# Unit-6

# Bi – Polar Junction Transistors

# Bi – Polar Junction Transistor

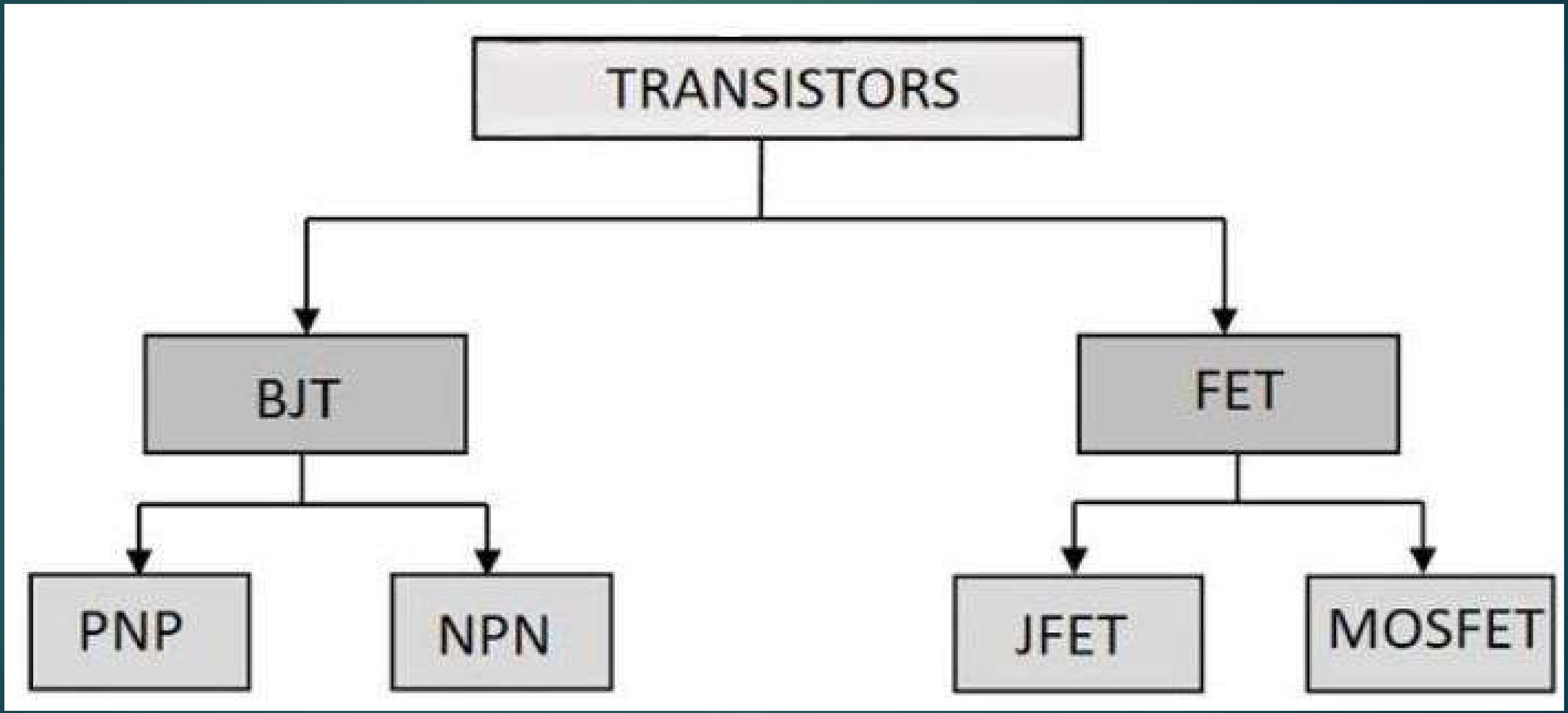
- Define Transistor : Transistor = Trans + Resistor ,Transfer of resistance from lower concentration to higher concentration or Vice versa
- BJT was invented by William Shockley ,John Bardeen and Barttain in 1947 Dec 23
- A BJT is device of two back to back connected PN junction diodes having three terminals like Emitter (E), Base (B) & Collector (C)
- BJT is a 3 terminal , 3 layer, 2 junctions , bi-directional & current controlled device
- 3 terminals : Base, Emitter, Collector
- 3 Layer : N P N or P N P
- 2 Junctions : E-B junction ($J_E$), C-B Junction ($J_C$)
- Bi-directional : Current flow due to both majority & minority charge carriers

# Continued…………

- Transistor terminal description :
- Emitter: It has moderate size, heavily doped terminal, its main function is to supply a number of majority carriers or charge carriers either electrons or holes. Emitter emits the charge carriers, it occupies moderate area
- Base: middle terminal is base terminal ,this is thin and lightly doped terminal
- Its main function is to pass the majority charge carriers from the emitter to collector
- It acts like a mediator in between emitter & collector
- It occupies less area
- Collector: it is moderately doped, it occupies more area compared to emitter and base, size of collector terminal is large, its function is to collect the charge carriers from base and emitter
- BJT is a Asymmetrical device

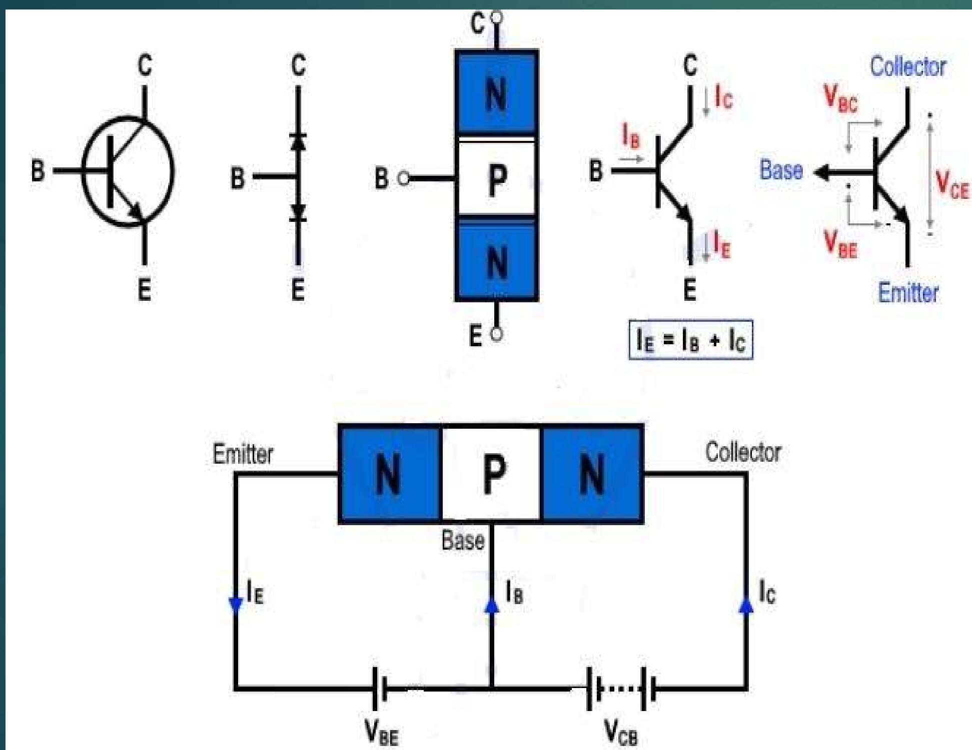
# Continued…………

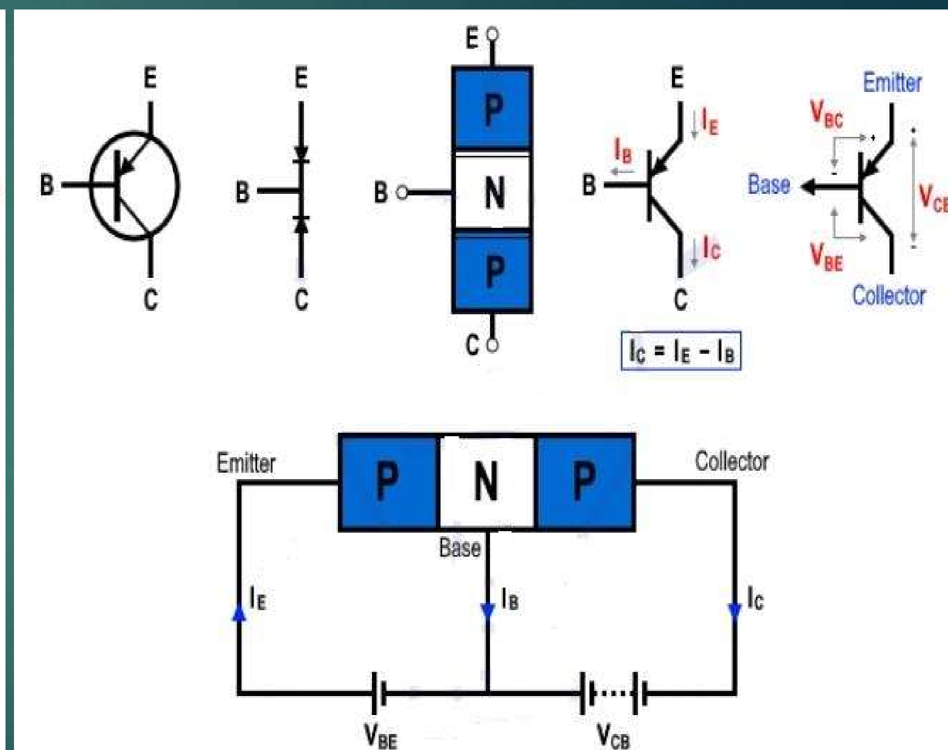
- Types of Transistors :



# Continued…………

- Symbols of NPN & PNP Transistors :



