Sweta

BIPOLAR JUNCTION TRANSISTOR (BJT)

Bipolar Junction transistor is a three terminal device Capable of amplification.

It is a current control device i.e o/p current is controlled by i/p current.

BJT is used in no. of application like power amplification, digital switching, analog amplification, high frequency small signal and large signal amplification.

In digital computer electronics, the transistor is used as a high speed electronic switch.

Bipolar junction Transistor (BJT) The term bipolar means that the transistor operation is carried out by two types of charge carriers: Majority and Minority carriers.

Transistor → Transfer + Resistance

i.e transfer of current from low resistance to high resistance circuit.

The Transistor was invented by Dr. William Shockley and Dr. John Bardeen at Bell Laboratory in America in 1951.

Amplification: Transistor has a very important property that it can raise the strength of an input weak signal, called amplification.

A transistor consist of two P-N junctions formed by sandwitching either P-type or N-type semiconductor layers between a pair of apposite type.

The two junctions give rise to three regions provided with three terminals.

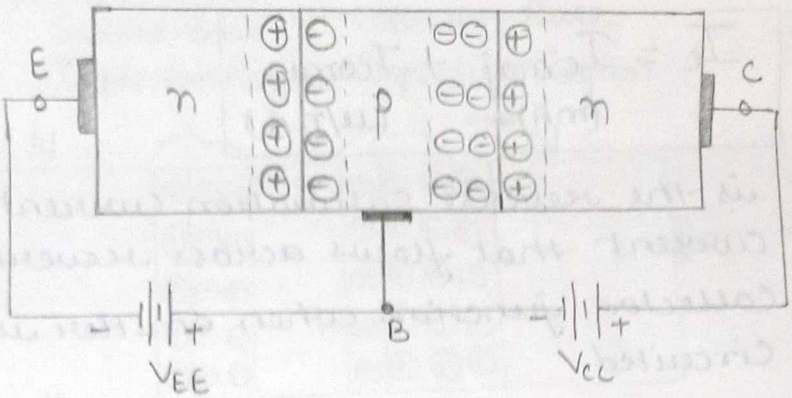
1) Emitter: It is an outer region situated in one side of transistor whose function is to inject majority charge carriers into base. The emitter is heavily doped so that it may be able to inject a large no. of charge carriers.

2.) Base: It is the middle region of the transistor.
→ It is very thin and lightly doped region.
→ Function of Base is to pass all the charge carriers onto the collector.

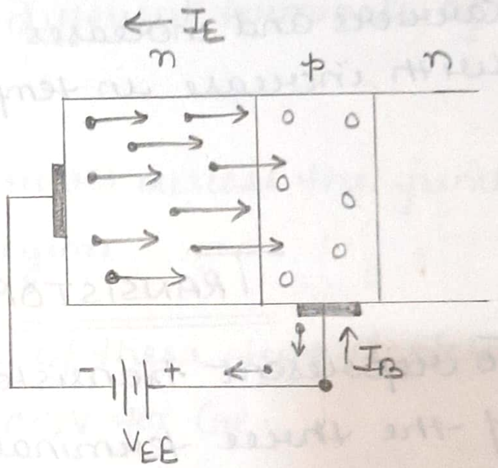
3) Collector: Outer region situated in the other side of transistor.
→ Moderately dopped.
→ Its function is to collect majority charge carriers

∃ Collector region is physically larger than the emitter because it has to dissipate more heat.

Note: To use transistor as an amplifier it must operate in active Region.

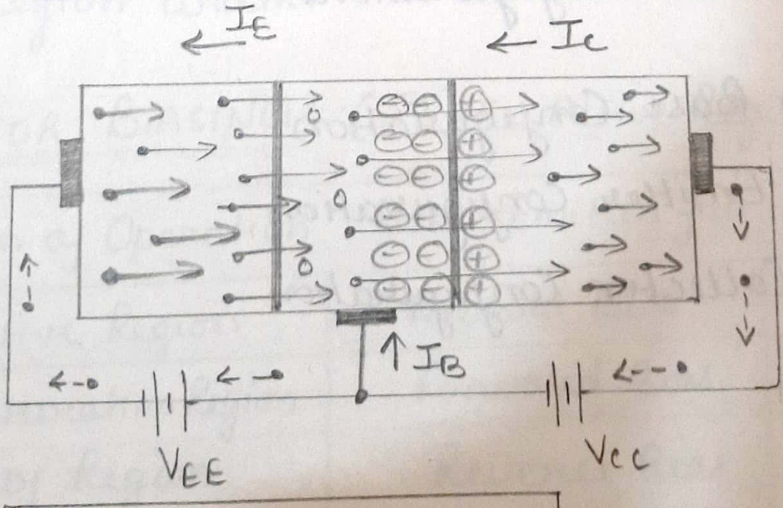


To operate transistor in active region Emitter-Base junction is forward bias and Collector-Base junction is reverse bias



