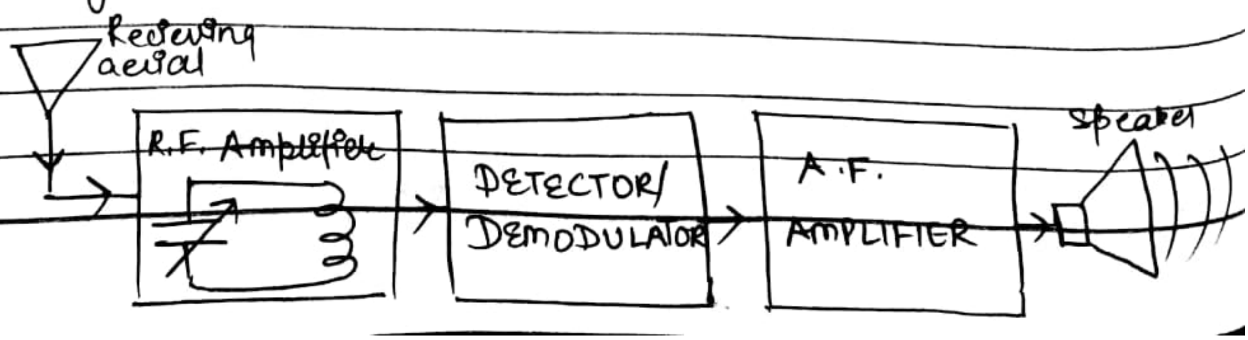
The process of recovering the audio signals from the modulated wave is known as Demodulation or detection. This process is accomplished in the radio reciever

A. M. Radio Recievers

A radio reciever is a device which reproduces the modulated or radiowaves into sound waves. In order to reproduce the A.M. wave into sound wave, every radio reciever must perform the following functions:

1. The recieving aerial must intercept a portion of the passing radio wave.
2. The radio reciever must select the desired radiowave. For this purpose, tuned, parallel, LC circuits must be used. These circuits will select only that radio frequency which is in resonance with them.
3. The selected radiowave must be amplified by the tuned frequency amplifiers.
4. Audio signal must be recovered from the amplified radio wave.
5. Audio signal must be amplified by suitable no. of audio amplifiers.
6. The amplified audio signal should be fed to the speaker for sound reproduction.

1. Straight Radio Reciever

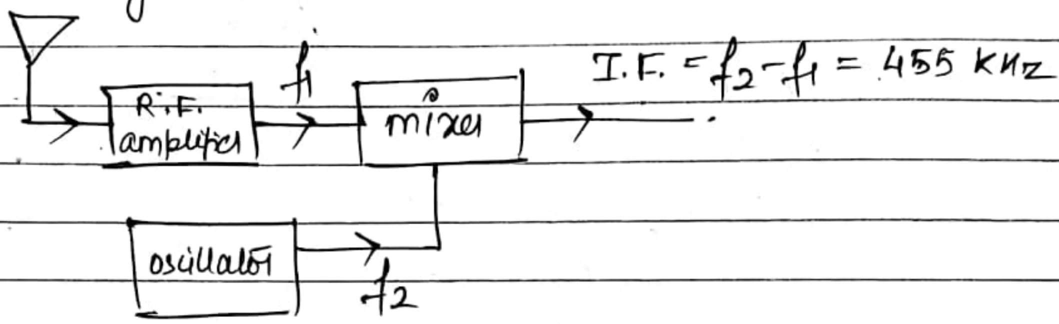


Limitations :

In straight radio recievers, ~~tun~~ ~~to~~ tuned circuits are used therefore, there is a considerable variation of quality factor. This changes the sensitivity and selectivity of the radio reciever.

There is too much interference of adjacent stations.

Super Hetrodyne Radio Reciever.