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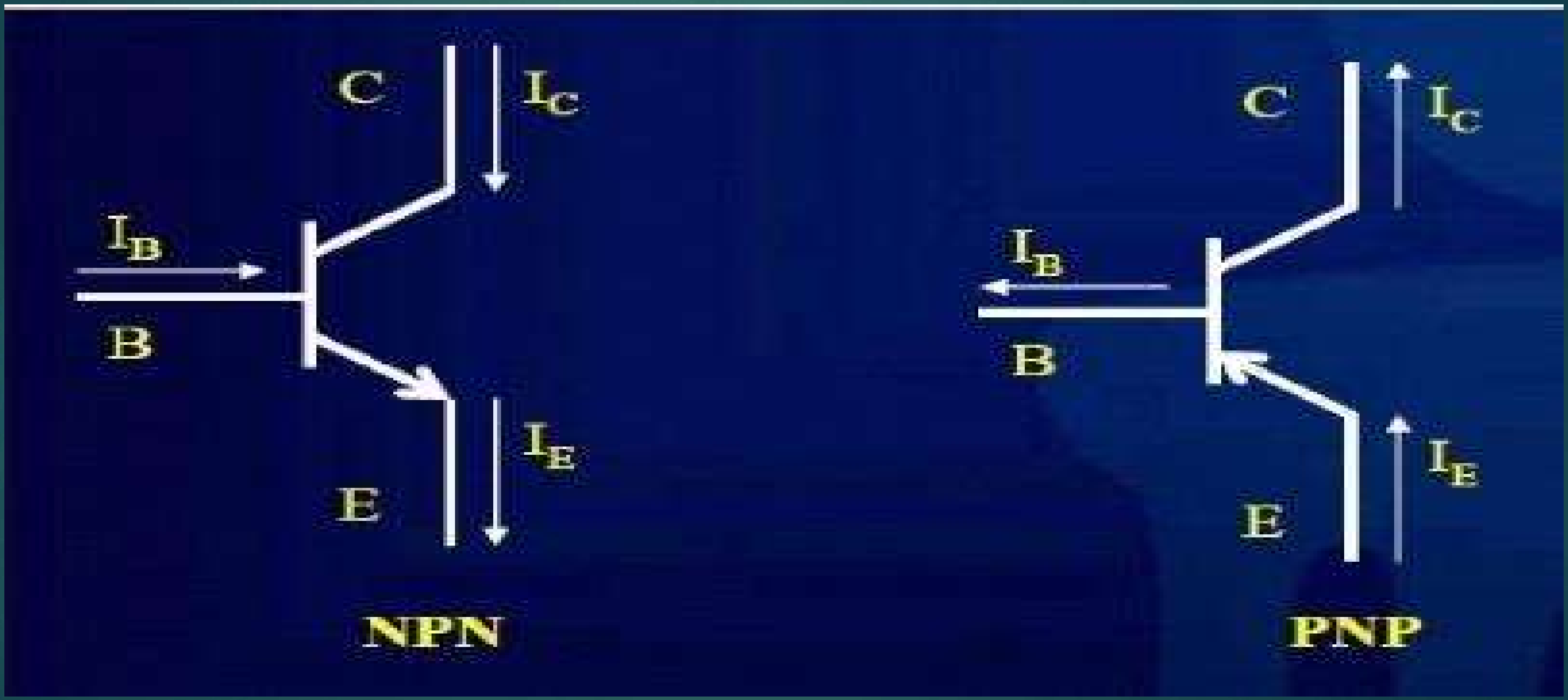
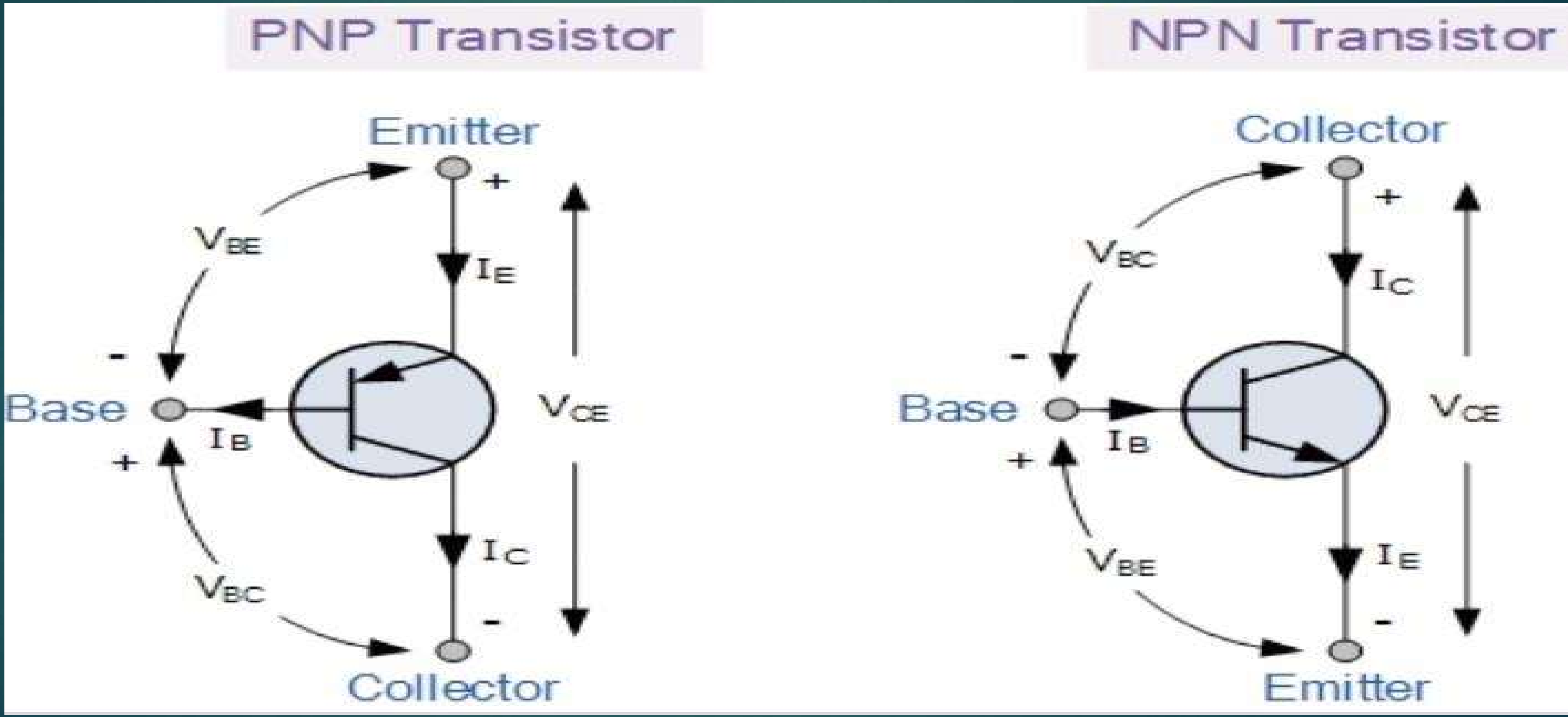
- Current Directions in both NPN & PNP Transistors :




From circuit : $I_E = I_C + I_B$

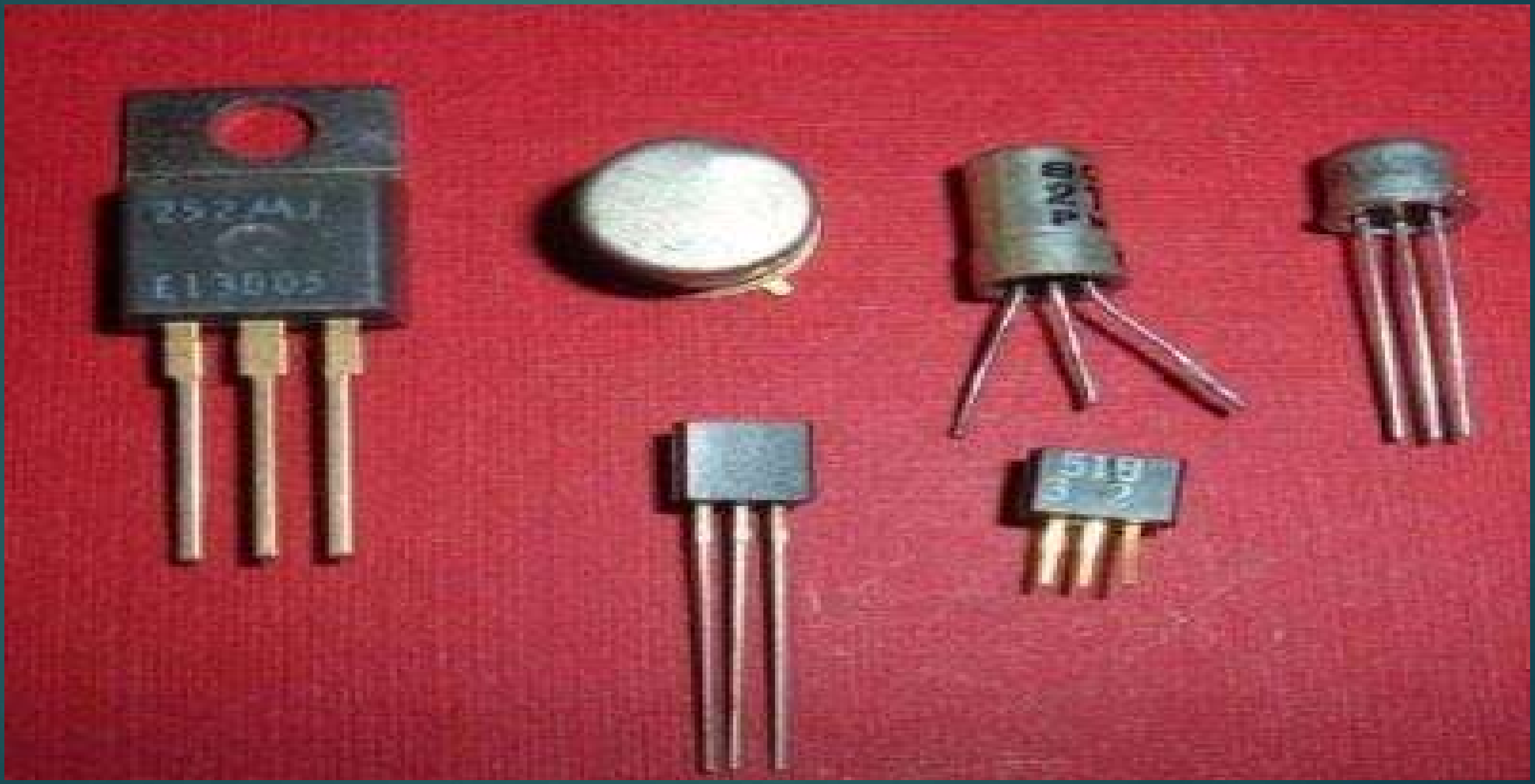
# Continued…………

- Voltage representation of PNP & NPN Transistor :



# Continued…………

- Different types of transistor packages in real life :



