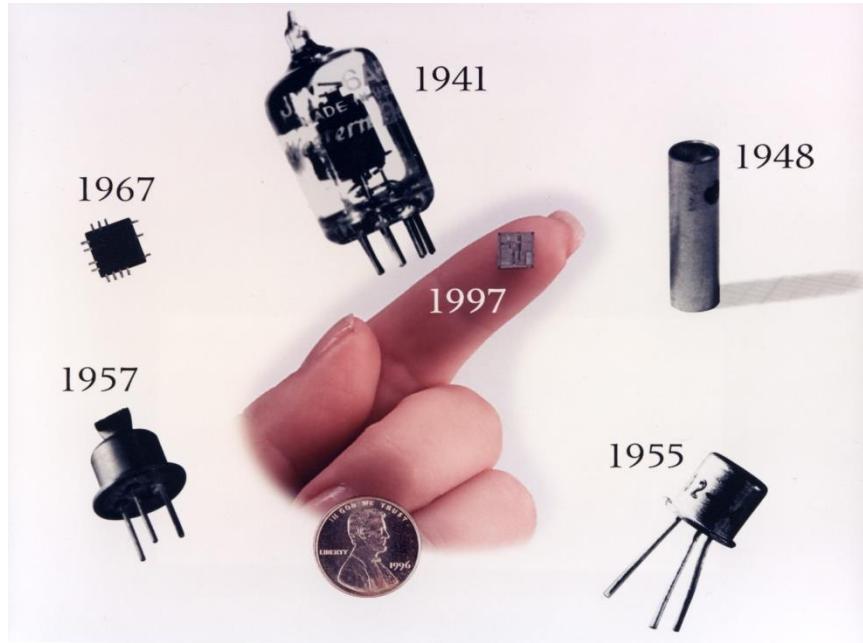


# BIPOLAR JUNCTION TRANSISTOR (BJT)

# BIPOLAR JUNCTION TRANSISTOR: HISTORY

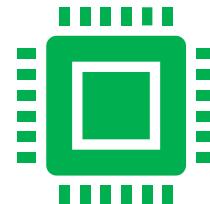
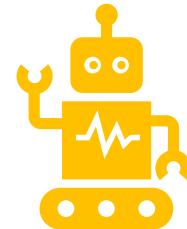


**Invented in 1947 by Shockley, Bardeen, and Brattain at Bell Laboratories**

Ref: [http://www.bellsystemmemorial.com/belllabs\\_transistor.html](http://www.bellsystemmemorial.com/belllabs_transistor.html)

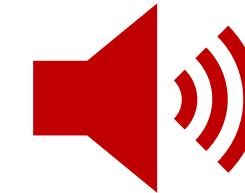
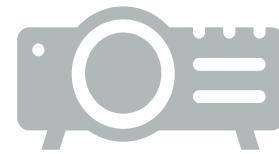
# BIPOLAR JUNCTION TRANSISTOR: APPLICATIONS

