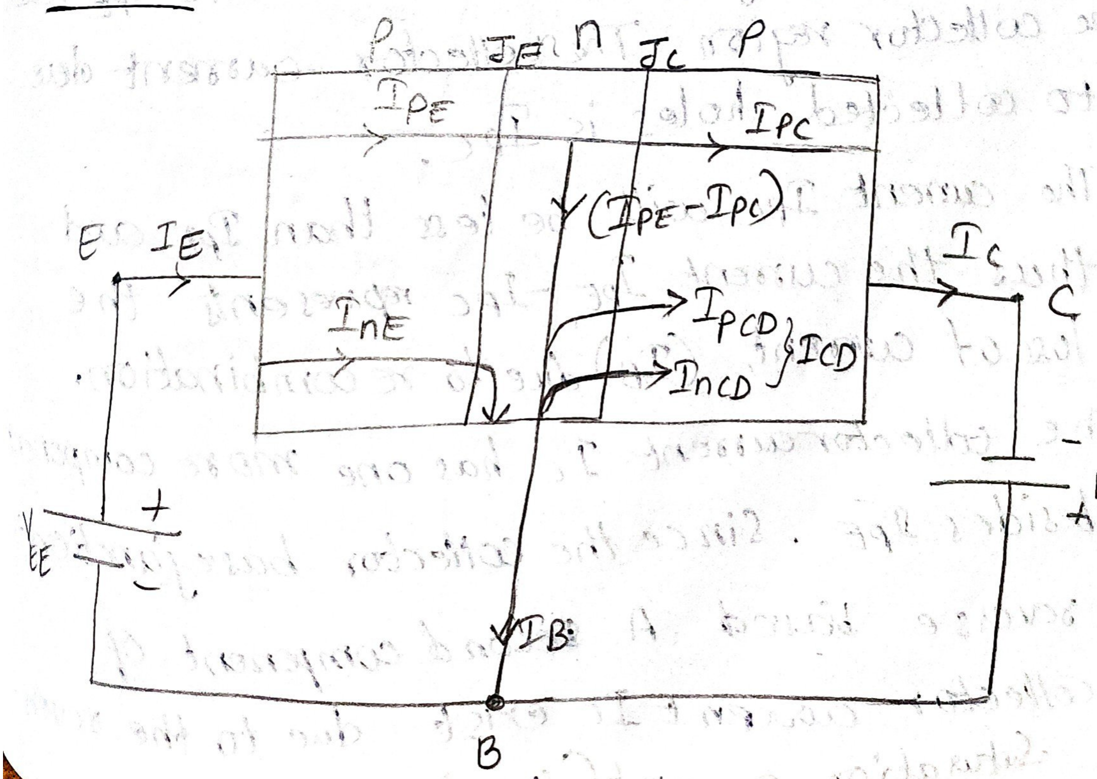
→ Transistors are widely used in digital logic circuits and switching applications, in these applications the voltage levels periodically alternate between a low and high voltage such as 0V & 5V

→ In switching applications the transistor operates in either cutoff region (or) saturation region. Consider it to be connected in CE (common emitter) configuration.

→ when the input is high [5V] base current flows and hence transistor is operated in saturation region. In this situation transistor acts as a closed switch.

→ when the input is low the base & collector current is 0. Hence transistor is operated in cutoff region and acts as an open switch.

## Transistor Current Components: (Mid)



* Consider a pnp transistor in which emitter base junction is forward biased and but collector base junction is reverse biased.

* The emitter current $I_E$ has 2 currents

i, Hole injected current ($I_{PE}$) due to holes crossing from emitter to base.

ii, Electron injected current ($I_{nE}$) due to electrons injected from base to emitter.

* Since the emitter region is heavily doped compare to base region, the hole current $I_{PE}$ is always much larger compare to e⊖ current $I_{nE}$ the total emitter current $I_E$ is $I_{PE}+I_{nE}$ → (1)

* Since the base region is very thin and has very low doping level only a few of injected holes of $I_{PE}$ are last due to recombination. Thus most of injected holes in current $I_{PE}$ reach the collector region. The collector current due to collected holes is $I_{PC}$.

* The current $I_{PC}$ will be less than $I_{PE}$ and thus the current $I_{PE}-I_{PC}$ represents the loss of current ($I_B$) due to recombination.

* The collector current $I_C$ has one more component besides $I_{PE}$. Since the collector base junction is reverse biased. A second component of collector current $I_C$ exist due to the reverse saturation current ($I_{CO}$).