# Continued…………

- Transistor Parameters :
- Transistor current : current flowing across the collector ($I_E$ , $I_B$ ,$I_C$ )
- Alpha ($\alpha$):It is the ratio of the DC collector current to the DC emitter current ,it is always equal to 1 or slightly less than 1

  $\alpha = I_C / I_E$ where $\alpha$ is "current amplification factor" of Common Base configuration
- Beta ($\beta$):It is the ratio of the DC collector current to the DC base current ,it is always equal to 1 or slightly less than 1

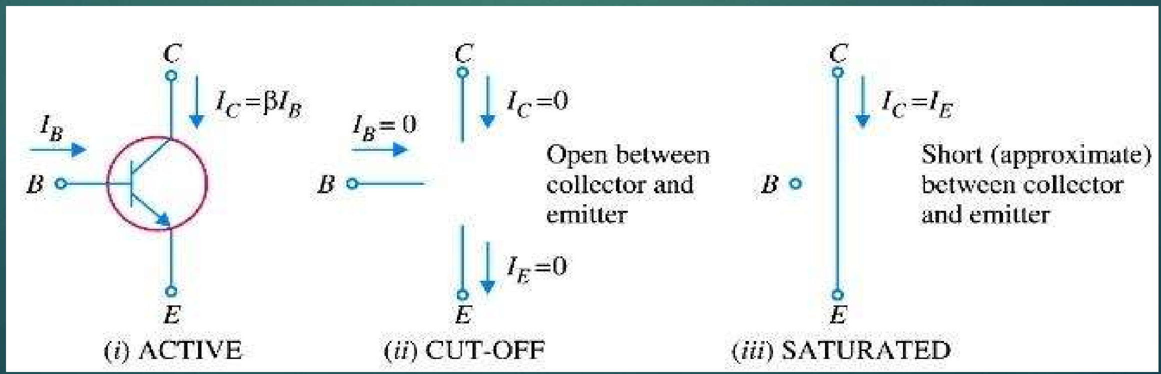
  $\beta = I_C / I_B$ where $\beta$ is "current amplification factor" of Common Emitter configuration
- Gamma ($\gamma$):It is the ratio of the DC emitter current to the DC base current

  $\gamma = I_E / I_B$ where $\gamma$ is "current amplification factor" of Common Collector configuration
- Current rating: Maximum current a transistor can pass through its collector and emitter Ic max

# Continued…………

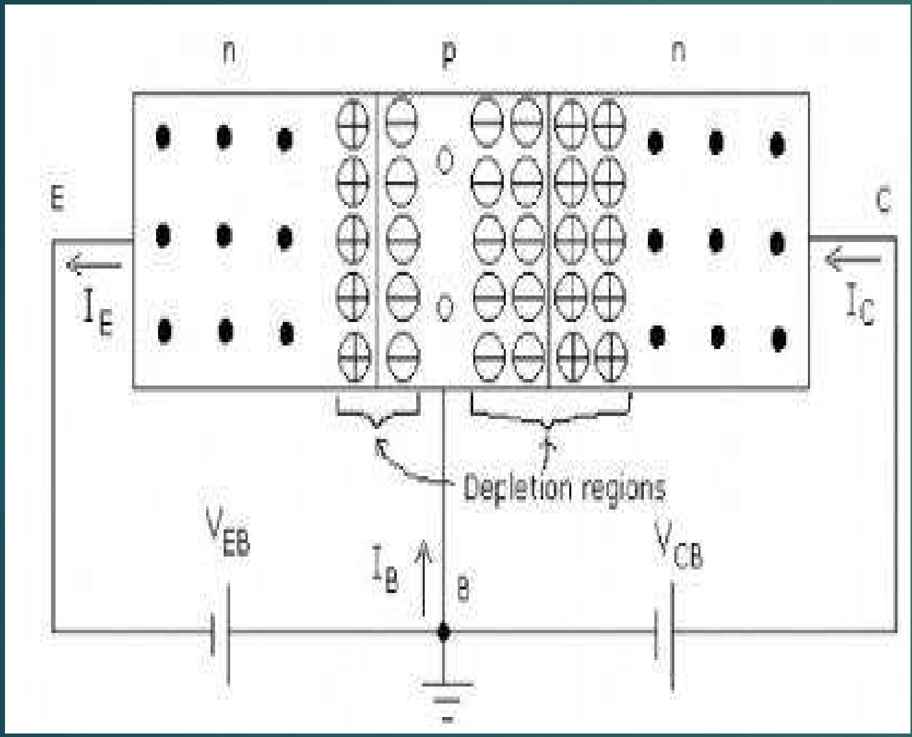
- Transistor Operating Regions :Transistor can be operating in four (4) regions depending on $J_E$ and $J_C$ junctions
- 

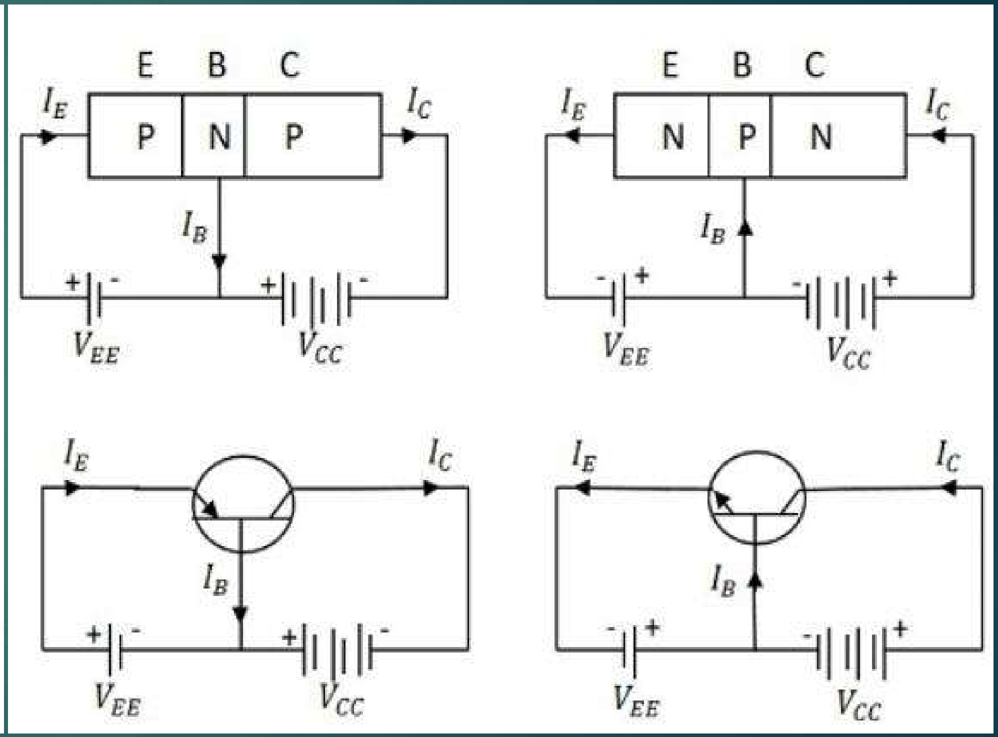
| Operating region | E - B Junction ($J_E$) | C - B Junction($J_C$) | Application |
|---|---|---|---|
| Active region | $J_E$ forward biased | $J_C$ reverse biased | Amplifier |
| Saturation region | $J_E$ forward biased | $J_C$ forward biased | ON switch or logic 1 |
| Cut off region | $J_E$ reverse biased | $J_C$ reverse biased | OFF switch or logic 0 |
| Inverse active region | $J_E$ reverse biased | $J_C$ forward biased | Attenuator |



# Transistor Regions Circuits

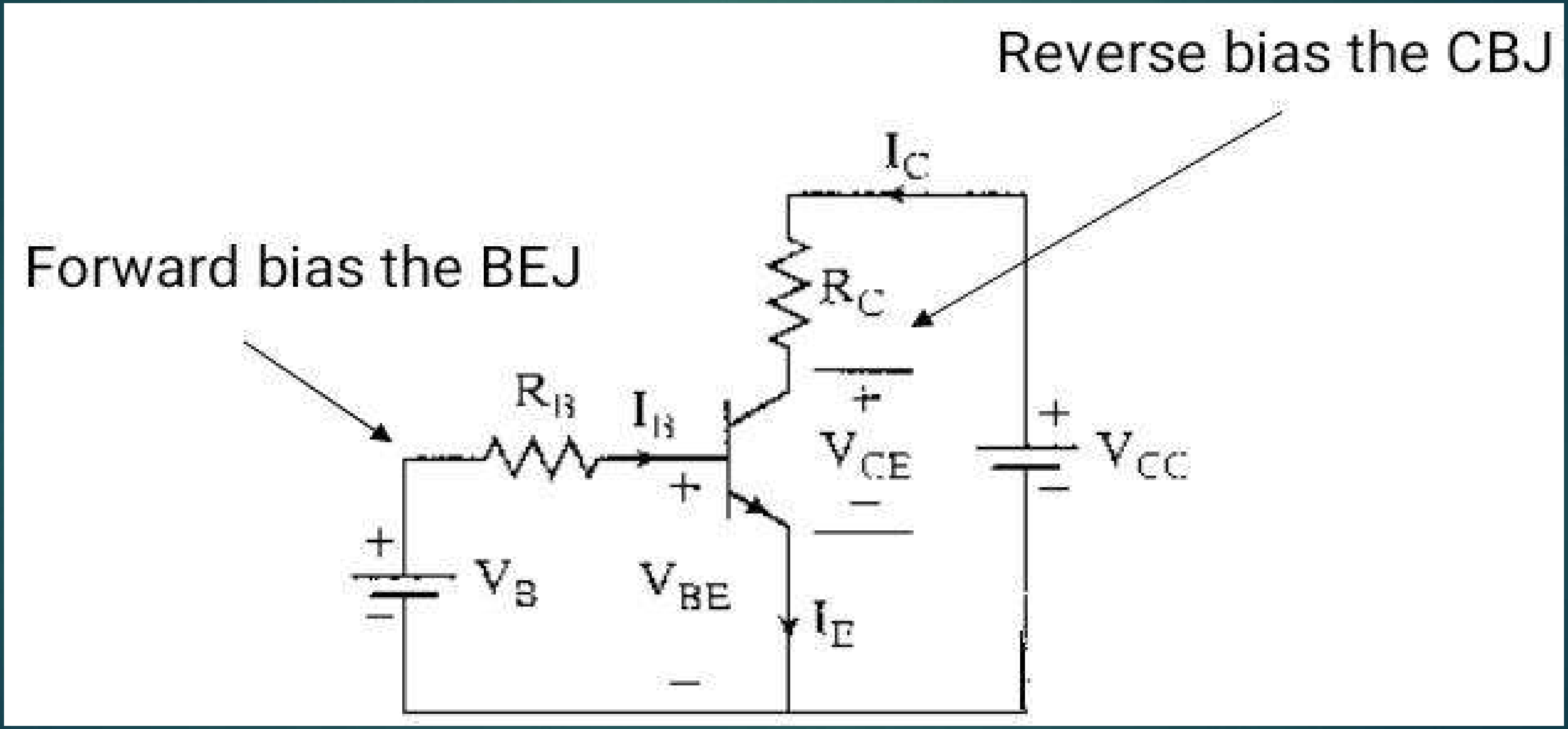
- Operating region circuits :