A large number of majority Carriers (electrons) diffuse across the forward biased p-n junction into base (p-type)

Since Base is lightly doped and very thin, a very Small number of carriers contribute of Base Current I_B. and large no. of majority carriers diffuse across the reverse biased junction (C-B) into the n-type material connected to the collector terminal.



$$\boxed{\underset{(mA)}{I_E} = \underset{(mA)}{I_C} + \underset{(\mu A)}{I_B}}$$

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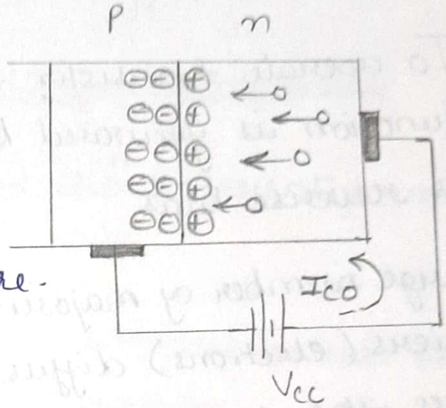
The collector current, however, comprises two components i,e

$$\boxed{I_c = \underset{(mA)}{I_{c\,maj}} + \underset{(\mu/nA)}{I_{co\,min}}}$$

I_{CO} :- is the reverse saturation current or leakage current that flows across reverse biased collector junction when emitter is open circuited.

- Leakage current I_{co} flows due to minority carriers and increases with increase in temperature.



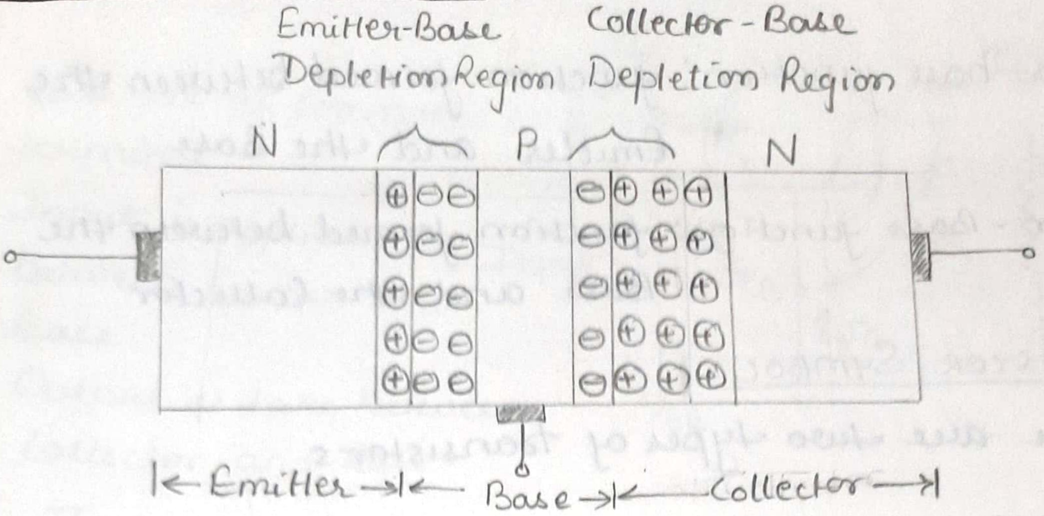
TRANSISTOR CONFIGURATION

To represent transistor as two port network one of the three terminal is treated "common" to input and output port.

Depending on which terminal is made common to input and output port there are three possible configurations.

1. Common Base Configuration
2. Common Emitter Configuration
3. Common Collector Configuration.

UNBIASED TRANSISTOR :



⇒ No battery is connected b/w different terminals of a transistor.

⇒ The diffusion of charge carriers across the junction produces two depletion region.

⇒ Barrier potential for each of these two depletion layer is 0.7 V for Si and 0.3V for Ge.

⇒ Three regions have different doping level
∴ the emitter-base depletion region width is smaller than that of collector base depletion region width.

