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Basic Electronics Engineering

"Unit - II : Transistors and Technology"

Bipolar Junction Transistor :→

A bipolar junction transistor (BJT) is a three terminal semiconductor device which is able to amplify a signal or switch a current ON.

- **Construction :→**

- A BJT consists of three differently doped semiconductor regions, the emitter region, the base region and the collector region.
- Each semiconductor region is connected to a terminal; emitter (E), base (B) and collector (C) respectively.
- The comparison of the area and the doping concentrations of the semiconductor regions of BJT is as follows :

Semiconductor region	Area	Doping
1) Emitter	Moderate	Heavily doped
2) Base	small	Lightly doped
3) Collector	Large	Moderately doped

- A BJT consists of two P-N junctions.
  - The P-N junction joining the base region and the emitter region is called the base-emitter junction
  - The P-N junction joining the base region and the collector region is called the base-collector junction.

Types :-

i) NPN transistor :-

NPN transistor consists of two layers of N-type semiconductor material with a thin layer of P-type in between.

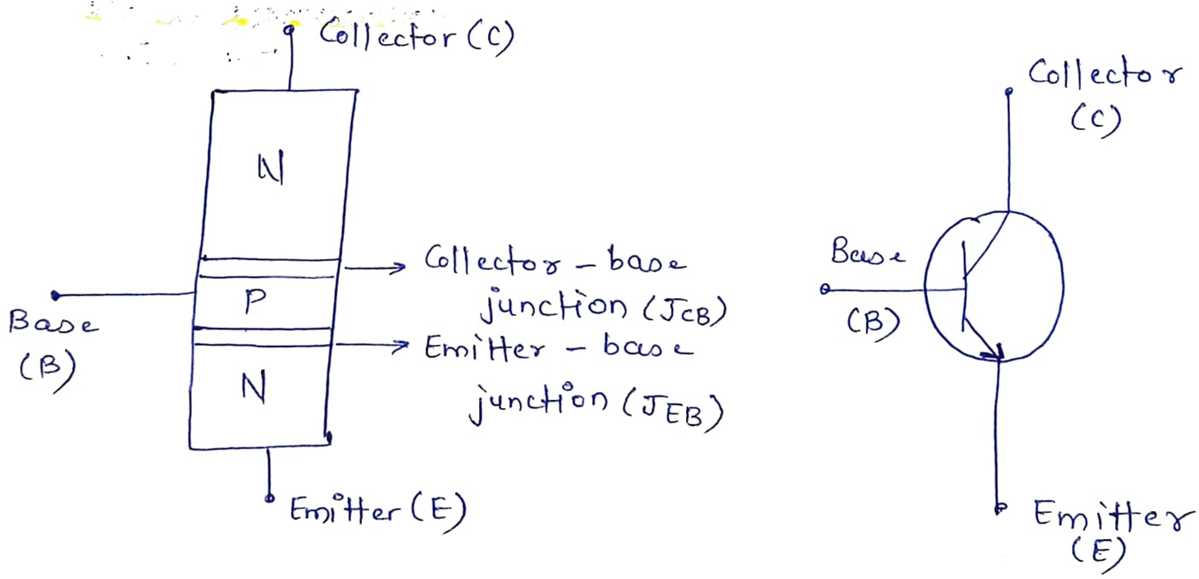


fig: NPN transistor

ii) PNP transistor :-

PNP transistor consists of two layers of P-type semiconductor material with a thin layer of N-type in between

