Bipolar Junction Transistors

- The transistor is a three-layer semiconductor device consisting of either two n- and one p-type layers of material or two p- and one n-type layers of material.
- The former is called an npn transistor, while the latter is called a pnp transistor
- So, there are two types of BJT-

  i) pnp transistor   ii) npn transistor

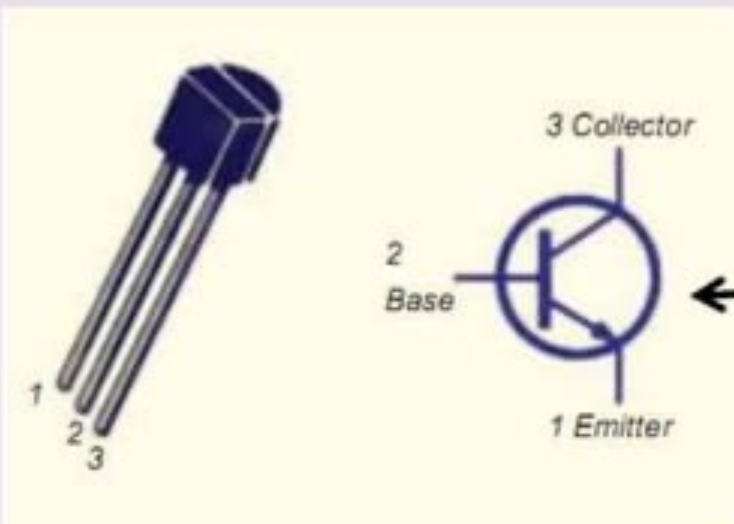
Bipolar Junction Transistors

In each transistor following points to be noted-

i) There are two junction, so transistor can be considered as two diode connected back to back.
ii) There are three terminals.
iii) The middle section is thin than other.

Naming of Transistor Terminals

- Transistor has three section of doped semiconductor.
- The section one side is called “emitter” and the opposite side is called “collector”.
- The middle section is called “base”.



Transistor symbol

Naming of Transistor Terminals

1) *Emitter:*

→ The section of one side that supplies carriers is called emitter.

→ Emitter is always forward biased wr to base so it can supply carrier.

→ For "npn transistor" emitter supply holes to its junction.

→ For "pnp transistor" emitter supply electrons to its junction.

Naming of Transistor Terminals

2) Collector:

→The section on the other side that collects carrier is called collector.

→ The collector is always reversed biased wr to base.

→For "npn transistor" collector receives holes to its junction.

→ For "pnp transistor" collector receives electrons to its junction.

Naming of Transistor Terminals

3) Base:

→The middle section which forms two pn junction between emitter and collector is called Base.

Some important factors to be remembered-

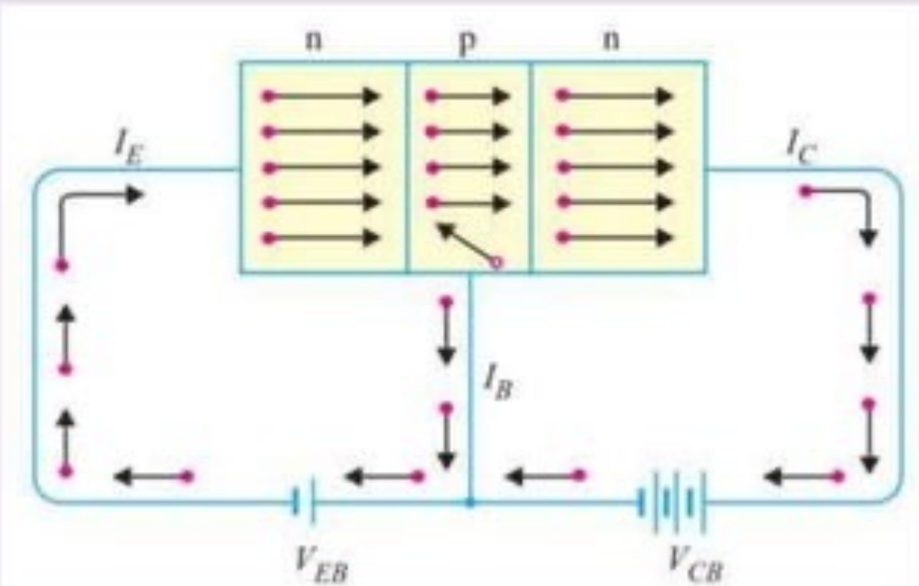
- The transistor has three region named emitter, base and collector.
- The Base is much thinner than other region.
- Emitter is heavily doped so it can inject large amount of carriers into the base.
- Base is lightly doped so it can pass most of the carrier to the collector.
- Collector is moderately doped.