TRANSISTOR BIASING : (in the Active Region)

Region of Operation	Base - Emitter jun	Collector-Base jun
Active Region	Forward Bias	Reverse Bias
Saturation Region	Forward Bias	Forward Bias
Cutoff Region	Reverse Bias	Reverse Bias
Inverse	Reverse Bias	Forward Bias

A transistor has two P-N junctions

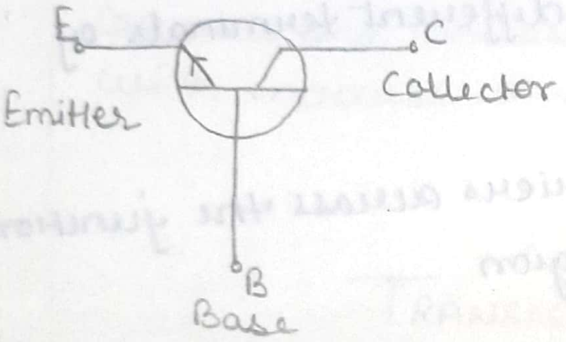
Emitter-base junction: junction formed between the Emitter and the Base

Collector-Base junction: junction formed between the Base and the Collector

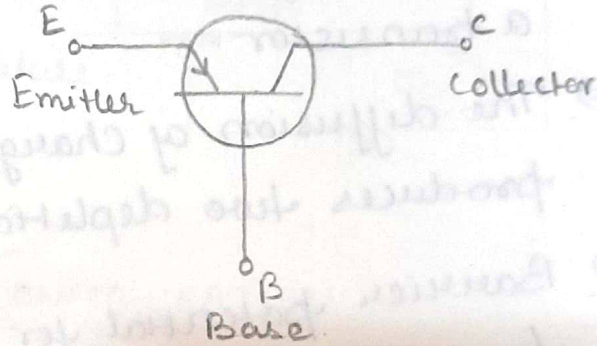
TRANSISTOR SYMBOLS:

There are two types of transistors

NPN



PNP



→ Majority Charge Carriers are free electrons

→ Majority Charge Carriers are holes.

The arrowhead indicates the direction of a conventional current flow in a transistor.

NPN transistor is mostly used?

In NPN transistors, current conduction is mainly by electrons where as in PNP current conduction is mainly by holes. Since the electrons are more mobile than holes, the conduction is higher in NPN transistor than PNP transistor.

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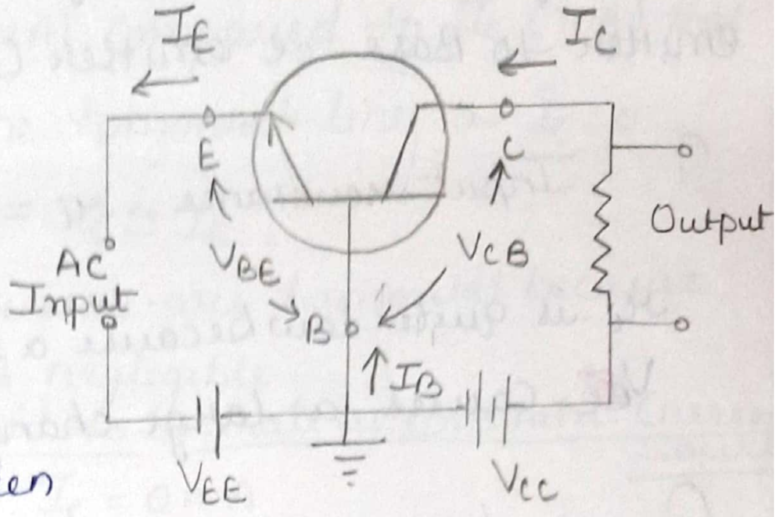
- Base act as Common terminal
- Input is applied between Emitter and Base
- Output is take between Collector and Base.

