SUB - Analog Electronics & OPAMP

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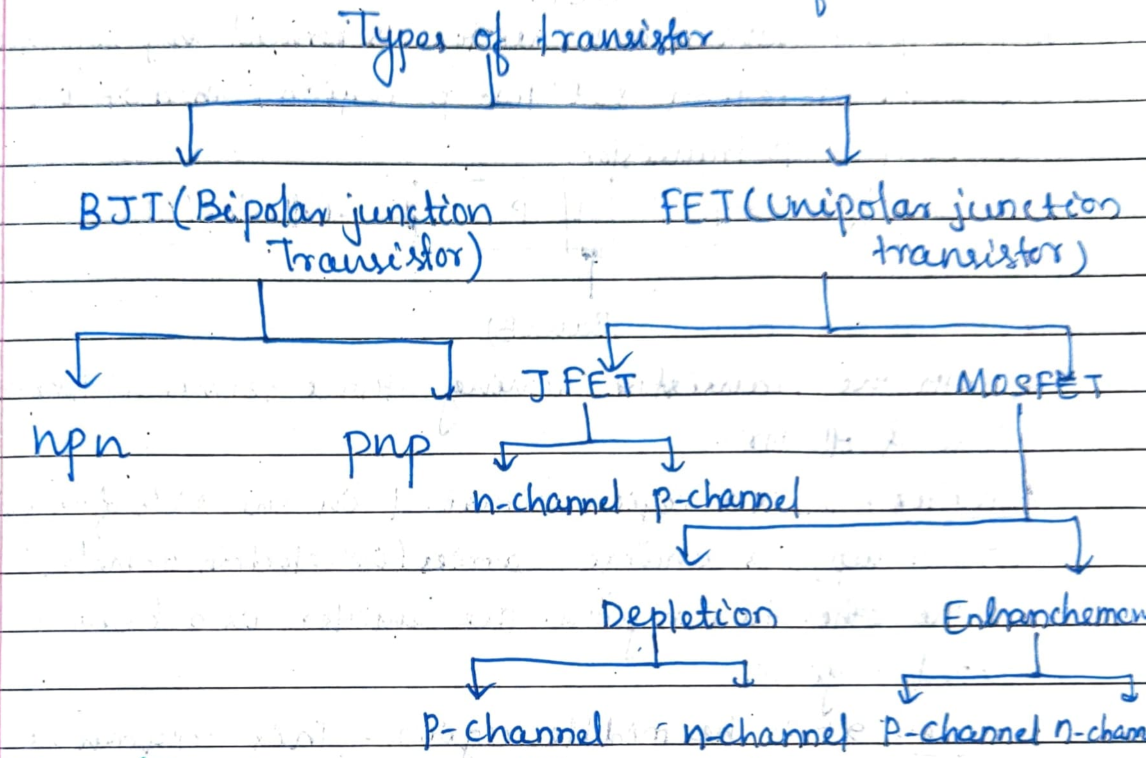
Transistors

* Transistor is a electronics device which are used for amplification of voltage as well as current.
* Amplification in transistor is achieved by passing input current signal from a region of low resistance to a region of high resistance. So this device is known as transistor (Transfer-resistor)

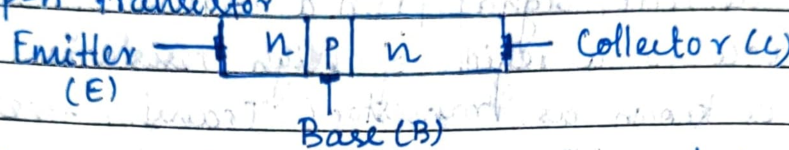


BJT (Bipolar Junction Transistor) :-

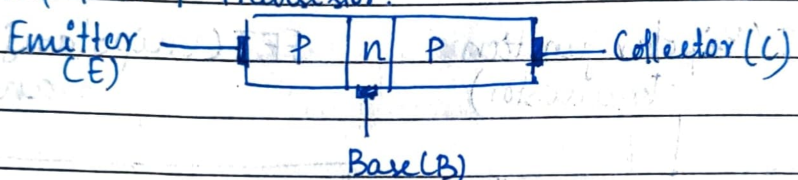
* Basically BJT is called a transistor. It is a three terminal, 3 layer and 2 junction device having the terminal Base, Emitter & Collector.
* It is operated in three configurations common base, Common Emitter & Common collector.
* BJT is called Bipolar Junction transistor because current conduction is due to both type of charge carries i.e. electrons and holes.
* BJT is also called current controlled device because the output current is controlled by input current.