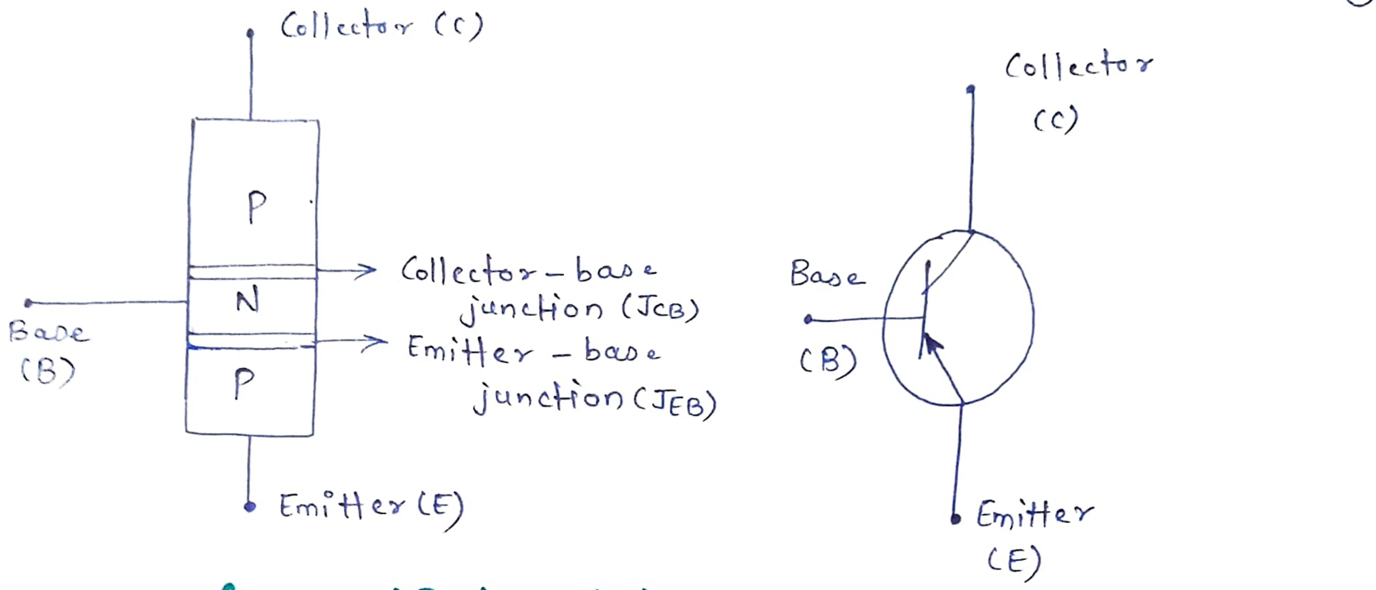
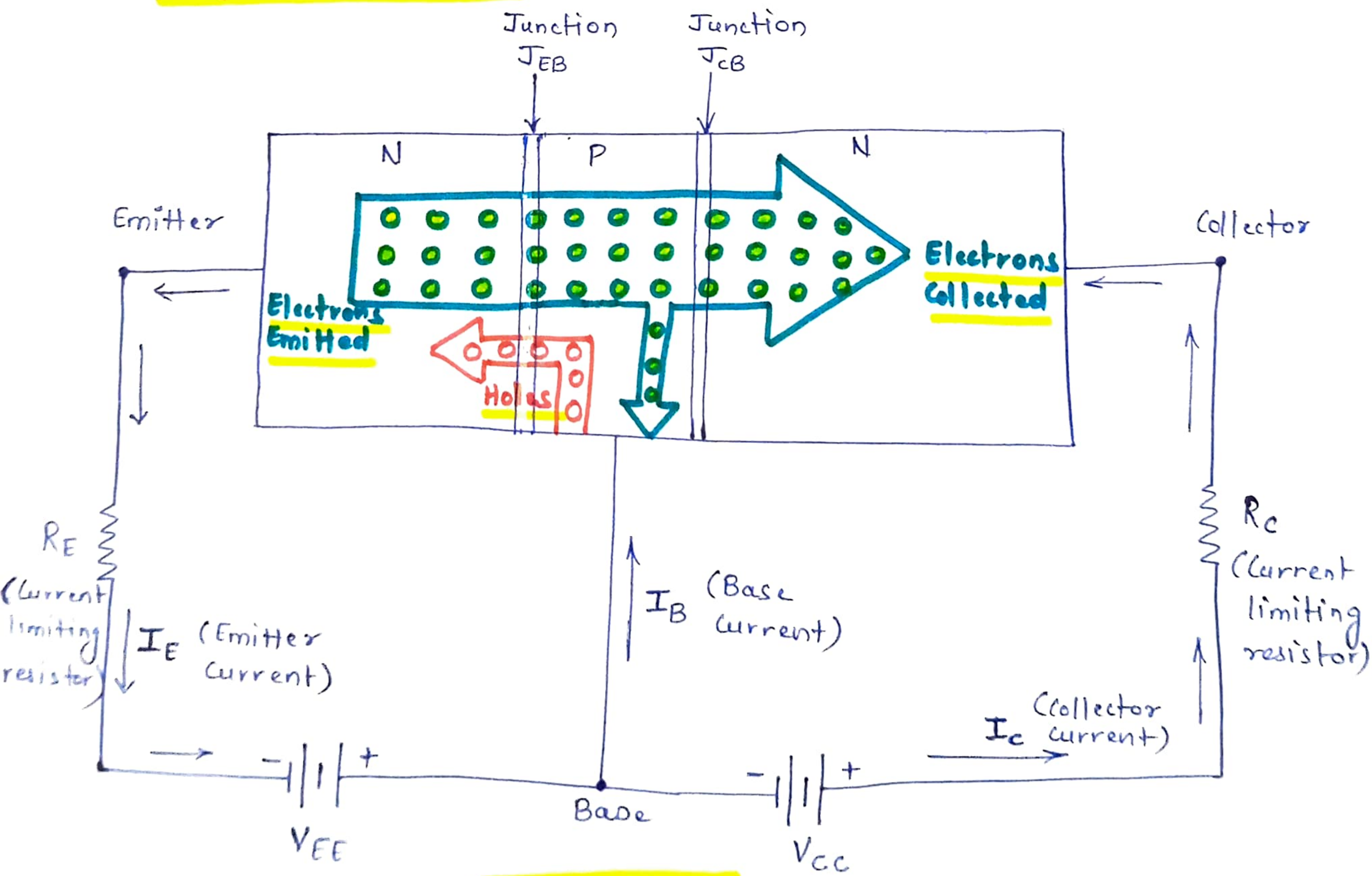


