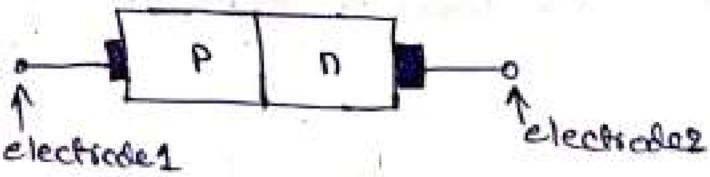
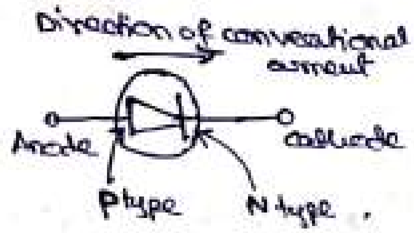
P-N junction diode:

The P-n junction forms a popular semiconductor device called P-n junction diode. The P-n junction has 2 terminals called electrodes, one each from P-region & n-region. Due to the electrodes it is called DIODE i.e di+ electrode.



a) Two electrodes



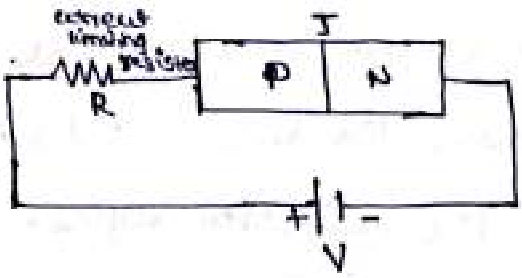
b) Symbol of Diode.

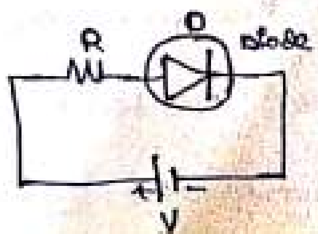
- Applying external dc voltage to any electronic device is called biasing.
- depending up on the polarity of the dc voltage externally applied to it, the biasing is ~~called~~ classified as FORWARD BIASING & REVERSE BIASING.

Operation of P-N junction diode:

The operation of pn junction diode is discussed in two modes. a) Forward biasing of pn junction diode
b) Reverse biasing of pn junction diode.

a) Forward biasing of P-N junction diode:





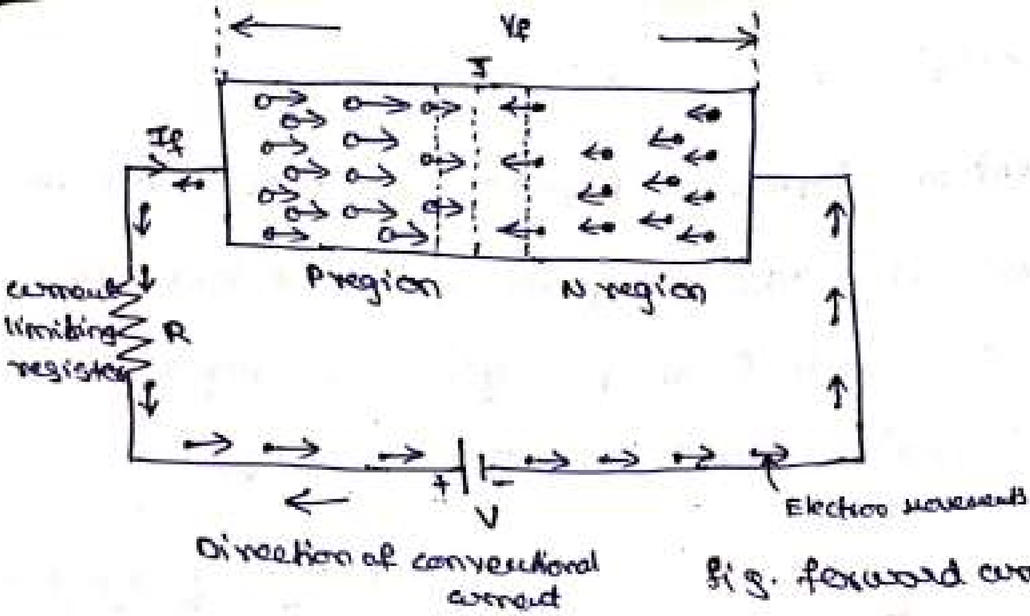


fig. forward current in a diode

cut in voltage for Ge is 0.3V

cut in voltage for si is 0.7V

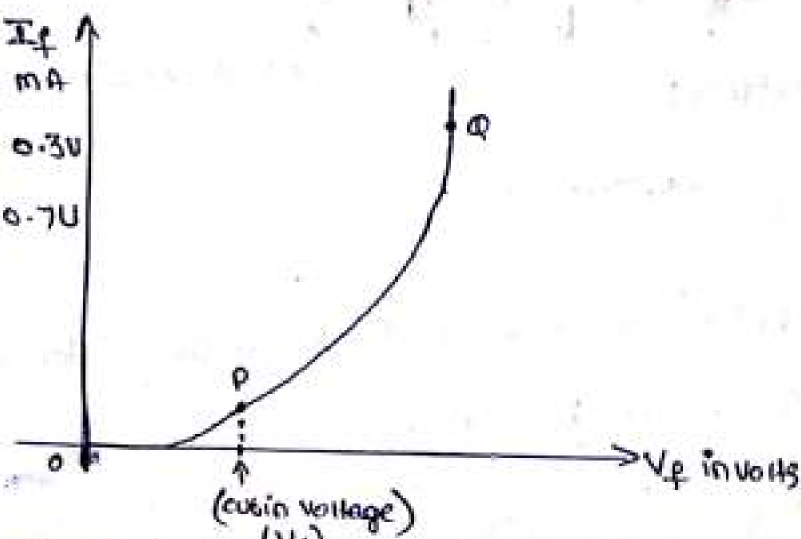


fig. forward V-I characteristics of diode.

When the p-n junction is forward biased as long as the applied voltage is less than the barrier potential, there cannot be any conduction.

When the applied voltage becomes more than barrier potential, the negative terminal of battery pushes the free electrons against barrier potential from n to p region. Similarly positive terminal pushes the holes from p to n region. Thus holes get repelled by +ve terminal and cross the junction against barrier potential. Thus the applied voltage overcomes the barrier potential. Thus reduces the width of the depletion region.

As forward voltage is increased at a particular value the depletion region becomes very much narrow such that large number of majority charge carriers can across the junction.

The large number of majority carriers constitute a current called forward current. Once the conduction ē s enter the p-region, they become valence electrons. Then they move from hole to hole towards the +ve terminal of the battery. The movement of valence electrons is nothing but movement of holes in opposite direction to that of electrons, in the ~~p~~ p-region. So current in the p-region is the movement of holes which are majority carriers. This is hole current while the current in the n-region is the movement of free electrons which are majority carriers. This is the electron current. Hence the overall forward current is due to majority carriers.

The graph of forward current, I_F against the forward voltage V_F across the diode is called forward characteristics of a diode. Basically forward characteristics can be divided in 2 ~~sta~~ regions.

① Region O to P : As long as V_F is less than cut in voltage (V_r) the current flowing is very small. Practically this current is assumed to be zero.

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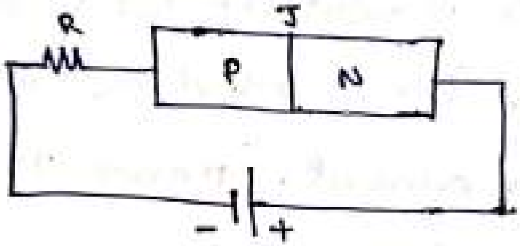
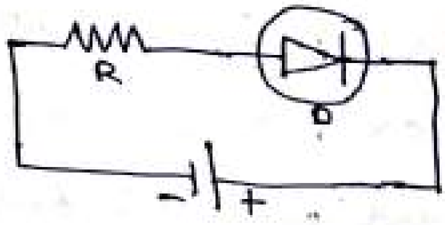
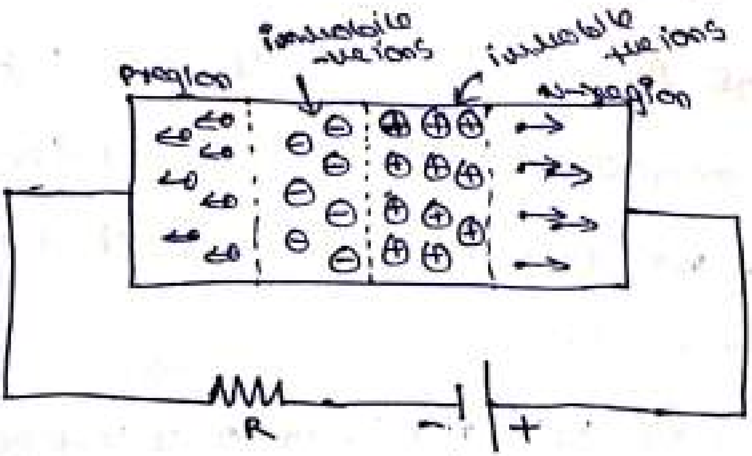
2. Region P to Q and onwards: As V_F increases towards V_γ the width of depletion region goes on reducing. When V_F exceeds V_γ i.e cut-in voltage, the depletion region becomes very thin and current I_F increases suddenly. This increase in the current is exponential as shown in figure by the region P to Q.

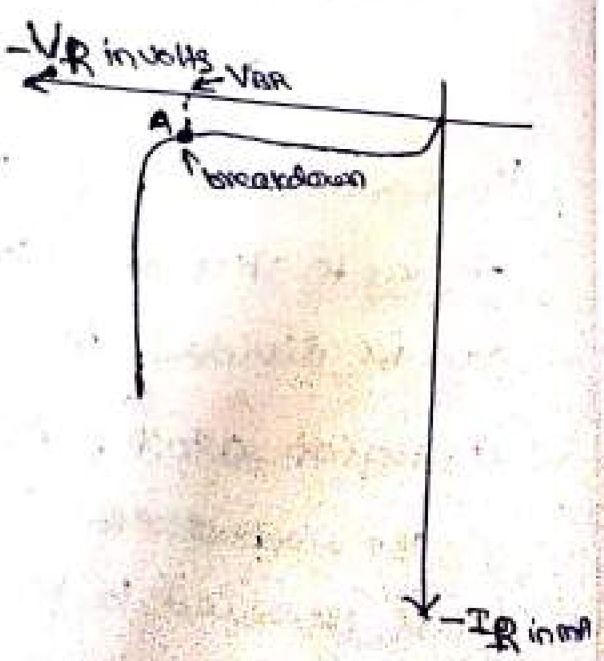
The forward current is the conventional current, hence it is treated as +ve and the forward voltage (V_F) is also treated +ve. Hence the forward characteristics is plotted in the 1st quadrant.

(b) <u>Reverse biasing of PN junction diode:</u>









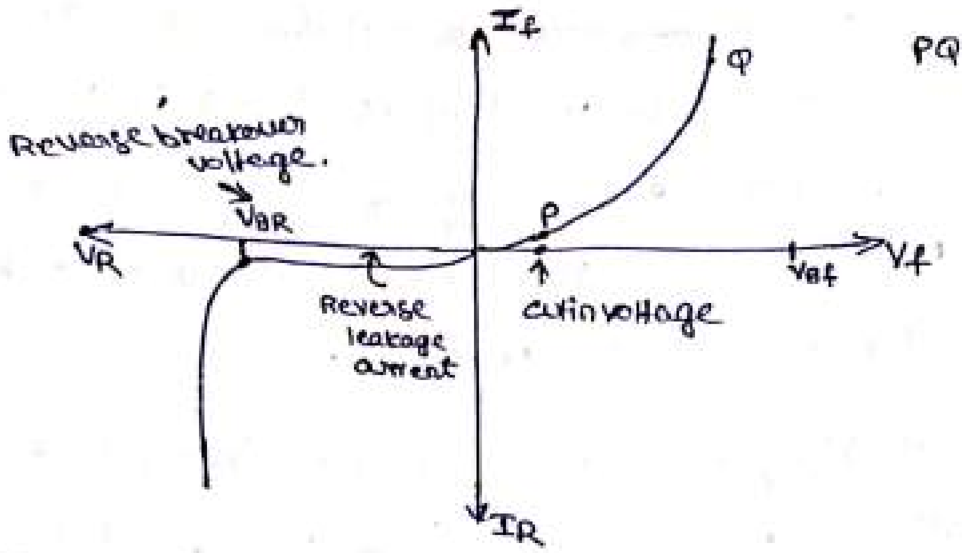
when the p-n junction is reverse biased the -ve terminal attracts the holes in the p-region, away from the junction. The +ve terminal attracts the free electrons in the n-region away from the junction. No charge carrier is able to cross the junction. As ē s & holes both move away from the junction, the depletion region widens.

The above diagram shows reverse biased diode. The reverse voltage across the diode is V_R while the current flowing is reverse current I_R flowing due to minority charge carriers. The graph of I_R against V_R is called reverse characteristics of a diode.

The polarity of reverse voltage applied is opposite to that of forward voltage. Hence in practice reverse voltage is taken as negative. Hence the reverse characteristics is plotted in the 3rd quadrant as shown in the figure above.

As reverse voltage is increased reverse current increases initially but after a certain voltage, the current remains constant equal to reverse saturation current I_0 though reverse voltage is increased. The point A where breakdown occurs and reverse current increases rapidly is called knee of the reverse characteristics.

Complete V-I characteristics of PN junction diode:



PQ region is ON period.

Applications of P-N junction Rectifier:

1) Rectifier

A rectifier is a device which converts a.c voltage to pulsating d.c voltage using 1 or more p-n junction diodes.

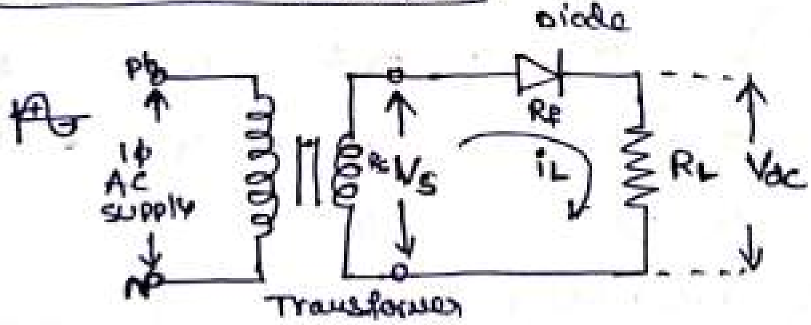
Using one or more diodes following rectifier circuits can be designed

a). Half wave Rectifier

b) Full wave rectifier

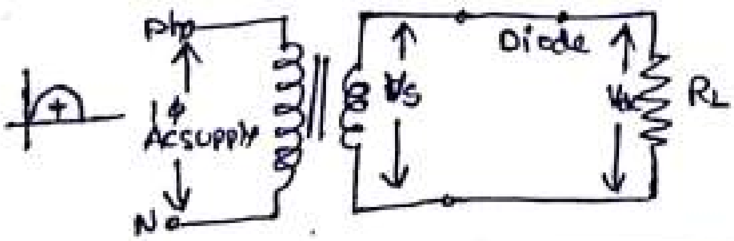
c) Bridge rectifier.