1010  
1010



Digital Electronics

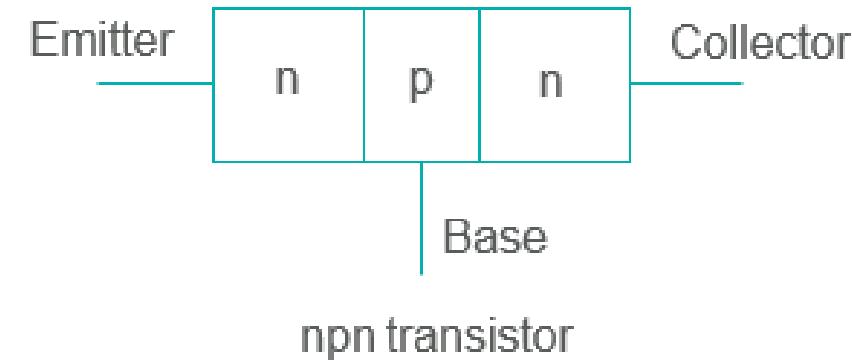
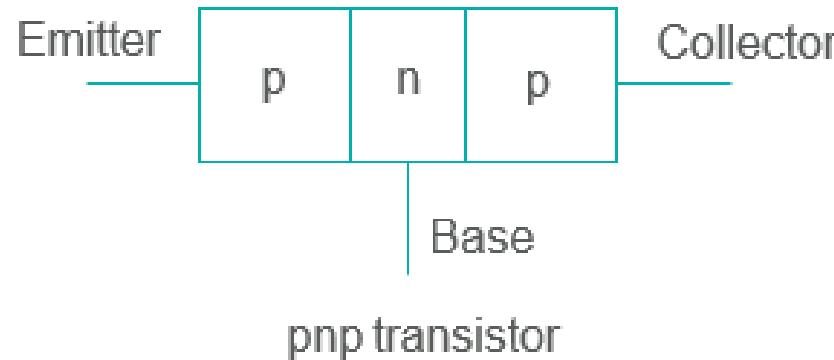
(switch)



Analog Electronics

(Amplifier)