* The thermally generated holes in base region move to collector region and constitute a current component ($I_{pco}$). Similarly thermally generated $e^{\ominus}$ in collector region moves to base region and constitute a current component $I_{nco}$. ∴

∴ The total Reverse saturation current.

$$I_{CO} = I_{pCO} + I_{nCO} \rightarrow (2)$$

* So, the total collector current $I_C = I_{pC} + I_{CO} \rightarrow (3)$
* As, a standard convention all the currents entering into the transistor are taken to be +ve.
* The current flowing out is taken as -ve. Hence, In a pnp transistor $I_E$ is positive & $I_C$ and $I_B$ are -ve

** Emitter injection ratio: The ratio of whole current to the total emitter current is known as emitter injection ratio.

$$\gamma = \frac{I_{pE}}{I_E}$$

Typically, $\gamma = 0.995$

Base Transportation factor: The ratio of injected carrier current at collector junction to the injected carrier current at emitted junction is known as Base transportation factor. Denoted by 'β''.

$$\beta' = \frac{I_{pC}}{I_{pE}}$$ Typically, $\beta' = 0.995$

<u>Current Gain</u>: The large signal current gain '$\alpha$', is defined as $\boxed{I_C = \alpha I_E}$

Since $I_C$ is always less than $I_E$, $\alpha$ has a less value less than unity ranging from 0.90 to 0.995

from eqn ③ $I_C = I_{pC} + I_{CO}$

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

$$\alpha I_E = I_C - I_O$$

$$\boxed{\alpha = \frac{I_C - I_O}{I_E}}$$

<u>Transistor Equation</u>:

* In active region of the transistor, the emitter is forward biased and collector is reverse biased. The Generalized expression for the collector current $I_C$ for collector junction voltage $V_C$ and Emitter current $I_E$.

$$\boxed{I_C = \alpha I_E + I_{CO}(1 - e^{V_C/V_T})} \rightarrow ①$$

* If $V_C$ is -ve and $|V_C|$ is very large compared with $V_T$. The above eqn reduces the

$$\boxed{I_C = \alpha I_E + I_{CO}} \rightarrow ②$$

We KT, $I_E = I_B + I_C$

sub $I_E$ value in eq ②

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

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

$I_C - \alpha I_C = \alpha I_B + I_{CO}$

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

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

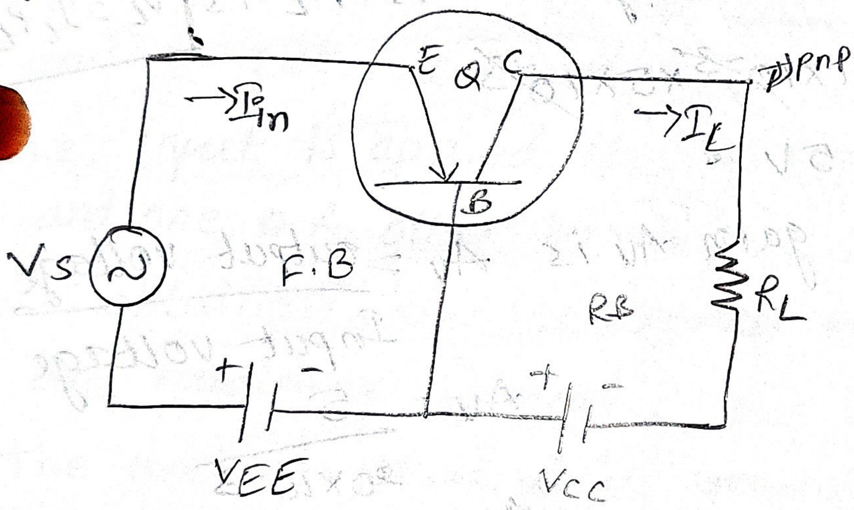
$$I_C = \frac{\alpha I_B}{1-\alpha} + \frac{I_{CO}}{1-\alpha}$$

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

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

Increasing the signal strength in terms of i, v is called Amplification

## Transistor as an Amplifier:




* Consider a pnp transistor in active region of operation the AC signal source ($V_s$) which is to be amplified is connected at input circuit.
* The load Resistor $R_L$ is connected in output circuit and amplifier o/p is taken across $R_L$
* The emitter base junction is forward biased hence the input resistance $R_i$ of circuit is small, the order 10Ω to 100Ω only.
* The collector base junction is reverse biased hence the output resistance $R_o$ of circuit is very high the order of 50kΩ to 1MΩ