fig: PNP transistor

⊛ Bipolar Junction Transistor — Operation in Active Region (NPN) :→



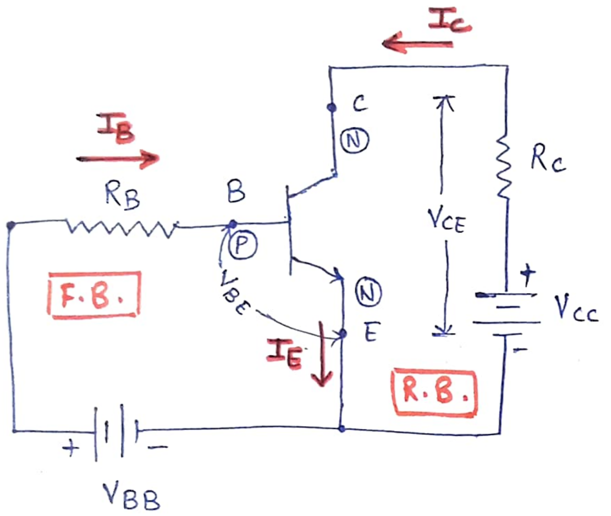
$$\boxed{I_E = I_c + I_B}$$

fig: operation of NPN transistor in active region

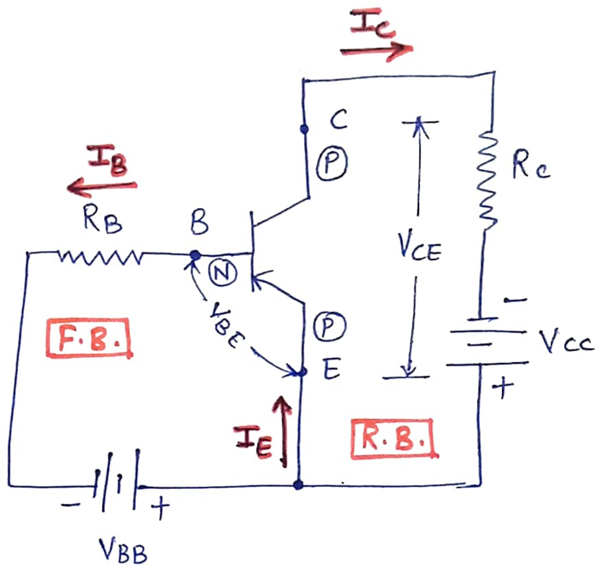
- The supply voltage V_{EE}, forward biases the emitter-base junction (J_{EB}) and the supply voltage V_{CC}, reverse biases the collector-base junction (J_{CB}) as shown.
- The forward biased emitter-base junction causes the electrons in the N-type emitter to flow towards the base. This constitutes the emitter current (I_E).
- As these electrons flow through the P-type base, they tend to combine with the holes in P-region.
- Due to light doping in P-region, very few electrons injected into the base from the emitter recombine with holes to constitute base current (I_B)
- Remaining large number of electrons cross the base region and move through the collector region to the positive terminal of the external DC source, V_{CC}. This constitutes collector current (I_C).
- Forward biased emitter-base junction also causes the holes to flow from P-type base to N-type emitter. But as base is lightly doped, holes become the minority carriers. Thus, the electron flow constitutes the dominant current in an NPN transistor.
- Since, 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.