Some important factors to be remembered-

- The junction between emitter and base is called emitter-base junction(emitter diode) and junction between base and collector is called collector-base junction(collector diode).
- The emitter diode is always forward biased and collector diode is reverse biased.
- The resistance of emitter diode is very small(forward) and resistance of collector diode is high(reverse).

Transistor Operation

1) Working of npn transistor:



✓ Forward bias Is applied to emitter-base junction and reverse bias is applied to collector-base junction.

✓The forward bias in the emitter-base junction causes electrons to move toward base. This constitute emitter current, I_E

Transistor Operation

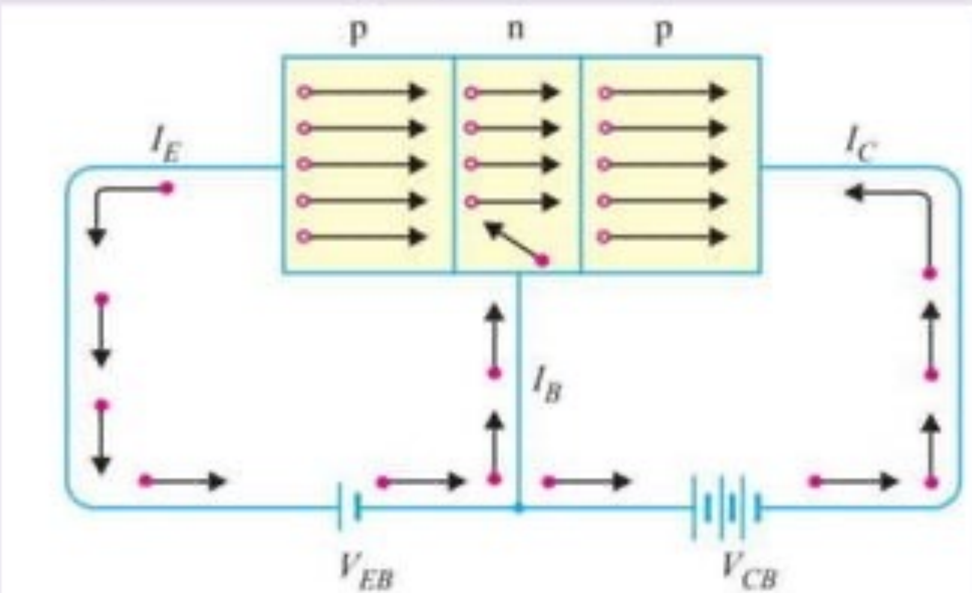
1) Working of npn transistor:

- ✓ As this electrons flow toward p-type base, they try to recombine with holes. As base is lightly doped only few electrons recombine with holes within the base.
- ✓ These recombined electrons constitute small base current.
- ✓ The remainder electrons crosses base and constitute collector current.

$$I_E = I_B + I_C$$

Transistor Operation

2) Working of pnp transistor:



✓ Forward bias is applied to emitter-base junction and reverse bias is applied to collector-base junction.