# BIPOLAR JUNCTION TRANSISTOR



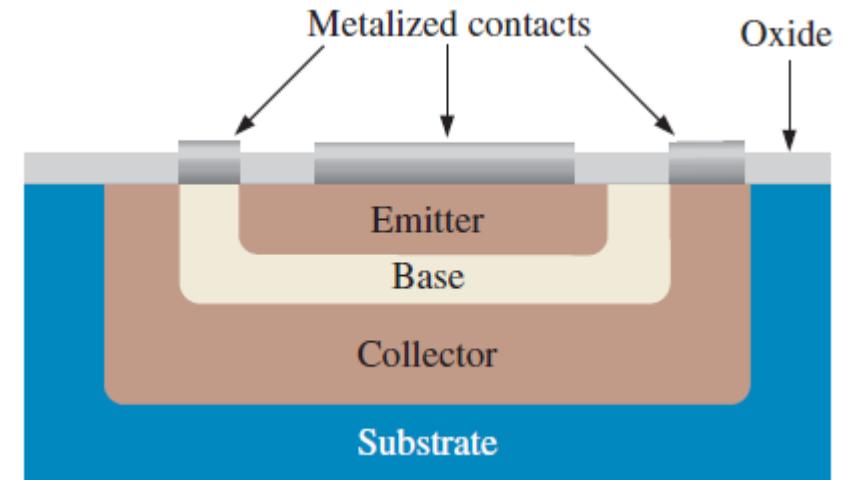
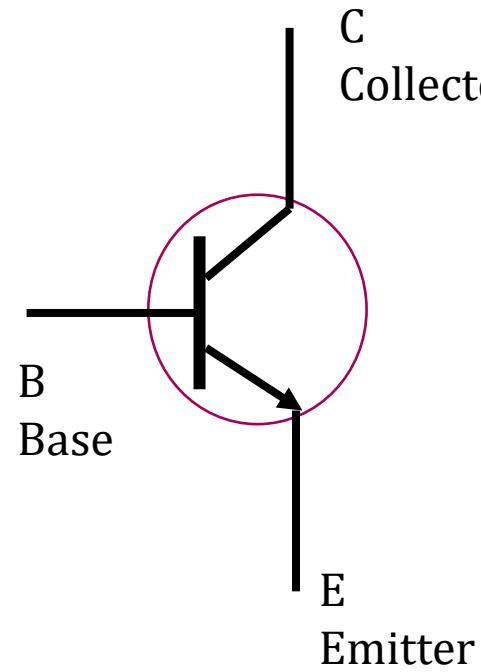
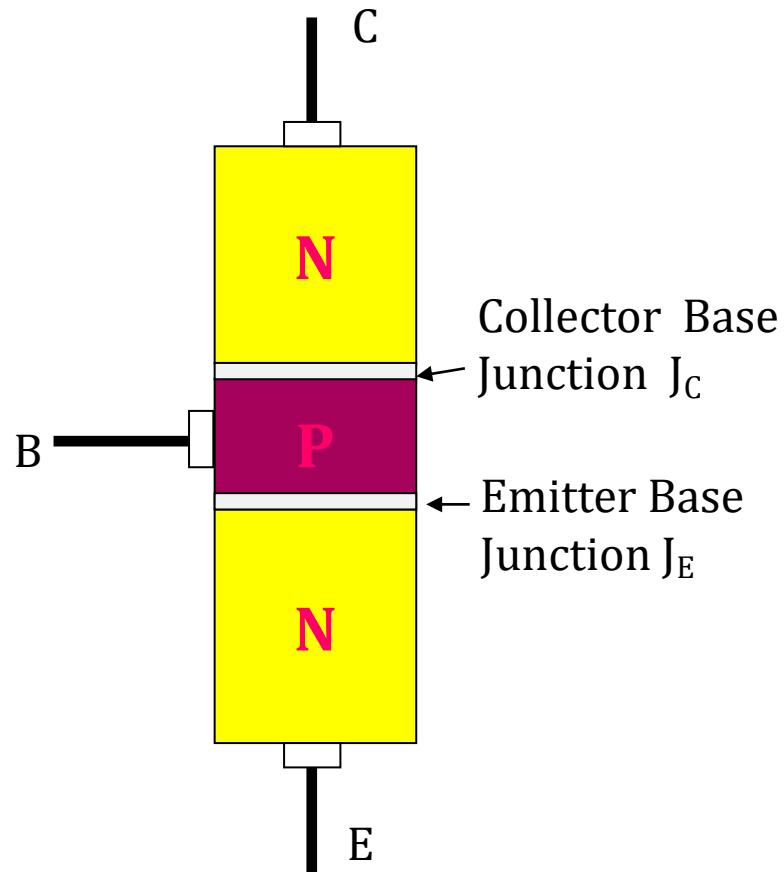
# BIPOLAR JUNCTION TRANSISTOR