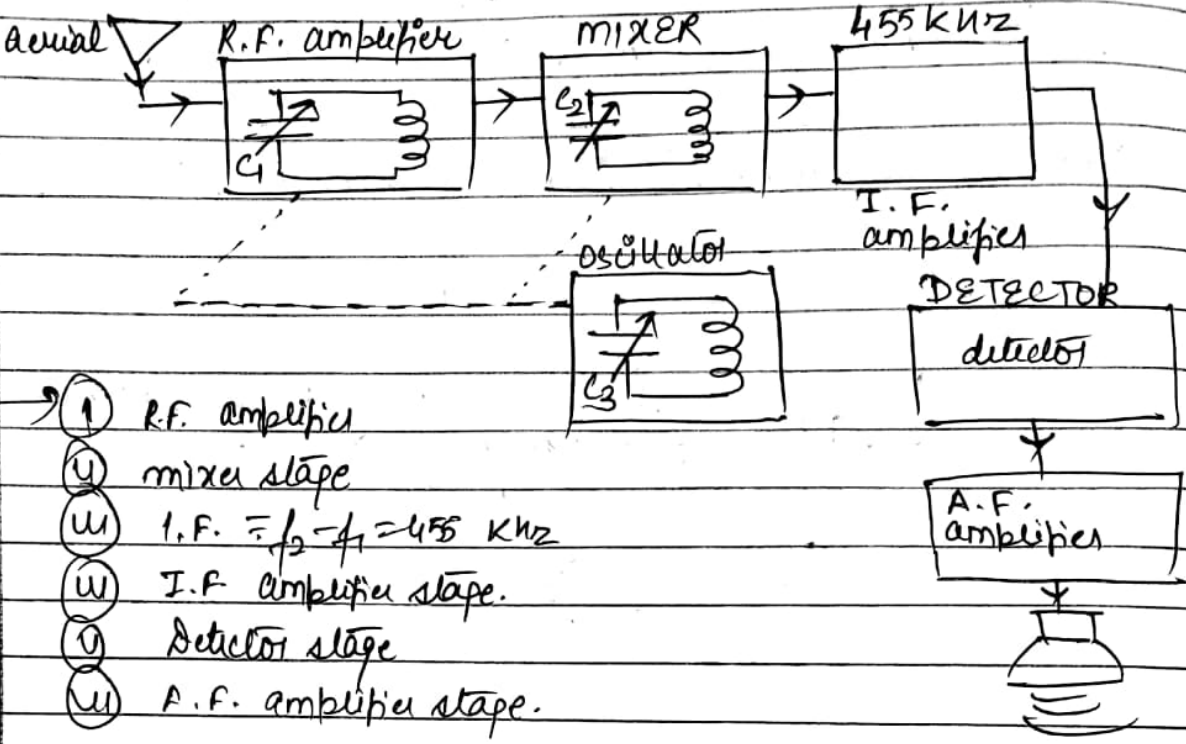


In this type of radio reciever, the selected radio frequency is converted to a fixed lower value called intermediate frequency. This is achieved by a special electronic circuit called mixer circuit. There is a local oscillator in the radio reciever itself which produces high frequency waves. The ~~the~~ selected radio frequency is mixed up with the high frequency wave in the mixer circuit. and the mixer produces a frequency equal to the difference between local oscillator frequency and radio frequency.

The circuit is so designed that oscillator always produces a frequency 455 KHz above the selected radio frequency so that the intermediate frequency is of 455 KHz.

At this fixed intermediate frequency, the amplifier circuits of rate with maximum stability, selectivity and sensitivity.

Stages of Superhetrodyne Radio Recievers.

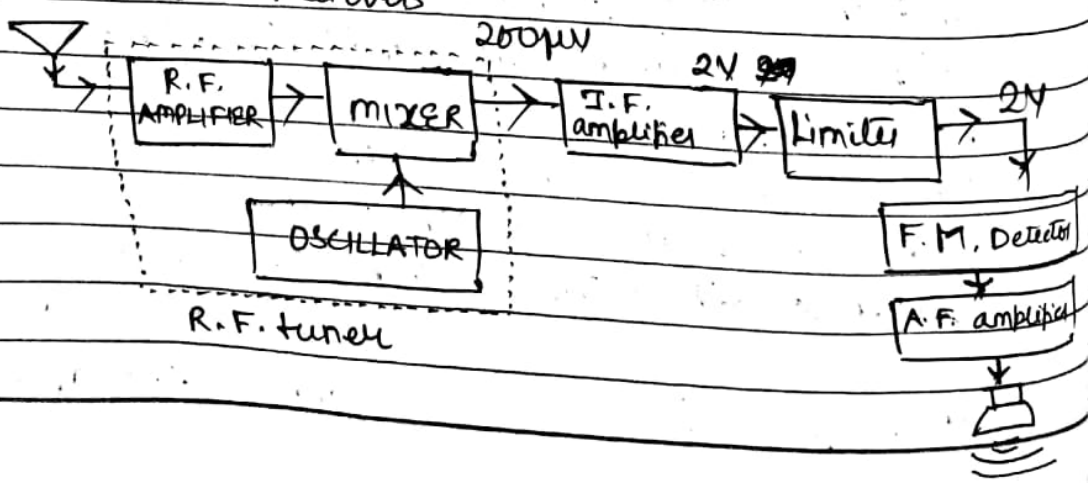


(i) R.F. amplifier
(ii) mixer stage
(iii) I.F. $= f_2 - f_1 = 455$ KHz
(iv) I.F amplifier stage.
(v) Detector stage
(vi) A.F. amplifier stage.

Advantages of Superhetrodyne Circuit

1. HIGH RF AMPLIFICATION:
2. IMPROVED SELECTIVITY.
3. LOWER COST

FM radio recievers



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Three stages : ① R.F. Tuner (i) R.F. amplifier
(ii) Oscillator
(iii) Mixer.

In this case, intermediate frequency is always 10.7 MHz

② I.F. amplifier

③ Limiter : To minimise the ~~am~~ unwanted amplitude variations. and makes the amplitude constant.

④ F.M. detector.

⑤ A.F. amplifier amplifies audio frequency & fed to the speaker.