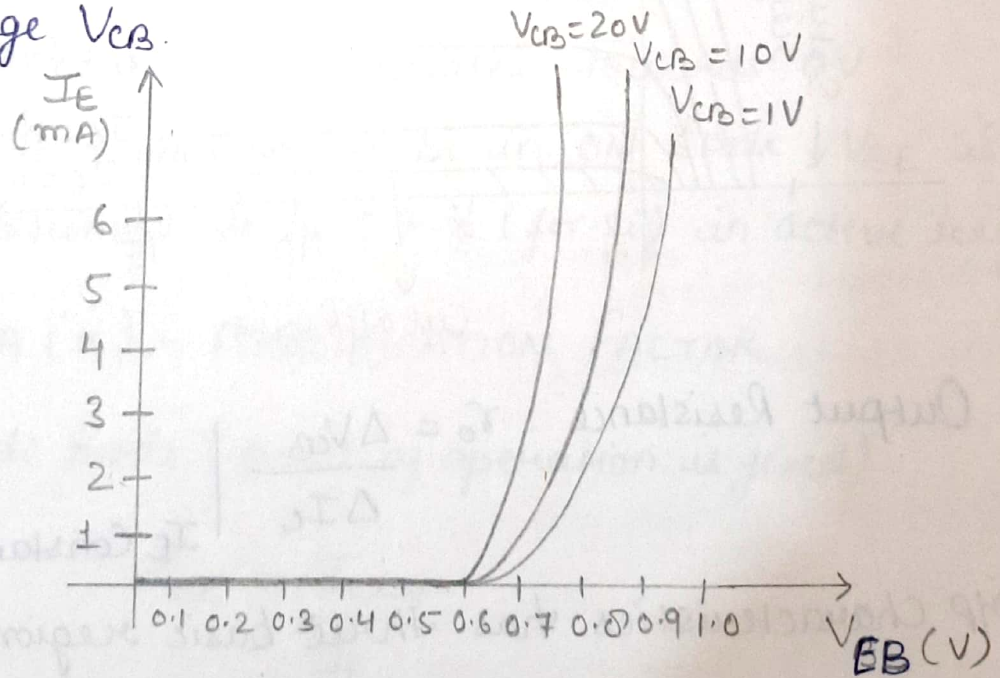


- I_E and V_{BB} are input Current and Voltage
  I_C Output Current and V_{CB} Output Voltage

CHARACTERISTICS

1) INPUT / DRIVING POINT CHARACTERISTICS

Input characteristics is plotted at a Constant output Voltage V_{CB}.



Emitter current increases slightly with increase in output Voltage V_{CB}, with increase in reverse voltage applied to CB junction effective width of Base decrease due to increase in depletion region.

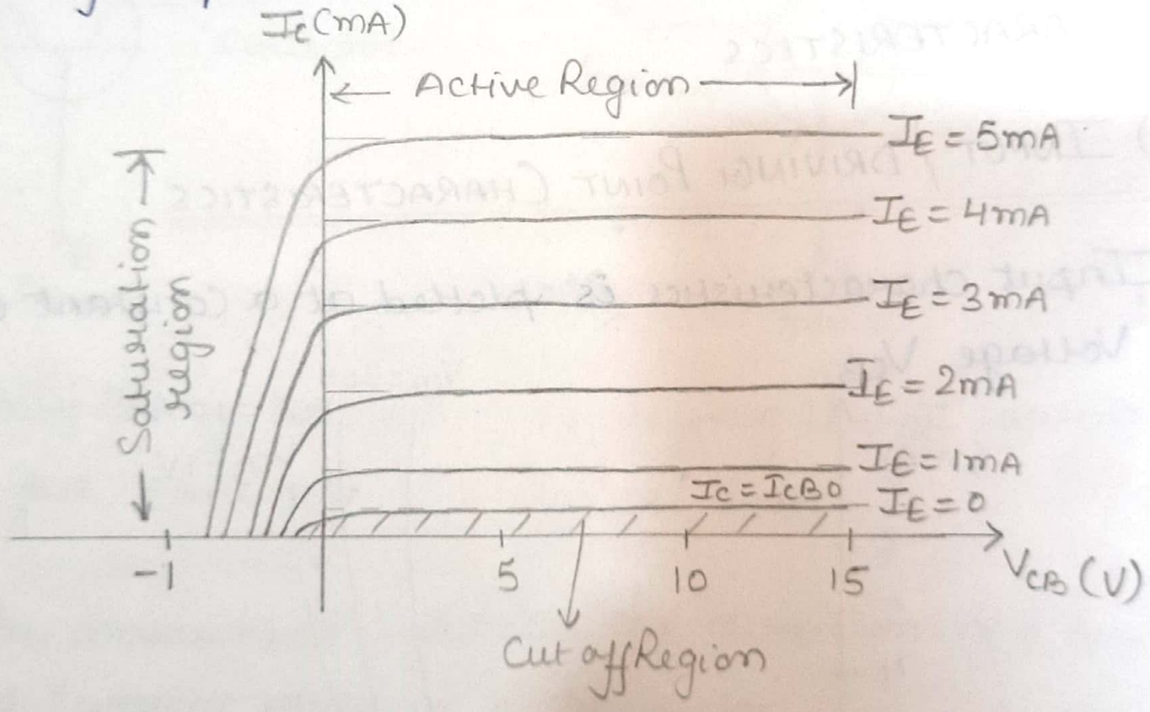
This increase the charge concentration gradient in base region ∴ more no. of electrons diffuse from emitter to Base i.e emitter current increases.