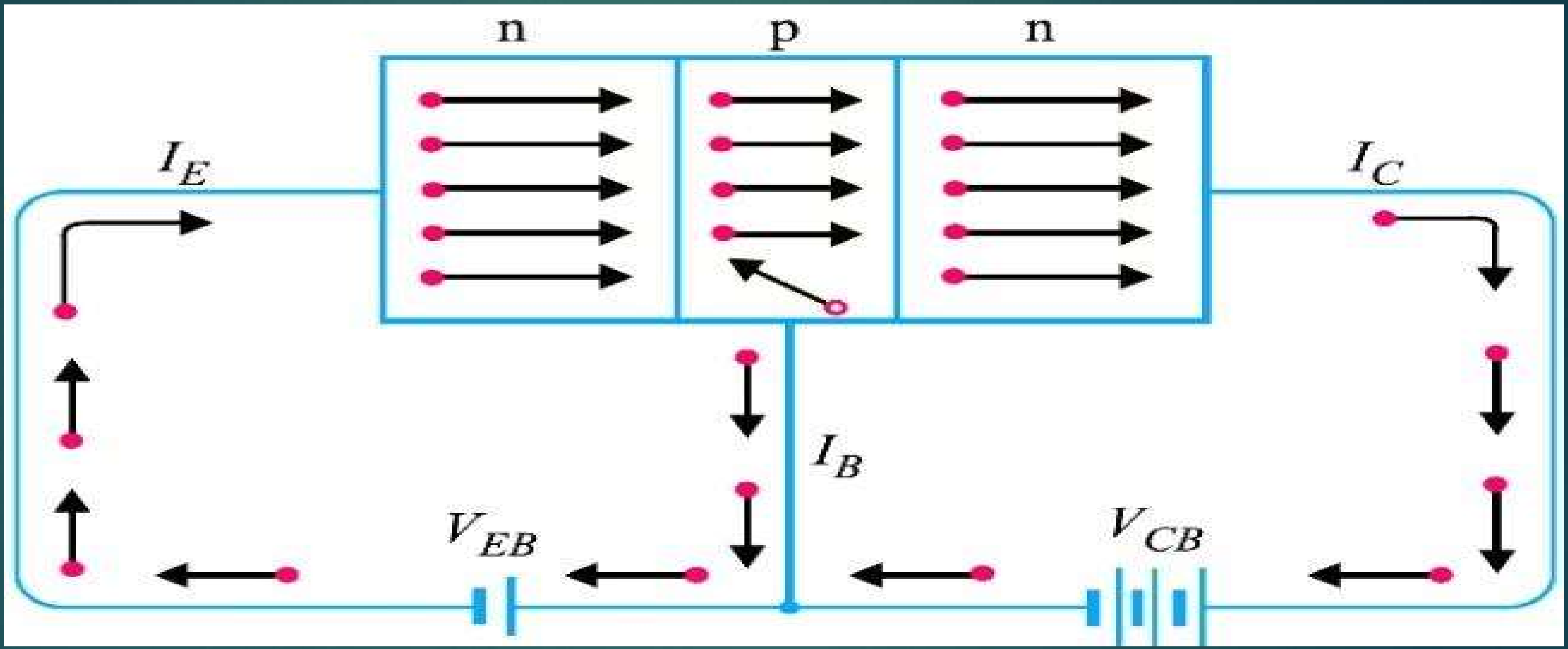
# Continued…………

- Common Emitter NPN Transistor :



# Operation of NPN Transistor

- NPN Transistor Construction:




$I_E = I_C + I_B$

# Continued…………

- Working Operation of NPN Transistor:
- The above figure shows the NPN transistor with forward bias to emitter-base junction ($J_E$) reverse bias to collector base junction ($J_C$)
- The forward bias causes the electrons in the N-type emitter to flow towards the base, this constitutes the emitter current $I_E$ .
- As these electrons flows through the P-type base, they tend to combine with holes, as the base is lightly doped and very thin
- Therefore only a few electrons (less than 5%) combine with holes to constitute the base current $I_B$ .
- The remaining 95% of the electrons cross over into the collector region to constitute collector current $I_C$ .
- In this way almost entire emitter current flows in the collector circuit

# Continued…………

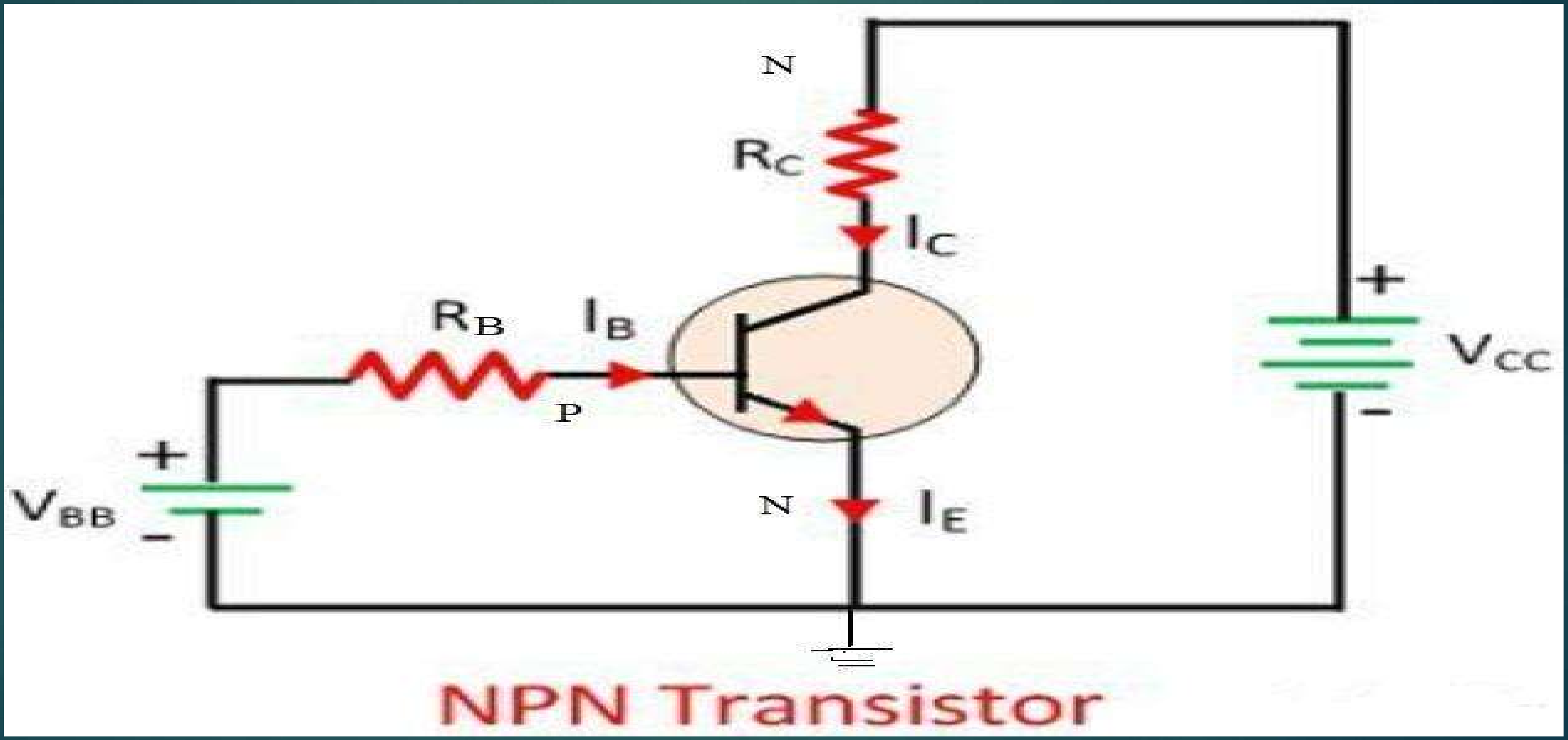
- It is clear that emitter current is the sum of the base current and collector current

$$I_E = I_B + I_C$$

- In actual practice a very little current (micro amperes) would flow in the collector circuit
- This is called collector cut off current and is due to minority carriers
- The electrons which combine with holes become valence electrons. Then as valence electrons they flow down through holes and into the external base lead, this constitutes base current $I_B$
- The reasons that most of the electrons from emitter continue their journey through the base to collector to form collector current (i) base is lightly doped and very thin ,therefore there are few holes which find enough time to combine with electrons
- Emitter is highly doped and collector is moderate doped ,high reverse bias

# Continued…………

- NPN Transistor Circuit :



# Continued…………

- Relationship between alpha & beta in NPN transistor :

**α and β Relationship in a NPN Transistor**

$$\text{DC Current Gain} = \frac{\text{Output Current}}{\text{Input Current}} = \frac{I_C}{I_B}$$

$$I_E = I_B + I_C \;\ldots\ldots\; (\text{KCL}) \quad \text{and} \quad \frac{I_C}{I_E} = \alpha$$

$$\text{Thus:} \quad I_B = I_E - I_C$$

$$I_B = I_E - \alpha I_E$$

$$I_B = I_E(1 - \alpha)$$

$$\therefore \; \beta = \frac{I_C}{I_B} = \frac{I_C}{I_E(1-\alpha)} = \frac{\alpha}{1-\alpha}$$

$$\alpha = \frac{\beta}{\beta + 1} \quad \text{or} \quad \alpha = \beta(1 - \alpha)$$

$$\beta = \frac{\alpha}{1 - \alpha} \quad \text{or} \quad \beta = \alpha(1 + \beta)$$