- \* Bipolar: both electrons and holes contribute to conduction
- \* Junction: device includes two *p-n* junctions
- \* Transistor: “**transfer resistor**”

When Bell Labs had an informal contest to name their new invention, one engineer pointed out that it acts like a resistor, but a resistor where the voltage is transferred across the device to control the resulting current.

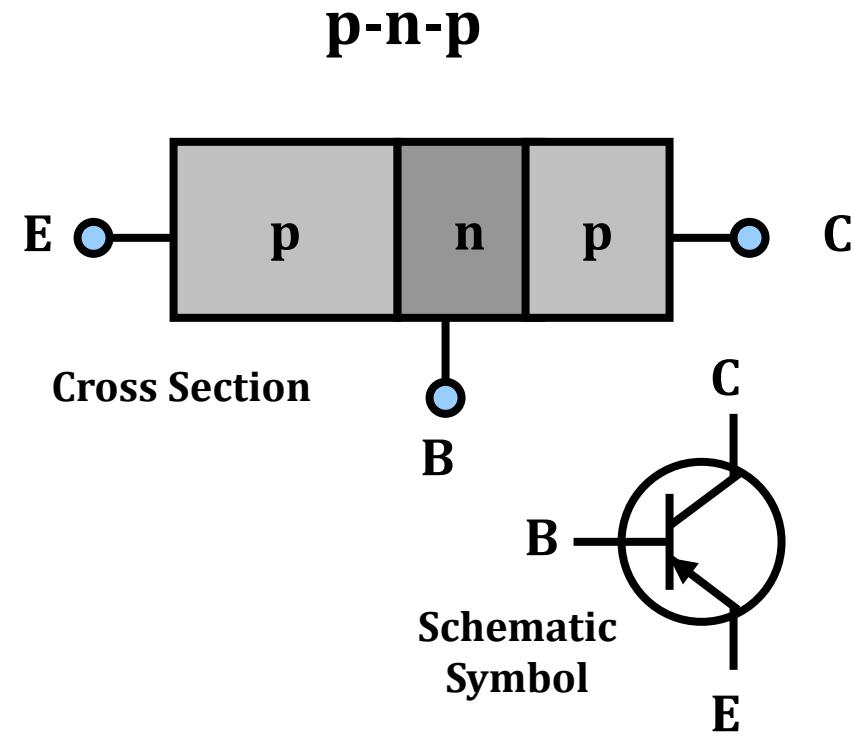
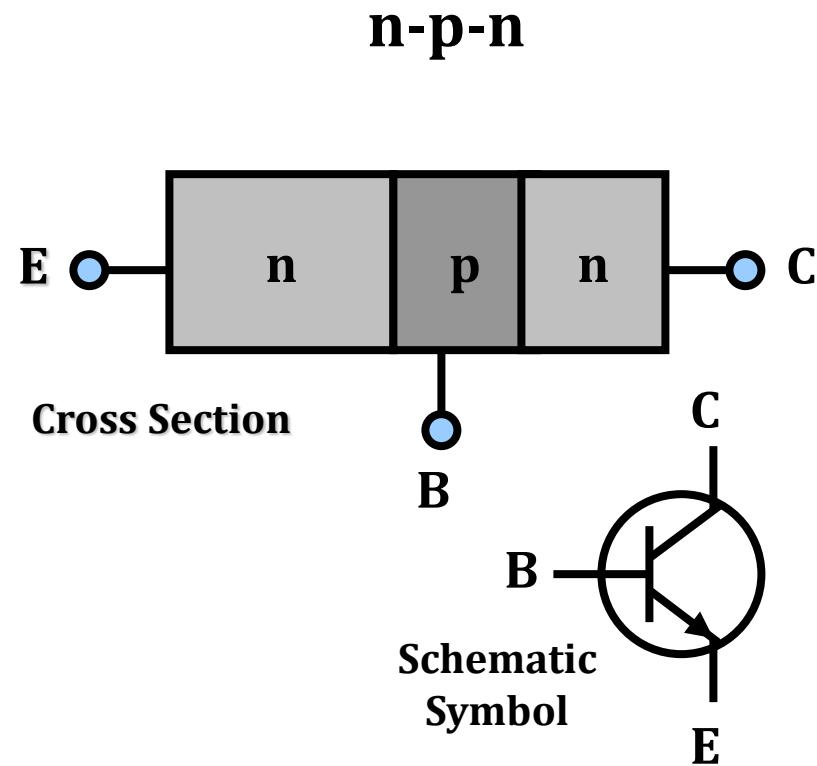
(<http://amasci.com/amateur/trshort.html>)