* The amplifying action of a transistor can be explained by taking a simple example assume $R_i = 20\,\Omega$, $R_o = 100\,k\Omega$, $V_s = 20\,mV$, $R_L = 5\,k\Omega$

Input current $I_{in} = \frac{V_s}{R_i} = \frac{20 \times 10^{-3} V}{20} = 1\,mv.$

We.KT $I_L \simeq I_{in}\,\alpha$

* In a transistor $\alpha$ is always equal to '1'

$\therefore\ I_L = I_{in}$

* The output voltage across $R_L$ is $V_L = I_L R_L$

$V_L = 1 \times 10^{-3} \times 5 \times 10^{+3}$

$V_L = 5V$

* The voltage gain Av is $A_V = \frac{\text{output voltage}}{\text{Input voltage}}$

$A_V = \frac{5}{20 \times 10^{-3}}$

$A_V = \frac{5 \times 10^{3}}{20}$

$A_V = 2.5 \times 10^{2}$

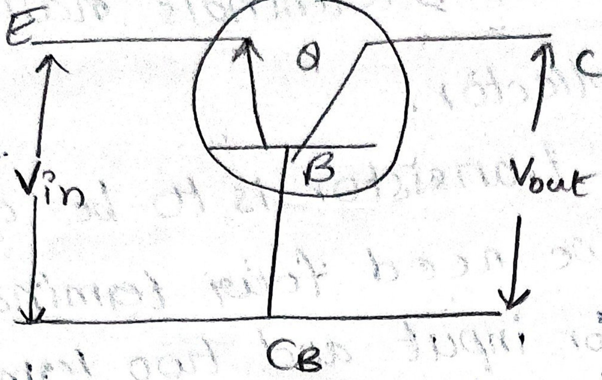
$A_V = 250\,V$

* Thus, the input voltage is amplified by 250 times.
* BJT's can be well used for amplification of small AC signals. This is possible because the input circuit has low resistance and output circuit has high "

# Transistor Configuration

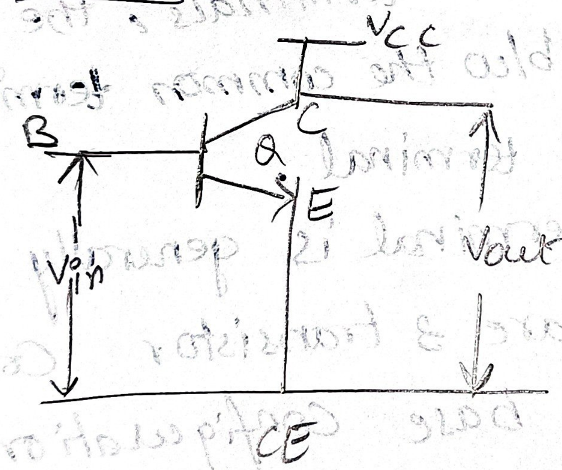
* A transistor has 3 terminals namely emitter, base and collector.
* But when a transistor is to be connected in circuit we need four terminals, two terminals for input and two terminals for output.
* This difficulty is overcome by making one terminal of transistor to both input and output terminals.
* The input is applied b/w the common terminal and one of other terminals, the output is obtained b/w the common terminal and remaining terminal.
* The common terminal is generally grounded. Hence there are 3 transistor Configurations
  1) Common base configuration
  2) " emitter "
  3) " Collector "
* In all configuration the emitter junction is forward biased and collector junction is reverse biased, is called Active region.

Common Base Confi...



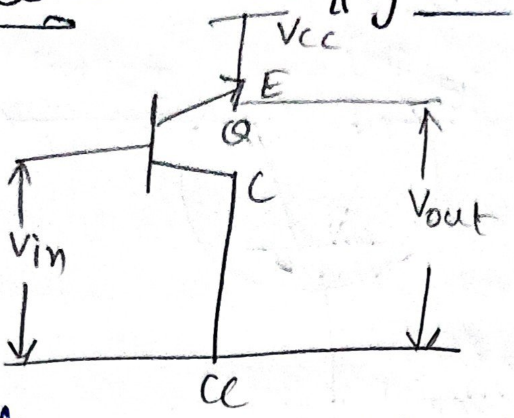

* In CB conf.. the transistor is connected with a base as common terminal the input is applied b/w base and emitter terminals and the output is taken between the collector and base terminals.

Common emitter confi...




* In CE confi... the transistor is connected with a emitter a common terminal the input is applied b/w the base and emitter terminals and the o/p is taken b/w collector & Emitter terminals.