$$\text{Input resistance, } r_i = \frac{\Delta V_{EB}}{\Delta I_E}\Bigg|_{V_{CB}\ \text{Constant}}$$

r_i is quite low because a small increase in V_{BE} causes a large change in I_E

OUTPUT / COLLECTOR CHARACTERISTICS

The output characteristics is plotted for a constant value of Input Current.



$$\text{Output Resistance } r_o = \frac{\Delta V_{CB}}{\Delta I_C}\Bigg|_{I_E\ \text{Constant}}$$

the o/p characteristics has three basic regions:

1. Active Region: (Amplification / Linear Region)
   Base-Emitter junction → forward Bias
   Collector-Base junction → Reverse Bias

- When $I_E = 0$, $I_C = I_{CBO}$ (Reverse Saturation Current)

I_{CO} is so small (μA) compared to I_C (mA) that it appears on same horizontal line as $I_C = 0$

- In active region $I_C \simeq I_E$
- Also, the characteristics are horizontal because the effect of V_{CB} is negligible.
- ∴ Transistor is said to operate as Constant Current Source

2) Cut-off Region: $I_C = 0\,mA$

Base-Emitter junction → Reverse biased
Collector-Base junction → Reverse biased
Transistor is in OFF State

3) Saturation Region: It is the characteristics to the left of $V_{CB} = 0$ (Transistor is ON)

Base-Emitter junction → forward Biased
Collector-Base junction → forward Biased

- There is exponential increase in collector current as voltage V_{CB} increases towards 0V

Note: for transistor to be in ON state, V_{BE} is assumed to be 0.7 V (for Si) in active region

ALPHA (α) - AMPLIFICATION FACTOR

In dc mode (point of operation is fixed)

$$\alpha_{dc} = \frac{I_{C_{maj}}}{I_E}$$

where I_C & I_E are due to majority carriers

Practically, $\alpha = 0.90$ to 0.998

Ideally, $\alpha = 1$

We know, $I_C = I_{C\,maj} + I_{CBO}$ minority

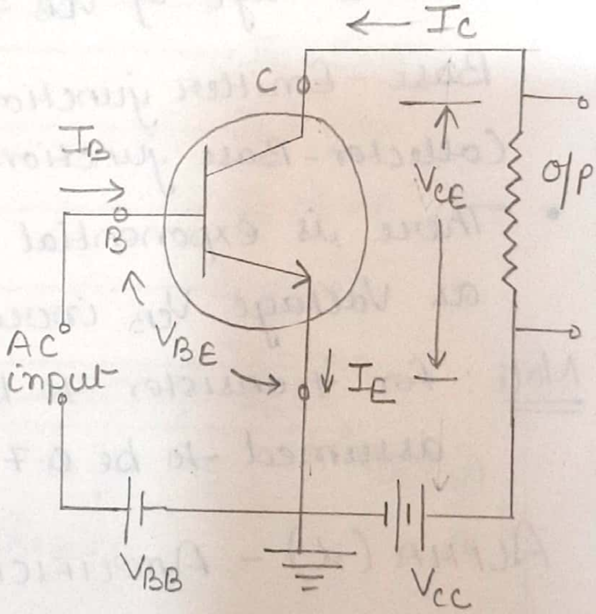
$$\therefore \boxed{I_C = \alpha I_E + I_{CBO}}$$

In ac mode (point of operation moves on characteristics curve)

$$\boxed{\alpha_{ac} = \frac{\Delta I_C}{\Delta I_E}\bigg|_{V_{CB} = \text{Constant}}}$$