Construction :-

* n-p-n :- when a transistor is formed by sandwiching a single p-region betn two n-region, then it is n-p-n transistor

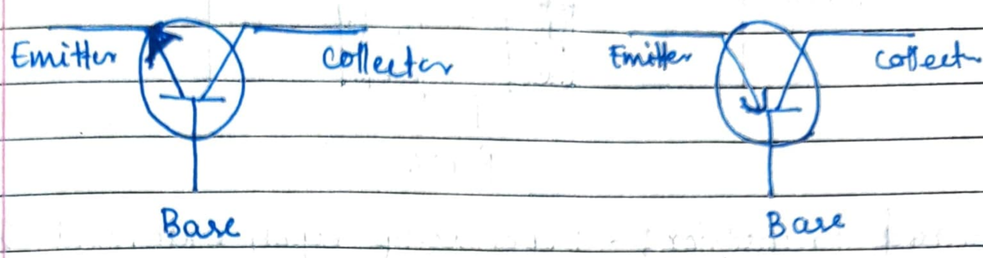


* P-n-p :- When a transistor is formed by sandwiching a single n-region betn two p-region, then it is called p-n-p transistor.



* Both the transistor having three terminal Emitter, Base & collector.
* Emitter : It is a region situated in one side of transistor which supplies charge carries (i.e. electron or holes) to the other two regions. The emitter is a heavily doped region.
* Base : It is the middle region. This region is thin & lightly doped.
* Collector : It is a region situated in the other side of transistor which collects charge carriers (i.e. electrons or holes). The collector of a transistor is always larger than the emitter and base of the transistor & doping level of collector is greather than base but lesser than emitter.
* Junction of transistor : Basically a transistor has two p-n junction. One junction in betn Emitter & Base and another junction in between Base & collector. Junction betn Emitter & Base are called Emitter Base junction & junction betn collector & Base are called collector-Base Junction.

Symbol :-



n-p-n

* The arrow mark indicates direction of conventional current.

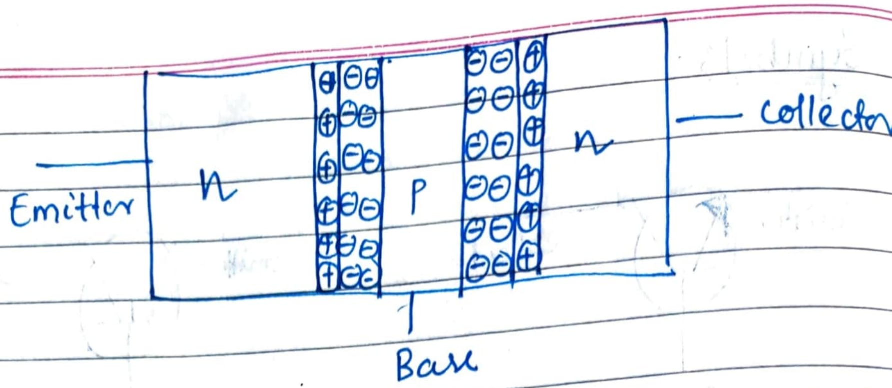
Transistor Operation :-

* The emitter-base junction of a transistor is forward biased where as collector-base junction is reverse biased