## Common Collector configuration

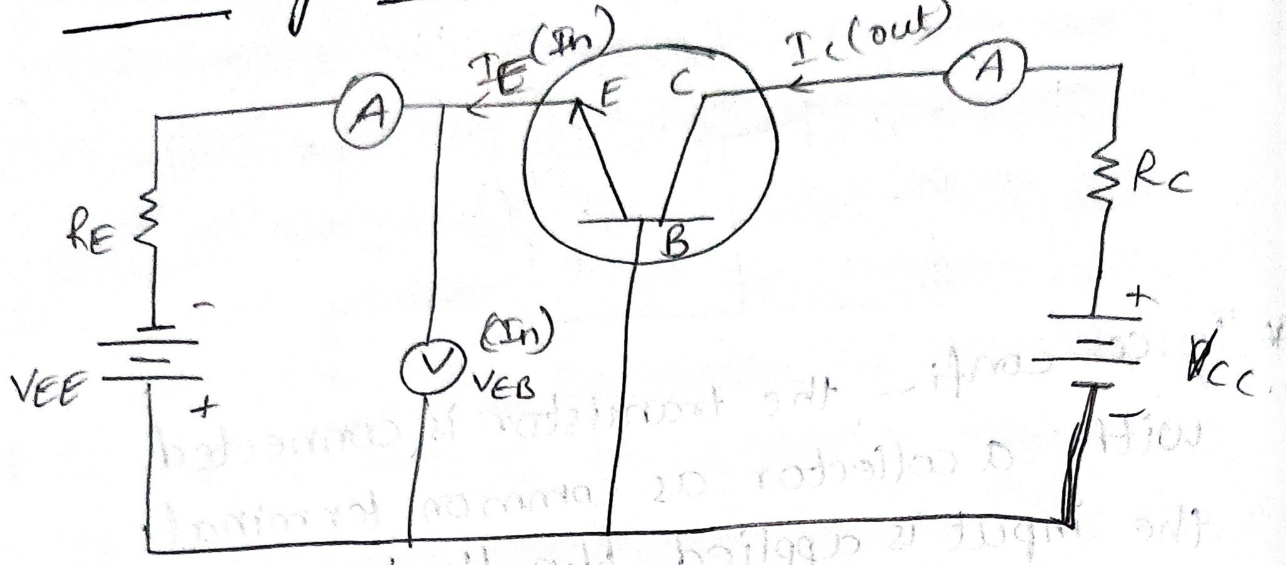



* In CC confi.. the transistor is connected with a collector as common terminal the input is applied b/w the base and collector terminals and o/p is taken b/w the collector and emitter terminals.

Transistor characteristics:

* Def: Many details about a transistor can be studied with help of curves which relate the transistor current and voltages.
* These curves are known as static chara... curves.
* The two sets of characteristics which completely describe the static operation of the transistor are input characteristics and output chara...
* The input chara... are plotted between the input voltage and input current at constant output voltage.
* The output chara.... are plotted between the output voltage and output current at constant input current.

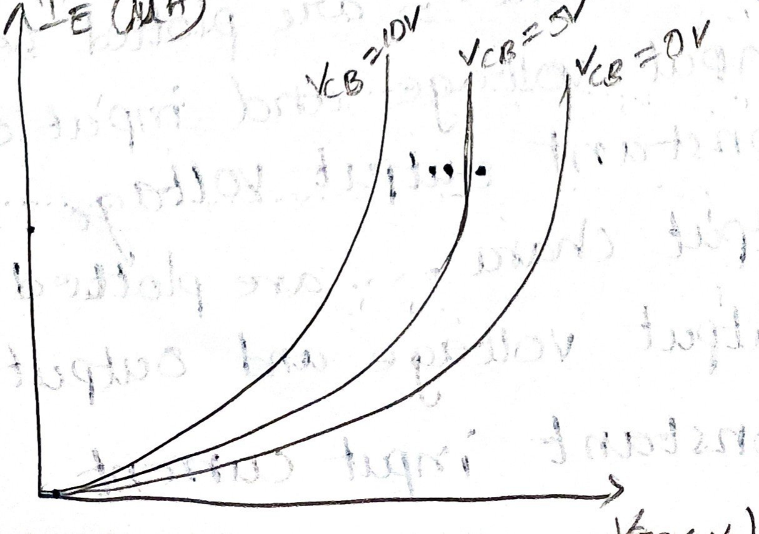
CB Configuration:




Input characteristics:

* The input characteristics in CB configuration are plotted between the input voltage that is '$V_{EB}$' and input current i.e, '$I_E$'. For constant output voltage i.e., '$V_{CB}$'

* When $V_{CB} = 0$, the output circuit will not be present and since the emitter base junction is forward biased, the transistor behaves as a forward biase diode. So, the emitter current increases exponentially.