# N-P-N TRANSISTOR



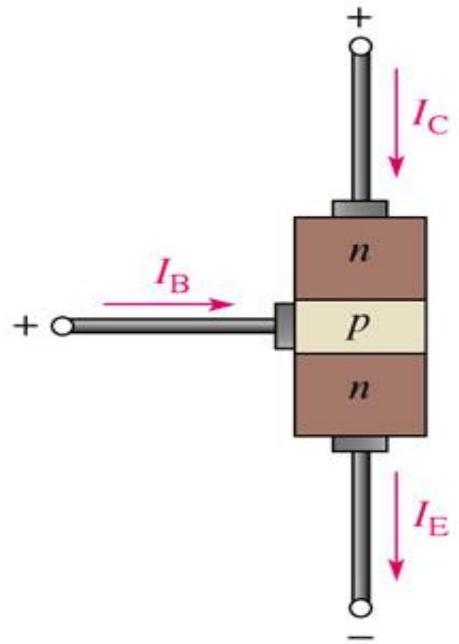
Basic epitaxial planar structure

# Bipolar Junction Transistor



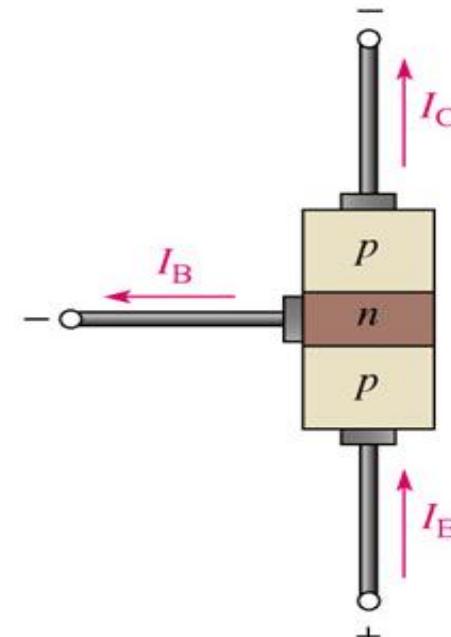
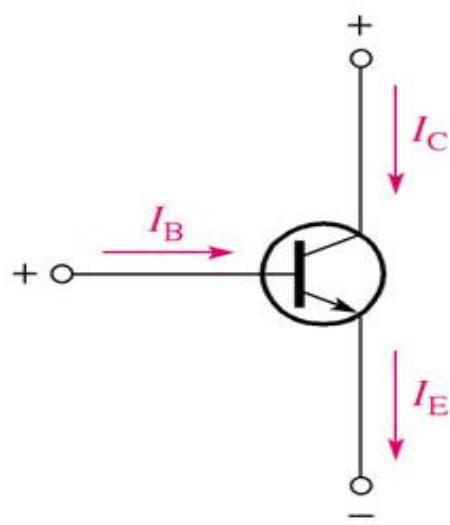
Normally Emitter is heavily doped, Base is lightly doped, and Collector has Moderate doping.

# BIPOLAR JUNCTION TRANSISTOR: CURRENTS



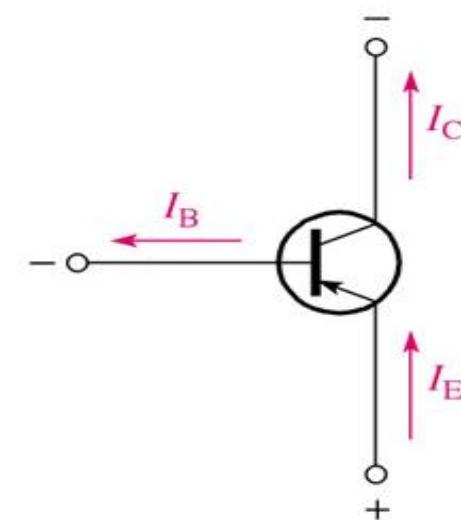
(a) npn

$$I_E = I_B + I_C$$

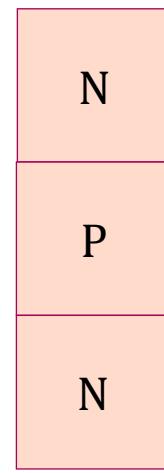
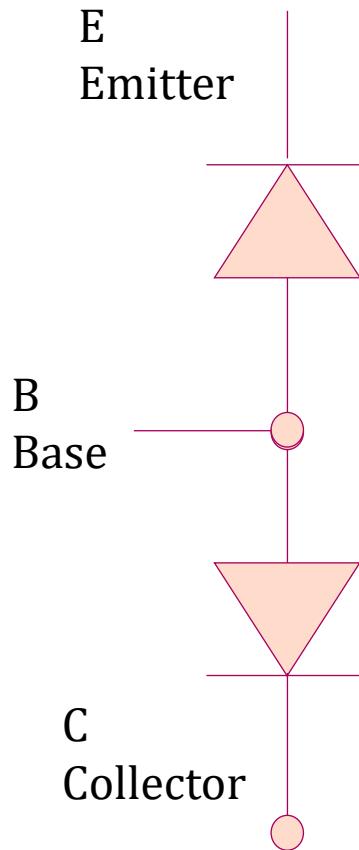