Note: α is also called Common base amplification factor and $\alpha \leq 1$

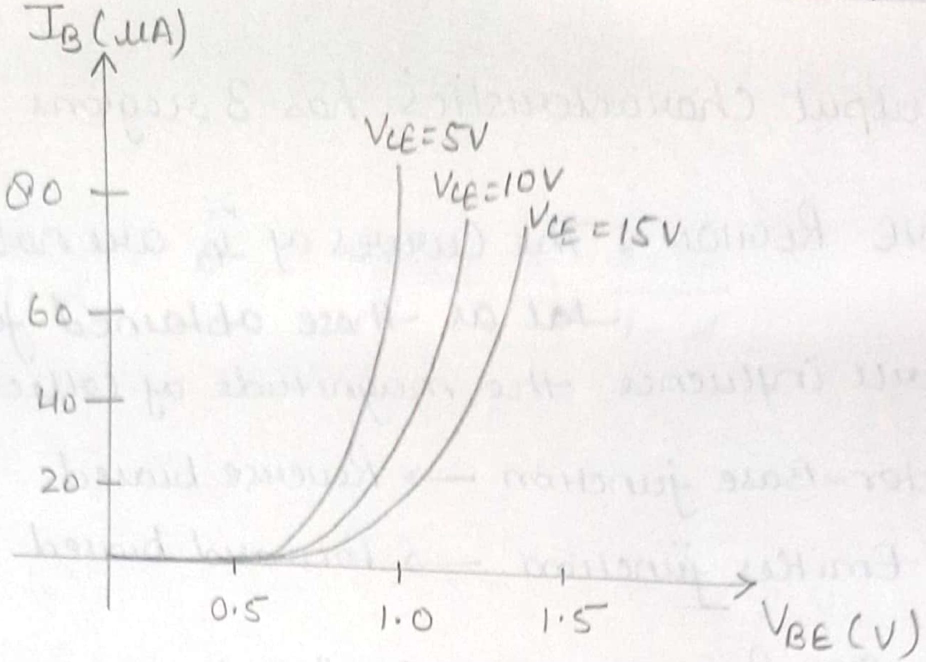
2. COMMON EMITTER CONFIGURATION



- Emitter is common to both the i/p and o/p terminals.
- Input is applied between Base and Emitter, V_{BE} is input voltage and I_B is input current
- Output is taken between Collector and Emitter, V_{CE} is output voltage and I_C is output current.

INPUT CHARACTERISTICS

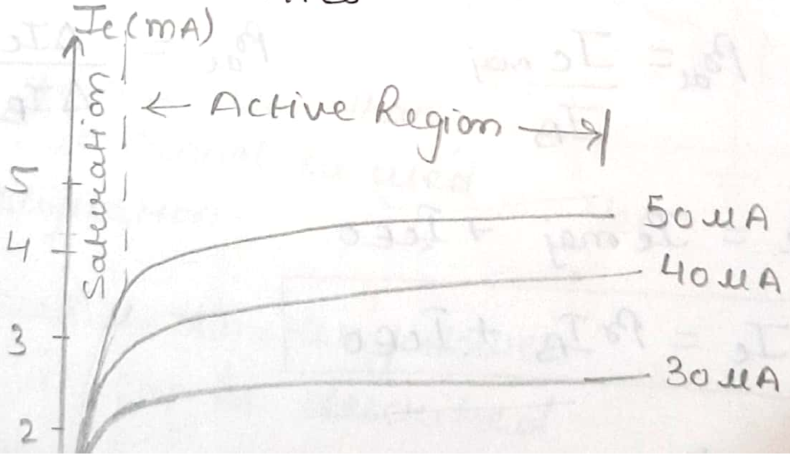
$$\text{Input resistance } r_i = \frac{\Delta V_{BE}}{\Delta I_B}$$



- I_B decreases with increase in V_{CE}

V_{CE} increase the CB junction is more Reverse Bias
↓
The depletion region at CB junction penetrate more into Base
↓
This reduces the electrical width of the Base
↓
The chances of recombination in base reduces
↓
Hence Base current reduce.

OUTPUT CHARACTERISTICS



The output characteristics has 3 regions

1) ACTIVE REGION : The curves of I_B are not as horizontal as those obtained for I_E because V_{CE} will influence the magnitude of collector current

Collector-Base junction $\rightarrow$ Reverse biased

Base-Emitter junction $\rightarrow$ forward biased

2) CUT-OFF REGION : Not similar to CB configuration because I_C is not equal to zero when $I_B = 0$

3) SATURATION REGION : The region to the left of $V_{CE\,sat}$ is called the saturation region.

Note : Equations $\left.\begin{array}{l} I_E = I_C + I_B \\ \text{and} \quad I_C = \alpha I_E \end{array}\right\}$ applicable in CE configuration

Common Emitter amplification factor (β)

$$\beta_{dc} = \frac{I_{C\,maj}}{I_B} \qquad \beta_{ac} = \frac{\Delta I_C}{\Delta I_B} \qquad \left[\begin{array}{l} \beta_{dc} = h_{FE} \\ \beta_{ac} = h_{fe} \end{array}\right.$$

$$I_C = I_{C\,maj} + I_{CEO}$$

$$\therefore \boxed{I_C = \beta I_B + I_{CEO}} \quad \text{— (1)}$$

We know that

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

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

$$I_C = \frac{\alpha I_B}{1-\alpha} + \frac{I_{CBO}}{1-\alpha} \quad \text{— (2)}$$

on comparing (1) & (2)