$$\boxed{I_E = I_B + I_C}$$

Bipolar Junction Transistor — Common Emitter Configuration :→



(a) CE configuration for NPN transistor



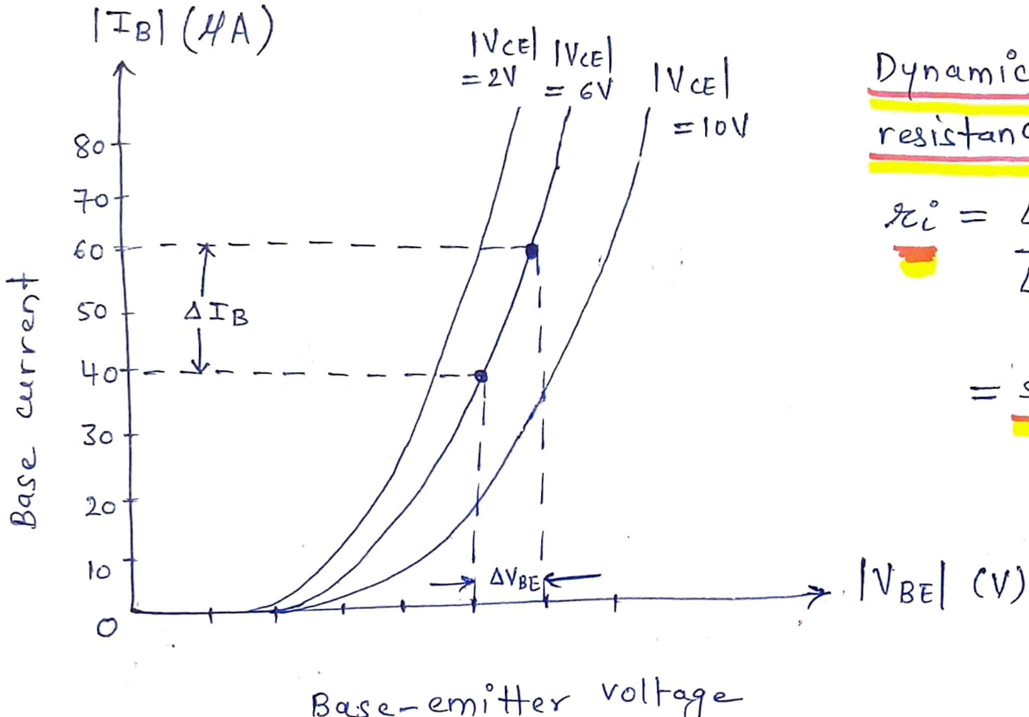
(b) CE configuration for PNP transistor

fig: Common Emitter Configuration for a bipolar junction transistor.

- The configuration in which the emitter is common to both base and the collector is known as a common emitter configuration.
- The input circuit is connected between emitter and base and the output circuit is taken from the collector and emitter.
- The common emitter configuration for NPN and PNP transistor is shown in the figure above.

• Common Emitter Configuration — Input characteristics :→

- The curve plotted between base current (I_B) and the base-emitter voltage (V_{BE}) for different values



Dynamic input resistance,

$$r_i = \left.\frac{\Delta V_{BE}}{\Delta I_B}\right|_{V_{CE} = \text{constant}}$$

= small

fig: Input characteristic curve for common emitter configuration

of collector-emitter voltage (V_{CE}) is called as input characteristic curve for common emitter configuration.

- As the emitter-base junction (J_{EB}) is essentially the same as a forward biased diode, the current-voltage characteristics is essentially the same as that of a diode.
- It can be observed that when the input voltage V_{BE} is increased initially, there is no current produced; further when it is increased the input current I_B increases steeply.
- The curve shifts to the right side when the value of output voltage i.e. collector-emitter voltage (V_{CE}) is increased. In other words, for a fixed value of V_{BE}, I_B decreases as V_{CE} is increased.