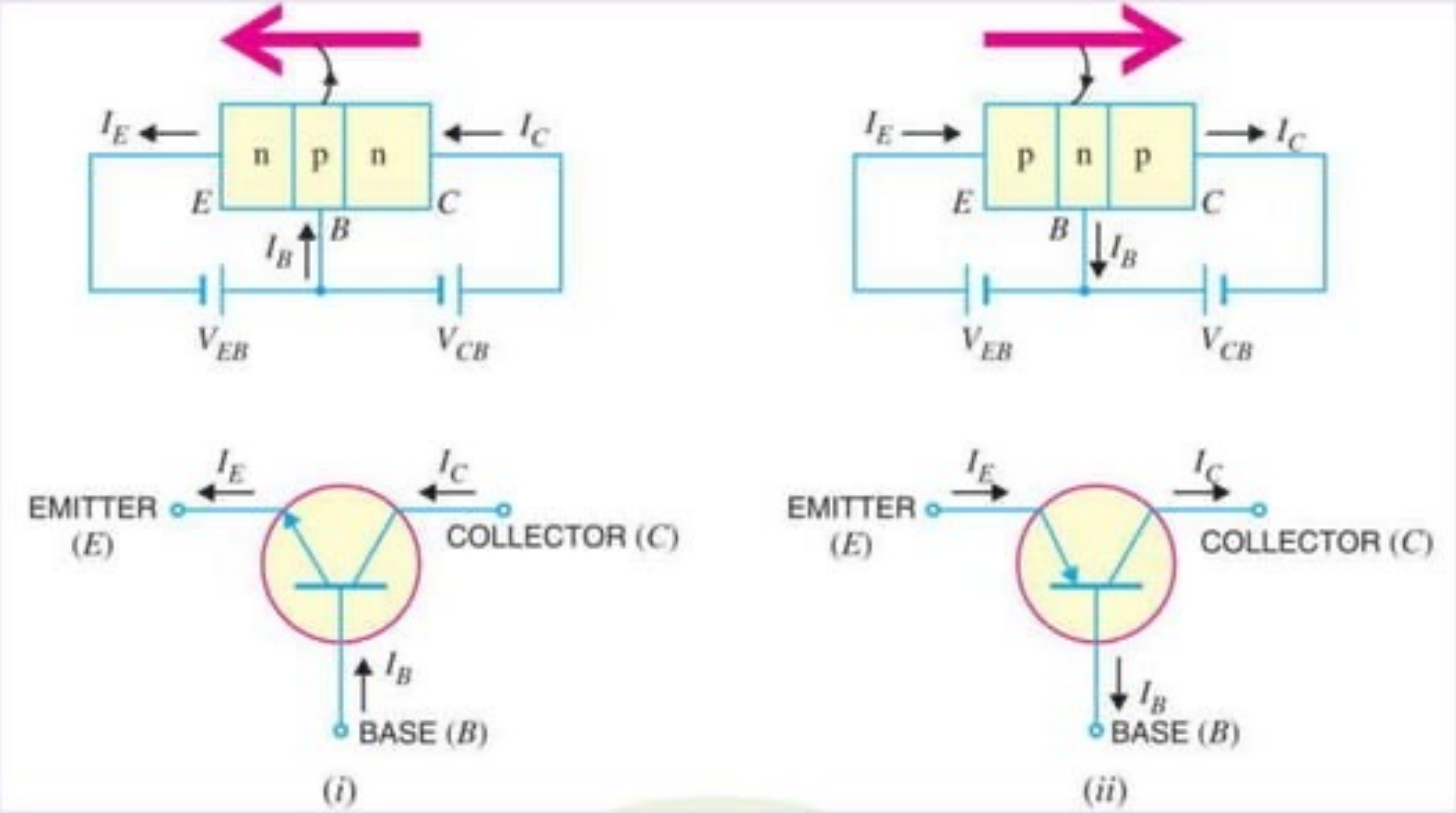
✓The forward bias in the emitter-base junction causes holes to move toward base. This constitute emitter current, I_E

Transistor Operation

2) Working of pnp transistor:

- ✓ As this holes flow toward n-type base, they try to recombine with electrons. As base is lightly doped only few holes recombine with electrons within the base.
- ✓ These recombined holes constitute small base current.
- ✓ The remainder holes crosses base and constitute collector current.

Transistor Symbol



Transistor Operating Modes

- Active Mode

  → Base- Emitter junction is forward and Base-Collector junction is reverse biased.
- Saturation Mode

  → Base- Emitter junction is forward and Base-Collector junction is forward biased.
- Cut-off Mode

  → Both junctions are reverse biased.

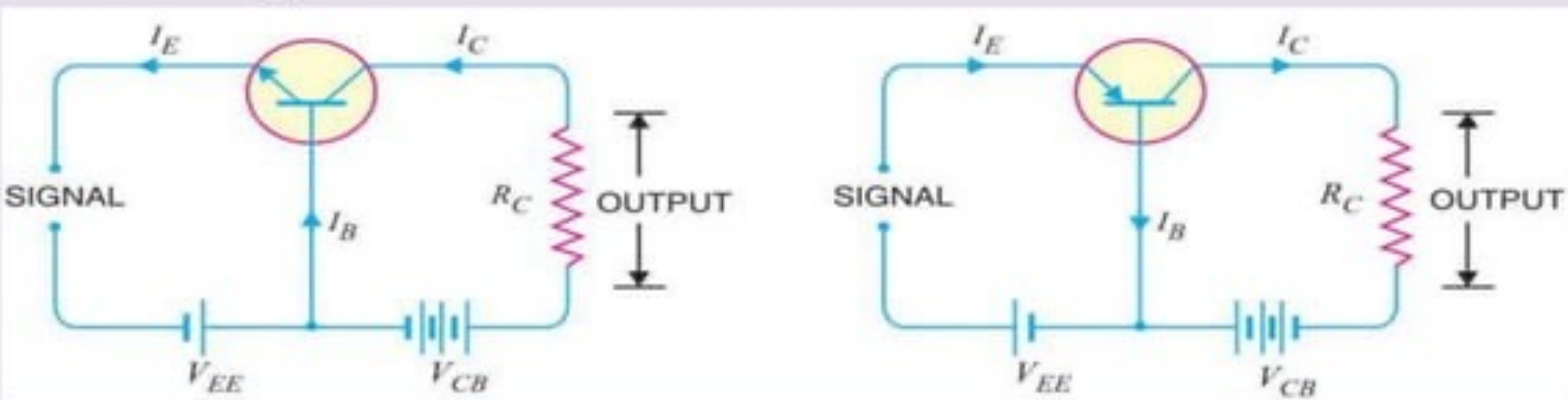
Transistor Connection

- Transistor can be connected in a circuit in following three ways-

1) Common Base
2) Common Emitter
3) Common Collector

Common Base Connection

- The common-base terminology is derived from the fact that the base is common to both the input and output sides of the configuration.