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

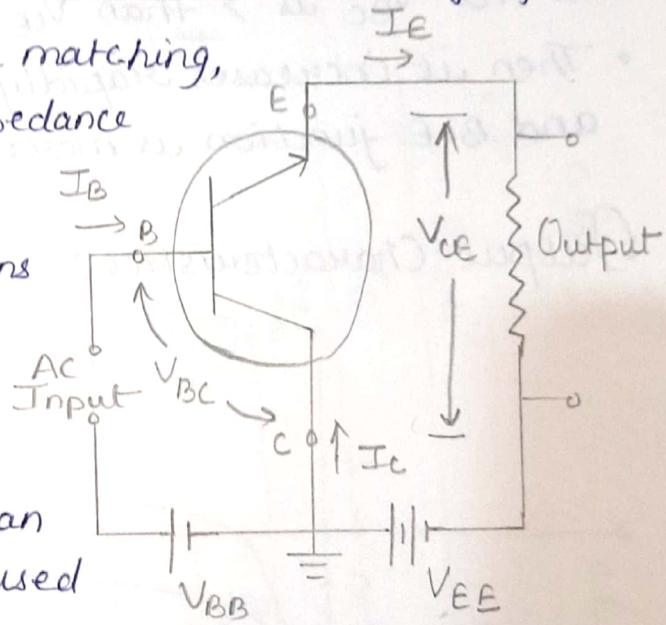
$$I_{CEO} = \frac{I_{CBO}}{1 - \frac{\beta}{1+\beta}}$$

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

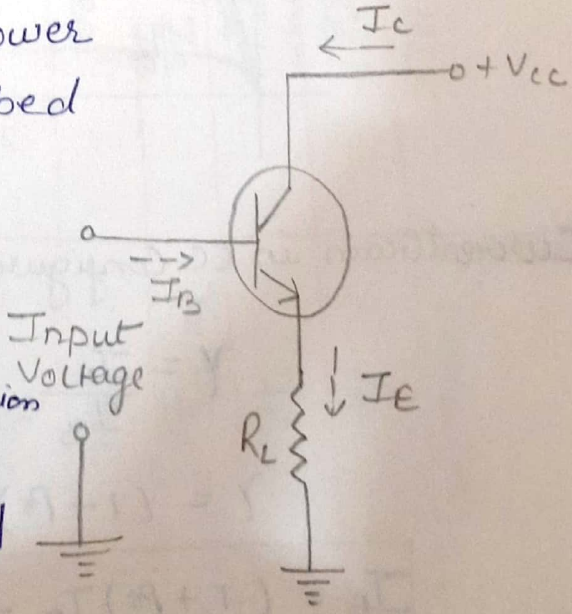
$$\therefore \boxed{I_C = \beta I_B + (1+\beta)\, I_{CBO}}$$

COMMON COLLECTOR CONFIGURATION (Voltage follower)

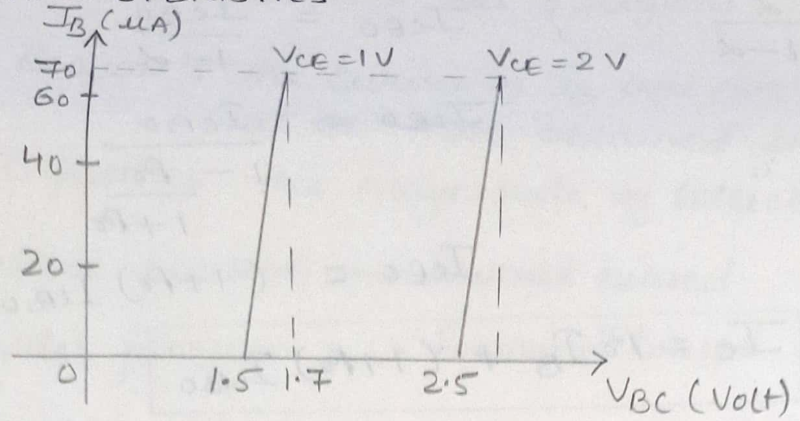
- It is used for impedance matching, Since it has high i/p impedance and low o/p impedance
- Impedance matching means driving low impedance from high impedance Source
- Voltage gain is less than unity ∴ it cannot be used for amplification.



- Also called as Emitter follower because it can be described as follows.
- The Common Collector Configuration is basically Same as the CE Configuration
- The only difference is that the load is Connected in the Emitter.