(b) pnp

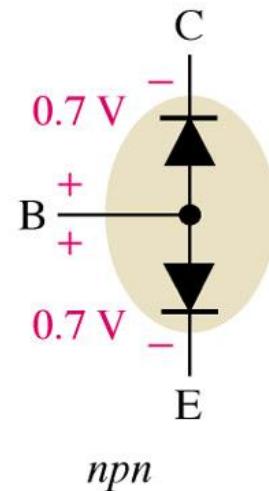
$$I_E = I_B + I_C$$



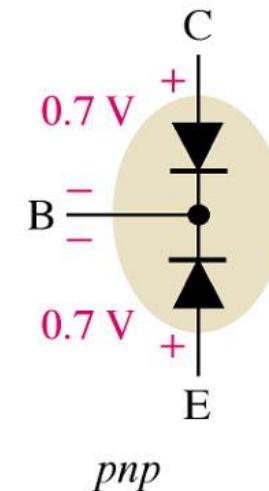
# NUMBER OF P-N JUNCTIONS AND EQUIVALENT CIRCUIT



E  
B  
C

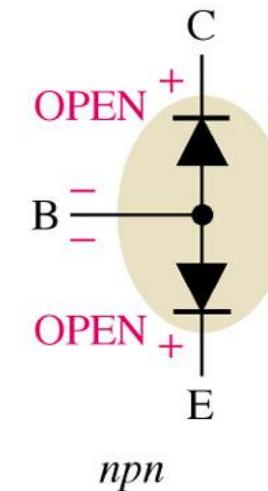


*npn*

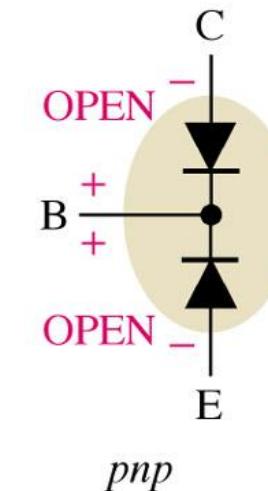


*pnp*

(a) Both junctions should read  $0.7 \text{ V} \pm 0.2 \text{ V}$  when forward-biased.



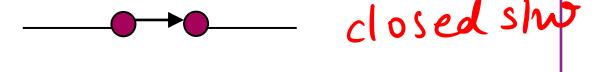
*npn*



*pnp*

(b) Both junctions should ideally read OPEN when reverse-biased.

# BIPOLAR JUNCTION TRANSISTOR: BIASING

Sr. No.	Region of Operation	<u>Base Emitter Junction</u>	<u>Collector Base Junction</u>	Application
✓1	<u>Cutoff Region</u>	Reverse Biased	Reverse Biased	Transistor is OFF  open switch
✓2	<u>Saturation Region</u>	Forward Biased	Forward Biased	Transistor is ON  closed switch
3	Active Region	<u>Forward Biased</u>	<u>Reverse Biased</u>	Amplifier
4	Reverse Active	Reverse Biased	Forward Biased	