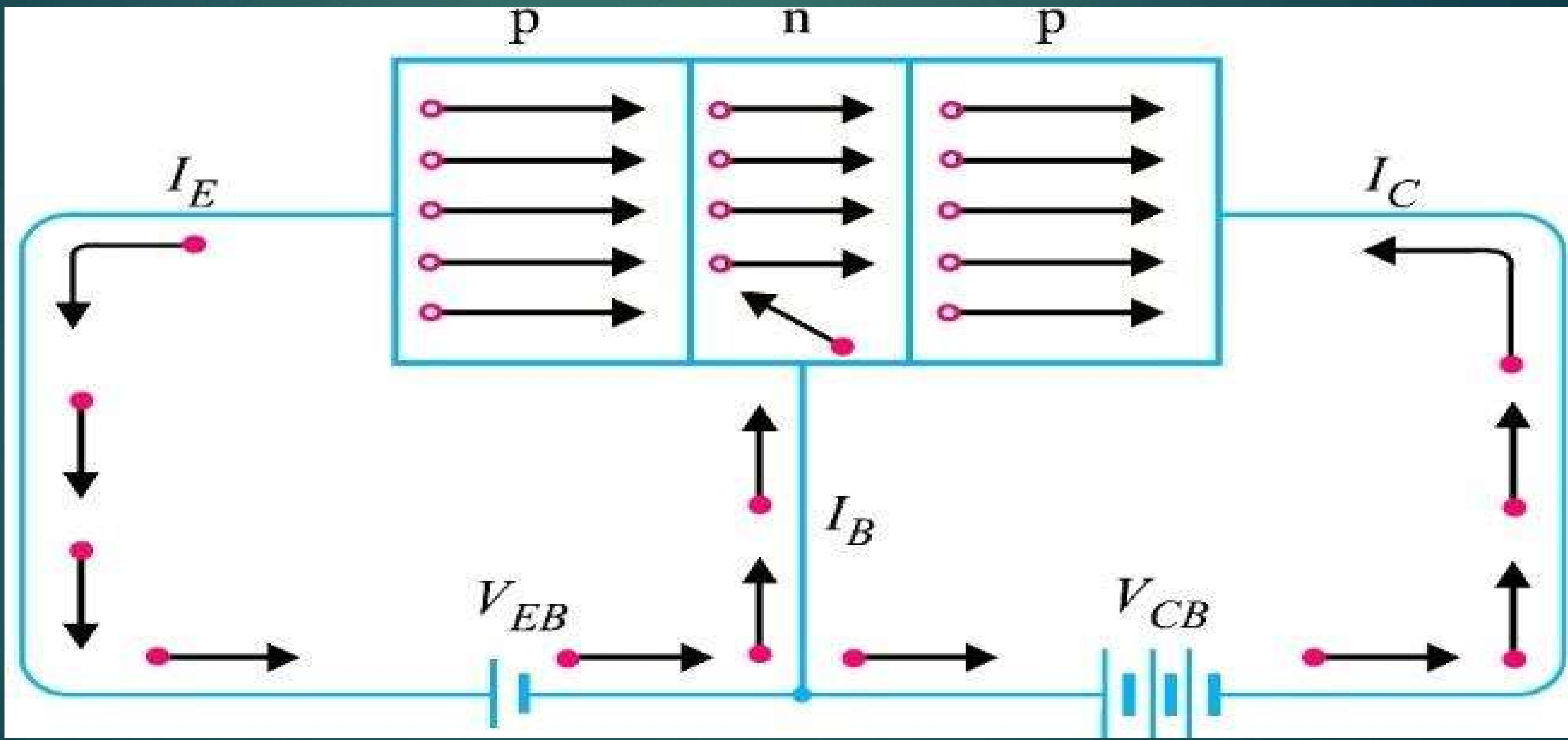
$$\text{If} \quad \alpha = 0.99 \qquad \beta = \frac{0.99}{0.01} = 99$$

# Continued…………

- Importance of Transistor action :
- The input circuit emitter base junction has low resistance because of forward bias ,where as output circuit collector base junction has high resistance due to reverse bias
- The input emitter current almost entirely flows in the collector circuit, therefore a transistor transfers the input signal current from low resistance circuit to high resistance circuit
- This is the key factor responsible for the amplifying capability of the transistor

# Operation of PNP Transistor

- PNP Transistor Construction :



# Continued…………

- Working operation of PNP Transistor:
- The above figure shows the basic connection of PNP transistor
- The forward bias causes the holes in the P-type emitter to flow towards the base ,this constitutes the emitter current $I_E$ .
- As these holes cross into N-type base ,they tend to combine with electrons ,as the base is lightly doped and very thin ,therefore only few holes (less than 5%) combine with electrons ,the remaining more than 95% cross into the collector region to constitute collector current $I_C$ .
- In this way almost entire emitter current flows in the collector circuit
- It may be noted that current conduction within PNP transistor is by holes
- However in the external connecting wires, the current is still by electrons

# Transistor Configurations

- Types of Transistor Configurations : Depending up on the terminals of transistors ,there are three types of configurations
- (i) Common Base Configuration (common terminal is base .i.e base terminal is grounded)

  Input parameters : $I_E$ , $V_{EB}$ (keep constant output voltage $V_{CB}$)

  Output parameters : $I_C$ , $V_{CB}$ (keep constant input current $I_E$)
- (ii) Common Emitter Configuration (common terminal is emitter .i.e E is grounded)

  Input parameters : $I_B$ , $V_{BE}$ (keep constant output voltage $V_{CE}$)

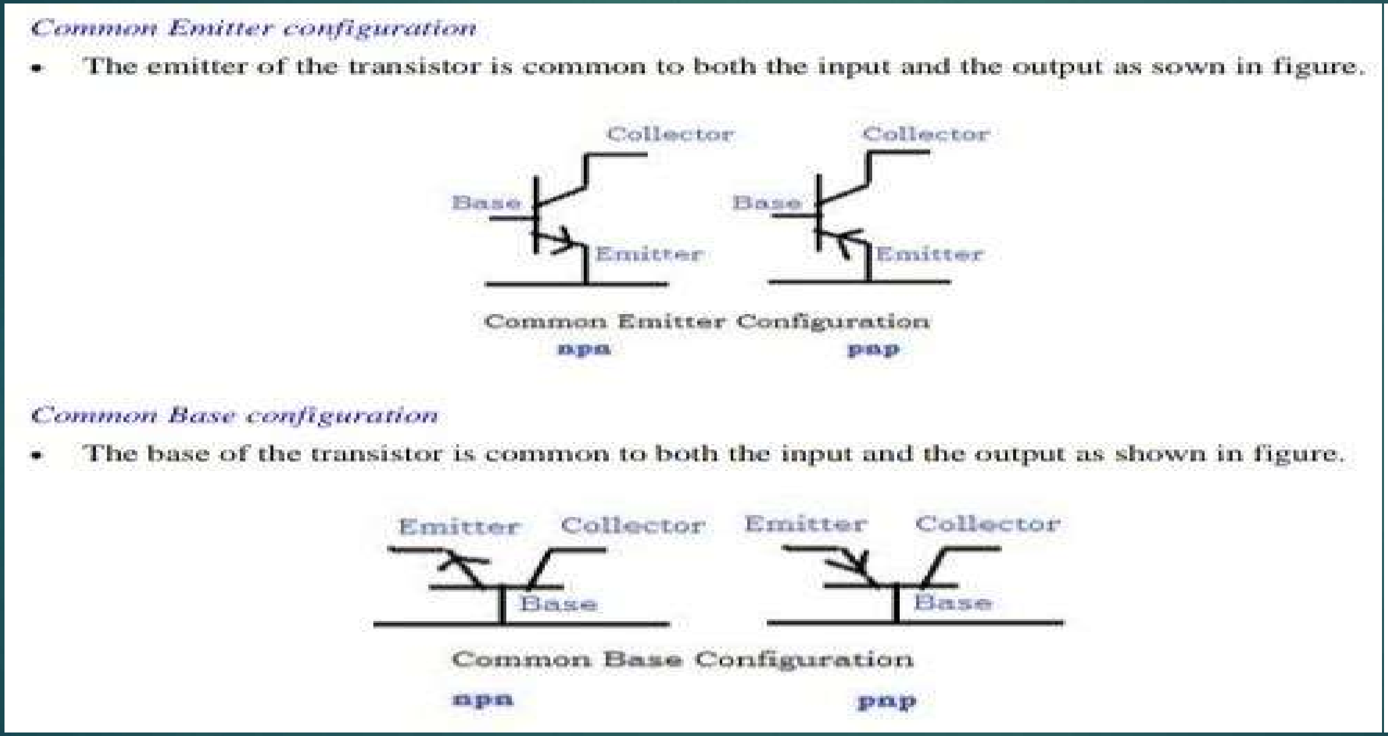
  Output parameters : $I_C$ , $V_{CE}$ (keep constant input current $I_B$)
- (iii) Common Collector Configuration (common terminal is collector .i.e C is grounded)

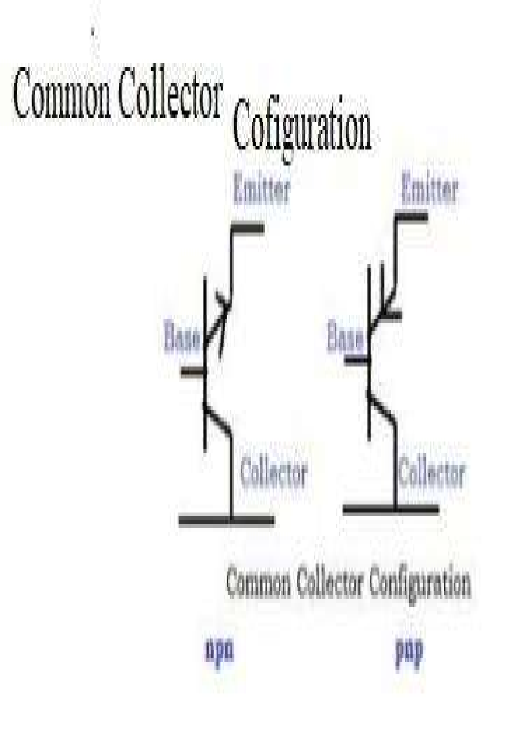
  Input parameters : $I_B$ , $V_{BC}$ (keep constant output voltage $V_{EC}$)

  Output parameters : $I_E$ , $V_{EC}$ (keep constant input current $I_E$)

# Continued…………

- Transistor configurations :