- First Figure shows common base npn configuration and second figure shows common base pnp configuration.

Common Base Connection

- <u>Current amplification factor (α) :</u>

  The ratio of change in collector current to the change in emitter current at constant V_{CB} is known as current amplification factor, α.

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \; at \text{ constant } V_{CB}$$

→ Practical value of α is less than unity, but in the range of 0.9 to 0.99

Expression for Collector Current

→Total emitter current does not reach the collector terminal, because a small portion of it constitute base current. So,

$$I_E = I_C + I_B$$

→Also, collector diode is reverse biased, so very few minority carrier passes the collector-base junction which actually constitute leakage current, I_{CBO}.

→ So, collector current constitute of portion of emitter current αI_E and leakage current I_{CBO}.

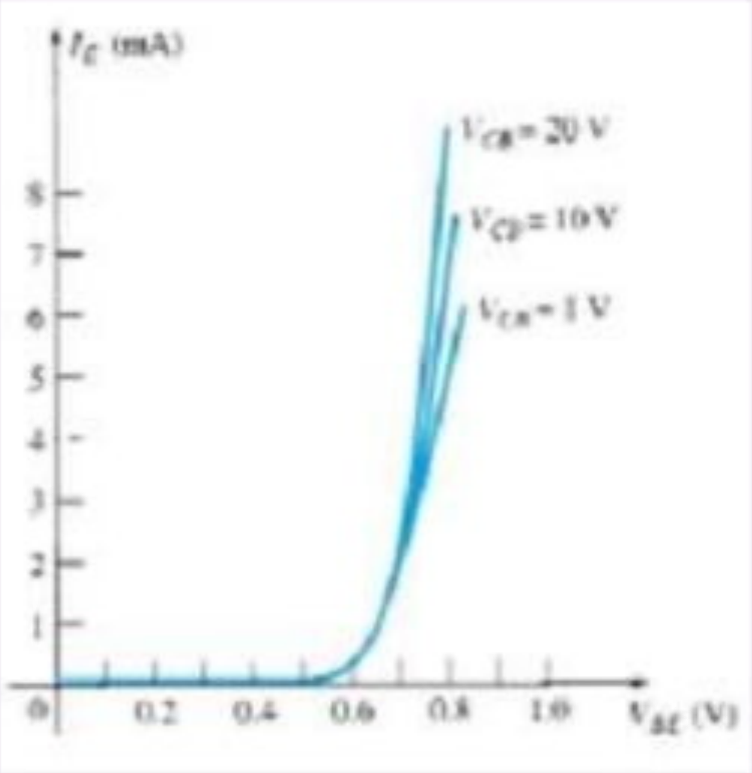
$$I_C = \alpha I_E + I_{CB0}$$

Expression for Collector Current

$$
\begin{aligned}
I_C &= \alpha\,(I_C + I_B) + I_{CBO} \\
I_C\,(1-\alpha) &= \alpha\, I_B + I_{CBO} \\
I_C &= \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}
\end{aligned}
$$