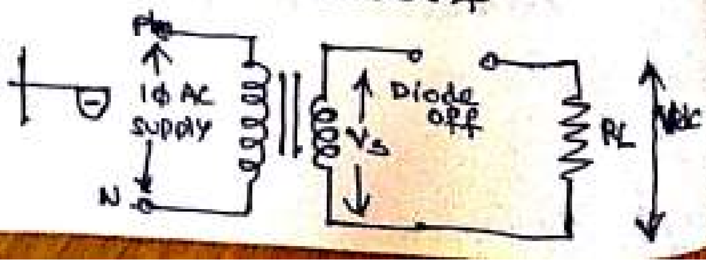
a) Half wave rectifier:



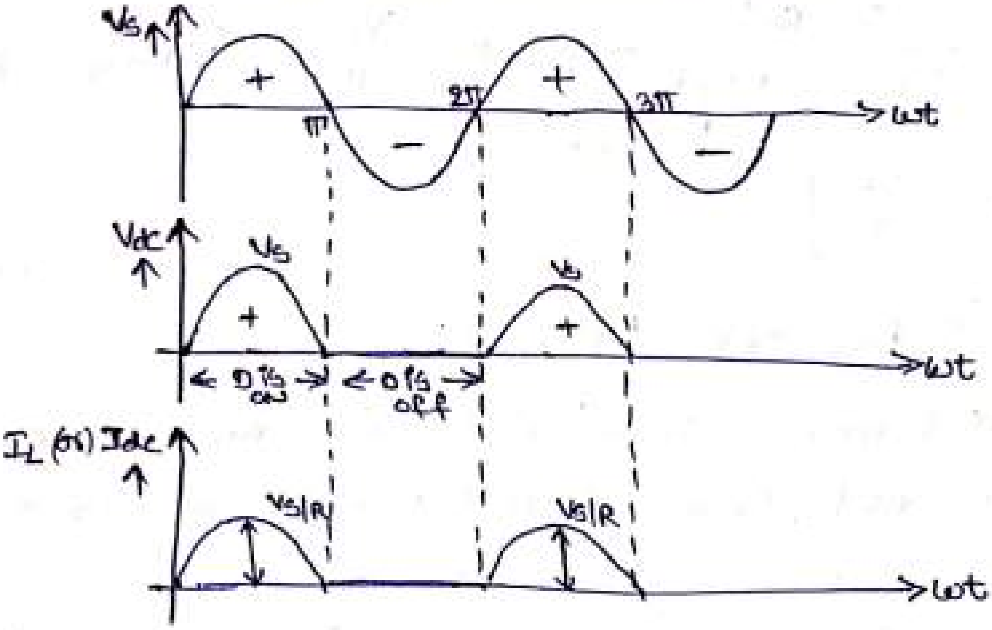
case(i) During +ve pulse Diode ON

case(ii) During -ve pulse Diode off





Wave forms of source & load



Mathematically current waveform can be described as

$$I_L = I_m \sin\omega t \quad \text{for } 0 \le \omega t \le \pi$$

$$I_L = 0 \quad \text{for } \pi \le \omega t \le 2\pi$$

where I_m is peak value of load current

Average dc load current I_{dc}

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} I_L \, d(\omega t)$$

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

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

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

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

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

Applying Kirchhoffs law for the circuit $I_m = \frac{V_s}{R_L + R_f + R_s}$

Average dc load voltage (V_{dc}):

It is the product of Average dc load current & R_L

$$V_{dc} = I_{dc} R_L = \frac{I_m}{\pi} R_L = \frac{V_s \quad R_L}{R_s + R_L + R_f}$$

$R_f, R_s << 1$

So $$V_{dc} = \frac{V_s R_L}{\pi R_L\left[\frac{R_f+R_s}{R_L}+1\right]} = \frac{V_s}{\pi} \quad (\because R_f+R_s << R_L)$$

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

RMS value of load current (I_{rms}):

The R.M.S means squaring, finding mean and then finding square root. Hence R.M.S value of load current can be obtained as

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

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

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

$$= I_m\sqrt{\frac{1}{2\pi}\left(\frac{\omega t}{2} - \frac{\sin 2(\omega t)}{4}\right)\Big|_0^{\pi}}$$

$$I_{rms} = I_m\sqrt{\frac{1}{2\pi}\left(\frac{\pi}{2}\right)}$$

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

DC output power: The dc output power can be obtained as

$$P_{dc} = V_{dc} I_{dc} = I_{dc}^2 R_L$$

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

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

where $I_m = \frac{V_s}{R_s+R_L+R_f}$ $\quad\therefore\quad I_{dc} = \frac{V_s^2 R_L}{\pi^2(R_s+R_L+R_f)^2}$

A.C power input P_{AC}:

The A.C power is given by $P_{AC} = I_{RMS}^2 (R_L + R_f + R_s)$

$\therefore I_{RMS} = \frac{I_m}{2}$ so $P_{AC} = \frac{I_m^2}{4} (R_L + R_f + R_s)$

Rectifier efficiency:

The rectifier efficiency is defined as the ratio of output dc power to input A.C power.

$$\eta = \frac{\text{DC outpower}}{\text{AC input power}} = \frac{P_{dc}}{P_{AC}}$$

Ripple factor: defind as the ratio of R.M.S value of the A.C component in the output to the average or d.c component present in the output.

$$\text{Ripple factor } (\gamma) = \frac{\text{RMS value of a.c component of output}}{\text{Average or d.c component of output}}.$$

Now the output current is composed of A.C component as well as d.c component

Let I_{ac} = r.m.s value of a.c comp present in o/p.

I_{dc} = dc component present in output.

I_{RMS} = R.M.S value of total output current.

$$I_{RMS} = \sqrt{I_{ac}^2 + I_{dc}^2}$$

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

$$\text{Ripple factor } (\gamma) = \frac{I_{ac}}{I_{dc}} = \frac{\sqrt{I_{RMS}^2 - I_{dc}^2}}{I_{dc}}.$$

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

Voltage Regulation:

The secondary voltage should not change w.r.t to the load current. The voltage regulation is the factor which tells us about the change in the d.c output voltage as load changes from no load to full load condition.

if $(V_{dc})_{NL}$ = DC voltage on no load.

$(V_{dc})_{FL}$ = DC voltage on full load.

voltage Regulation is defined as $= \dfrac{(V_{dc})_{NL} - (V_{dc})_{FL}}{(V_{dc})_{FL}}$

Problem: A half wave rectifier circuit connected to 230V, 50Hz source through a transformer of turn ratio of 10:1. The rectifier circuit is to supply power to a 500Ω, 1 watt resistor and diode forward resistance is 100Ω.

calculate 1) maximum, average & r.m.s value of I & V
2) Efficiency of rectification.
3) percentage regulation.

given data is $V_{P_{rms}} = 230V$,

$N_1/N_2 = 10:1$

$R_L = 500\Omega$, $R_f = 100\Omega$

$$\frac{N_2}{N_1} = \frac{1}{10} = \frac{E_{S(rms)}}{E_{P(rms)}}$$

$(V_s)_{rms} = \frac{1}{10} \times 230 = 23V.$

$V_{sm} = \sqrt{2}\, V_{srms} = \sqrt{2} \times 23 = 32.59V.$

case (I)

$$I_m = \frac{E_{sm}}{R_f + R_L} = \frac{32.59}{100+500} = 54.211\,mA$$

$$I_{av} = I_{dc} = \frac{I_m}{\pi} = \frac{54.211m}{\pi} = 17.25mA.$$

$$I_{rms} = \frac{I_m}{2} = \frac{54.211m}{2} = 27.105mA$$

$$V_{dc} = I_{dc} . R_L = 17.25m \times 500 = 8.628V$$

case (2) output dc power $P_{dc} = I_{dc}^2 R_L = (17.25m)^2 \times 500$

$$= 0.1488W.$$

input AC power $P_{AC} = I_{rms}^2 (R_L + R_f)$

$$= (27.105m)^2 [500+100]$$

$$= 0.44083W$$

$$\% \eta \text{ efficiency} = \frac{P_{dc}}{P_{AC}} \times 100$$

$$= \frac{0.44083}{0.1488} \times 100 = 33.77\%$$

case (3)

$$(V_{dc})_{N.L} = \frac{V_{sm}}{\pi} = \frac{32.59}{\pi} = 10.35V$$

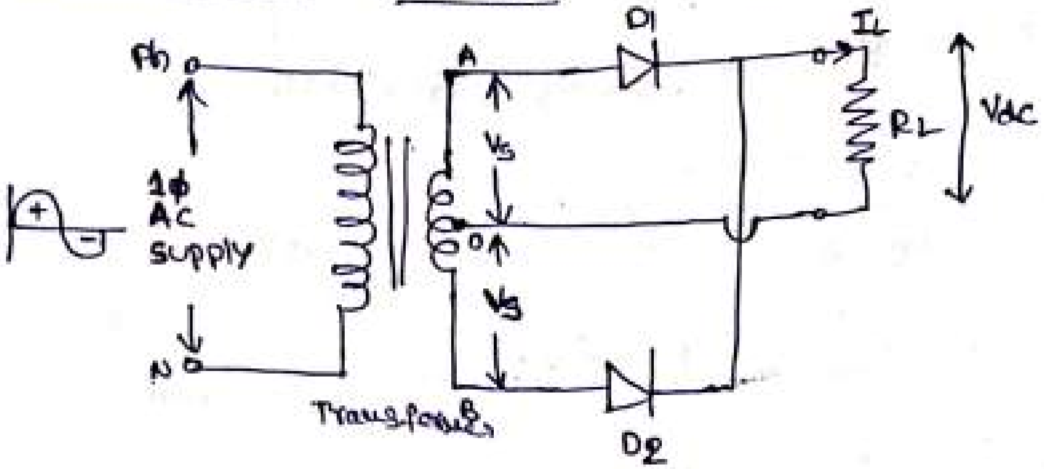
$$(V_{dc})_L = V_{dc} = 8.628V$$

$$\% \text{ Regulation} = \frac{(V_{dc})_{NL} - (V_{dc})_L}{(V_{dc})_L} \times 100$$

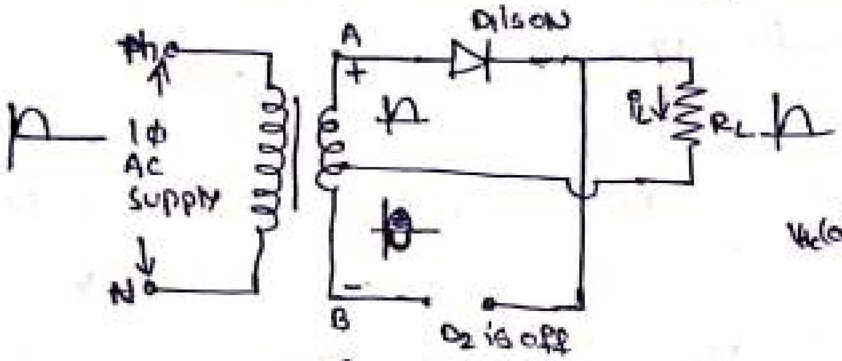
$$= \frac{10.35 - 8.628}{8.628} \times 100$$

$$= 20\%$$

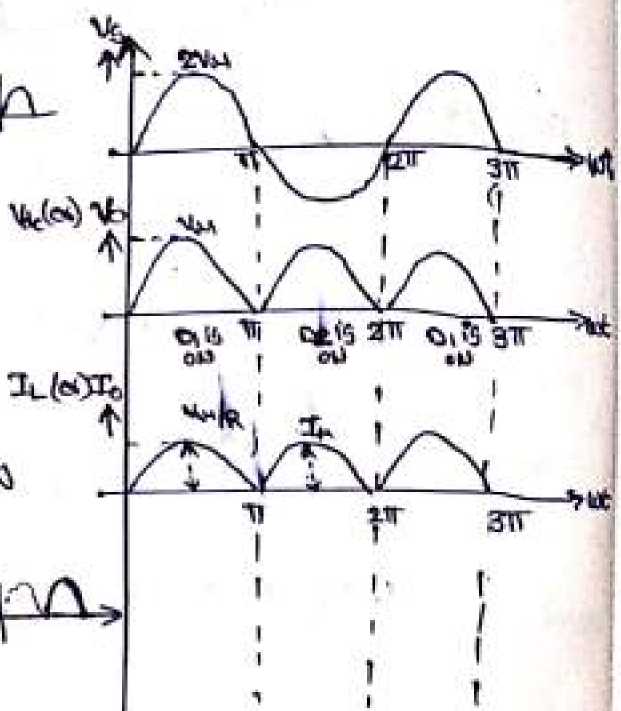
Full wave Rectifier : circuit diagram



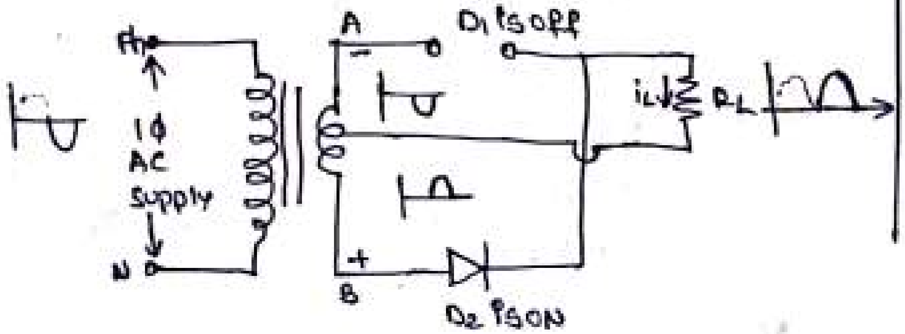
Operation of the circuit: during +ve half cycle : D_1 is ON



case ①



During -ve half cycle : D_2 is ON



consider the +ve half cycle of a.c input voltage in which terminal A is positive and terminal B is negative. The diode D_1 will be forward biased and hence will conduct; while diode D_2 will be reverse biased and will act as an open circuit and will not conduct. This is illustrated in case ① during this period 0 to π D_1 is conduct, output voltage across RL is upper half of transformer winding voltage is V_m appeared shown in V_{dc} waveform.

In the next half cycle of a.c voltage polarity reverses and terminal A becomes negative and B is positive. The diode D_2 conducts being forward biased, while D_1 does not being reverse biased. This is shown in case ②. During this period (π to 2π) D_2 is conduct, output voltage across R_L is lower half of transformer winding voltage is V_m appeared shown in V_{dc} waveform.

Average dc load current (I_{dc}):

Let R_f = forward resistance of diodes.

R_s = winding resistance of each half of secondary

R_L = load resistance.

$V_s = V_m \sin\omega t$ = instantaneous a.c voltage across each half of secondary.

$i_L = I_m \sin\omega t \quad 0 \le \omega t \le \pi$

$$I_{Average} = I_{dc} = \frac{1}{\pi}\int_0^{\pi} i_L \, d(\omega t)$$

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

$$= \frac{I_m}{\pi}(-\cos\omega t)\Big|_0^{\pi}$$

$$= \frac{I_m}{\pi}(-\cos\pi + \cos 0)$$

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

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

Average dc load voltage (V_{dc}): $V_{dc} = I_{dc} R_L$

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

$$V_{dc} = \frac{2 V_{sm} R_L}{\pi (R_f + R_s + R_L)}$$

$$V_{dc} = \frac{2 V_{sm}}{\pi \left(1 + \frac{R_f + R_s}{R_L}\right)} = \frac{2 V_{sm}}{\pi}$$

R.M.S value of load current (I_{RMS})

RMS value of current can be obtained as follows:

$$I_{RMS} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i_L^2 \, d(\omega t)}$$

since 2 half wave rectifier are similar in operation we can write

$$I_{RMS} = \sqrt{\frac{2}{2\pi}\int_0^{\pi} (I_m \sin\omega t)^2 \, d(\omega t)}$$

$$= \sqrt{\frac{I_m^2}{\pi}\int_0^{\pi} \frac{(1-\cos 2\omega t)}{2} \, d(\omega t)}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\left\{\omega t\Big|_0^{\pi} - \frac{\sin 2\omega t}{2}\Big|_0^{\pi}\right.}$$

$$I_{RMS} = \sqrt{\frac{I_m^2}{2\pi}\pi} = \frac{I_m}{\sqrt{2}}$$

R.M.S value of the load voltage:

$$V_{RMS} = I_{RMS} R_L = \frac{I_m}{\sqrt{2}} R_L.$$

DC output power (P_{dc}):

$$P_{dc} = V_{dc} I_{dc} = I_{dc}^2 R_L$$

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

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

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A.c power input ($P_{A.C}$):

$$P_{A.C} = I_{rms}^2 (R_f + R_s + R_L)$$

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

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

Rectifier efficiency $\eta = \frac{P_{dc}\ \text{output}}{P_{AC}\ \text{input}}$

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

Voltage Regulation $= \frac{(V_{dc})_{N.L} - (V_{dc})_{FL}}{(V_{dc})_{FL}} \times 100$

$$(V_{dc})_{NL} = \frac{2V_{sm}}{\pi}, \quad (V_{dc})_{FL} = I_{dc} R_L$$

Problem: A full wave rectifier circuit is fed from a transformer having a centre-tapped secondary winding. The rms voltage from either end of secondary to centre tap is 30V. If the diode forward resistance is 2Ω and that of the half secondary is 8Ω, for a load of 1kΩ, calculate

a) power delivered to load
b) % Regulation at full load
c) Efficiency of rectification
d) Ripple factor.

given data $V_s = 30V = V_{rms}$

$$R_f = 2\Omega, \ R_s = 8\Omega, \ R_L = 1k\Omega$$

a) power delivered to load $= V_{dc} \cdot I_{dc} = I_{dc}^2 R$

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

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

$$V_m = \sqrt{2} V_s$$

$$\therefore V_m = \sqrt{2} \times 30 = 42.43V$$

$$I_m = \frac{42.43}{2 + 1000 + 8} = 42mA$$

$$I_{dc} = \frac{2(42m)}{\pi} = 26.74mA.$$

(a) power deliverd to load $= I_{dc}^2 R_L$

$$= (26.74m) 1k$$

$$= 0.715W.$$

(b) % Regulation at full load

$$= \frac{(V_{dc})_{NL} - (V_{dc})_{FL}}{(V_{dc})_{FL}} \times 100$$

$$(V_{dc})_{NL} = \frac{2V_m}{\pi} = \frac{2(30\sqrt{2})}{\pi} = 27V$$

$$(V_{dc})_{FL} = I_{dc} R_L = 26.74m \times 1k$$

$$= 26.74V.$$

$$\%\ \text{Regulation} = \frac{27 - 26.74}{26.74} \times 100$$

$$= 0.97\%.$$

(c) Efficiency of rectification $= \frac{\text{DC output}}{\text{AC input}}$

DC output $P_{dc} = I_{dc}^2 R_L = (26.74m)^2 \times 1k$

$$= 0.715W$$

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

$$= \left(\frac{I_m}{\sqrt{2}}\right)^2 (2 + 8 + 1k)$$

$$= \left(\frac{42m}{\sqrt{2}}\right)^2 (10 + 1k)$$

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$$P_{A.C} = 8.22\times10^{-4}\times 1010 = 0.891W.$$

$$\text{Efficiency of rectification} = \frac{P_{dc}}{P_{AC}} = \frac{0.715}{0.891}\times100$$
$$= 0.8024\times100$$
$$= 80.24\%$$