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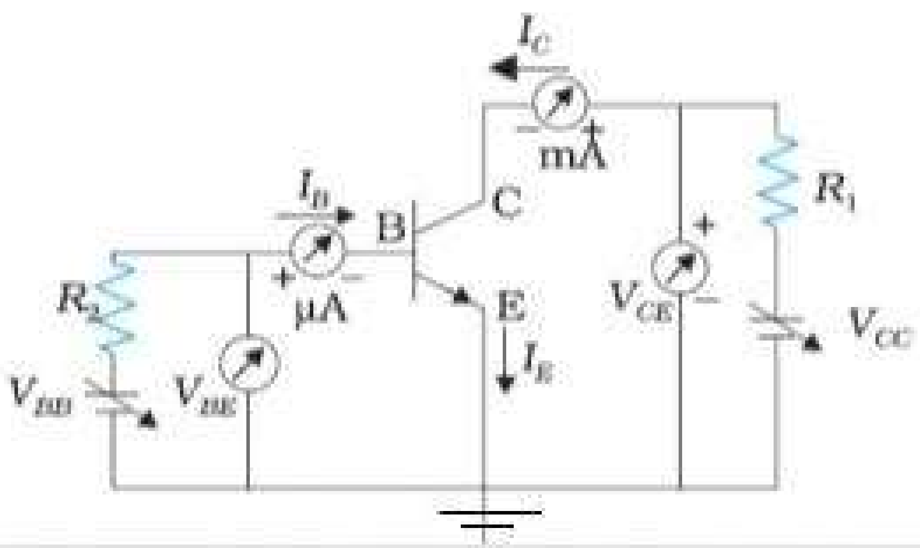
**Common Emitter characteristics**

When the transistor is used in Common Emitter configuration, the input is measured between the base and the emitter; the output is measured between the collector and the emitter.

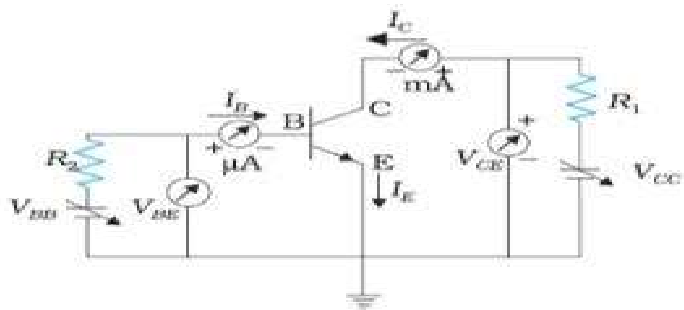


# Continued…………

- Common Emitter Input Characteristics :

**Common Emitter characteristics**

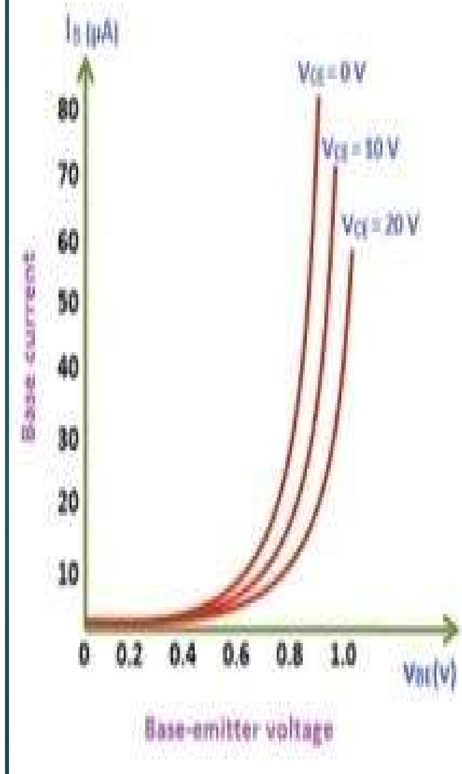
When the transistor is used in Common Emitter configuration, the input is measured between the base and the emitter; the output is measured between the collector and the emitter.




*Input characteristics*

- The variation of base current $I_B$ with base-emitter voltage $V_{BE}$ is called input characteristics.
- While studying the dependence of $I_B$ on $V_{BE}$, the collector-emitter voltage $V_{CE}$ is kept fixed.
- The current is small as long as $V_{BE}$ is less than the barrier voltage.
- When $V_{BE}$ is greater than the barrier voltage, the curves look similar to that of a forward biased diode.
- Input dynamic resistance of transistor – Input dynamic resistance of transistor ($R_i$) is defined as the ratio of change in base-emitter voltage $\delta V_{BE}$ to the resulting change in the base current $\delta I_B$ at constant collector-emitter voltage $V_{CE}$.

$$R_i = \left(\frac{\delta V_{BE}}{\delta I_B}\right) \quad \text{when } V_{CE} \text{ is constant}$$



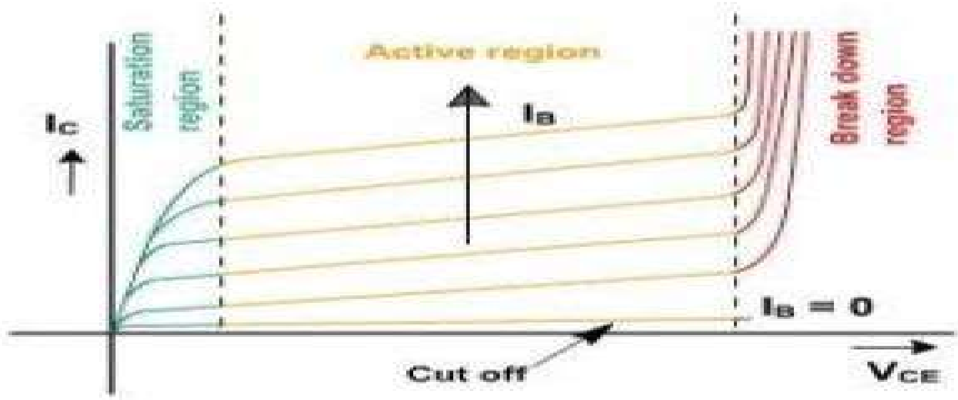
# Continued…………

- Output Characteristics of CE Configuration :

*Output characteristics*

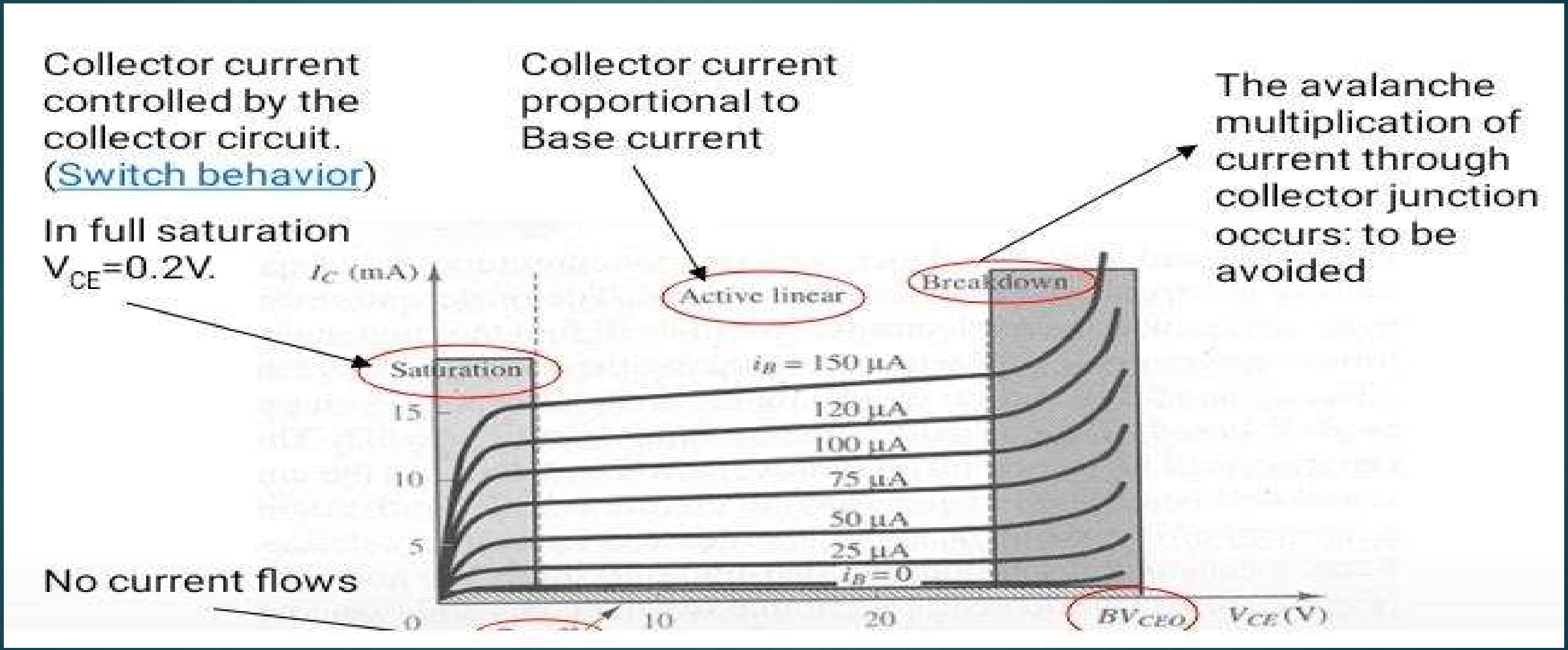
- The variation of collector current $I_C$ with collector-emitter voltage $V_{CE}$ is called output characteristics.
- While studying the dependence of $I_C$ on $V_{CE}$, the base current $I_B$ is kept constant.
- From the graph, we see that as long as the collector-emitter junction is reverse biased, we get $I_C$ almost independent of $V_{CE}$.
- We also find that for the given value of $V_{CE}$, $I_C$ is large for large value of $I_B$.
- Output dynamic resistance of transistor – Output dynamic resistance of transistor ($R_o$) is defined as the ratio of change in collector-emitter voltage $\delta V_{CE}$ to the resulting change in the collector current $\delta I_C$ at constant base current $I_B$.

$$R_O = \left(\frac{\delta V_{CE}}{\delta I_C}\right) \quad \text{when } I_B \text{ is constant}$$



# Continued…………

- Output Characteristics :



# Continued…………

- Common Emitter Amplification Factor :
- It is the ratio of change in collector current to change in base current ,when collector voltage $V_{CE}$ kept constant, $\beta = \Delta I_C / \Delta I_B$ at constant $V_{CE}$
- Expression for collector current:
- In the Common Emitter configuration, $\mathbf{I_B}$ is the input current and $\mathbf{I_C}$ is the output current.