Characteristics of common base configuration

- <u>Input Characteristics:</u>



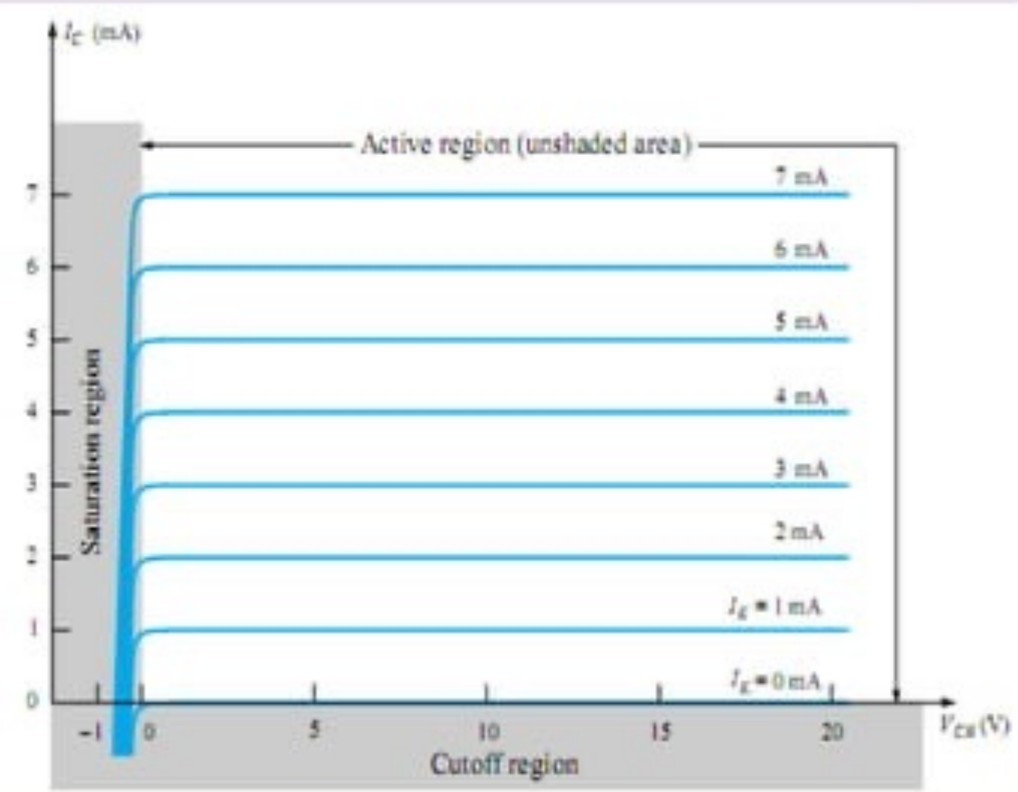
→V_{BE} vs I_E characteristics is called input characteristics.

→ I_E increases rapidly with V_{BE}. It means input resistance is very small.

→ I_E almost independent of V_{CB}.

Characteristics of common base configuration

Output Characteristics:



→V_{Bc} vs I_c characteristics is called output characteristics.

→ I_c varies linearly with V_{Bc} ,only when V_{Bc} is very small.

→ As, V_{Bc} increases, I_c becomes constant.

Input and Output Resistance of common base conf.

- <u>Input Resistance:</u> The ratio of change in emitter-base voltage to the change in emitter current is called Input Resistance.

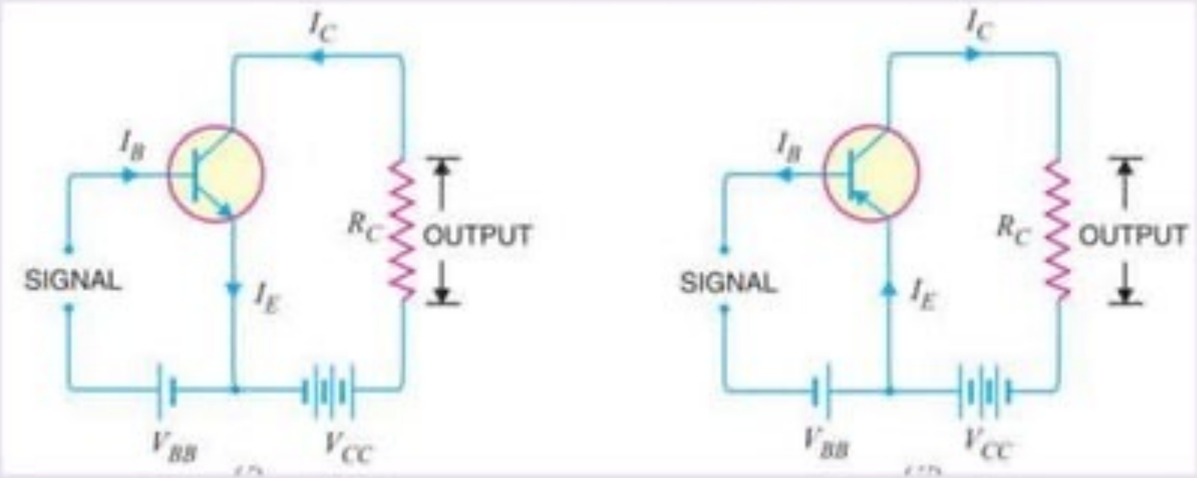
$$r_i = \frac{\Delta V_{BE}}{\Delta I_E}$$

- <u>Output Resistance:</u> The ratio of change in collector-base voltage to the change in collector current is called Output Resistance.

$$r_0 = \frac{\Delta V_{BC}}{\Delta I_C}$$

Common Emitter Connection

- The common-emitter terminology is derived from the fact that the emitter is common to both the input and output sides of the configuration.



- First Figure shows common emitter npn configuration and second figure shows common emitter pnp configuration.

Common Emitter Connection

- Base Current amplification factor (β) :
- In common emitter connection input current is base current and output current is collector current.
- The ratio of change in collector current to the change in base current is known as base current amplification factor, β.