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

$$I_{rms} = I_m/\sqrt{2} = \frac{42m}{\sqrt{2}} = 0.0296$$

$$\text{Ripple factor} = \sqrt{\left(\frac{0.0296}{26.74m}\right)^2 - 1}$$
$$= \sqrt{1.225 - 1} = \sqrt{0.2253} = 0.474$$

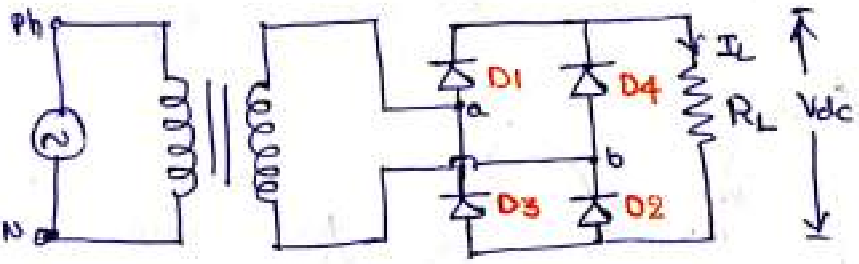
1 ϕ Fullwave Bridge Rectifier:

The bridge rectifier circuits are mainly used as

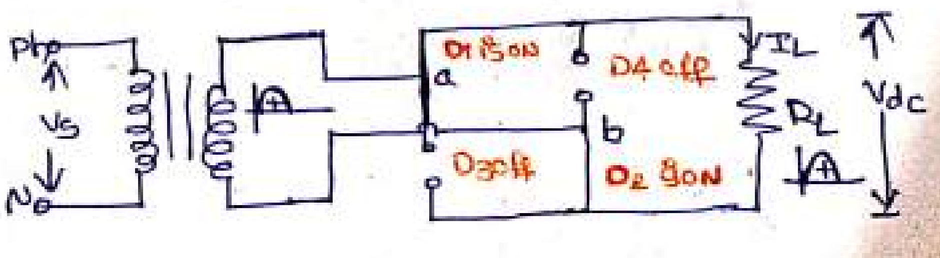
a) A power rectifier circuit for converting AC power to dc power &

b) A rectifying system in rectifier type AC meters.

basic RECTIFIER CIRCUIT:

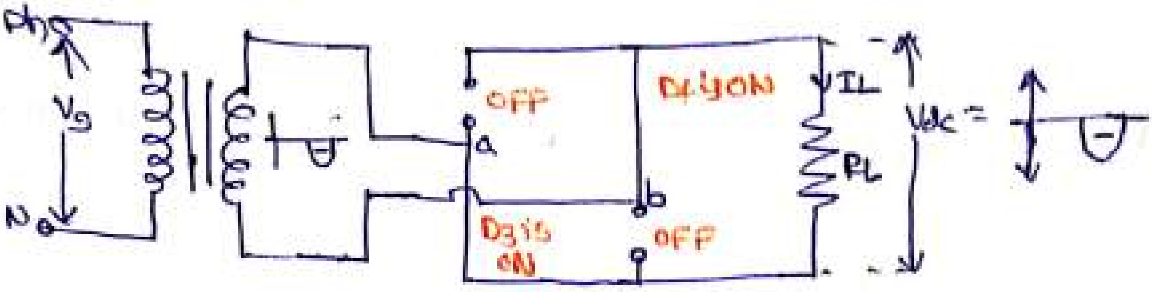


During $0 < \omega t < \pi$ D_1 & D_2 is ON & D_3, D_4 is OFF



during $180° < \omega t < 360°$ D_1 & D_2 is OFF &

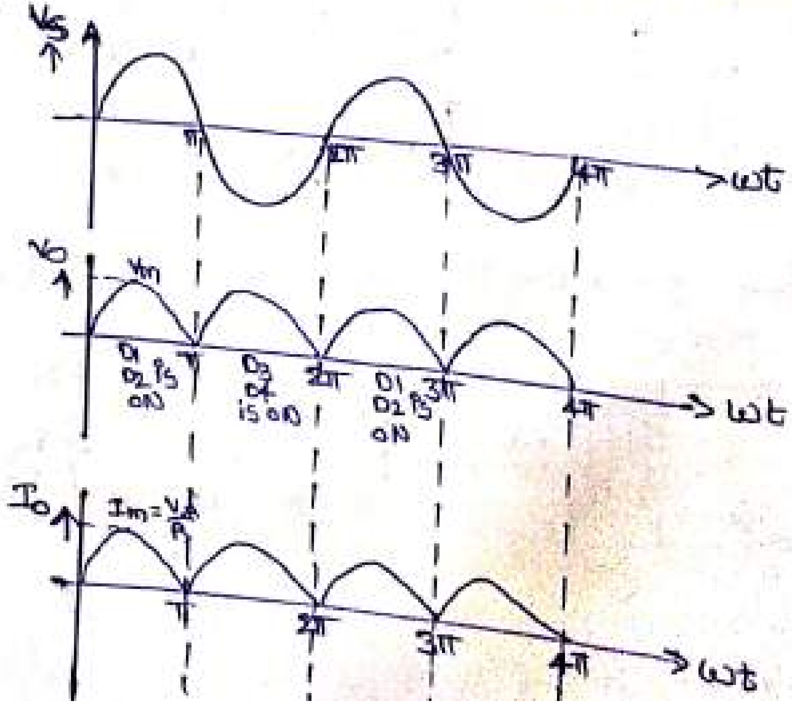
D_3 & D_4 is ON.



during $0 < \omega t < 180°$, operation of rectifier D_1 & D_2 is turned on and output voltage across R load is same as input voltage i.e $V_L = +V_m$. during this period we are getting +ve half pulse across the load. D_3 & D_4 are reverse biased.

During $180° < \omega t < 360°$ the diodes D_1 & D_2 are reverse biased, D_3 & D_4 are forward baised so the resultant circuit shown in above figure. during in this interval we are getting output voltage -ve. so $V_0 = -V_m$. and we are getting -ve half cycle across the load.

wave forms:



Expressions for various parameters:

$$I_{dc} = \frac{2I_m}{\pi} = \text{Average o/p current}$$

$$I_{RMS} = \frac{I_m}{\sqrt{2}} = \text{RMS value of load current}$$

$$V_{dc} = \text{Average dc load voltage} = \frac{2V_{sm}}{\pi}$$

$$P_{dc} = \text{DC power output} = I_{dc}^2 R_L$$

$$= \frac{4}{\pi^2} I_m^2 R_L.$$

$$P_{AC} = \text{AC power input} = I_{rms}^2 (R_s + 2R_f + R_L)$$

$$\text{Rectifier efficiency } \eta = \frac{P_{dc}\text{ output}}{P_{AC}\text{ input}} \times 100.$$

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Operational Amplifier

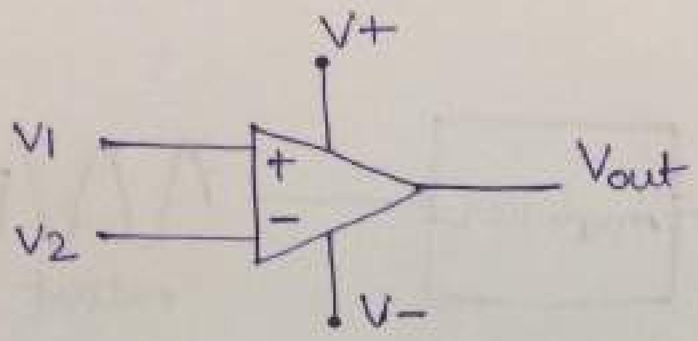
→ the basic job of an amplifier is to amplify the input signal.

→ In early days when digital Computers are not evolved, at that time, different mathematical functions like addition, Subtraction, integration, and differentiation were performed using this operational amplifier.

→ Just by connecting few resistors and capacitors it is possiable to perform different mathematical. operations. and that is why this amplifier is known as the operational amplifiers.

→ design of different circuits using this operational amplifier is possiable.

→ Circuit symbol of operational amplifier is



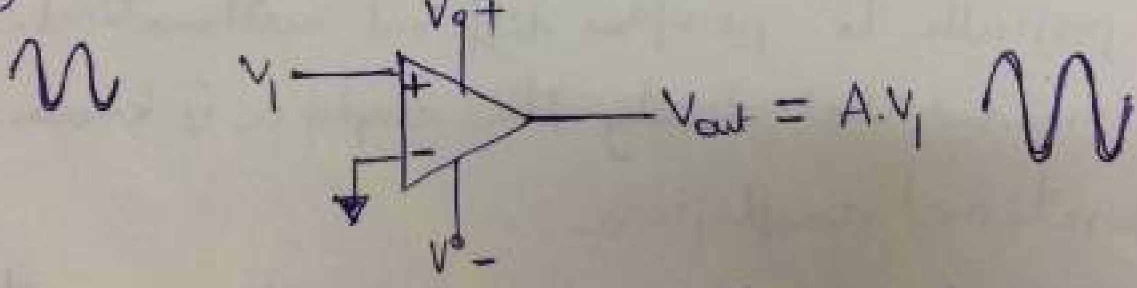
→ the input terminal which is marked by +ve sign is called non inverting input terminal.

the input terminal which is marked by −ve sign is called inverting input terminal.

→ the above opamp is one kind of a differential amplifier which means that the opamp amplifies the difference between the two input signals.

→ the input signal can be given in three ways.

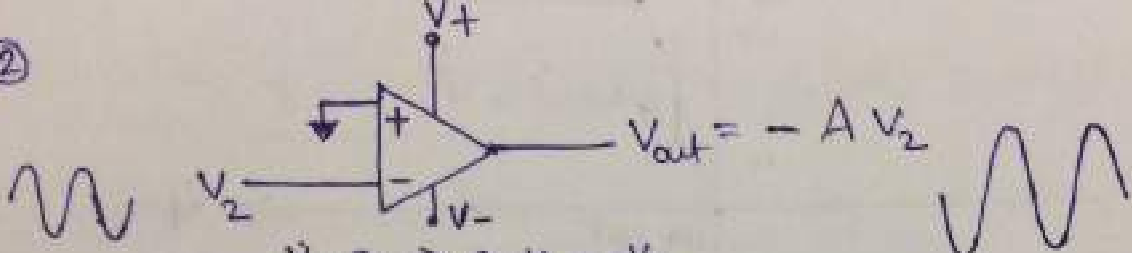
①



where A is the open loop gain of the opamp

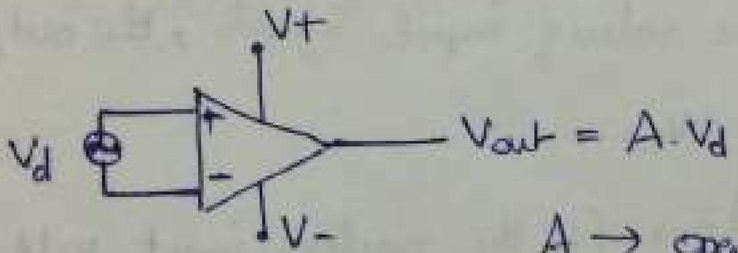
→ 'A' is called open loop gain bcs it is the gain when there is no feedback from output to input side.

→ the phase of the output voltage will be same as the input voltage

② 

$V_1 = 0 \Rightarrow 0 - V_2 = -V_2$

→ the phase of the output voltage will be 180 with respect to input voltage. So this input terminal is known as inverting input terminal.

③ 

A → open loop gain of opamp.

→ the opamp is a very high gain op amp.

the gain is as large as 10^5 to 10^6

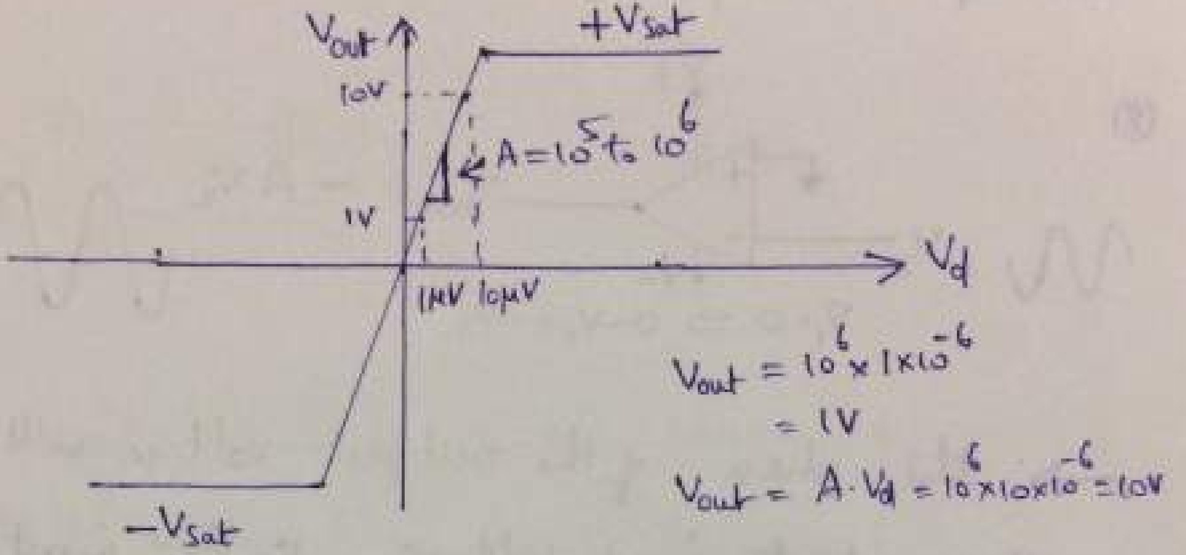
If we apply 1mV of signal i.e. if $V_d = 1mV$

If A is 10^6 then $V_{out} = 10^6 \times 1 \times 10^{-3} V$
$= 1000V$

which is not possible.

→ o/p of opamp is restricted by the biasing voltage applied to the op amp. o/p voltage will be b/w the biasing voltages ($V+$ & $V-$)

Voltage transfer curve of opamp.

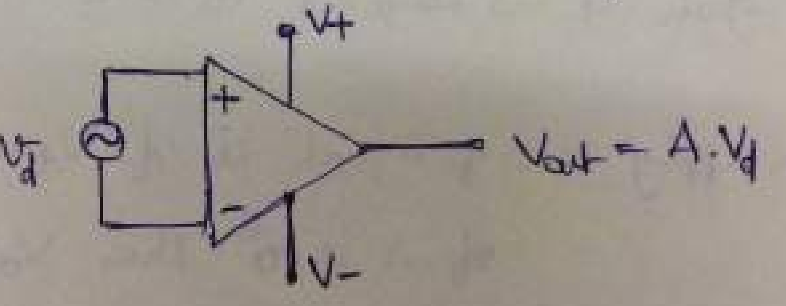


→ slop represents the gain of the amplifier

→ after some value of input signal, the output will get saturated to $+V_{sat}$

→ same is true for the negitive input voltages.

→ whenever an op amp is used in open loop configuration which is no feed back from output to input side



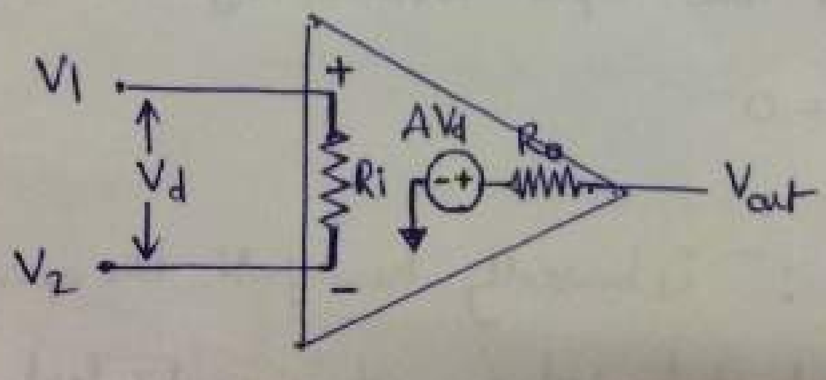
→ even if we apply very small voltage between +ve & −ve i/p terminals. o/p will be get saturated to +ve & −ve voltages.

→ this characteristic of an opam is particularly useful when we use this op-amp as a comparator.

applications of opamp :- 1) active filters 2) oscillators 3) wave-form converters and 4) analog to digital and D to A converters.

→ the reason this opamp is used in so many applications is because of its different characteristics.

op-amp equivalent circuit :-



R_i = input impedance

R_o = output impedance.

Characteristics of Ideal op-amp :

It should have :

→ Input Impedance $R_i = \infty$ so that what ever the input applied across input terminals is applied to opamp.

→ out put Impedance $R_o = 0$; ie whenever o/p load is Connected the output voltage should directly come across R_L.

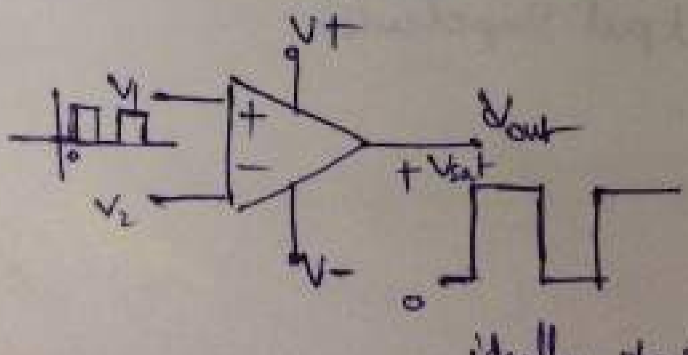
→ Band width $B.W = \infty$; ie It should Support all the frequencies Starting from $0Hz$ to ∞.