* ~~If~~

(c) Unbiased transistor :-

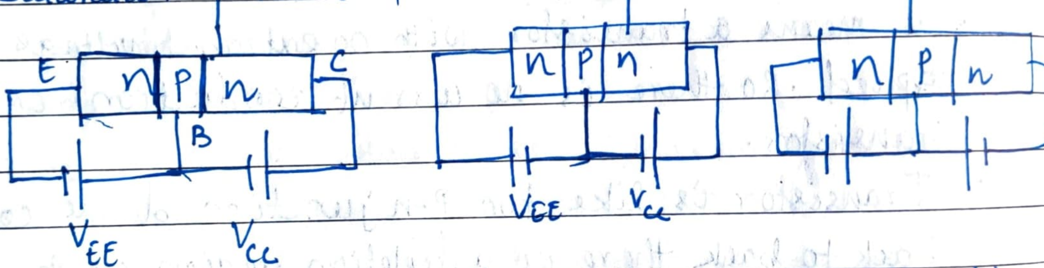
* It means a transistor with no external voltage is applied. So there is no current conduction in this transistor.
* Transistor is like two p-n junction diode connected back to back there is a depletion region at both the junction.
* During diffusion process, depletion region penetrate more deeply into light doped side.
* Depletion region at emitter junction penetrates less in heavily doped emitter and extended more in base region.
* Similarly depletion region at collector junction penetrates less in heavily doped collector and extends more in base region.
* Barrier potential also exists in transistor
* ~~The Bo~~



Biased transistor :- Depending upon external bias voltage polarities used, the transistor works in one of the three region - active region, cutoff region and saturation region.

Mode of operation :-

Region	Emitter-Base junction	collector base junction	Function
Active	Forward biased	Reverse biased	Amplifier
Cut off	Reverse biased	Reverse biased	OFF Switch
Saturation	Forward biased	Forward biased	ON Switch



Active region Cutoff Saturation

* Normally the transistor operate in active region. Due to supply voltage V_{EE} & V_{CC} make the transistor in active region.

operation of n-p-n transistor :-

* The base to emitter junction is forward bias by a dc source V_{EE}. So depletion ~~width~~ width at this junction is reduced. The collector to base junction is reverse biased by V_{CC} So depletion

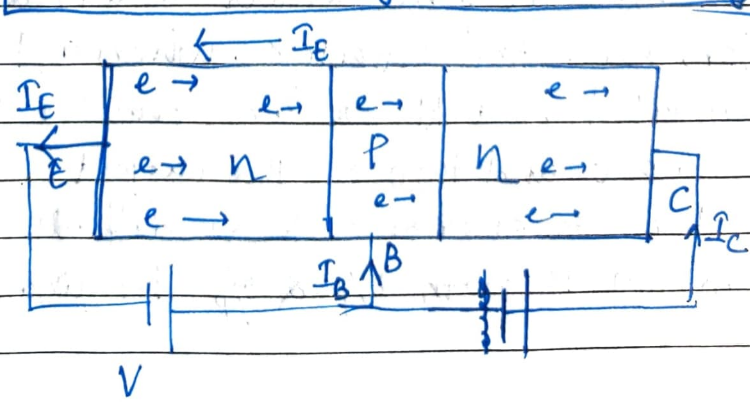
width at this junction is increased.

* The forward biased Emitter - Base (EB) junction causes electrons in the emitter to flow towards the base. This produces the emitter current I_E.
* At the free few electrons recombine with holes in p-region [base] due to lightly doping. Thus such recombination produce the base current I_B. The remaining large no of electrons crosses the base region and moves towards the collector region to Positive terminal of the external source. This produce the collector current I_C.
* Due to this electron flow constitude the current across the transistor ckt.
* The current relation of the transistor is given by $I_E = I_B + I_C$
* Since it is a bipolar device so current is flows due to both minority & majority carriers.