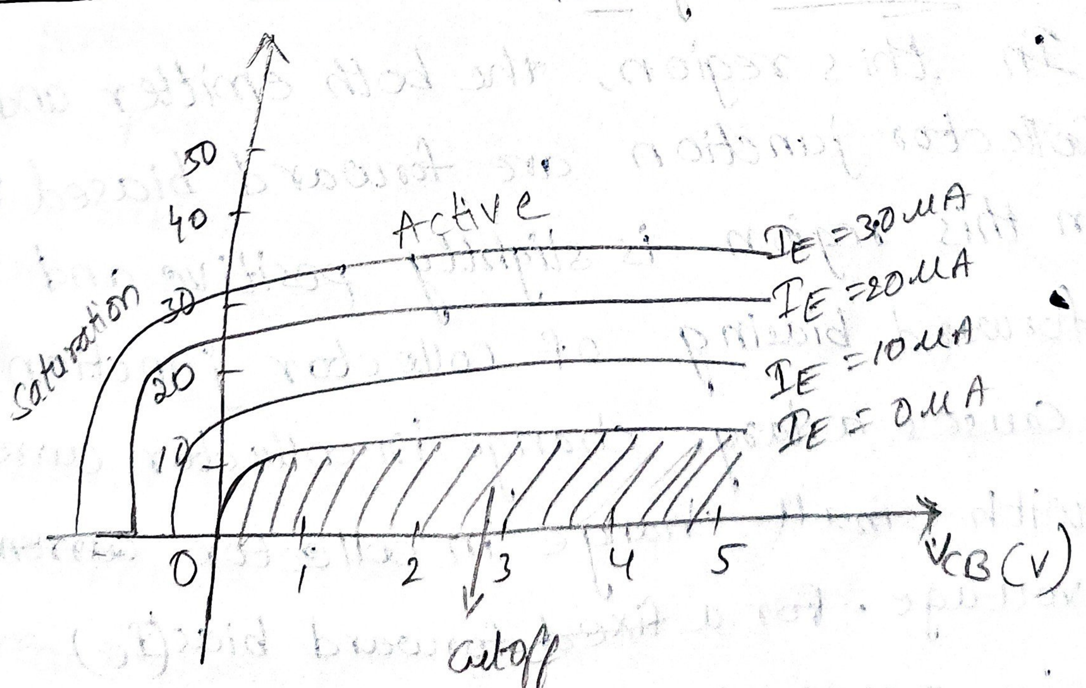


* when $V_{CB}$ is increased for higher fixed values the width of base region decreases and thus emitter current further increases. Thus, the curve shifts towards the left.

## Early Effect (or) basewidth modulation:

* When the applied reverse voltage increases The width of depletion region at collector junction increases.
* The depletion region Penetrates deeper into the base region thus the effective base width decreases.
* The dependency of base width on collector to base voltage is known as early effect (or) Basewidth modulation.

## Output characteristics:



* The CB output characteristics are plotted between output voltage that is collector base voltage and output current i.e, Collector current '$I_C$'. For, constant input current that is emitter current.

* The output characteristics of transistor is done in three operating regions.

1. Active Region:

In this region, the emitter junction is forward biased and the collector junction is reverse biased. For $V_{CB} \geq 0$, the characteristics are essentially flat i.e $I_C$ is independent of $V_{CB}$. In this region. $I_C \simeq I_E$ and $\alpha = 1$

2. Saturation region:

In this region, the both emitter and Collector junction are forward biased $V_{CB}$ in this region is slightly positive and forward biasing of collector junction causes a large change in collector current with small change in collector ~~current~~ voltage. For a ~~fixed~~ forward bias($I_C$) increases exponentially with voltage.

3) Cut-off region:

In this region, the both emitter and collector junction are reverse biased. Hence the collector current $I_c$ flows even when the emitter current $I_E = 0$. This is due to the collector leakage current '$I_{CO}$'. This region is below and to the right of $I_E = 0$ characteristic curve.

Punch through (or) reach through

According to early effect, the width of depletion region at collector junction decreases with increasing the collector junction voltage.

* As $V_{CB}$ increases, the depletion region penetrates deeper into the base, At the particular level of $V_{CB}$ the effective base width is equal to 0 as result the emitter and collector are effectively shorted. This causes large increasing emitter current result in breakdown such breakdown is called as punch through (or) reach through.