→ / Gain of an ideal opamp $= \infty$ ie $A = \infty$

→ also when the two input terminal Signal's are Zero.

$V_{out} = 0$

→ Slew rate : is basically how fast the opamp is able to ~~will~~ reach it's final ~~state~~ value. It is particularly useful when square wave is applied as V_d.



in zero time

ideally o/p should reach from 0 to $+V_{sat}$

$\therefore$ Slew rate $= \infty$

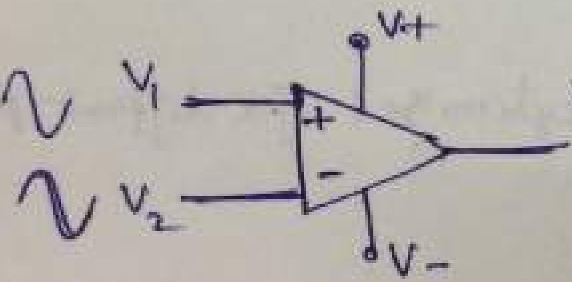
generally defined as $V/\mu s$ ie how fast the o/p amp respondsto the input square wave

→ ~~CMMR:-~~ CMRR:-

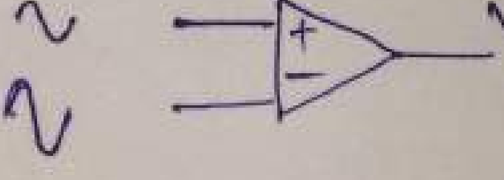
If we apply same voltage to V_1 & V_2 then $V_d = 0$ and at the output $V_{out} = 0$

and if V_1 and V_2 are different then $V_d = V_1 - V_2$ and the opamp must amplify V_d ie $V_{out} = A \cdot V_d$

$\therefore$ CMMR is basically ~~defined as~~ how well the opamp is able to reject the Common input voltage's $V_1 = V_2$, and how well it is able to amplify V_d.



$V_{out} = \frac{V_1 - V_2}{} = 0$



$V_0 = A \cdot V_d$ (how well it is able to amplify V_d)

$$\therefore \text{CMRR} = \frac{A_d}{A_c} = \infty \quad \because A_c = 0 \text{ ideally.}$$

Common mode gain ← A_c $\qquad$ A_d → differential gain.

But If we see any practical opamp

R_i is in $M\Omega$

R_o is in Ω

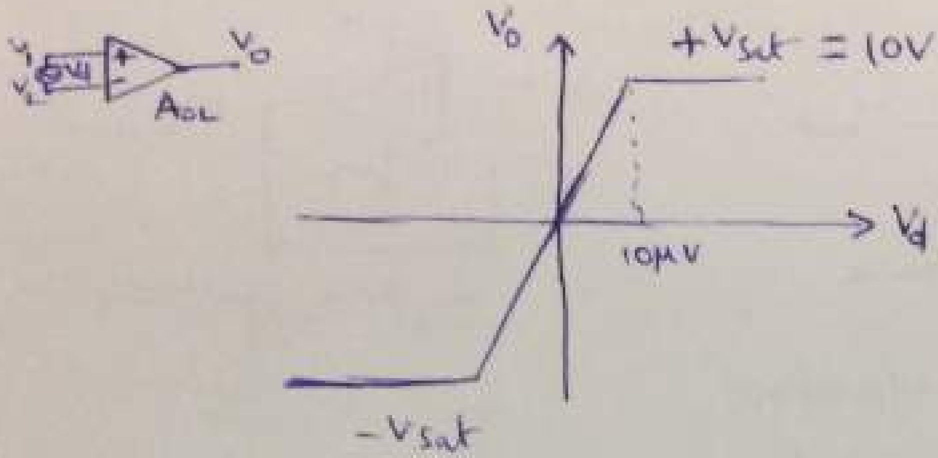
$A = 10^5$ to 10^6

$V_{out} \neq 0$ mV called offset voltage
when $V_{in} = 0$

op amp 741 Specification

R_i	— I/p Impedance		$2M\Omega$
R_o	— o/p Impedance		75Ω
A	— openloop gain		10^5
offset voltage		—	1mV
slew rate		—	$0.5V/\mu s$
CMMR		—	70-90dB.

different opamp IC's are optimized for different parameters depending on the application.



$A_{OL} = 10^6$

→ with a saturation voltage of 10V and openloop gain of 10^6 this op-amp will be saturated at a differential input voltage of $10\mu V$.

→ If we want to use it as an amplifier we need to use in linear region.

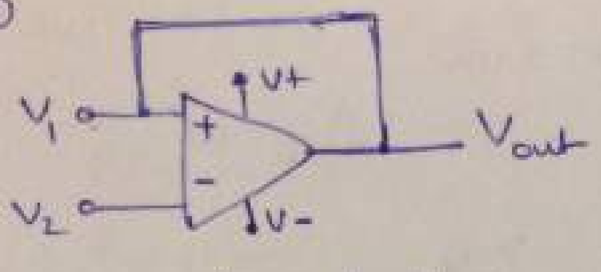
→ whenever we are using the opamp in open loop configuration this linear range is very small.

→ we need to control the gain of the amplifier if we want to use it as an amplifier.

→ we can control the gain by applying feed back to the input side.

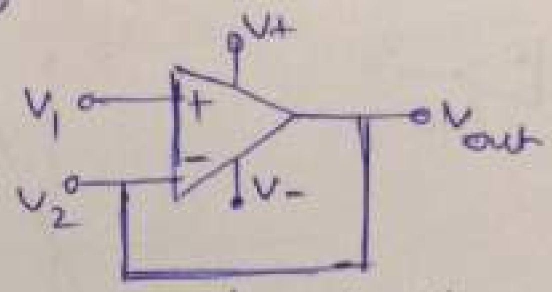
→ there are two ways by which we can apply the feed back

①



positive feedback

②

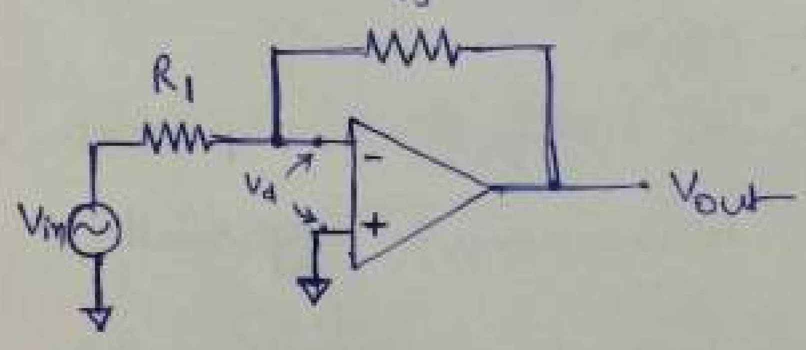


negative feedback

→ fraction of the o/p voltage is added to the input.

→ when ever we use +ve feed back ~~the~~ it leads the system to unstability so we cannot use the +ve feedback alone.

→ Inverting operational amplifier



Rule 1:-

Concept of virtual ground :- It is applicable when we provide -ve feed back to an op-amp

let $A_{OL} = 10^6$

$V_{out} = A \times V_d$

let ~~us~~ assume that through the -ve feed back we are using the opamp in linear region and controlling output voltage so that the output voltage is always less than the saturation voltage

let $V_{out} = 10$

i.e $10 = 10^6 \cdot V_d$

$V_d = 10\mu V$

$V^+ - V^- = 10\mu V$

$V^+ - V^- \cong 0V$

$\Rightarrow V^+ = V^-$

It means that inverting and non inverting input terminals are at the same potential.

we can say that there is a virtual ~~ground~~ short between inverting and non inverting input terminals. (which means both are at the same potential).

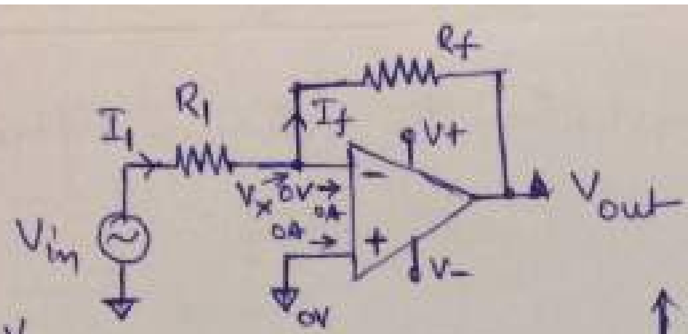
$\because V^+ = 0$

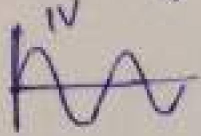
$V^- = 0$ so inverting input terminal is not grounded but it is at virtual ground.

→ the negative feed back will ensure that the difference between the inverting and non inverting i/p terminal is very small. & it is almost negligible.

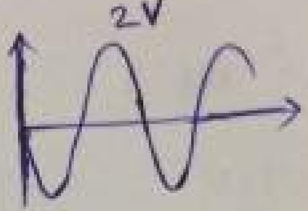
this concept is called the concept of virtual ground.

Rule 2 : no current flows in & out of an ideal op amp





$I_1 = I_f$



$$\frac{V_{in} - V_x}{R_1} = \frac{V_x - V_{out}}{R_f}$$

by using the concept of virtual ground.

$V_x = 0$

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

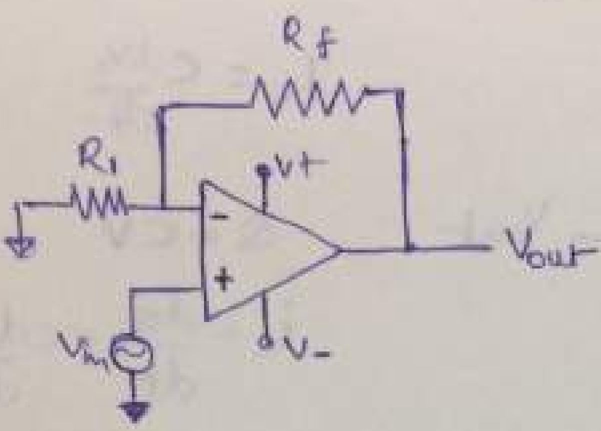
$$\Rightarrow \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_1} = A_{CL}$$

→ by controlling the value of R_f and R_1 we can control the gain.

If $R_f = 2k\Omega$ & $R_1 = 1k\Omega$

$$A_{CL} = \frac{-2k\Omega}{1k\Omega} = -2$$

Non inverting operational amplifier



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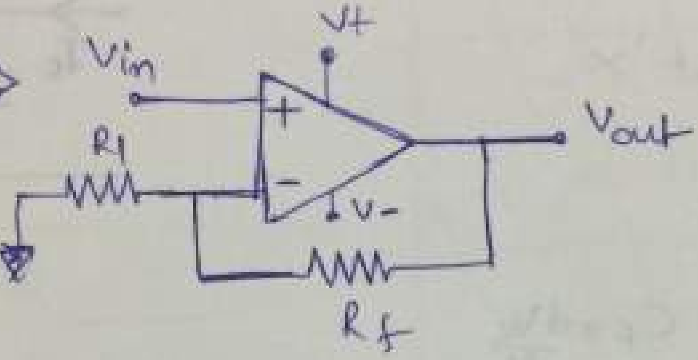

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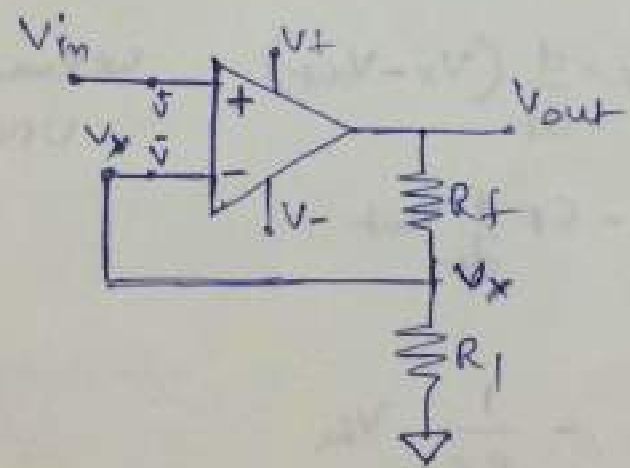


$$V_x = \frac{R_1}{R_1 + R_f} \times V_{out}$$

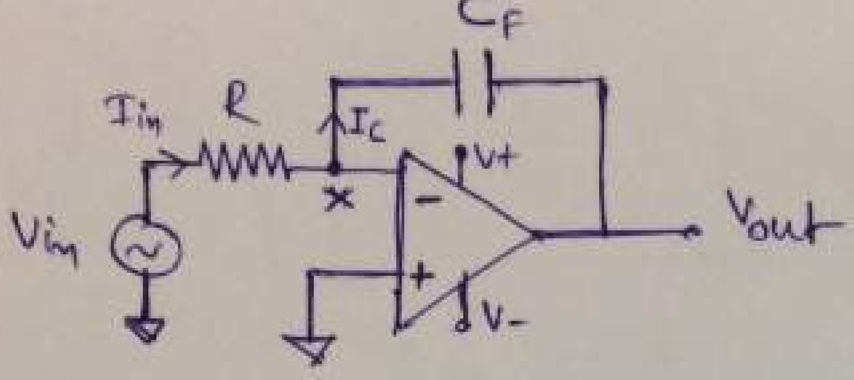
$\because \overset{+}{V} = \overset{-}{V}$ $\quad \because$ virtual short.

$\overset{+}{V} = V_{in} = V_x$

$V_{in} = \frac{R_1}{R_1 + R_f} \times V_{out} \Rightarrow \frac{V_{out}}{V_{in}} = \frac{R_1 + R_f}{R_1} = 1 + \frac{R_f}{R_1} = A_{CL}$

ACL

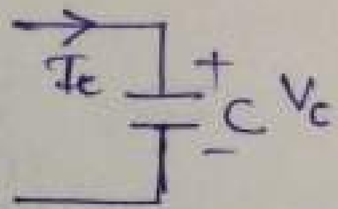
opamp as integrator



$$I_c = C\frac{dV_c}{dt}$$

$$Q = CV$$

$$i_c = \frac{dQ}{dt} = C\frac{dV_c}{dt}$$



Using KCL at 'x'

$$I_{in} = I_C$$

$$\frac{V_{in} - V_x}{R} = C_F \times \frac{dV_c}{dt}$$

$$= C_F \times \frac{d}{dt}(V_x - V_{out})$$

we know $V_x = 0$ using virtual ground.

$$\frac{V_{in}}{R} = -C_F \frac{d}{dt} V_{out}$$

$$\frac{dV_{out}}{dt} = -\frac{1}{RC_F} \cdot V_{in}$$

integrating on both sides.

$$V_{out} = -\frac{1}{RC_F}\int V_{in}\, dt$$

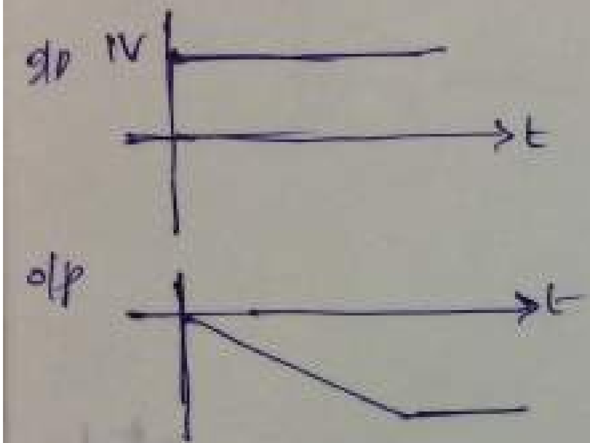
∵ V_{in} is a function of time

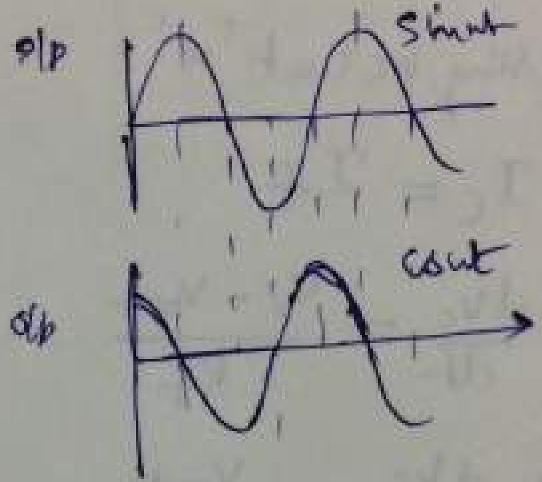
$$V_{out} = -\frac{1}{RC_F}\int V_{in}(t)dt$$