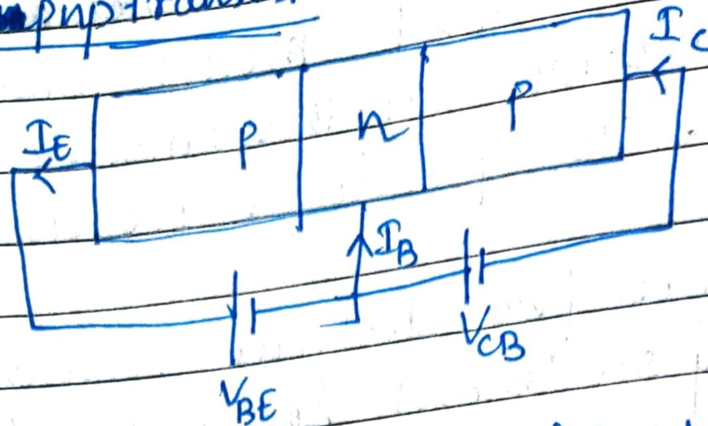
~~So total~~ The minority component is called the leakage current when input ckt is open and given by symbol I_{co}.

So total collector current

$$I_C = I_{C majority} + I_{C minority}$$

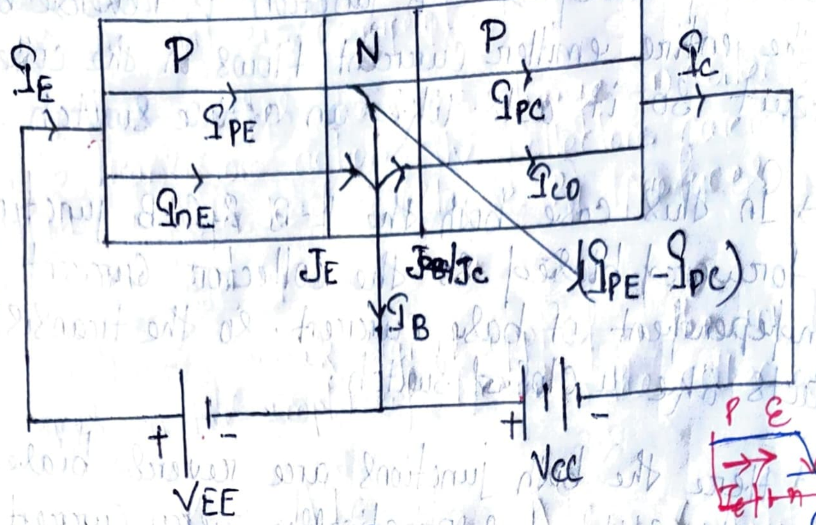


Operation of pnp transistor :-



* The pnp transistor with forward bias to emitter base junction and reverse bias to collector base junction.
* The forward bias causes the holes in the p-type emitter to flow towards the base. This constitutes the emitter current I_E.
* As the holes cross into n-type base, they tend to combine with the electron but due to the base is lightly doped ~~who~~ only 5% holes are recombine to form base current. The remaining (more than 9... cross the collector region constitute the collector current (I_C).
* There fore the current conduction of pnp is due to the holes.
* The input junction (i.e emitter-base junction) has low resistance due to forward bias and the output ckt has high resistance due to reverse bias.

Current Components in the transistor



→ Here the hole current I_{PE} constituted by holes. Electron current I_{nE} constituted by electrons.

∴ Total emitter current $\boxed{I_E = I_{PE} + I_{nE}}$

(I_{PE} → Majority, I_{nE} → Minority)

→ We know the doping of emitter region is made much heavier than base and hence the electron current component I_{nE} is negligible small in comparision with hole current I_{PE}.

→ A few ~~electron~~ of holes crossing the junction J_E combine with the electrons in N-type base and rest of them cross the collector junction J_C.

→ This reduces the no. of holes which ultimately reach the collector. To reduce the no. of holes so lost through recombination with electrons in N-region, the width of the base region is kept extremely small.

→ Let, I_{PC} = hole current in junction J_C

$I_{PE} - I_{PC}$ = difference combination current I_B

→ In fact, electrons enter the base region through the base lead to replenish those electrons which have been lost by recombination with the holes injected into the base across J_E.