- **Common Emitter Configuration - Output Characteristics :→**

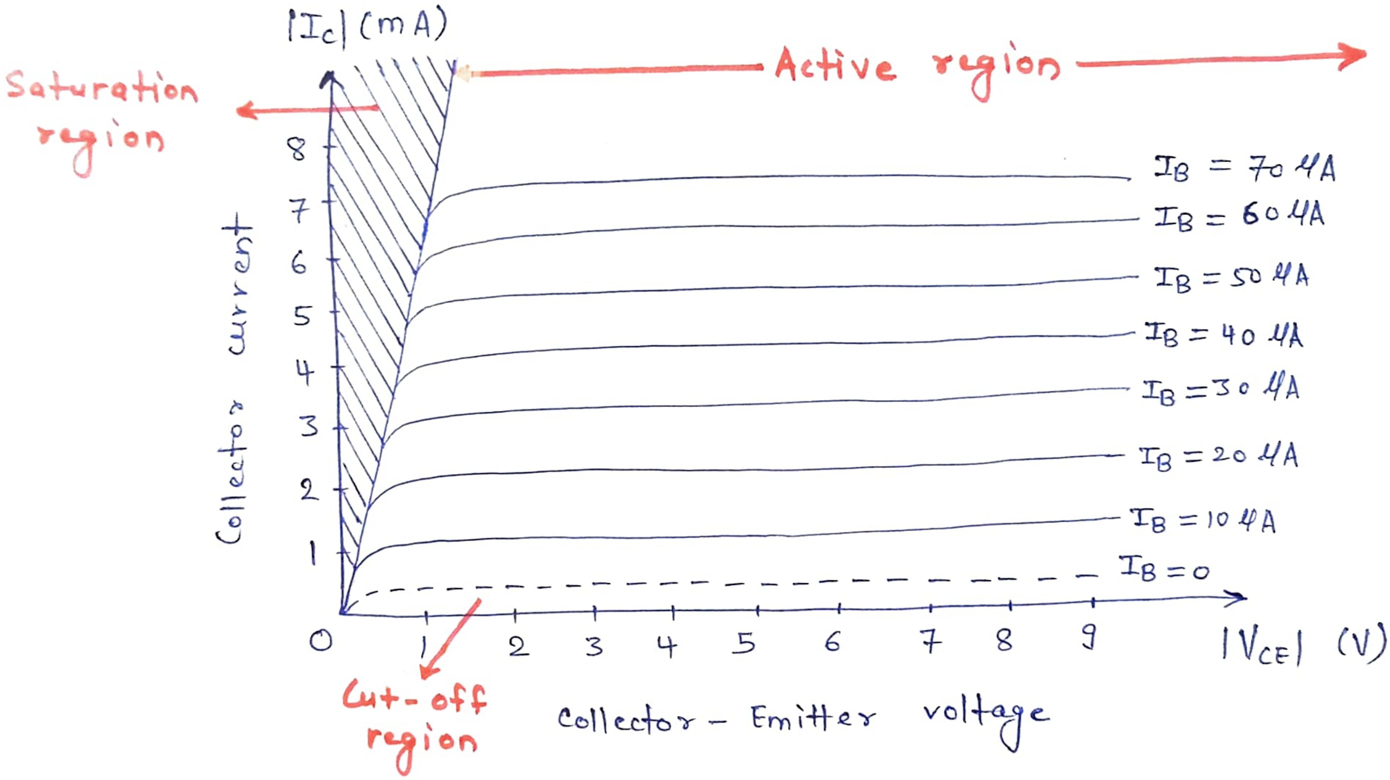


fig: Output characteristic curve for common emitter configuration

- The curve plotted between collector current (I_C) and the collector - emitter voltage (V_{CE}) for different values of base current (I_B) is called as output characteristic curve for common emitter configuration.
- In active region, the change in collector - emitter voltage (V_{CE}) causes little change in the collector current (I_C) for a constant base current (I_B).

∴ Dynamic output resistance,

$$r_o = \left.\frac{\Delta V_{CE}}{\Delta I_C}\right|_{I_B = \text{constant}} = \text{high}$$

- Cut off region is the region where the input current is below zero.
- When both the junctions are forward biased, it is in saturation region.