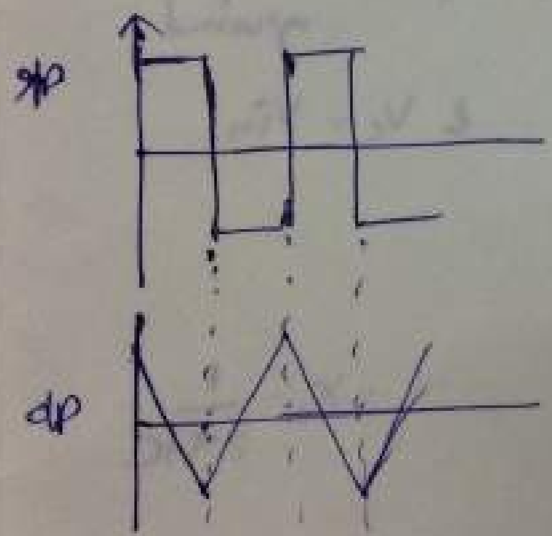
the capacitive reactance $X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$

$$\therefore V_{out} = -\frac{X_C}{R} \cdot V_{in}$$

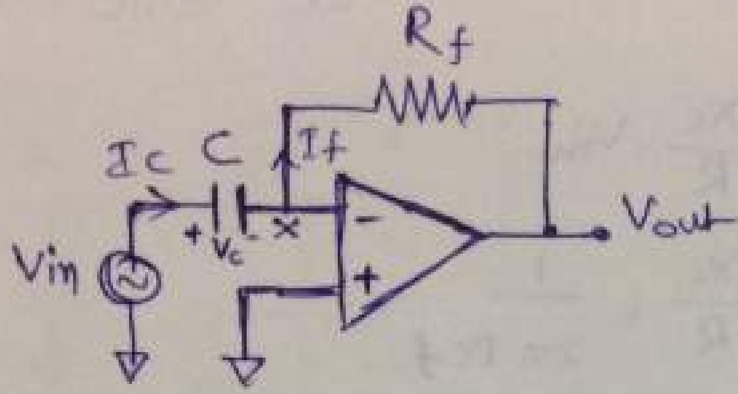
$$A_V = -\frac{X_C}{R} = \frac{1}{2\pi RCf}$$







op-amp as differentiator



Using kcl at 'x'

$$I_C = I_f$$

$$C\frac{dV_c}{dt} = \frac{V_x - V_{out}}{R_f}$$

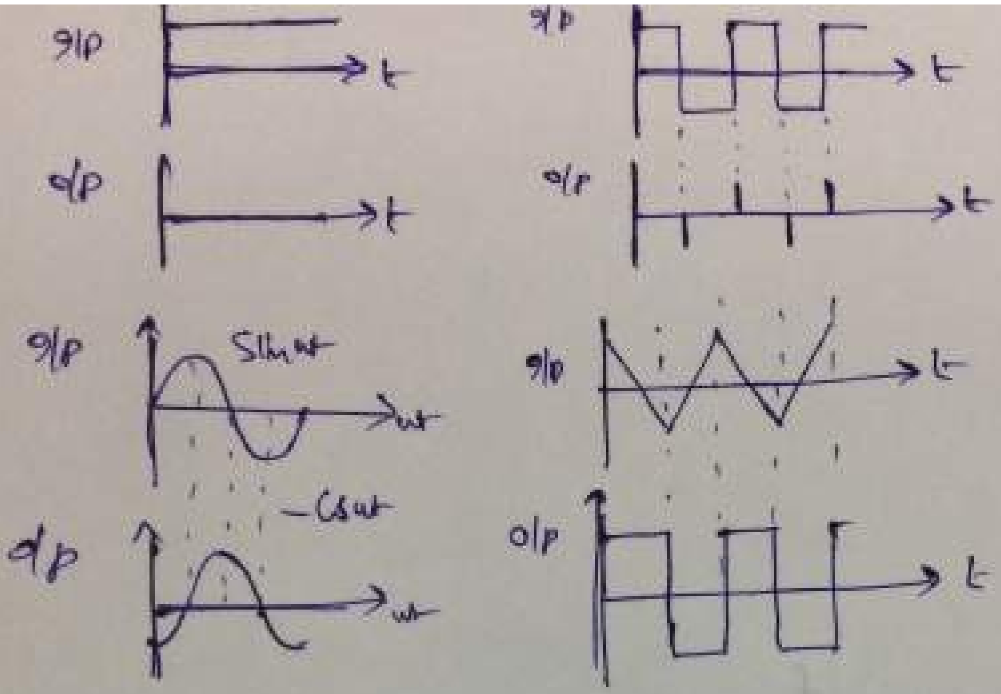
$$C \cdot \frac{dV_{in}}{dt} = -\frac{V_{out}}{R_f} \qquad \because V_x = 0 \text{ using virtual ground.}$$

$$\& \ V_c = V_{in}$$

$$\Rightarrow V_{out} = -R_f \times C \frac{dV_{in}}{dt}$$

$$\text{also } V_{out} = \frac{-R_f}{X_C} \times V_{in} \qquad \because X_C = \frac{1}{2\pi f C}$$

$$\frac{V_{out}}{V_{in}} = A = -R_f \times 2\pi \times f \times C$$



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6 Transistors

6.1 Junction Transistor

In 1951, William invented the first junction transistor, a semiconductor device that can amplify electronic signals such as radio and television signals. It is essential ingredient of every electronic circuit; from the simplest amplifier or oscillator to the most elaborate digital computer. Thus a proper understanding of transistor is very important.

Before transistor, the was achieved by using vacuum tubes as an amplifier. Now a days vacuum tubes are replaced by transistors because of following advantages of transistors.

- Low operating voltage.
- Higher efficiency.
- Small size and ruggedness and
- Does not require any filament power.

Transistor is a three terminal device : Base, emitter and collector, can be operated in three configurations common base, common emitter and common collector. According to configuration it can be used for voltage as well as current amplification. The input signal of a small amplitude is applied at the base to get the magnified output signal at the collector. Thus provides an amplification of the signal. The amplification in the transistor is achieved by passing input current signal from a region of low resistance to a region of high resistance. This concept of transfer of resistance has given the name (TRANSISTOR). In transistor, the output current is controlled or the input current and hence it is a current controlled device.

There are two types of transistors : **Unipolar junction transistor and bipolar junction transistor**. In unipolar transistor the current conduction is only due to one type of carriers, majority carriers. The current conduction in bipolar transistor is because of both the types of charge carriers, holes and electrons. Hence this is called **Bipolar junction transistor**, hereafter referred to as

The are of two types :

- n-p-n type
- p-n-p type.

6.1.1 Structure of Bipolar Junction Transistor

When a transistor is formed by sandwiching a single p-region between two n-regions, as shown in the Fig. 6.1 (a), it is an n-p-n type transistor. The p-n-p type transistor has a single n region between two p-regions, as shown in Fig. 6.1(b).

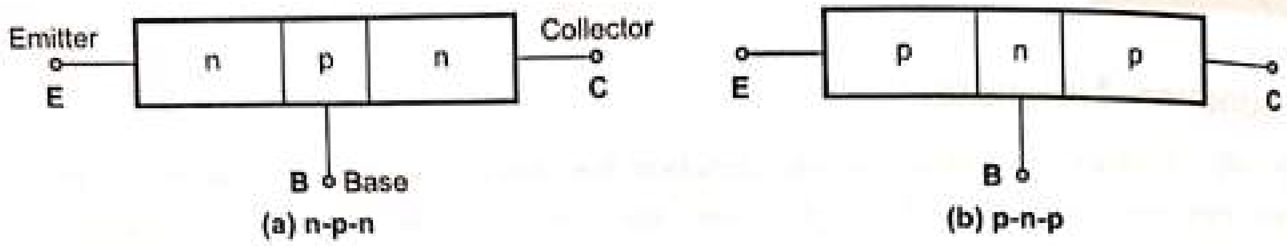


Fig. 6.1 Bipolar transistor construction

The middle region of each transistor type is called the base of the transistor. This region is very thin and lightly doped. The remaining two regions are called **emitter** and **collector**. The emitter and collector are heavily doped. But the doping level in emitter is slightly greater than that of collector and the collector region-area is slightly more than that of emitter.

Fig. 6.2 (a) and (b) shows the symbols of npn and pnp transistors.

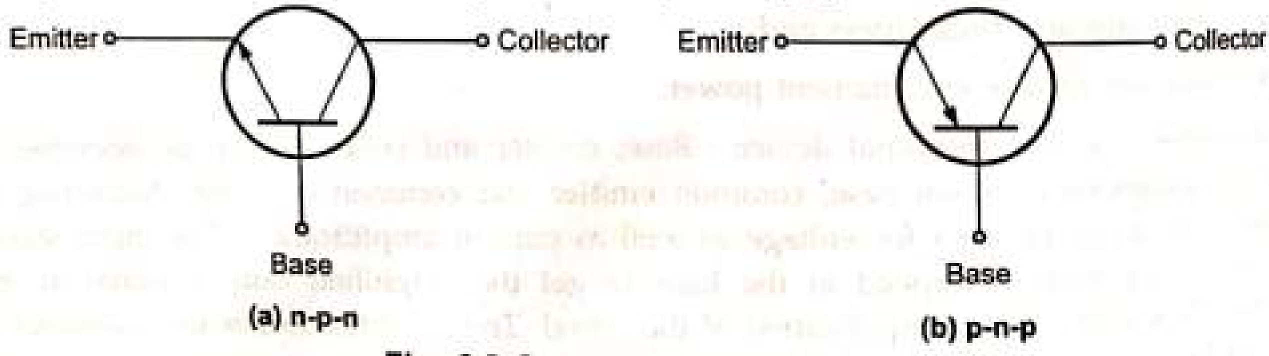


Fig. 6.2 Standard transistor symbols

A transistor has two p-n junctions. One junction is between the emitter and the base, and is called the **emitter base junction,** or simply the **emitter junction** J_E. The other junction is between the base and the collector, and is called **collector-base junction,** or simply **collector junction** J_C. Thus transistor is like two pn junction diodes connected back-to-back as shown in the Fig. 6.3 (a) and (b).

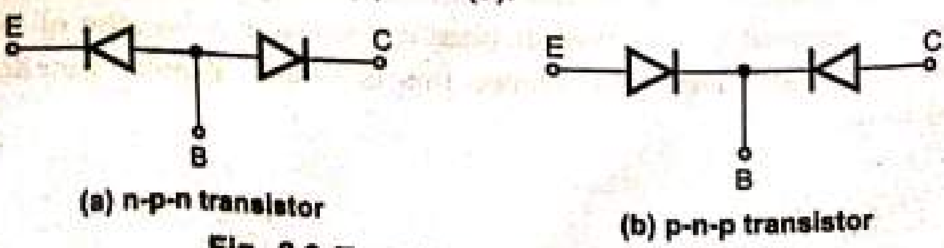


Fig. 6.3 Two-diode transistor analogy

However, we cannot replace transistor by back to back connected diodes because of the following reasons :

1. *Relative doping levels in the base, emitter and collector junctions must be satisfied to work that device as a transistor. Two normal p-n junction diodes cannot satisfy this requirement.*

2. *In a transistor, emitter to base junction is forward biased while base to collector junction is reversed biased. But due to* ***diffusion process*** *almost entire emitter current reaches to collector and base current is negligibly small. Thus due to diffusion, device works as a transistor. While in back to back connected diodes there are two separate diodes, one forward biased and one reverse biased and diffusion cannot take place. Thus maximum series current which can flow is reverse saturation current of a reverse biased diode. Hence the combination of back to back connected diodes can not be used as transistor.*

Another important point is that, the emitter area in the transistor is considerably smaller than the collector area. This is because the collector region has to handle more power than the emitter and more surface area is required for heat dissipation.

6.1.2 Unbiased Transistor

An unbiased transistor means a transistor with no external voltage (biasing) is applied. Obviously, there will be no current flowing from any of the transistor leads. Since transistor is like two pn junction diodes connected back to back, there are depletion regions at both the junctions, emitter junction and collector junction, as shown in the Fig. 6.4.

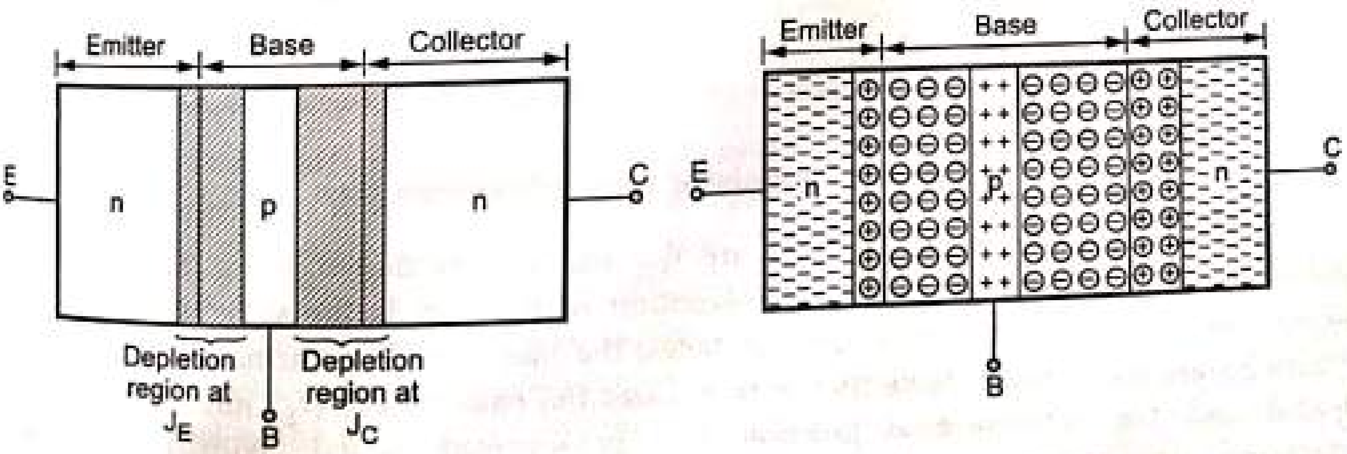


Fig. 6.4 Unbiased npn transistor

During diffusion process, depletion region penetrates more deeply into the lightly doped side in order to include an equal number of impurity atoms in the each side of the junction. As shown in the Fig. 6.4, depletion region at emitter junction penetrates less in the heavily doped emitter and extends more in the base region. Similarly, depletion region at collector junction penetrates less in the heavily doped collector and extends more in the base region. As collector is slightly less doped than the emitter, the depletion layer width at the collector junction is more than the depletion layer width at the emitter junction.

6.1.3 Biased Transistor

In order to operate transistor properly as an amplifier, it is necessary to correctly bias the two pn junctions with external voltages. Depending upon external bias voltage polarities used, the transistor works in one of the three regions, viz.

1) *Active region* 2) *Cut-off region* and 3) *Saturation region*.

Region	Emitter base junction	Collector base junction
Active	Forward biased	Reverse biased
Cut-off	Reverse biased	Reverse biased
Saturation	Forward biased	Forward biased

To bias the transistor in its active region, the emitter base junction is forward biased, while the collector-base junction in reverse-biased as shown in Fig. 6.5.

The Fig. 6.5 show the circuit connections for active region for both npn and pnp transistors.

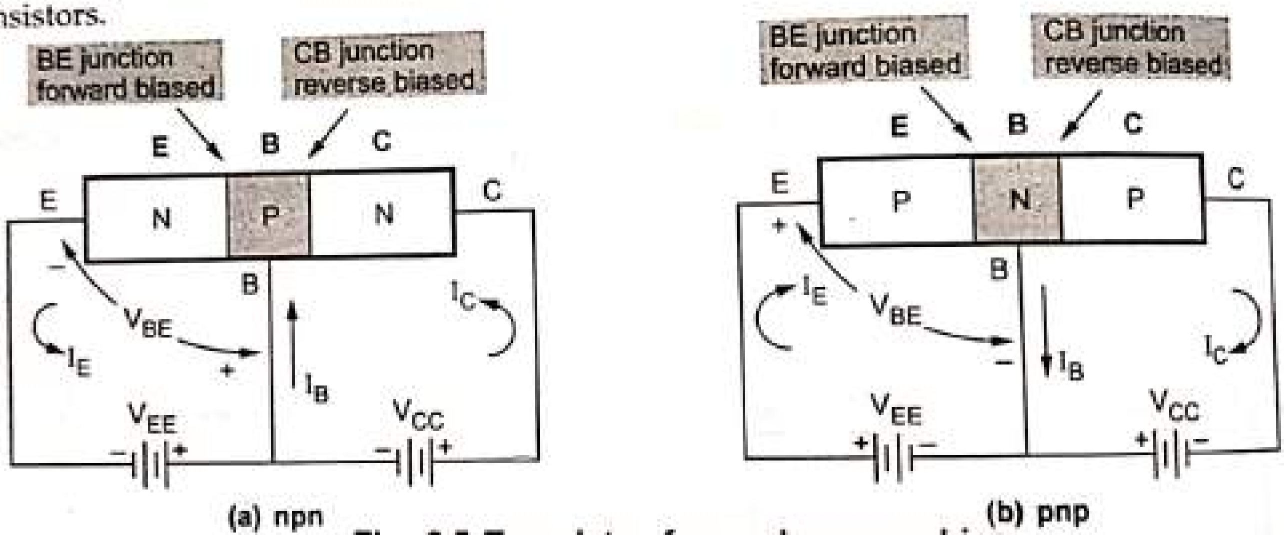


Fig. 6.5 Transistor forward-reverse bias

The externally applied bias voltages are V_{EE} and V_{CC}, as shown in Fig. 6.5, which bias the transistor in its active region. The operation of the pnp is the same as for the npn except that the roles of the electrons and holes, the bias voltage polarities and the current directions are all reversed. Note that in both cases the base-emitter (J_E) junction is forward biased and the collector-base junction (J_C) is reversed biased. With these biasing conditions, what happens inside the transistor, is discussed in the next section.