→ The holes on reaching the collector junction cross this junction readily and enter the p-region of the collector.

→ If the emitter is open circuit then,
$I_E = 0$ i.e I_{pc} would be zero

→ Under this condition the base and collector together act as a reversed diode & the collector current I_c equals the reverse saturation current I_{co}.

→ I_{nco} caused by electrons moving across J_c from P region to N region;

→ I_{pco} caused by holes moving across J_c from N region to P-region

$$\Rightarrow I_{co} = I_{nco} + I_{pco} \quad \text{—— (ii)}$$

$$\Rightarrow I_c = I_{pc} + I_{co} \quad \text{—— (iii)}$$

$$\Rightarrow \boxed{I_E = I_B + I_C} \quad \text{—— (iv)}$$

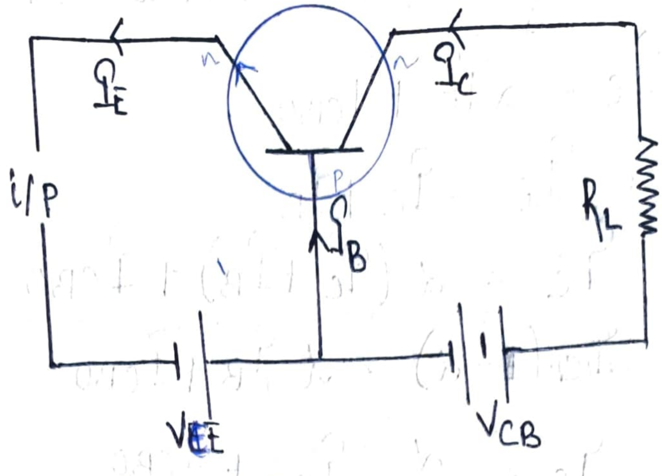
Transistor circuit Configuration & it's characteri

i. Common - Base config.
ii. Common - emitter config.
iii. Common - collector config.

i. Common - Base configuration :-

→ In this circuit arrangment, input is applied between the emitter base junction & output is taken from the collector - base.

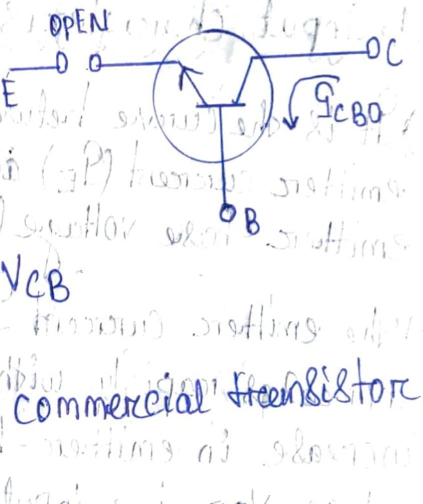
→ Here base of the transistor is common to bothe input and output of circuit so it is known as common - base configuration.



Current Amplification Factor :-

It is the ratio of change in collector current to the change in emitter current at constant collector base voltage V_{CB} is known as current amplification factor.

Current Amplification factor (α) → It is the ratio of output current to input current.



Input Current $= I_E$
Output Current $= I_C$

So, $\alpha = \dfrac{\Delta I_C}{\Delta I_E}$ at constant V_{CB}

→ Practical value of α in commercial transistor range from 0.9 to 0.99.

Expression for collector current :-

∴ The total collector current $I_C = \alpha I_E + I_{Leakage}$.

→ Here the leakage current is due to movment of minority carriers across base - collector junction due to reverse biased.

→ It is generally smaller than αI_E.

→ If the $I_E = 0$, a small leakage current still flow in the collector circuit.

→ So the leakage current is known as I_{CBO}.