We know

$$I_E = I_B + I_C$$

And

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

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

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

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

If base circuit is open, i.e. if $\mathbf{I_B} = 0$,

The collector emitter current with base open is $I_{CEO}$

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

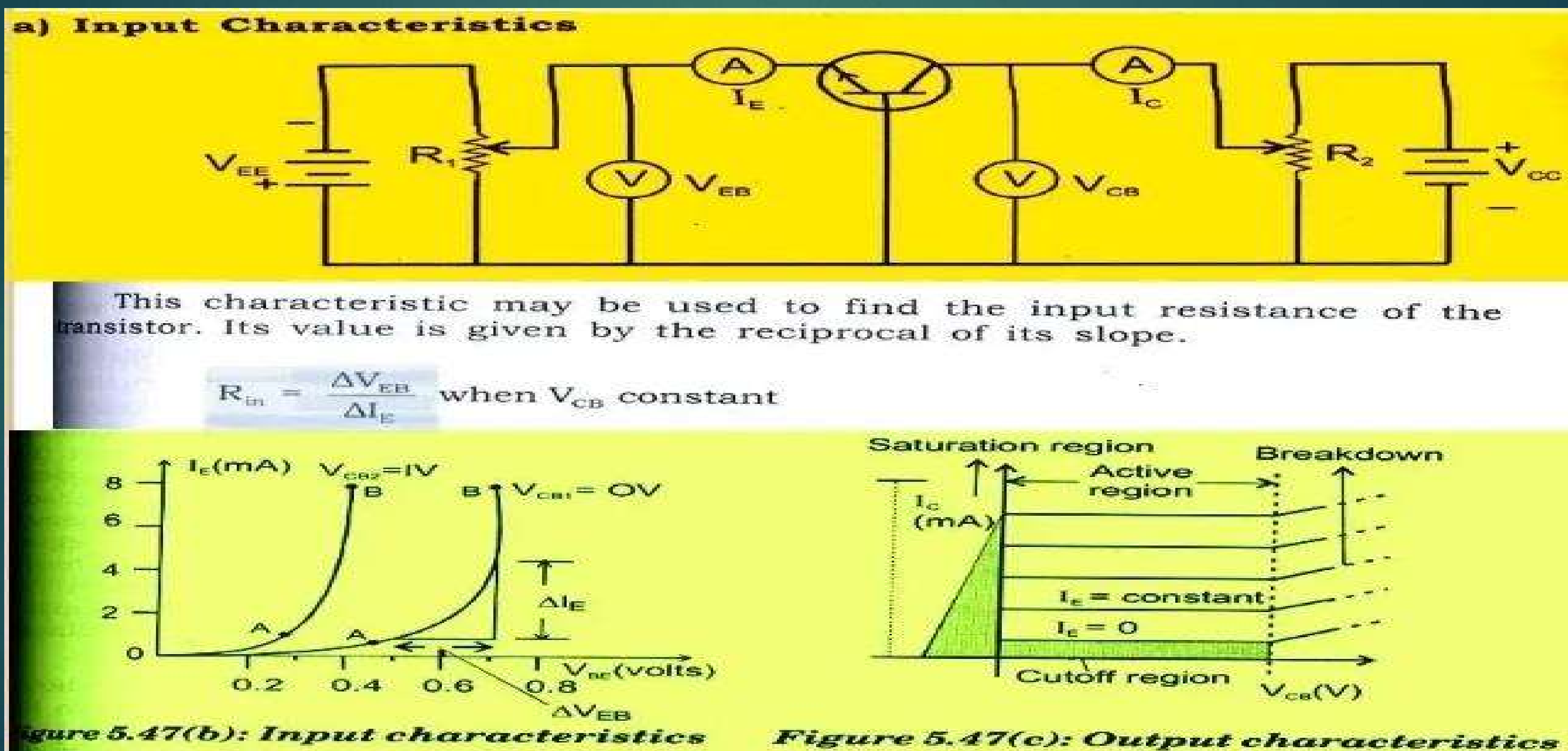
Substituting the value of this in the previous equation, we get

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

$$I_C = \beta I_B + I_{CEO}$$

# Continued…………

- Common Base Characteristics :



# Continued…………

- Common Base Amplification Factor :
- It is the ratio of change in collector current to change in emitter current ,when collector voltage $V_{CB}$ kept constant, $\alpha = \Delta I_C / \Delta I_E$ at constant $V_{CB}$
- Expression for collector current:
- The Emitter current that reaches the collector terminal is $\alpha I_E$
- Total collector current $I_C = \alpha I_E + I_{leakage}$ (due reverse bias junction)
- If the emitter base voltage is zero $V_{EB} = 0$ even then ,there flows a small leakage current which can be termed as $I_{CB0}$ collector base current with emitter terminal is open

# Continued…………

- Collector current :

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

$$I_E = I_C + I_B$$

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

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

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

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

# Continued…………

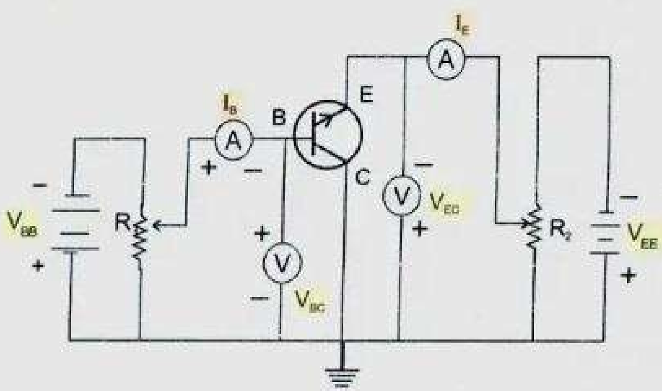
- Common Collector Configuration :

It means that collector terminal is common to input and output. In his case, input signal is applied between base and collector and output ignal is taken out from emitter-collector circuit. Obviously, conventionally peaking, here $I_B$ is the input current and $I_E$ is the output current as hown in figure 5.49(a). The current gain of the circuit is defined as the atio of output current ($I_E$) to input current $I_B$. It is designated as $\gamma$.

$$\gamma = I_E / I_B$$

**haracteristics of CC Configuration**

The circuit arrangement for common collector configuration is shown figure 5.49(a).




The CC output characteristics are plotted, $I_E$ Vs $V_{CE}$ for several fixed lues of $I_B$. We know that the CE output characteristics are plotted $I_C$ $V_s$ $_E$. Since $I_C$ is approximately equal to $I_E$ thus, common collector characteristics identical to CE configuration.

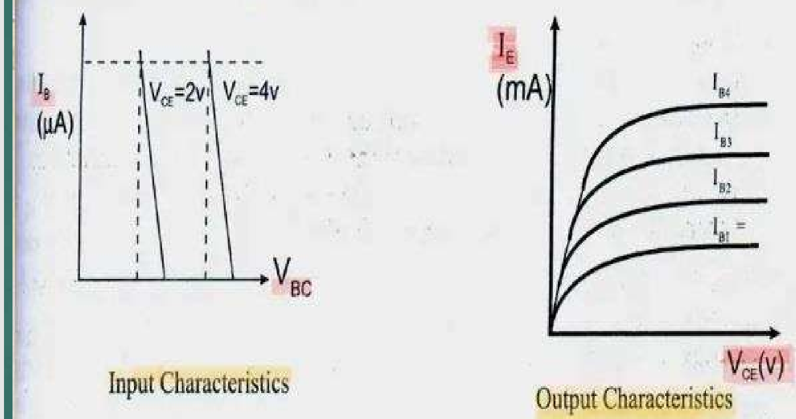



*Figure 5.49(b): VI Characteristics of CC configuration*

The common collector input characteristics are different from CB and configuration. The difference is due to the fact that the input voltage is largely determined by the level of CE voltage.

# Continued…………

- Common Collector Amplification Factor :
- It is the ratio of change in emitter current to change in base current ,when collector voltage $V_{CE}$ kept constant, $\gamma = \Delta I_E / \Delta I_B$ at constant $V_{EC}$
- Expression for collector current:

Expression for collector current

We know

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

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

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

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

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

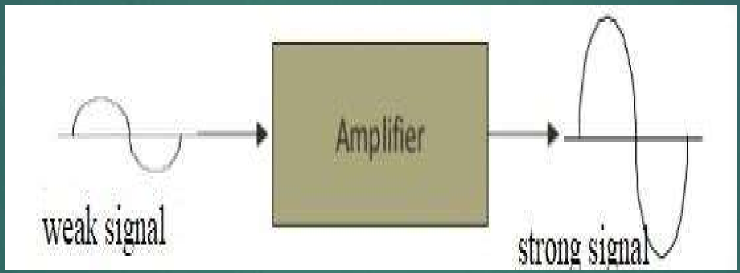
# Continued…………

## Comparison of three configurations

| Characteristics | CB | CE | CC |
|---|---|---|---|
| Input Impedance | low (about 100Ω) | low (about 750kΩ) | high(about 750kΩ) |
| Output Impedance | Very high (about 1MΩ) | High (about 45kΩ) | Low (about 50Ω) |
| Voltage Gain | about 150 (Medium) | about 500 (Medium) | Less than 1 |
| Current Gain | less than unity | High | High |
| Application | for high frequency application | for audio frequency application | for impedance matching |