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

- Normally only 5% of emitter current flows to base, so amplification factor is greater than 20. Usually this range varies from 20 to 500.

Relation Between β and α

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

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

$$I_E = I_B + I_C$$

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

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

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

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

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

Expression for Collector Current

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

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

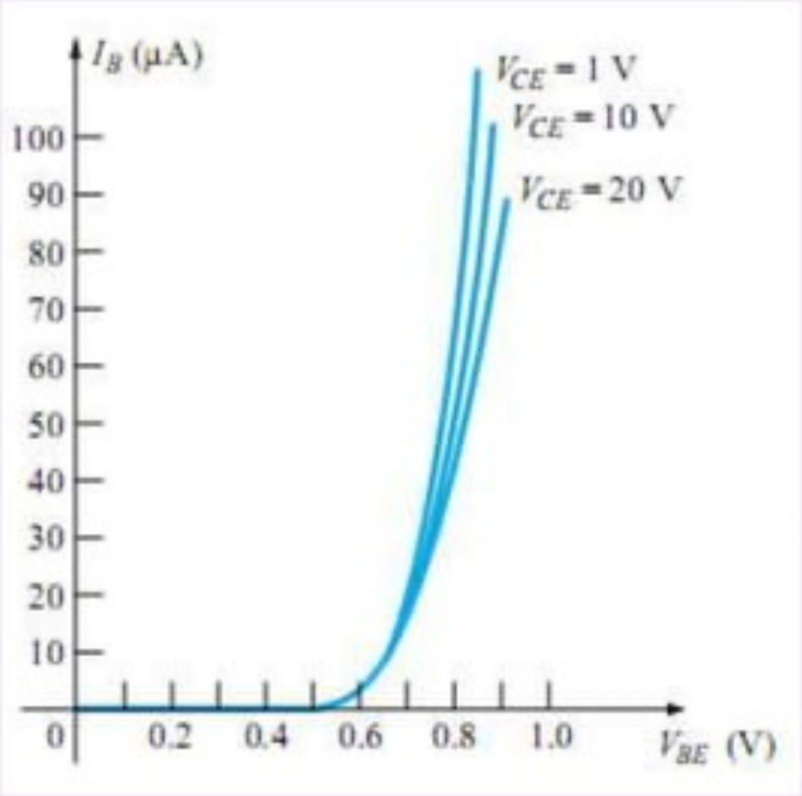
$$I_E(1-\alpha) = I_B + I_{CBO}$$

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

$$I_C \; ; \; I_E = {}^{*}(\beta + 1) I_B + (\beta + 1) I_{CBO}$$

Characteristics of common emitter configuration

- <u>Input Characteristics:</u>



→ V_{BE} vs I_B characteristics is called input characteristics.

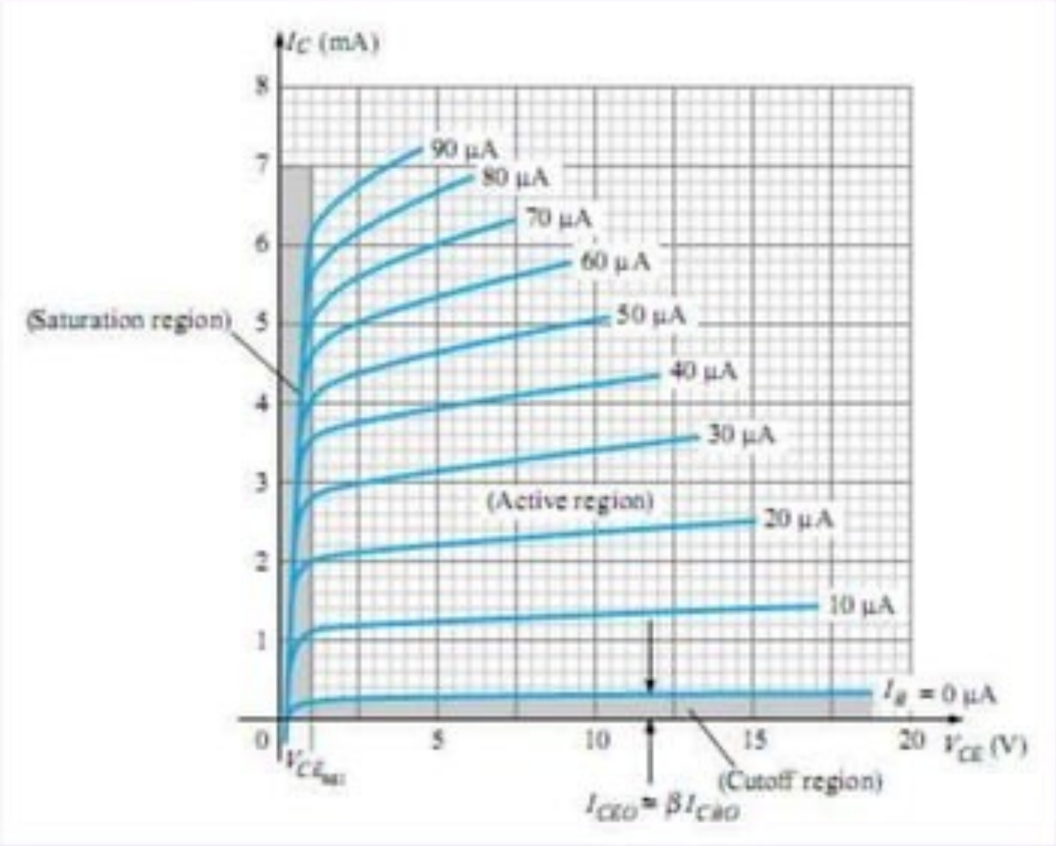
→ I_B increases rapidly with V_{BE}. It means input resistance is very small.