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

Now, $I_E = I_C + I_B$

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

$$= \alpha I_C + \alpha I_B + I_{CBO}$$

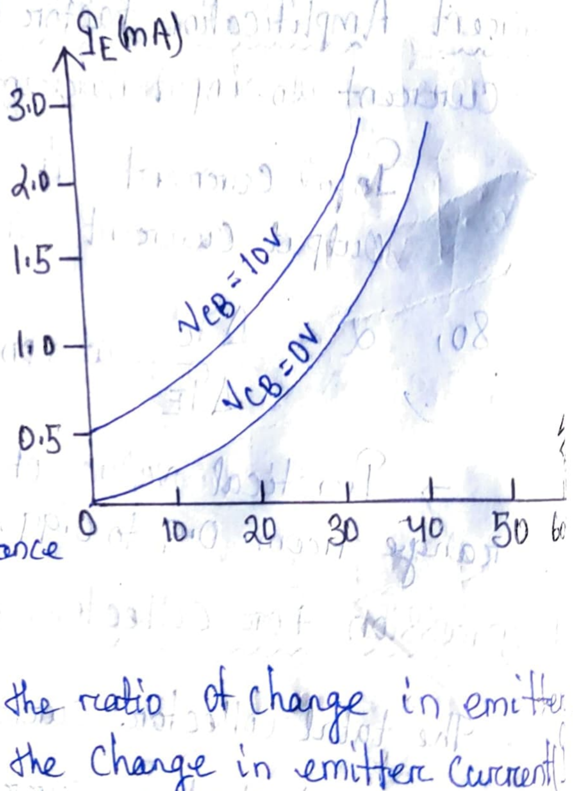
$$I_C (1 - \alpha) = \alpha I_B + I_{CBO}$$

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}$$

Characteristics of Common-Base Connection :-

→ It is the complete electrical behaviour of transistor current and voltage in graphical curve is known as characteristics of transistor.

1. Input characteristic :-



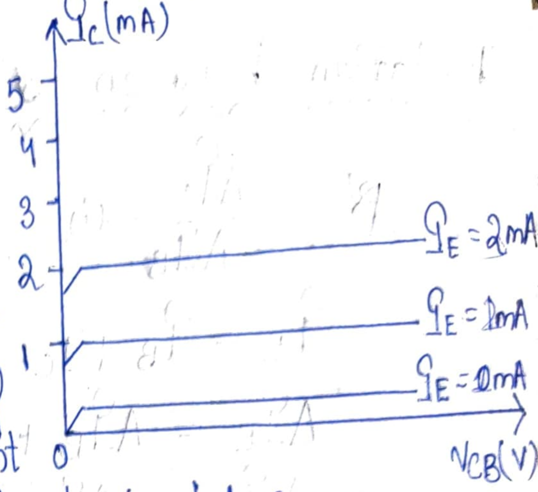
→ It is the curve between emitter current (I_E) and emitter-base voltage (V_{EB}).

→ The emitter current I_E increases rapidly with small increase in emitter-base voltage V_{EB} i.e input resistance is very small.

→ **Input Resistance** → It is the ratio of change in emitter-base voltage (ΔV_{EB}) to the change in emitter current (ΔI_E) at constant collector-base voltage (V_{CB}).

$$\therefore \boxed{r_i = \frac{\Delta V_{BE}}{\Delta I_E} \text{ at constant } V_{CB}}$$

2. Output Characteristics :- It is the curve betⁿ collector current (I_C) and collector-base voltage (V_{CB}) at constant emitter current (I_E).



→ The collector current I_C varies with V_{CB} only at very low voltage (<1V). The transistor is never operated in this region.