⊛ Current Amplification Factor :→

- The current amplification factor of a bipolar junction transistor (BJT) is the ratio of the change in output current to the change in input current. It is also known as the current gain
- It is dependent on the configuration of the transistor.

i) Current amplification factor, α :→

The current amplification factor in common base configuration is represented by the symbol α. In this configuration, I_E is the input current and I_C is the output current.

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

The value of α is always less than unity as $I_C < I_E$.

ii) Current amplification factor, β :→

The current amplification factor in common emitter configuration is represented by the symbol β. In this configuration, I_B is the input current and I_C is the output current.

$$\therefore \boxed{\beta = \frac{I_C}{I_B}}$$

The value of β is always greater than unity as $I_C > I_B$.

iii) Current amplification factor, γ :→

The current amplification factor in common collector configuration is represented by the symbol γ. In this configuration, I_B is the input current and I_E is the output current.

$$\therefore \boxed{\gamma = \frac{I_E}{I_B}}$$

- **Relationship between α, β and γ :→**

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

Also, we have, $I_E = I_C + I_B$

i.e. $I_B = I_E - I_C$

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

Dividing the numerator and denominator of RHS by I_E, we get,

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

$$\therefore \boxed{\beta = \frac{\alpha}{1-\alpha}} \quad \text{———} \left(\because \alpha = \frac{I_C}{I_E}\right)$$

Now consider, $\alpha = \dfrac{I_C}{I_E}$

$$= \frac{I_C}{I_B + I_C} \quad \text{———} \left(\because I_E = I_C + I_B\right)$$

Dividing the numerator and denominator of RHS by I_B, we get,

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

$$\therefore \boxed{\alpha = \frac{\beta}{1+\beta}} \quad \text{———} \left(\because \beta = \frac{I_C}{I_B}\right)$$

Now consider, $\gamma = \dfrac{I_E}{I_B}$

$$= \frac{I_B + I_C}{I_B} \quad \text{———} \left(\because I_E = I_C + I_B\right)$$

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

$$\therefore \boxed{\gamma = 1 + \beta} \quad \text{———} \left(\because \beta = \frac{I_C}{I_B}\right)$$

$$\therefore \gamma = 1 + \frac{\alpha}{1-\alpha} \quad \text{———} \left(\because \beta = \frac{\alpha}{1-\alpha}\right)$$

$$\therefore \boxed{\gamma = \frac{1}{1-\alpha}}$$

Numerical :→

1) Calculate I_C and I_E for a BJT with $\alpha_{dc} = 0.98$ and $I_B = 50\ \mu A$. Also determine β_{dc} for the BJT.

⇒

Given : $\alpha_{dc} = 0.98$

$I_B = 50\ \mu A$

To find: I_C, I_E, β_{dc}

solution :

$$\beta_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}}$$

$$= \frac{0.98}{1-0.98}$$

$$\therefore \boxed{\beta_{dc} = 49}$$ ⇒ current amplification factor for common emitter configuration

Now, $I_C = \beta I_B$

$$= 49 \times 50 \times 10^{-6}$$

$$\therefore \boxed{I_C = 2.45\,mA}$$ ⟹ Collector current

Also, $I_E = I_C + I_B$

$$= 2.45\times10^{-3} + 50\times10^{-6}$$

$$\therefore \boxed{I_E = 2.5\,mA}$$ ⟹ emitter current

2) Determine the DC current gain β and the emitter current I_E for a transistor where $I_B = 50\ \mu A$ and $I_C = 3.65\ mA$. [Jan 25]

⇒ **Given:** $I_B = 50\,\mu A$

$I_C = 3.65\,mA$

To find: β, I_E

Solution:

$$I_E = I_C + I_B$$
$$= 3.65\times10^{-3} + 50\times10^{-6}$$
$$\therefore \boxed{I_E = 3.7\ mA} \Rightarrow \text{emitter current}$$

Also,
$$\beta = \frac{I_C}{I_B}$$
$$= \frac{3.65\times10^{-3}}{50\times10^{-6}}$$
$$\therefore \boxed{\beta = 73} \Rightarrow \text{DC current gain}$$

⊛ Bipolar Junction Transistor as a Switch :→

- For switching operation, a bipolar junction transistor must be biased in cut-off or saturation regions