6.1.4 BJT Operation

In the previous section we have seen that base is taken as common point/terminal to connect transistor in common-base configuration. Similarly, we can use emitter and collector as a common points/terminals to connect transistor in common emitter and common collector configurations, respectively. Thus, the transistor can be connected in a circuit in the following three configurations.

1. Common base configuration.
2. Common emitter configuration.
3. Common collector configuration.

Key Point : *Regardless of circuit configuration, the base emitter junction is always forward biased while the collector-base junction is always reverse biased, to operate transistor in active region.*

6.1.4.1 Operation of NPN Transistor

Let us consider the npn transistor for our discussion. The base to emitter junction is forward biased by the d.c. source V_{EE}. Thus, the depletion region at this junction is reduced. The collector to base junction is reverse biased, increasing depletion region at collector to base junction as shown in Fig. 6.6.

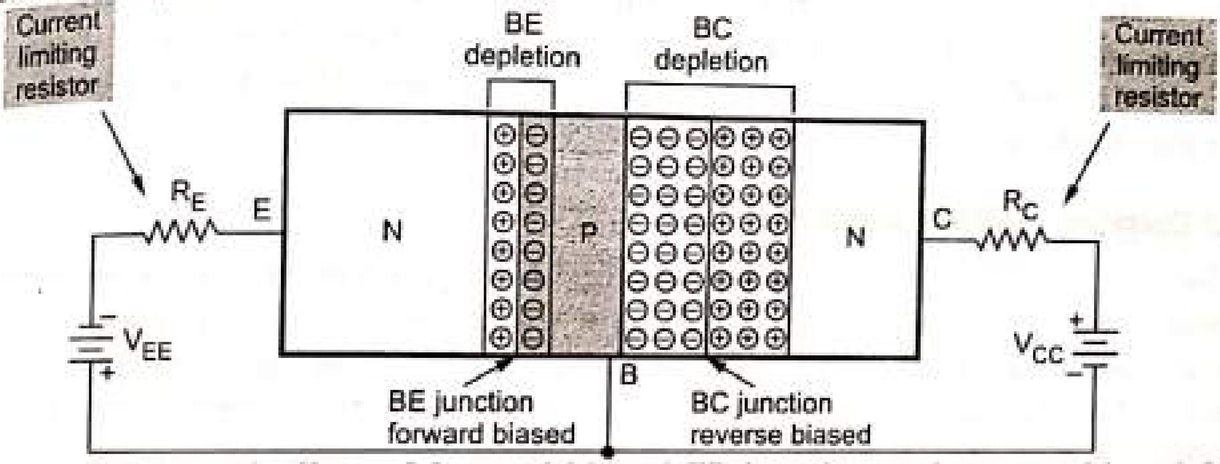


Fig. 6.6 Internal effect of forward biased EB junction and reverse biased CB junction

The forward biased EB junction causes the electrons in the n-type emitter to flow towards the base. This constitutes the emitter current I_E. As these electrons flow through the p-type base, they tend to combine with holes in p-region (base).

We know that, the base region is very thin and lightly doped. The light doping means that the free electrons have a long lifetime in the base region. The very thin base region means that the free electrons have only a short distance to go to reach the collector. For these two reasons, very few of the electrons injected into the base from the emitter recombine with holes to constitute base current, I_B (Refer Fig. 6.7) and the remaining large number of electrons cross the base region and move through the collector region to the positive terminal of the external d.c. source as shown in Fig. 6.8.

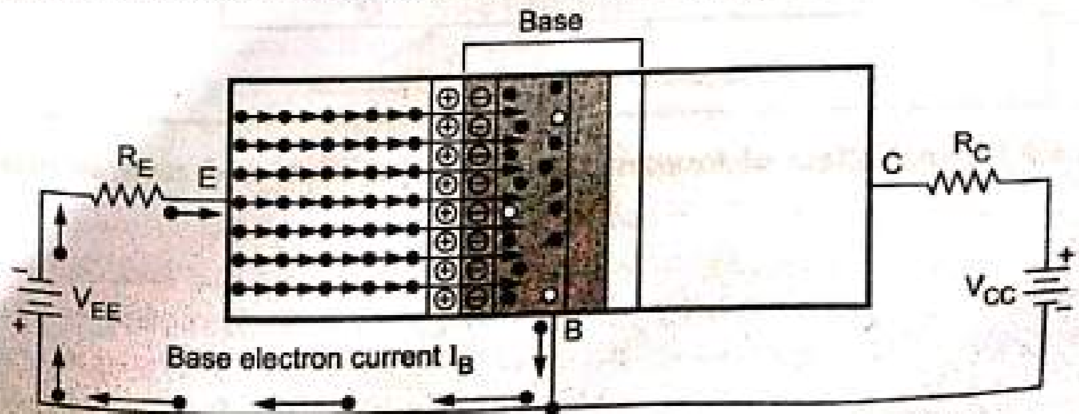


Fig. 6.7 Electron flow across emitter-base junction

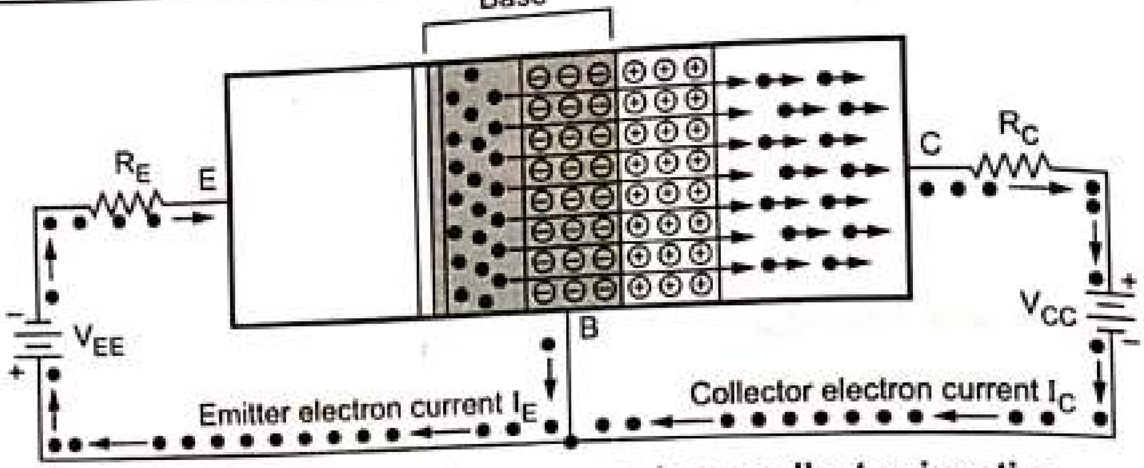


Fig. 6.8 Electron flow across base-collector junction

This constitutes collector current I_C. Thus the electron flow constitutes the dominant current in an npn transistor. Since, the most of the electrons from emitter flow in the collector circuit and very few combine with holes in the base. Thus, the collector current is larger than the base current.

6.1.4.2 Operation of PNP Transistor

The pnp transistor has its bias voltages V_{EE} and V_{CC} reversed from those in the npn transistor. This is necessary to forward-bias the emitter-base junction and reverse-bias the collector base junction. The forward biased EB junction causes the holes in the p-type emitter to flow towards the base. This constitutes the emitter current I_E. As these holes flow through the n-type base, they tend to combine with electrons in n-region (base). As the base is very thin and lightly doped, very few of the holes injected into the base from the emitter recombine with electrons to constitute base current, I_B, as shown in the Fig. 6.10.

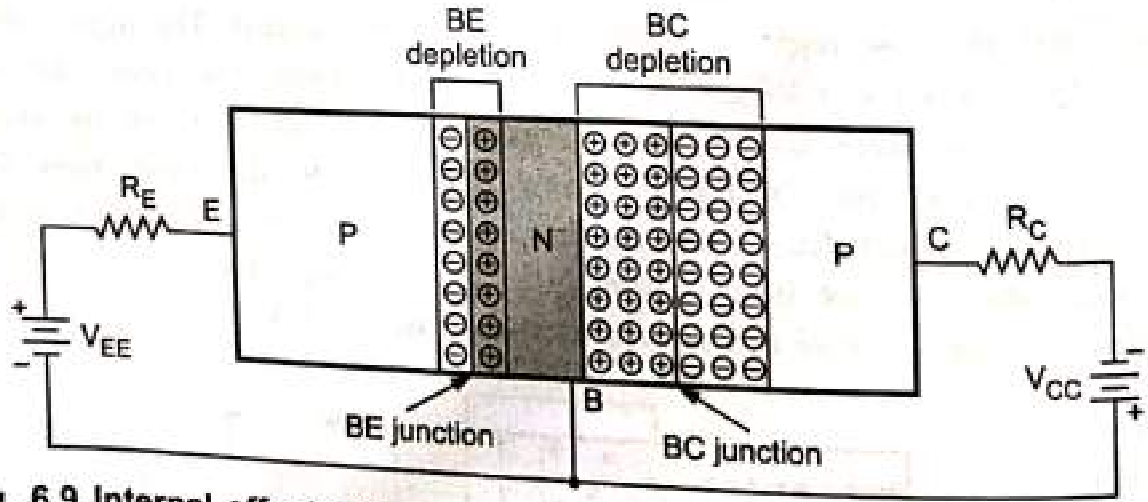


Fig. 6.9 Internal effect of forward biased EB junction and reverse biased CB junction

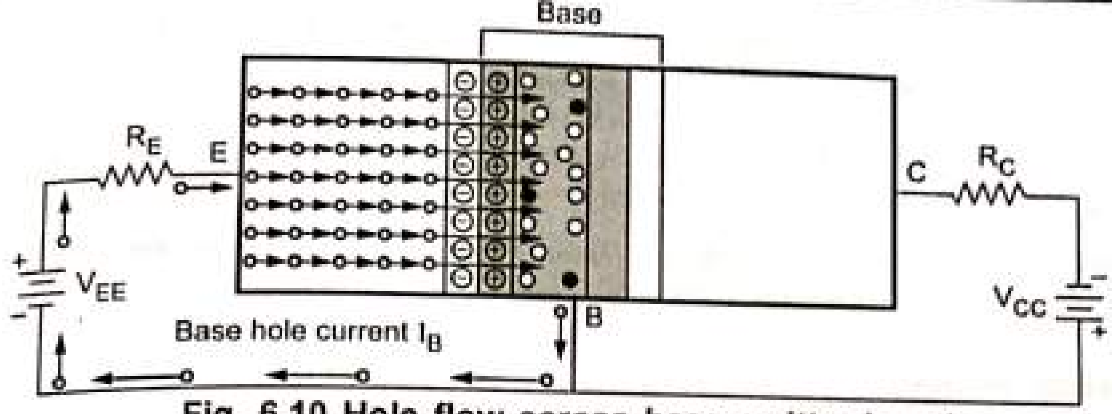


Fig. 6.10 Hole flow across base emitter junction

The remaining large number of holes cross the depletion region and move through the collector region to the negative terminal of the external d.c. source, as shown in Fig. 6.11. This constitutes collector current I_C. Thus the hole flow constitutes the dominant current in an pnp transistor.

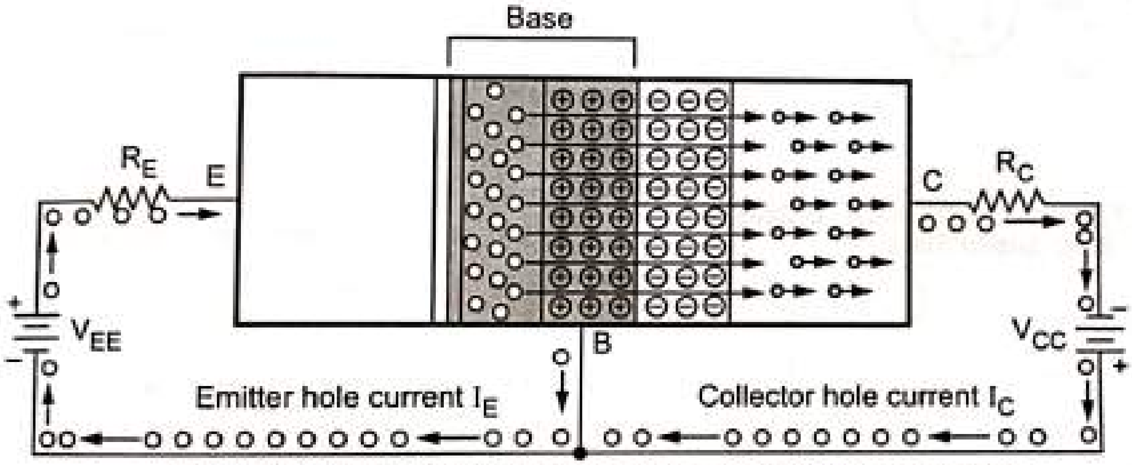


Fig. 6.11 Hole flow across base-collector junction

Highly doped emitter ensures that the emitter current consists almost entirely of holes in a pnp transistor and almost entirely of electrons in a npn transistor. Such a situation is desired since the current which results from electrons (in case of pnp transistor) or from holes (in case of npn transistor) crossing the emitter junction from base to emitter does not contribute carriers which can reach the collector.

6.1.5 Transistor Voltages and Currents

The common-emitter configuration is widely used amongst three transistor configurations. The main reasons for the wide-spread use of this circuit arrangement are :

1. The CE configuration is the only configuration which provides both voltage gain as well as current gain greater than unity. In case of CB configuration current gain is less than unity and in case of CC configuration voltage gain is less than unity.

The power gain is a product of voltage gain and current gain. CE configuration provides voltage gain nearly equal to voltage gain provided by CB configuration (voltage gain is maximum in CB) and current gain nearly equal to current gain provided CC configuration (current gain is maximum in CC). Thus the power gain of the CE amplifier is much greater than the power gain provided by the other two configurations (voltage gain in CC and current gain in CB are less than unity).

2. In a common emitter circuit, the ratio of output resistance to input resistance is small, may range from 10 Ω to 100 Ω. This makes configuration an ideal for coupling between various transistor stages. However, in other connections, the ratio of output resistance to input resistance is very large and hence coupling becomes highly inefficient due to large mismatch of resistance.

Note : Maximum power is transferred from stage 1 to stage 2, when output resistance of stage 1 is equal to the input resistance of stage 2.

6.1.5.1 Transistor Voltages

NPN Transistor

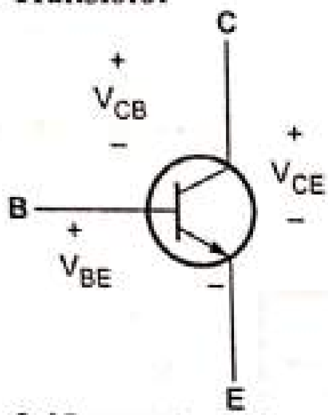


Fig. 6.12 npn transistor voltage and polarities

The Fig. 6.12 shows the terminal voltages and its polarities for an npn transistor. The voltage between base and emitter is denoted as V_{BE}. For V_{BE}, base is positive than emitter because for npn transistor, the base is biased positive with respect to the emitter.

The voltage between the collector and the emitter is denoted as V_{CE} and the voltage between the collector and the base is denoted as V_{CB}. Since collector is positive with respect to base and emitter the polarities are as shown in the Fig. 6.12.

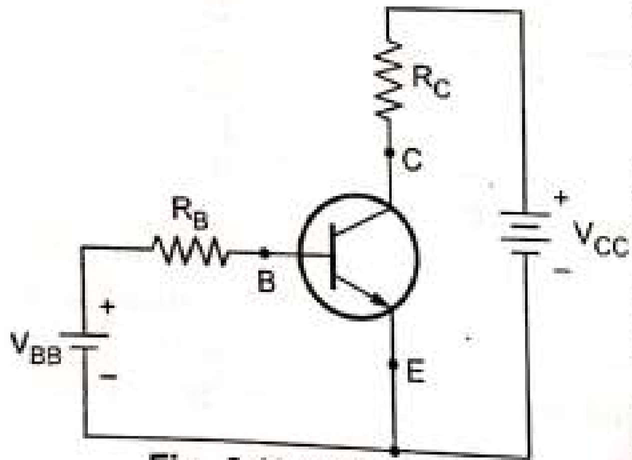


Fig. 6.13 Voltage source connections for npn transistor

The Fig. 6.13 shows the npn transistor with voltage source connections. The voltage sources are connected to the transistor with series resistors. These resistors are called **current limiting resistors**. The base supply voltage V_{BB} is connected via resistor R_B and the collector supply voltage, V_{CC} is connected via resistor R_C. The negative terminals of both the supply voltages are connected to emitter terminal of the transistor. To make CB junction reverse biased, the supply voltage V_{CC} is always much larger than supply voltage V_{BB}.

PNP Transistor

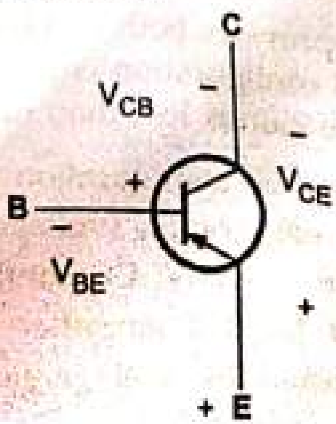


Fig. 6.14 pnp transistor voltages and polarities

The Fig. 6.14 shows the terminal voltages and its polarities for a pnp transistor. For a pnp transistor, the base is biased negative with respect to the emitter and the collector is made more negative than the base.