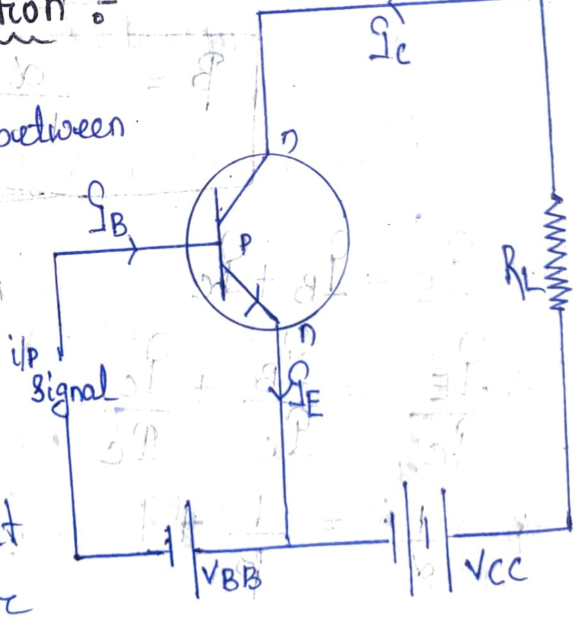
→ When the value of V_{CB} raised above 1-2 V, the collector current becomes constant as indicated by horizontal curve.

→ It means that now I_C is independent of V_{CB} and depend upon I_E only.

Output Resistance :- It is the ratio of change in collector-base voltage to the collector current.

$$\therefore r_o = \frac{\Delta V_{CB}}{\Delta I_C} \text{ at constant } I_E$$

Common Emitter Connection :-



→ Here the input is applied between base emitter and output is taken from collector emitter junction.

→ Here emitter of the transistor is common to both input and output ~~so~~ hence it is known as Common emitter connection.

Base Current Amplification factor (β) → It is the ration of change in collector current to base current (I_B).

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

Relation between α and β :-

$$\beta = \frac{\Delta I_C}{\Delta I_B} \quad \text{—(i)} \qquad \alpha = \frac{\Delta I_C}{\Delta I_E} \quad \text{—(ii)}$$

$$I_E = I_B + I_C$$

$$\Delta I_E = \Delta I_B + \Delta I_C$$

$$\Delta I_B = \Delta I_E - \Delta I_C$$

Substituting the value of ΔI_B in eq (i)

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

Dividing ΔI_E in both numerator and denominator

$$\beta = \frac{\Delta I_C / \Delta I_E}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} = \frac{\alpha}{1-\alpha} \quad \left[\because \alpha = \frac{\Delta I_C}{\Delta I_E}\right]$$

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

OR, $I_E = I_B + I_C$

$$\Rightarrow \frac{I_E}{I_C} = \frac{I_B}{I_C} + \frac{I_C}{I_C}$$

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

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

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

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

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

Expression for collector current :

We know,

$$I_E = I_B + I_C \quad \text{---- (i)}$$

$$I_C = \alpha I_E + I_{CBO} \quad \text{---- (ii)}$$

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

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO} \quad \text{---- (iii)}$$

If the value of $I_B = 0$, then

$$I_{CEO} = \frac{1}{1-\alpha} I_{CBO}$$

Substituting the value of $I_{CEO} = \frac{1}{1-\alpha} I_{CBO}$ in eq(iii)

$$I_C = \frac{\alpha}{1-\alpha} I_B + I_{CEO}$$

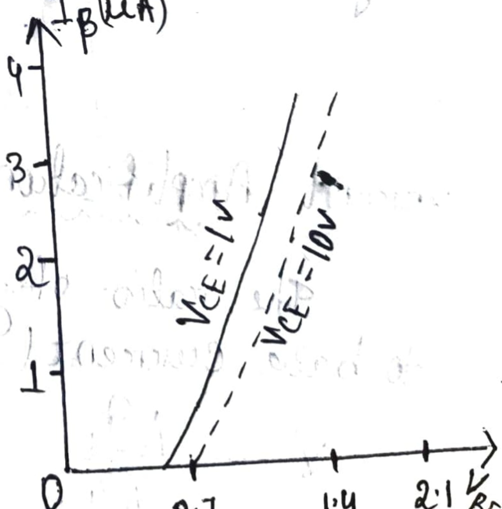
OR

$$I_C = \beta I_B + I_{CEO} \quad \left(\because \beta = \frac{\alpha}{1-\alpha}\right)$$

Characteristics of Common Emitter Connection :

1. Input characteristic → It is the curve between base current I_B and base emitter voltage V_{BE} at constant collector emitter voltage V_{CE}

→ Input resistance of a CE circuit is higher than of CB circuit.