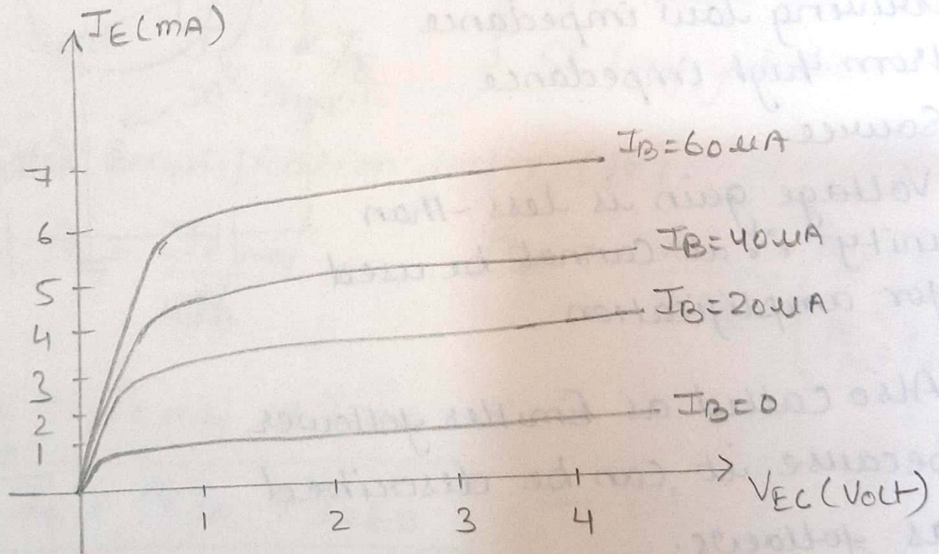


INPUT CHARACTERISTICS



- The Base-Emitter junction is not forward biased till V_{BC} is > than V_{CE}
- Then it increases rapidly as the V_{BC} is increased, and B-E junction is more and more forward biased.

Output Characteristics:



Current Gain in CC Configuration (γ)

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

$$\gamma = (1+\beta)$$

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

Comparision of Configuration

Parameter	CB	CE	CC
Common terminal b/w input & output	Base	Emitter	Collector
Input Current	I_E	I_B	I_B
Output Current	I_C	I_C	I_E
Current gain	$\alpha_{dc} = \frac{I_C}{I_E}$	$\beta_{dc} = \frac{I_C}{I_B}$	$\gamma = \frac{I_E}{I_B} = (1+\beta_{dc})$
Input voltage	V_{EB}	V_{BE}	V_{BC}
Output Voltage	V_{CB}	V_{CE}	V_{EC}
Voltage gain	Medium	Medium	Less than 1
Input Resistance	Very low (20 Ω)	Low (1K Ω)	High (500K Ω)
Output Resistance	Very high (1M Ω)	High (40K Ω)	Low (50 Ω)
Application	As Preamplifier	Audio Amplifier	For impedance matching

Why CE configuration most preferred.

1. high voltage gain as well as high current gain
2. high power gain
3. Moderate values of R_i and R_o

∴ Many such stages can be coupled to each other without using any additional impedance matching circuits. Due to this automatic impedance matching, maximum power transfer will take place from one stage to the other.

DIFFERENCE BETWEEN THREE CONFIGURATIONS

S.No	CHARACTERISTICS	CB	CE	CC
1.	Input Resistance	VERY LOW	LOW	HIGH
2.	Output Resistance	VERY HIGH	HIGH	LOW
3.	Current Gain	LESS THAN UNITY	HIGH	HIGH
4.	VOLTAGE GAIN	SMALL	HIGH	LESS THAN UNITY
5.	Leakage Current	VERY SMALL	VERY LARGE	VERY LARGE
6.	Applications	HIGH FREQUENCY Application	AUDIO FREQUENCY Application	IMPEDANCE MATCHING

Out of all CE configuration is widely used because of the following reasons :-

1) HIGH CURRENT GAIN

$\beta \rightarrow$ range (50 – 500)

2) HIGH VOLTAGE & POWER GAIN

Due to High output resistance and high current gain the voltage gain & power gain are high

3) MODERATE OUTPUT TO INPUT IMPEDANCE RATIO

$$\frac{\text{Output Resistance}}{\text{Input Resistance}} = \text{Moderate Value (about 50)}$$

RELATIONSHIPS BETWEEN α, β and γ

We know that

$$I_E = I_C + I_B \quad , \qquad \alpha = \frac{I_C}{I_E} \quad \beta = \frac{I_C}{I_B} \quad \gamma = \frac{I_E}{I_B}$$

Dividing by I_C

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

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

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

Also, $\gamma = \frac{I_E}{I_B}$

$$I_E = I_C + I_B$$

Dividing by I_E

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

$$1 = \alpha + \frac{1}{\gamma}$$

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

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