→ I_E almost independent of V_{CE}.

→ I_B is of the range of micro amps.

Characteristics of common emitter configuration

- <u>Output Characteristics:</u>



→ V_{CE} vs I_c characteristics is called output characteristics.

→ I_c varies linearly with V_{CE}, only when V_{CE} is very small.

→ As, V_{CE} increases, I_c becomes constant.

Input and Output Resistance of common emitter conf.

- <u>Input Resistance:</u> The ratio of change in emitter-base voltage to the change in base current is called Input Resistance.

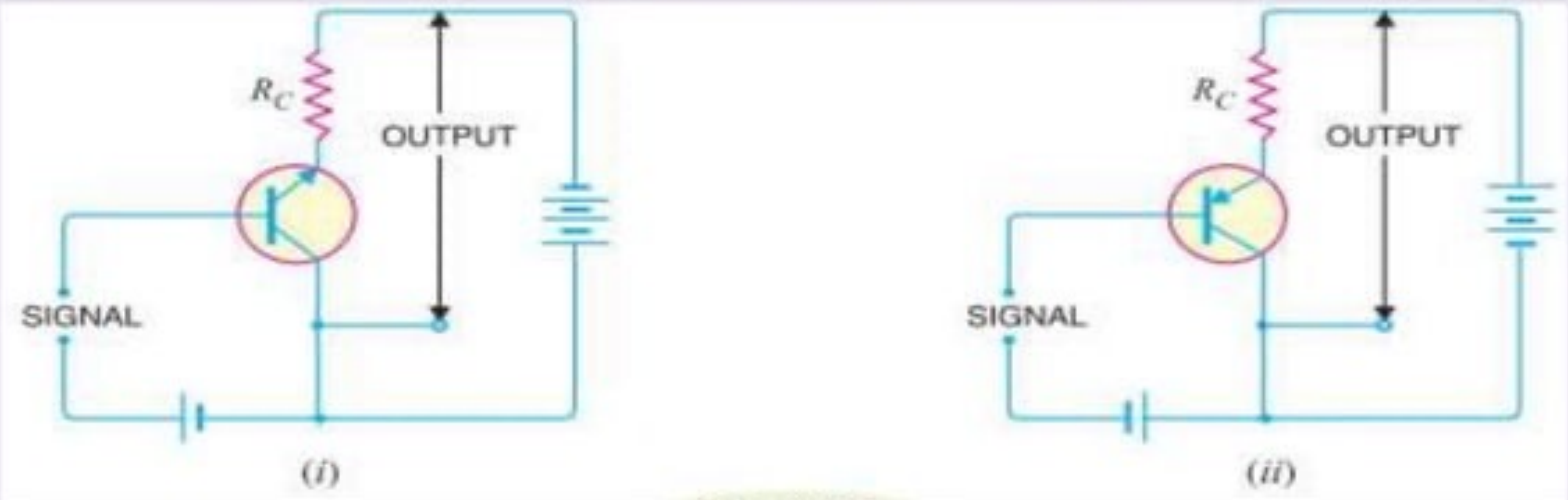
$$r_i = \frac{\Delta V_{BE}}{\Delta I_B}$$

- <u>Output Resistance:</u> The ratio of change in collector-emitter voltage to the change in collector current is called Output Resistance.

$$r_0 = \frac{\Delta V_{CE}}{\Delta I_C}$$

Common Collector Configuration

- The common-collector terminology is derived from the fact that the collector is common to both the input and output sides of the configuration.



- First Figure shows common collector npn configuration and second figure shows common collector pnp configuration.

Common Collector Configuration

- <u>Current amplification factor (γ) :</u>
- In common emitter connection input current is base current and output current is emitter current.
- The ratio of change in emitter current to the change in base current is known as current amplification factor in common collector configuration.