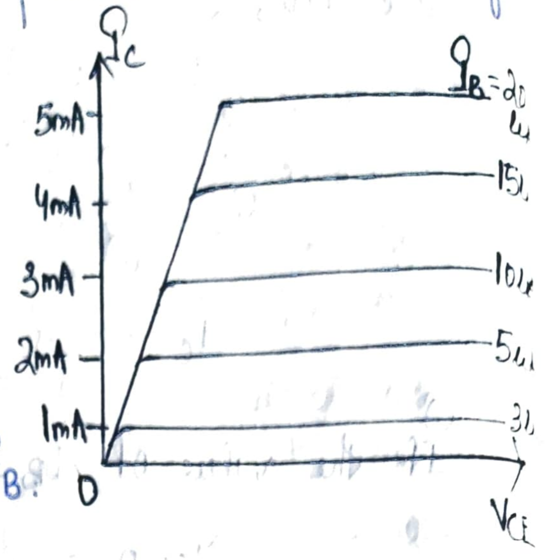


Input Resistance :

It is the ratio of change in base-emitter voltage to base current, at constant V_{CE}.

$$\therefore r_i = \frac{\Delta V_{BE}}{\Delta I_B} \text{ at constant } V_{CE}$$

Output characteristic → It is the curve between collector current I_C and collector emitter voltage V_{CE} at constant I_B.



Output Resistance :-

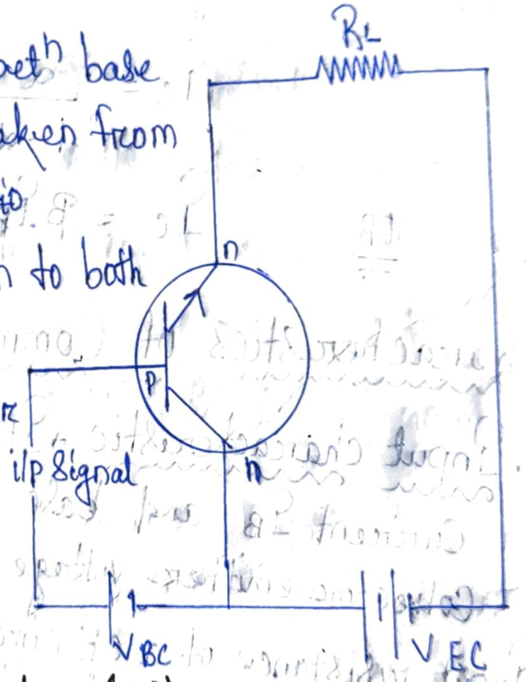
→ It is the ratio of change in collector-emitter voltage to collector current.

$$\therefore r_o = \frac{\Delta V_{CE}}{\Delta I_C} \text{ at constant } I_B$$

Common Collector Connection :-

→ Here input is applied in betn base and collector and o/p is taken from the emitter collector. ~~junctio~~

→ Here collector is common to both i/p and o/p of circuit so it's name is common collector configuration.



Current Amplification factor (γ) :-

The ratio of change in emitter current (I_E) to base current (I_B).

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

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

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

So, $\gamma = \beta + 1$

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

$= \dfrac{\alpha + 1 - \alpha}{1-\alpha} \Rightarrow \gamma = \dfrac{1}{1-\alpha}$

Expression for Collector Current :-

$$I_C = \alpha I_E + I_{CBO}$$

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

$$\Rightarrow I_E(1-\alpha) = I_B + I_{CBO}$$

$$\Rightarrow I_E = \frac{I_B}{1-\alpha} + \frac{I_{CBO}}{1-\alpha}$$

$$\Rightarrow I_E = \frac{1}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO}$$

$$I_C \simeq I_E = \gamma I_B + \gamma I_{CBO}$$

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

Application :- This circuit has very high i/p resistance and very low o/p resistance. Due to this reason it is used for impedance matching.