# Transistor as an Amplifier

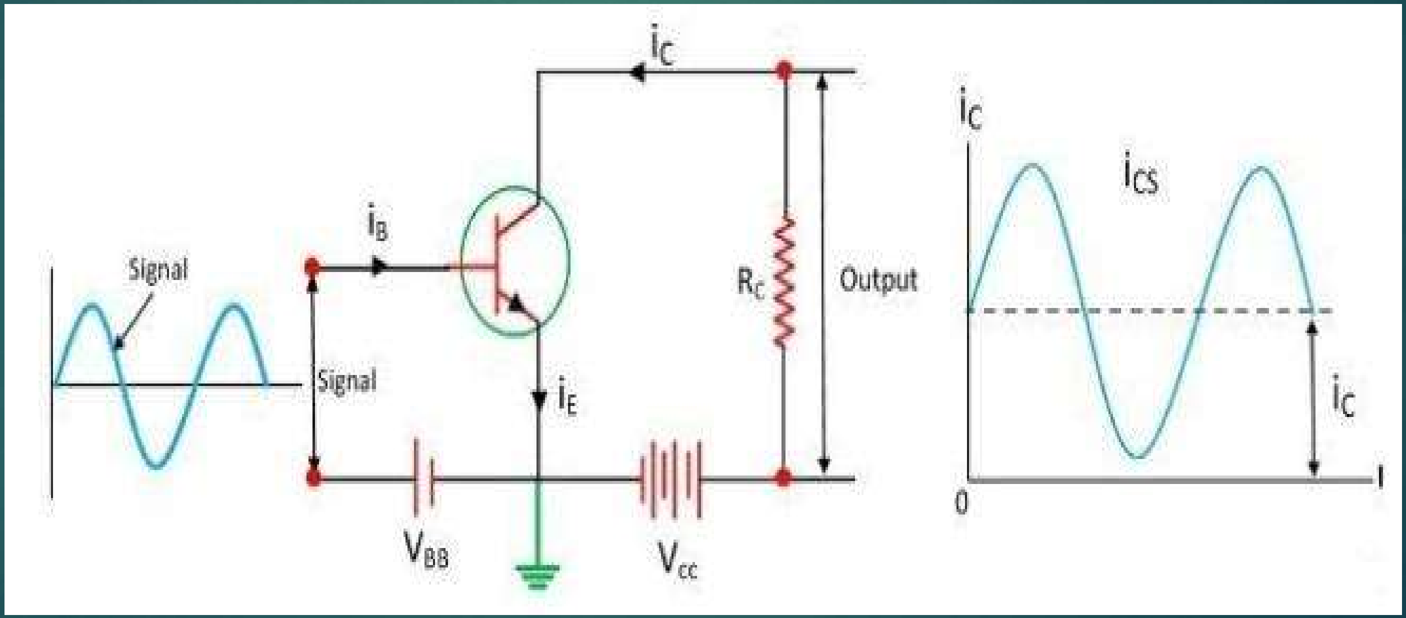
- What is an Amplifier :It is an electronic circuit ,it increases the strength of weak signal without changing its corresponding shape and frequency
- The function of amplifier is to provide an output which is greater than input




- Types of Amplifiers:
- Voltage amplifier: intended provide to voltage gain , $A_V = V_{out} / V_{in}$
- Current amplifier: intended to give current gain , $A_I = I_{out} / I_{in}$
- Power amplifier: both current and voltage can be amplifier
- Inverting amplifier: Gives an amplified output out of phase from input

# Continued…………

- Amplification :The ability of a circuit to receive a small change of input voltage or current and produce a large change in the output volage or current
- Amplification is depends on the change in the transistors resistance caused by an input signal



# Continued…………

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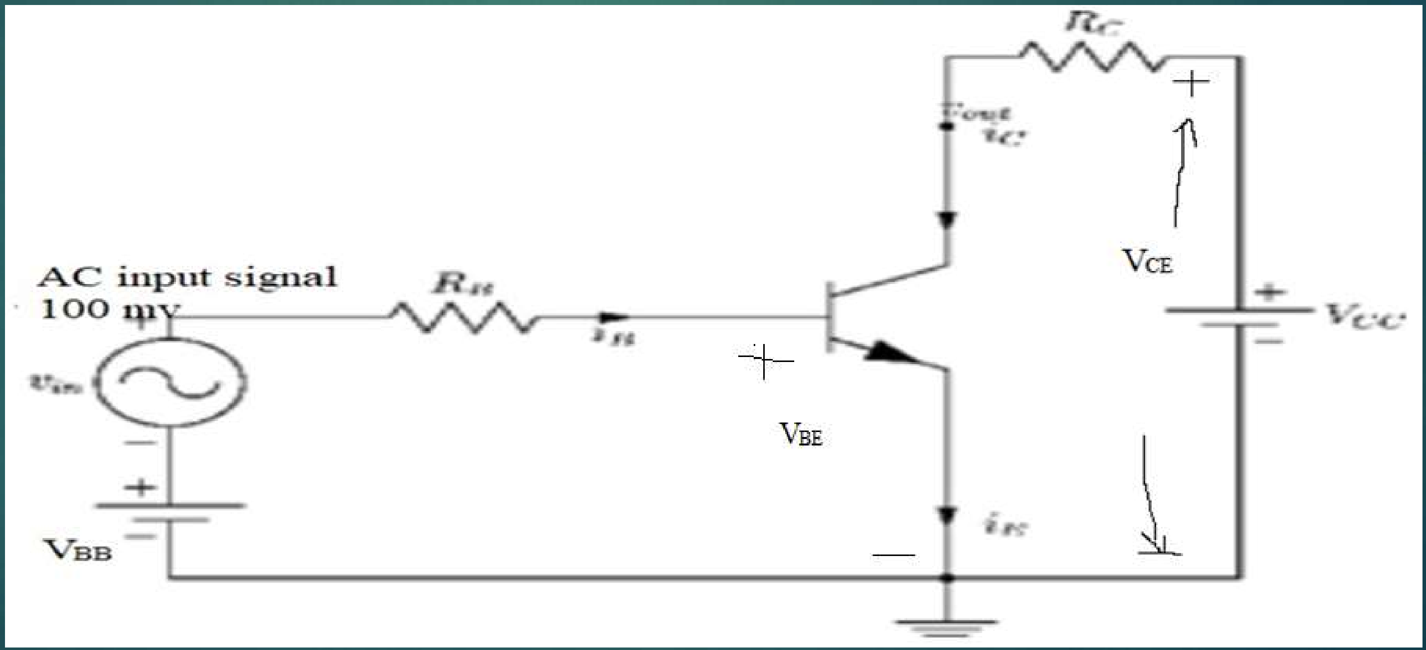

# Continued…………

- Amplification :The ability of a circuit to receive a small change of input voltage or current and produce a large change in the output volage or current
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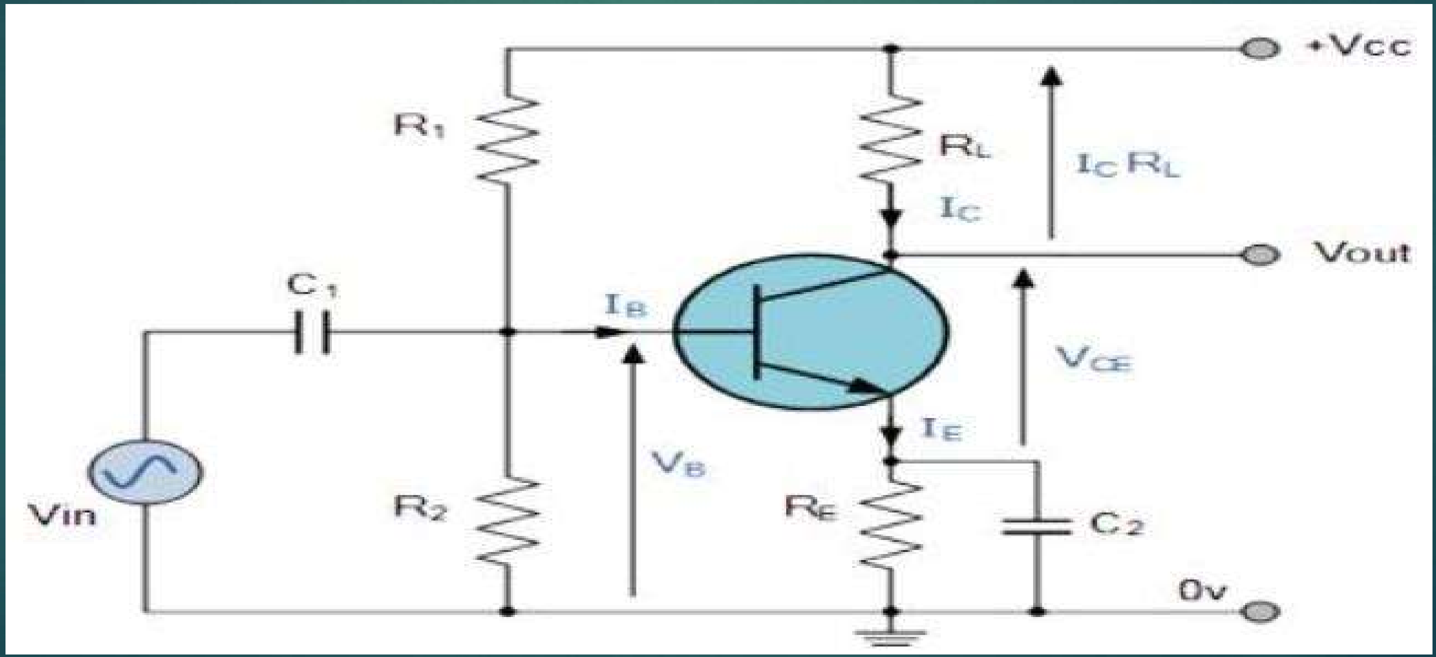

# Continued…………

- Analysis :if you considered $V_0$ or $V_{CE}$ and $V_{in}$ as small changes in output and input voltages respectively ,then V0 / Vin is called as small signal voltage gain $A_V$ of the amplifier
- Apply KVL for the output loop : $-V_{CC} + I_C R_C + V_{CE} = 0$

$$V_{CE} = V_{CC} - I_C R_C$$

$$I_C = (V_{CC} - V_{CE}) / R_C$$

For AC analysis DC supply is Zero ,So collector current

$$I_C = (0 - V_{CE}) / R_C$$

$$I_C = - V_{CE} / R_C$$

Finally output voltage is expressed as $V_{CE} = - I_C R_C \rightarrow$ (i)

# Continued…………

- Analysis : Apply KVL for input loop : $-V_{BB} - V_{in} + I_B R_B + V_{BE} = 0$

$$V_{in} = -V_{BB} + I_B R_B + V_{BE}$$

For AC analysis DC supply is zero ,So input voltage is

$$V_{in} = 0 + I_B R_B + 0$$

$$V_{in} = I_B R_B \rightarrow \text{(ii)}$$

$$I_B = V_{in} / R_B$$

Voltage gain $A_V = V_{CE} / V_{in} = -I_C R_C / I_B R_B$

$$A_V = -\beta R_C / R_B$$

# Continued…………

- Amplification :The ability of a circuit to receive a small change of input voltage or current and produce a large change in the output volage or current
- Amplification is depends on the change in the transistors resistance caused by an input signal