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

- This circuit provides same gain as CE configuration as,

$$\Delta I_E \approx \Delta I_C$$

Relation Between γ and α

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

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

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

$$I_E = I_B + I_C$$

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

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

$$\gamma = \frac{\frac{\Delta I_E}{\Delta I_E}}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} = \frac{1}{1 - \alpha}$$

Expression for Collector Current

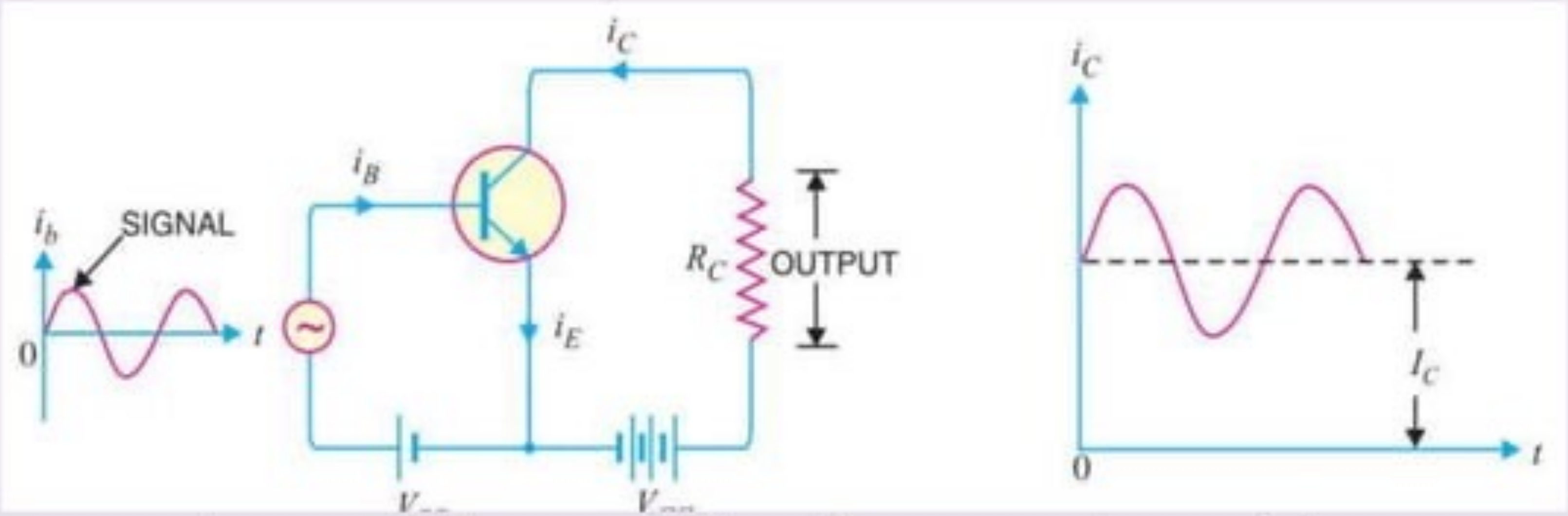
$$
\begin{aligned}
I_C &= \alpha I_E + I_{CBO} \\
I_E &= I_B + I_C = I_B + (\alpha I_E + I_{CBO}) \\
I_E(1-\alpha) &= I_B + I_{CBO} \\
I_E &= \frac{I_B}{1-\alpha} + \frac{I_{CBO}}{1-\alpha} \\
I_C \;;\; I_E &= *(\beta + 1) I_B + (\beta + 1) I_{CBO}
\end{aligned}
$$

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

Comparison of Transistor Connection

S. No.	Characteristic	Common base	Common emitter	Common collector
1.	Input resistance	Low (about 100 Ω)	Low (about 750 Ω)	Very high (about 750 kΩ)
2.	Output resistance	Very high (about 450 kΩ)	High (about 45 kΩ)	Low (about 50 Ω)
3.	Voltage gain	about 150	about 500	less than 1
4.	Applications	For high frequency applications	For audio frequency applications	For impedance matching
5.	Current gain	No (less than 1)	High (β)	Appreciable

Transistor as an amplifier in CE conf.



- Figure shows CE amplifier for npn transistor.
- Battery V_{BB} is connected with base in-order to make base forward biased, regardless of input ac polarity.
- Output is taken across Load R

Transistor as an amplifier in CE conf.

- During positive half cycle input ac will keep the emitter-base junction more forward biased. So, more carrier will be emitted by emitter, this huge current will flow through load and we will find output amplified signal.
- During negative half cycle input ac will keep the emitter-base junction less forward biased. So, less carrier will be emitted by emitter. Hence collector current decreases.
- This results in decreased output voltage (In opposite direction).