The Fig. 6.15 shows the pnp transistor with voltage source connections. Like npn transistor voltage sources are connected with series resistors. The source voltage positive terminals are connected at the emitter with V_{CC} larger than V_{BB} to keep collector-base junction reverse biased.

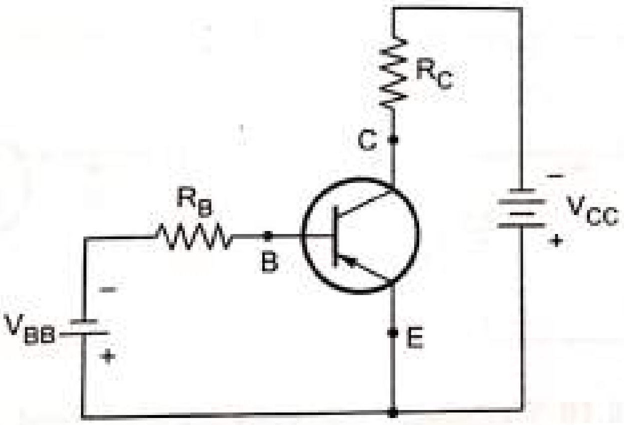


Fig. 6.15 Voltage source connection for pnp transistor

Junction voltages

In different conditions such as active, saturation and cutoff there are different junction voltages. The junction voltages for a typical npn transistor at 25 ℃ are given in the Table 6.1.

Type	$V_{CE\ sat}$	$V_{BE\ sat}$	$V_{BE\ active}$	$V_{BE\ cutin}$	$V_{BE\ cut\text{-}off}$
Si	0.2	0.8	0.7	0.5	0.0
Ge	0.1	0.3	0.2	0.1	− 0.1

Table 6.1 Typical npn transistor junction voltages at 25 °C

The entries in the table are appropriate for an npn transistor. For pnp transistor the signs of all entries should be reversed.

6.1.5.2 Transistor Currents

The directions of conventional currents in an npn transistor are as shown in Fig. 6.16 (a) and Fig. 6.16 (c) and those for a pnp are shown in Fig. 6.16 (b) and 6.16 (d). Figures show the conventional currents using the schematic symbols of npn and pnp transistors, respectively. It can be noticed that the arrow at the emitter of the transistor's symbol points in the direction of conventional current.

Let us consider pnp transistor. The current flowing into the emitter terminal is referred to as the emitter current and identified as I_E. The currents flowing out of the collector and base terminals are referred to as collector current and base current, respectively. The collector current is identified as I_C and base current as I_B.

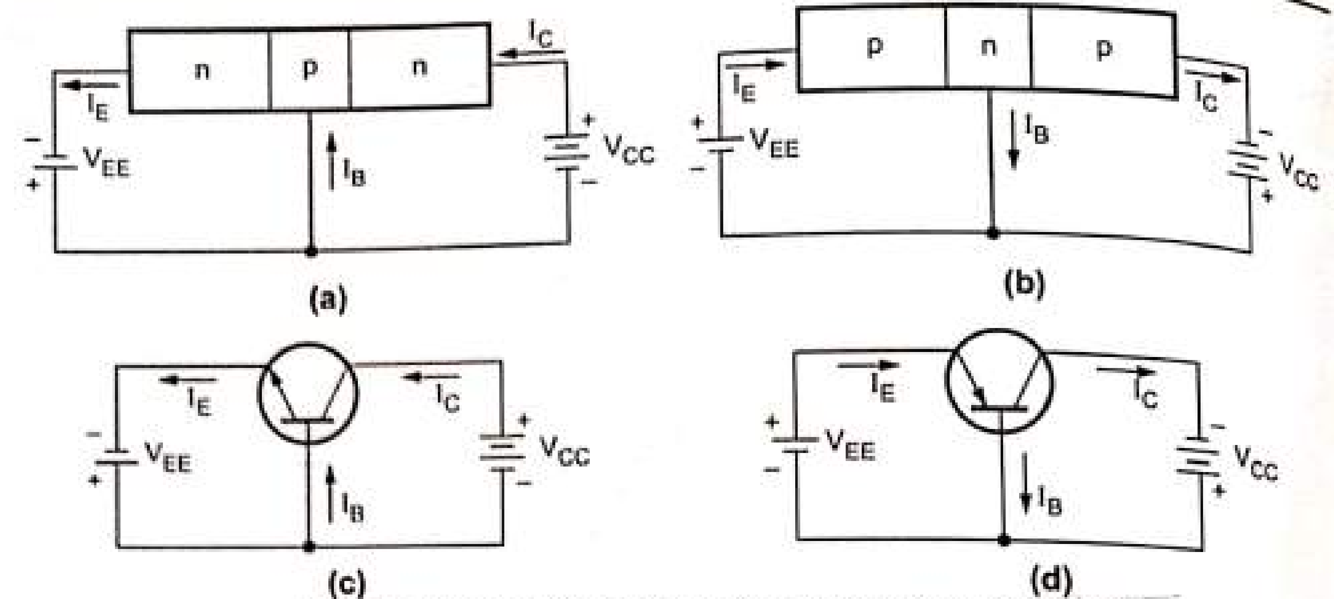


Fig. 6.16 Transistor conventional current directions

We have seen, for an n-p-n transistor, electrons are injected into the base. These electrons constitute the emitter current, I_E. For sake of explanation, assume that 100 electrons are injected into the base region. Since the base is very thin, very few of them, say 2 in number, recombine with holes. This constitutes the base current, I_B. The remaining electrons, 98 in this case, cross the base-collector reverse biased p-n junction and appear on the collector side, constituting the collector current I_C. Thus we see that the emitter current I_E is always equal to the sum of base and collector currents, I_B and I_C respectively. This is true for both types of transistor. Hence

$$I_E = I_B + I_C$$

Example 6.1 : *In a certain transistor, the emitter current is 1.02 times as large as the collector current. If the emitter current is 12 mA, find the base current.*

Solution : Given : $I_E = 12$ mA $\quad I_E = 1.02\, I_C$

$$\therefore \quad 1.02\, I_C = 12 \times 10^{-3}$$

$$I_C = 11.765 \text{ mA}$$

$$I_E = I_B + I_C$$

$$\therefore \quad I_B = I_E - I_C = (12 - 11.765) \text{ mA}$$

$$\therefore \quad I_B = 0.235 \text{ mA} = \mathbf{235\ \mu A}$$

6.1.5.3 Current Amplification Factors Alpha (α) and Beta (β)

- In transistor, the emitter current I_E is always equal to the sum of base and collector currents, I_B and I_C respectively. This is true for both types of transistor. Hence,

$$I_E = I_B + I_C$$

- α_{dc} : It is defined as the ratio of the collector current resulting from carrier injection to the total emitter current.

$$\therefore \quad \alpha_{dc} = \alpha = \frac{I_C}{I_E}$$

- Since $I_C < I_E$ the value of α_{dc} is always less than unity. It ranges from 0.95 to 0.995. It represents the current gain in the CB configuration.

- β_{dc} : It is defined as the ratio of the collector current to the base current.

$$\therefore \quad \beta_{dc} = \beta = \frac{I_C}{I_B}$$

6.1.5.4 Relationship between α and β

We know that, $\beta = \frac{I_C}{I_B}$

We have, $I_E = I_C + I_B$ i.e. $I_B = I_E - I_C$

$$\beta = \frac{I_C}{I_E - I_C} \qquad \because I_B = I_E - I_C$$

Dividing the numerator and denominator of R.H.S. of above equation by I_E, we get,

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

$$\therefore \quad \boxed{\beta = \frac{\alpha}{1-\alpha}} \qquad \because \alpha = \frac{I_C}{I_E}$$

We know that, $\alpha = \frac{I_C}{I_E}$ and $I_E = I_B + I_C$

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

Dividing the numerator and denominator of R.H.S. of above equation by I_B, we get,

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

$$\therefore \quad \boxed{\alpha = \frac{\beta}{1+\beta}} \qquad \because \beta = \frac{I_C}{I_B}$$

Example 6.2 : *a) Find α_{dc} for each of the following values of β_{dc} = 50 and 190.*
b) Find β_{dc} for each of the following values of α_{dc} = 0.995 and 0.9765.

Solution :

a) $\alpha_{dc} = \dfrac{\beta_{dc}}{1+\beta_{dc}}$

For $\beta_{dc} = 50$, $\alpha_{dc} = \dfrac{50}{1+50} = \mathbf{0.9804}$

For $\beta_{dc} = 190$, $\alpha_{dc} = \dfrac{190}{1+190} = \mathbf{0.9947}$

b) $\beta_{dc} = \dfrac{\alpha_{dc}}{1-\alpha_{dc}}$

For $\alpha_{dc} = 0.995$, $\beta_{dc} = \dfrac{0.995}{1-0.995} = \mathbf{199}$

For $\alpha_{dc} = 0.9765$, $\beta_{dc} = \dfrac{0.9765}{1-0.9765} = \mathbf{41.55}$

Example 6.3 : *If the base current in a transistor is 20 µA when the emitter current is 6.4 mA, what are the values of α_{dc} and β_{dc} ? Also calculate the collector current.*

Solution : Given : $I_B = 20\ \mu A$ $I_E = 6.4\ mA$

$$I_E = I_B + I_C = I_B + I_B\,\beta_{dc}$$

$$= I_B\,(1+\beta_{dc})$$

$$\beta_{dc}+1 = \frac{I_E}{I_B} = \frac{6.4\times10^{-3}}{20\times10^{-6}} = 320$$

$\therefore$ $$\beta_{dc} = \mathbf{319}$$

$$\alpha_{dc} = \frac{\beta_{dc}}{1+\beta_{dc}} = \frac{319}{1+319} = \mathbf{0.9968}$$

$$I_C = \beta_{dc}\,I_B = (319)\,(20\ \mu A) = 6380\ \mu A = \mathbf{6.38\ mA}$$

Also, $$I_C = \alpha_{dc}\,I_E = (0.9968)\,(6.4\ mA) = \mathbf{6.379\ mA}$$

Large-signal current gain α :

It is the ratio of the current due to injected carriers I_{pC} to the total emitter current I_E.

$$\alpha = \frac{I_{pC}}{I_E} = \frac{I_C - I_{CO}}{I_E}$$

$$\therefore \qquad I_C = \alpha I_E + I_{CO}$$

I_{CO} is very small and neglect. ... (5)

6.3 Transistor as an Amplifier

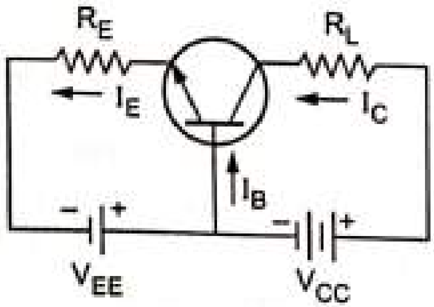


Fig. 6.18

Consider the transistor circuit shown in Fig. 6.18. Here, the load resistance R_L is in series with the collector supply voltage V_{CC}. For this circuit, a small voltage change ΔV_i between emitter and base causes a relatively large emitter-current change ΔI_E. The fraction of change in ΔI_E which is collected and passes through R_L is defined as α'. Therefore, the change in the output current is $\alpha\, \Delta I_E$ and the change in the output voltage across the load resistor $\Delta V_o = \alpha' R_L\, \Delta I_E$. The change in the input voltage ΔV_i can be represented in terms of dynamic resistance of emitter junction r'_e. It is given as,

$$\Delta V_i = r'_e \, \Delta I_E$$

Under these circumstances the voltage amplification (A) can be given as,

$$A = \frac{\Delta V_o}{\Delta V_i} = \frac{\alpha' R_L \Delta I_E}{r'_e \Delta I_E} = \frac{\alpha' R_L}{r'_e} \quad \text{... (1)}$$

The dynamic resistance of emitter junction r'_e is defined as V_T/I_E, where I_E is the quiescent emitter current. Considering $r'_e = 40\ \Omega$, $\alpha' = 1$ and $R_L = 2\ k\Omega$, $A = 50$. This calculation is in the simplified form, but in essence it is correct and gives the physical explanation of why the transistor acts as an amplifier. From the above discussion it is clear that current in the low-resistance input circuit is transferred to the high-impedance output circuit. The word "transistor", which originated as a contraction of "transfer resistor", is based upon the above explanation of device.

The parameter α' **:** The parameter α' mentioned above is defined as the ratio of change in the collector current to the change in the emitter current at constant collector-to-base voltage and is called the small-signal forward short-circuit current transfer ratio or gain

$$\alpha' = \left| \frac{\Delta I_C}{\Delta I_E} \right|_{V_{CB}}$$

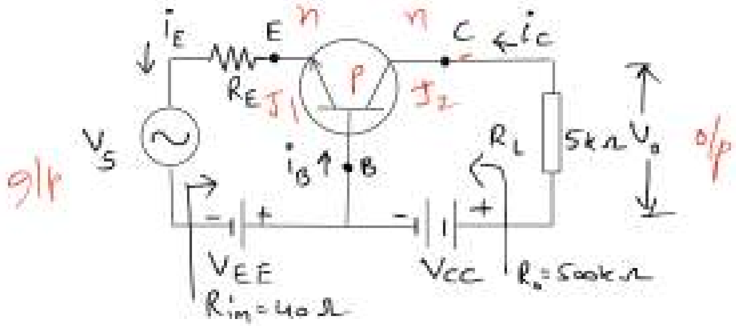
6.4 Characteristics of Transistor in Different Configurations

We have seen that base is taken as common point/terminal to connect transistor in common-base configuration. Similarly, we can use emitter and collector as a common points/terminals to connect transistor in common emitter and common collector configurations, respectively. Thus, the transistor can be connected in a circuit in the following three configurations.

1. Common base configuration.
2. Common emitter configuration.
3. Common collector configuration.

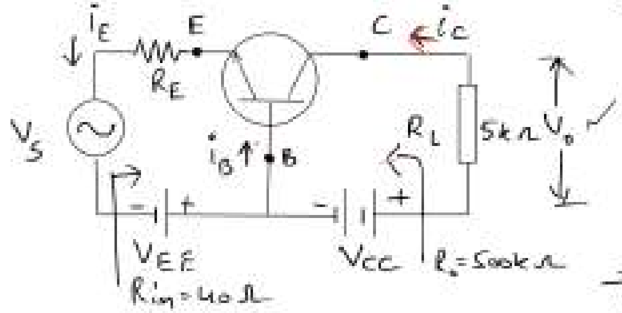
Key Point: *Regardless of circuit configuration, the base emitter junction is always forward biased while the collector-base junction is always reverse biased, to operate transistor in active region.*

Transistor as an amplifier :



V_{EE} forward biases the emitter junction
V_{CC} reverse biases the collector junction
$V_s \rightarrow$ signal source
$R_L \rightarrow$ load resistance $(5k\Omega)$

though a transistor can perform number of other functions its main use lies in amplifying electrical signals.
in the above diagram npn transistor is connected in C.B. configuration.
the transistor is biased to operate in active region.



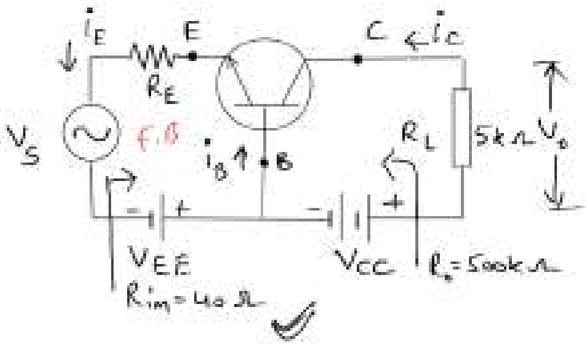
→ when the signal V_s is superimposed on the dc voltage V_{EE}, the emitter voltage V_{EB} varies with time.
So I_E also varies with time.

→ Since I_C is a function of I_E, a similar variation occurs in I_C.

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

this varying I_C passes through R_L develops varying voltage "V_o".

→ the output voltage V_o is many times greater than the input voltage "V_s".



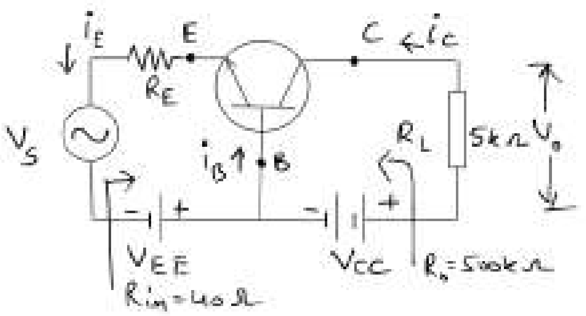
to understand how the signal voltage is magnified (amplified), let us consider how the transistor responds to ac signal.

→ Since the E.B Junction is F.Biased it offers very low Resistance to V_S

→ in C-B configuration R_i ranges from 20Ω to 100Ω.

→ the C-B Junction is R-biased offers high resistance.