(I) BJT as an open switch :→

NPN : E > B < C

cutoff mode

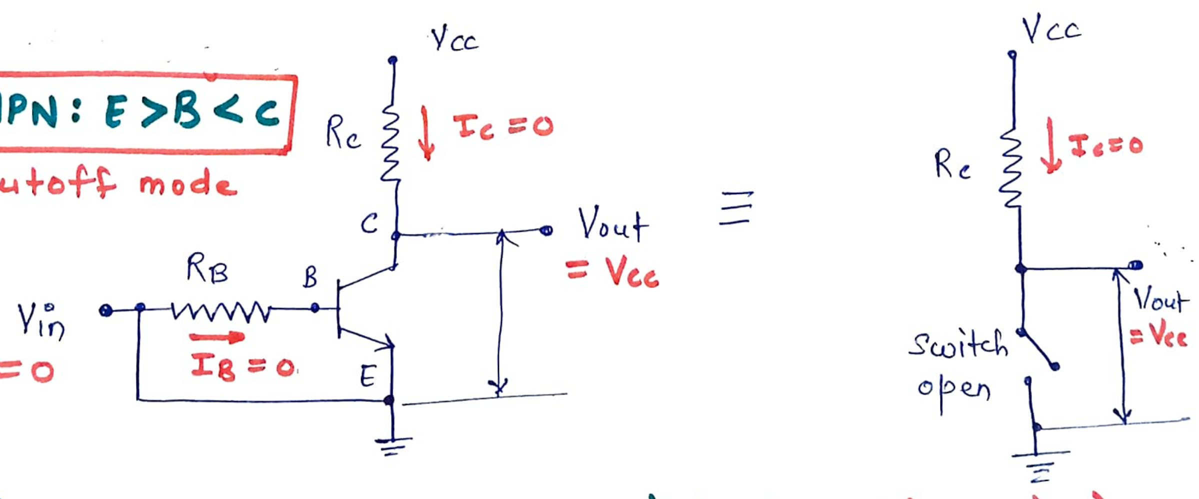


fig: BJT as an open switch (Cutoff region)

- For a bipolar junction transistor, when the voltage condition is E > B < C, it is considered to be in cut-off mode; meaning base-emitter junction is reverse biased, preventing any significant current flow through the transistor, essentially acting like an open switch.

(II) BJT as a closed switch :→

NPN : E < B > C

saturation mode

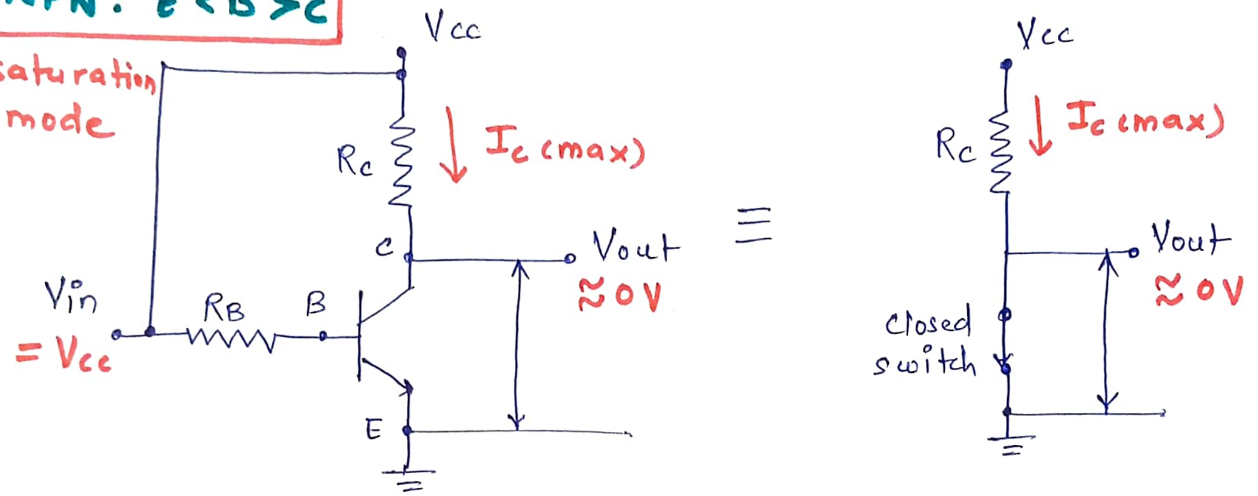


fig: BJT as a closed switch (saturation region)

- For a bipolar junction transistor, when the voltage condition is E < B > C, it is considered to be in saturation mode; where both the input as well as the output junctions are forward biased, allowing maximum current flow.

(*) Bipolar Junction Transistor as a Common Emitter (CE) amplifier :→ (Single stage BJT amplifier in Common Emitter Configuration)

- A single stage BJT amplifier in Common Emitter configuration is shown in the figure below.

Note: Only one transistor is used for amplification & hence the name "Single stage BJT amplifier in CE configuration.

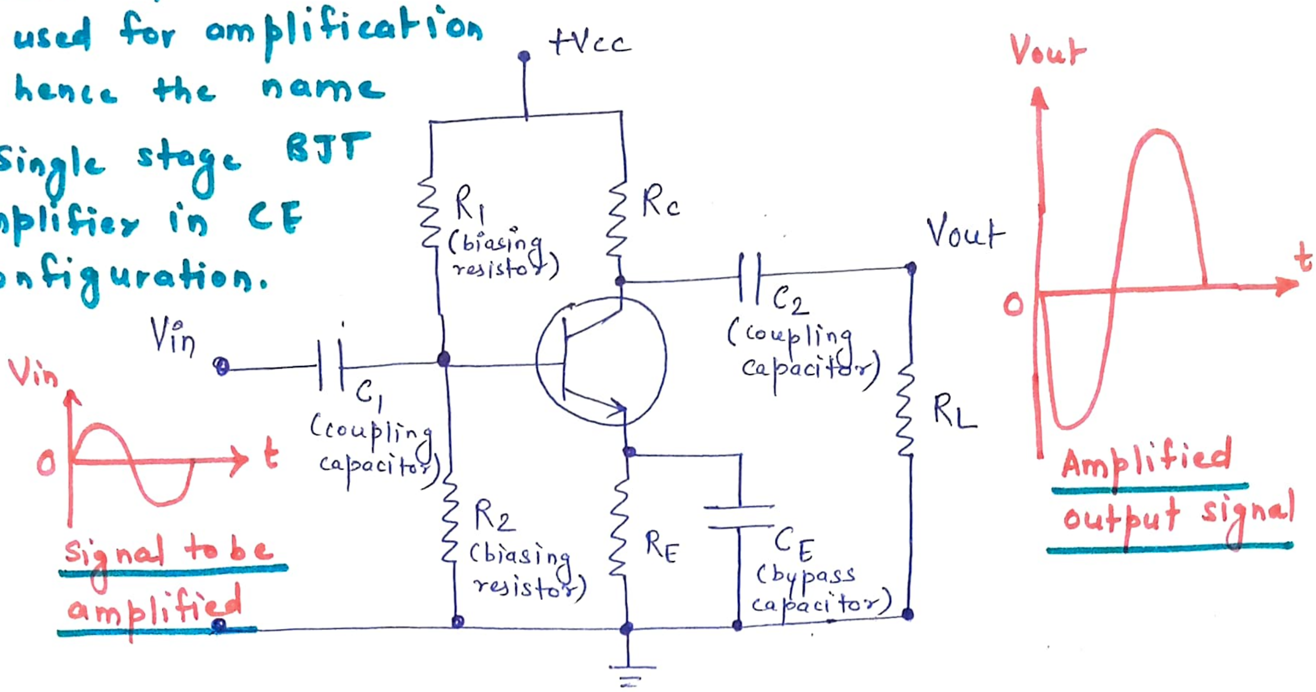


fig: Single stage BJT amplifier in Common Emitter Configuration

- It consists of a voltage divider biasing wherein a potential divider with two resistors are connected in a way that the midpoint is used for supplying base bias voltage.

  Thus, the voltage divider biasing is used to supply the base bias voltage as per the necessity.

- The capacitor C_1 is the coupling capacitor which allows only Ac signal to pass through it.

- A small base current flows when a weak input Ac signal is given to the base of the transistor through Capacitor C_1.

- A much larger Ac current flows through collector load Rc due to transistor action.

- A large voltage appears across Rc and hence we get a large voltage at the output which is 180° phase shifted from the input.

- Thus, a weak signal applied to the base came out in amplified form in the collector circuit.