R_o ranges from $100k\Omega$ to $1M\Omega$



→ assume that the $V_S = 20mV$ (rms)

if $R_{in} = 40\Omega$

$$I_E = \frac{20\times10^{-3}}{40} = 0.5mA$$

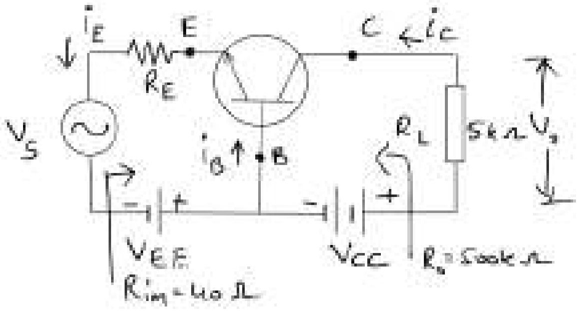
$\therefore I_C \simeq I_E \simeq 0.5mA$

$R_o = 500k\Omega$

$R_L = 5k\Omega$ (smaller compared to R_o)

almost all the current I_C passes through R_L.

$\therefore V_o = I_C \times R_L = 0.5mA \times 5k\Omega$
$= 2.5V$



The ratio of V_0 to input voltage V_s is known as the voltage amplification & voltage gain A_V.

$$A_V = \frac{V_0}{V_s} = \frac{2.5}{20\times10^{-3}} = 125$$

→ the transistor's amplifying action is basically due to its capability of transferring its signal current from a low resistance circuit to high resistance circuit.

Using the two terms transfer and resistor put together transistor

transfer + resistor → transistor.

Configuration of Transistor Circuit: CB, CE, CC configuration Input and Output Characteristics

A transistor is a three terminal device. But require ‘4‘terminals for connecting it in a circuits.(i.e.) 2 terminals for input, 2 terminals for output.

Hence one of the terminal is made common to the input and output circuits. Common terminal is grounded.

TYPES OF CONFIGURATIONS

Three types of configuration is available

1) Common base (CB) configuration
2) Common emitter (CE) configuration
3) Common collector (CC) configuration

1. COMMON BASE (CB) CONFIGURATION

In common base configuration circuit is shown in figure. Here base is grounded and it is used as the common terminal for both input and output.

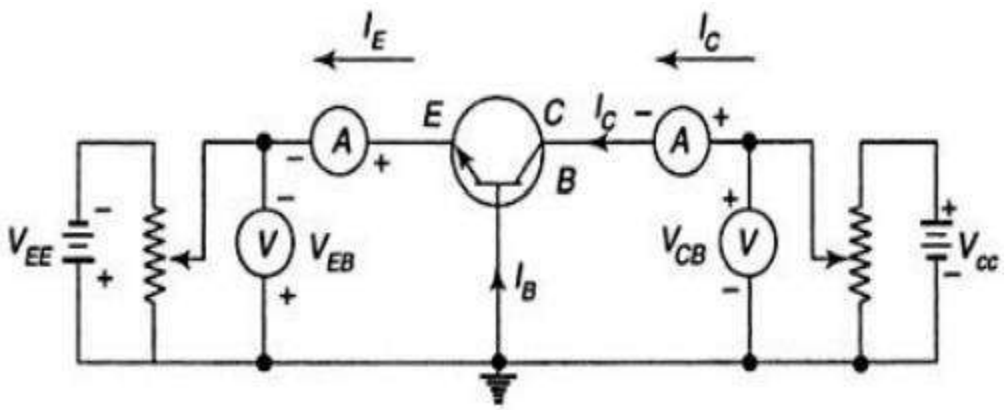


Figure 2.10 Circuit to determine CB static characteristics

It is also called as grounded base configuration. Emitter is used as a input terminal whereas collector is the output terminal.

CB Input characteristics:

It is defined as the characteristic curve drawn between input voltage to input current whereas output voltage is constant.

To determine input characteristics, the collector base voltage V_{CB} is kept constant at zero and emitter current I_E is increased from zero by increasing V_{EB}. This is repeated for higher fixed values of V_{CB}.

A curve is drawn between emitter current and emitter base voltage at constant collector base voltage is shown in figure 2.11.When V_{CB} is zero EB junctions is forward biased. So it behaves as a diode so that emitter current increases rapidly.

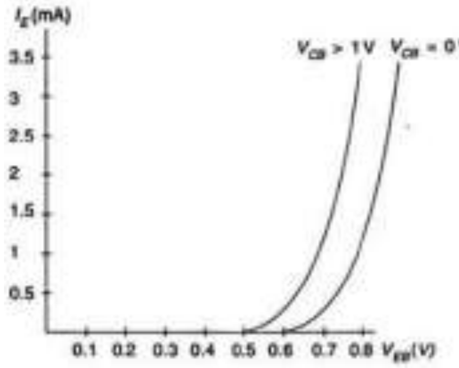


Figure 2.11 CB input characteristics

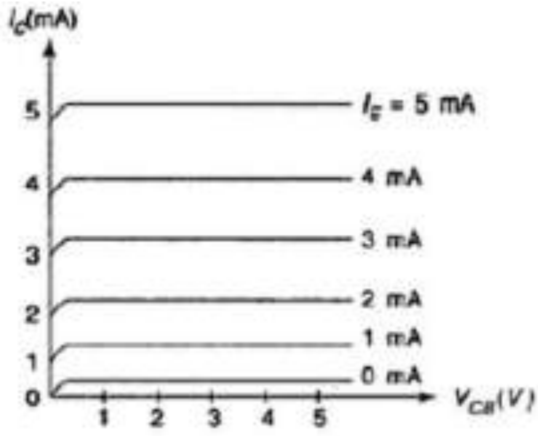


Figure 2.12 CB output characteristics

CB Output Characteristics

It is defined as the characteristic curve drawn between output voltage to output current whereas input current is constant. To determine output characteristics, the emitter current IE is kept constant at zero and collector current Ic is increased from zero by increasing V_{CB}.This is repeated for higher fixed values of I_E.

From the characteristic it is seen that for a constant value of I_E, Ic is independent of V_{CB} and the curves are parallel to the axis of V_{CB}.As the emitter base junction is forward biased the majority carriers that is electrons from the emitter region are injected into the base region.

In CB configuration a variation of the base-collector voltage results in a variation of the quasi- neutral width in the base. The gradient of the minority-carrier density in the base therefore changes, yielding an increased collector current as the collector-base current is increased. This effect is referred to as the Early effect.

---

2) COMMON EMITTER (CE) CONFIGURATION

In common emitter configuration circuit is shown in figure. Here emitter is grounded and it is used as the common terminal for both input and output. It is also called as grounded emitter configuration. Base is used as a input terminal whereas collector is the output terminal.

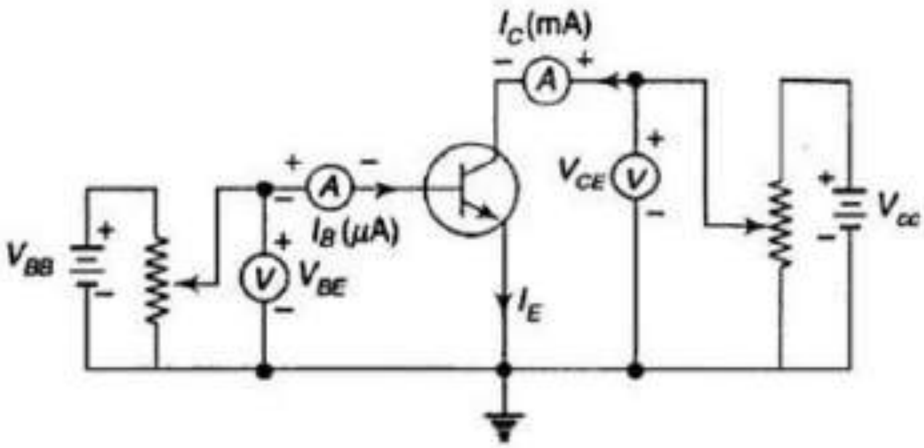


Figure 2.13 Circuit to determine CE static characteristics

Input Characteristics

It is defined as the characteristic curve drawn between input voltages to input current whereas output voltage is constant.

To determine input characteristics, the collector emitter voltage V_{CE} is kept constant at zero and base current I_B is increased from zero by increasing V_{BE}. This is repeated for higher fixed values of V_{CE}.

A curve is drawn between base current and base emitter voltage at constant collector emitter voltage is shown in figure2.14. Here the base width decreases. So curve moves right as V_{CE} increases.

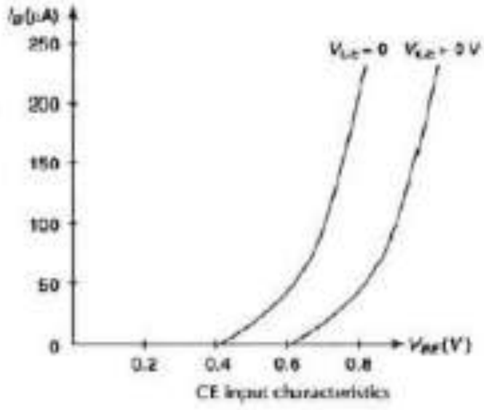


Figure 2.14 CE input characteristics

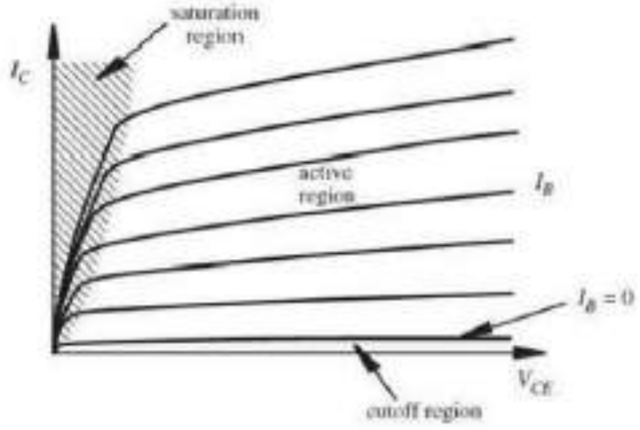


Figure 2.15 CE output Characteristics

Output Characteristics

It is defined as the characteristic curve drawn between output voltage to output current whereas input current is constant.

To determine output characteristics, the base current I_B is kept constant at zero and collector current I_C is increased from zero by increasing V_{CE}. This is repeated for higher fixed values of I_B.

From the characteristic it is seen that for a constant value of I_B, I_C is independent of V_{CE} and the curves are parallel to the axis of V_{CE}.

The output characteristic has 3 basic regions:

- Active region –defined by the biasing arrangements.
- Cutoff region – region where the collector current is 0A
- Saturation region- region of the characteristics to the left of VCB = 0V.

Active region	Saturation region	Cut-off region
□ I_E increased, I_C increased. □ BE junction forward bias and CB junction reverse bias. □ Refer to the graph, $I_C \approx I_E$ □ I_C not depends on V_{CB} □ Suitable region for the transistor working as amplifier.	□ BE and CB junction is forward bias □ Small changes in V_{CB} will cause big different to I_C □ The allocation for this region is to the left of V_{CB}=0V.	□ Region below the line of I_E=0 A □ BE and CB is reverse biase □ No current flow at collector, only leakage current.

3) Common collector (CC) configuration

In common collector configuration circuit is shown in figure. Here collector is grounded and it is used as the common terminal for both input and output. It is also called as grounded collector configuration. Base is used as a input terminal whereas emitter is the output terminal.

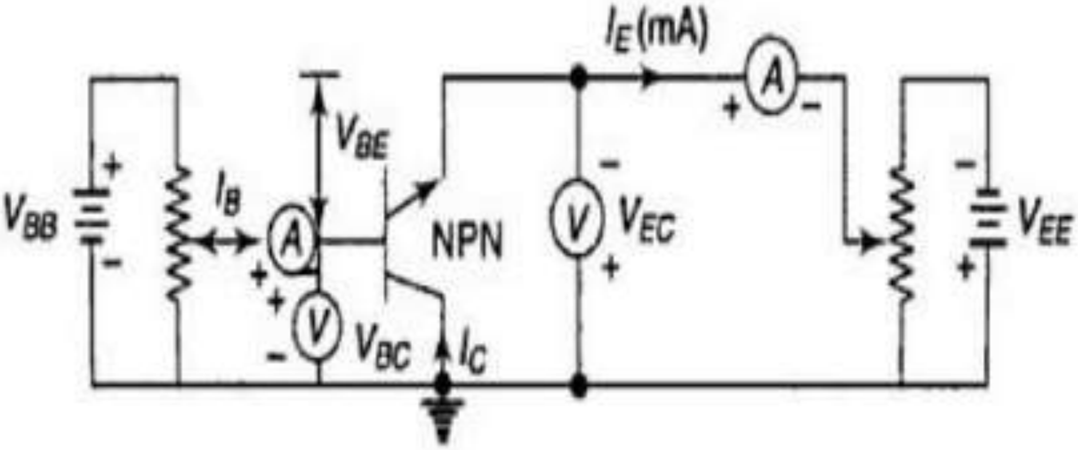


Figure 2.16 Circuits to determine CC static characteristics

Input Characteristics

It is defined as the characteristic curve drawn between input voltage to input current whereas output voltage is constant.

To determine input characteristics, the emitter collector voltage V_{EC} is kept constant at zero and base current I_B is increased from zero by increasing V_{BC}. This is repeated for higher fixed values of V_{CE}. A curve is drawn between base current and base collector voltage at constant collector emitter voltage is shown in figure2.17.

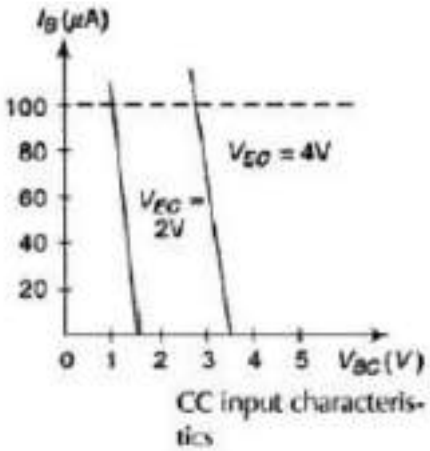


Figure 2.17 CC input characteristics

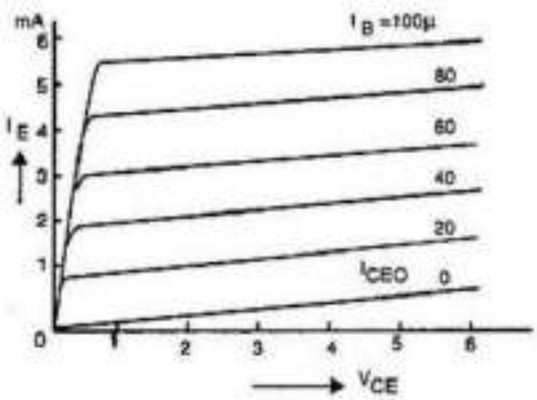


Figure 2.18 CC output characteristics

Output Characteristics

It is defined as the characteristic curve drawn between output voltage to output current whereas input current is constant.

To determine output characteristics, the base current I_B is kept constant at zero and emitter current I_E is increased from zero by increasing V_{EC}. This is repeated for higher fixed values of I_B.

From the characteristic it is seen that for a constant value of I_B, I_E is independent of V_{EC} and the curves are parallel to the axis of V_{EC}.

A comparison of CB, CE and CC Configurations

Property	*CB*	*CE*	*CC*
Input resistance	Low (about 100 Ω)	Moderate (about 750 Ω)	High (about 750 kΩ)
Output resistance	High (about 450 kΩ)	Moderate (about 45 kΩ)	Low (about 25 Ω)
Current gain	1	High	High
Voltage gain	About 150	About 500	Less than 1
Phase shift between input & output voltages	0 or 360°	180°	0 or 360°
Applications	for high frequency circuits	for audio frequency circuits	for impedance matching

Applications of Transistor

The transistor is a semiconductor device and its use to regulate the supply current or voltage. It can be used as a switch in electrical circuits and also use as an amplifier. So here we sort out the main applications of transistor for you.

Here we **list the applications of transistors. (Practical applications of transistors)**:

1. Transistors are used in digital and analog circuits as a switch.

2. uses in signal amplifier devices

3. Cellular phones would be one of the most widely used applications of transistors. Every cell phone uses a transistor amplifier.

4. uses in power regulator and controllers

5. in modern electronics IC uses in almost every electronics applications. Transistors are used in building some of the integrated circuits (IC).

6. The microprocessor includes more than billion of transistors in each chip.

7. Transistors are used in almost every electronics devices from stoves to computers and pacemakers to aircraft.

8. in calculators, computers, radios and also hearing phones every daily life device which requires good sound quality (because transistor are often used in amplifying circuits)

9. The military used the transistor's high-power radio frequency (RF) abilities in radar and hand-held two-way radios.

10. Darlington transistor pairs are often used in touch- and light-sensing devices.

11. Radiation – hardened transistor is often used in satellite and other aerospace applications.

Transistor use as a switch & as an amplifier:

In most of the applications, transistors are used as a switch in circuits. If the electronic circuit uses the transistor as a switch, then the biasing of the transistor either use PNP transistor or an NPN transistor that we must have to see. A transistor basically operated in three different modes,

an active region, saturation region, and cut-off region.

The transistor works as an amplifier in an active region only. The other two operating regions of transistor **Saturation Region** and the **Cut-off Region** were used to operate a transistor switch. Transistor is operated as a switch in only this two operating regions.