# BIPOLAR JUNCTION TRANSISTOR: ACTIVE REGION

Base Emitter Junction : Forward Bias

Collector Base Junction: Reverse Bias

$$\frac{n-p-n}{1 > B-E :}$$

$$V_B > V_E$$

$$2 > C-B :$$

$$V_C > V_B$$

$$\Rightarrow V_C > V_B > V_E$$

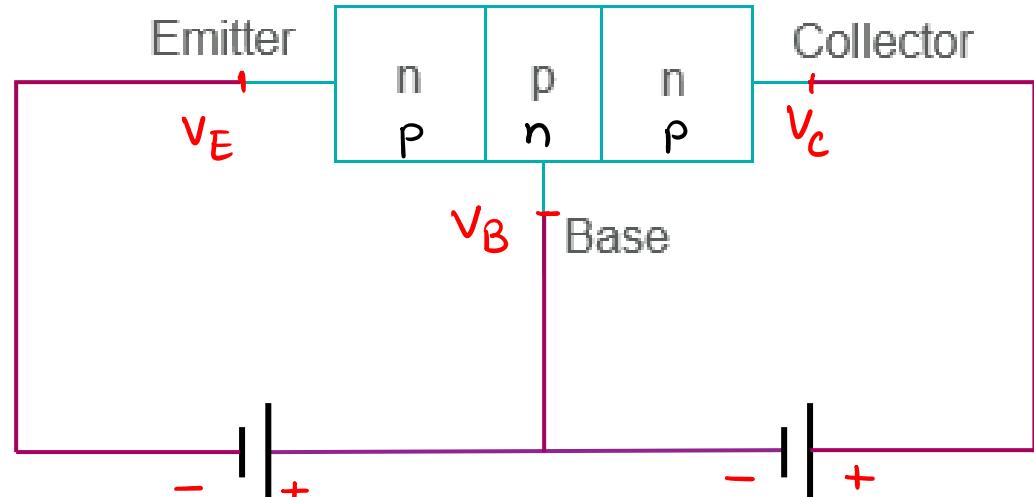
$$\frac{p-n-p}{1 > B-E :}$$

$$V_E > V_B$$

$$2 > C-B :$$

$$V_B > V_C$$

$$\Rightarrow V_E > V_B > V_C$$



# BIPOLAR JUNCTION TRANSISTOR: SATURATION REGION

Base Emitter Junction : Forward Bias

Collector Base Junction: Forward Bias

$$\frac{n-p-n}{I > B-E :}$$

$$V_B > V_E$$

$$2) c-B :$$

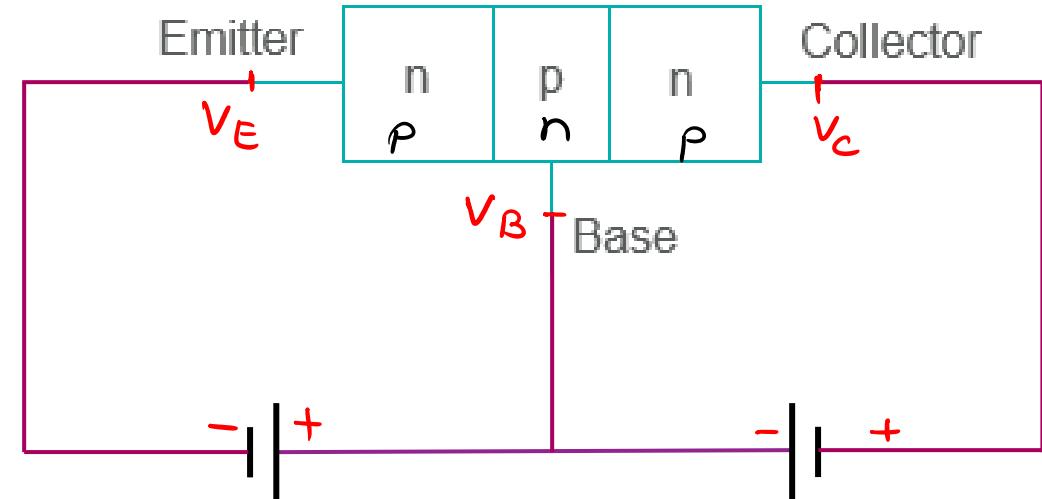
$$V_B > V_C$$

$$\frac{p-n-p}{I > B-E :}$$

$$V_E > V_B$$

$$2) c-B :$$

$$V_C > V_B$$



# BIPOLAR JUNCTION TRANSISTOR: CUT-OFF REGION

Base Emitter Junction : Reverse Bias

Collector Base Junction: Reverse Bias

n-p-n

1> B-E :

$$V_E > V_B$$

2> C-B :

$$V_C > V_B$$

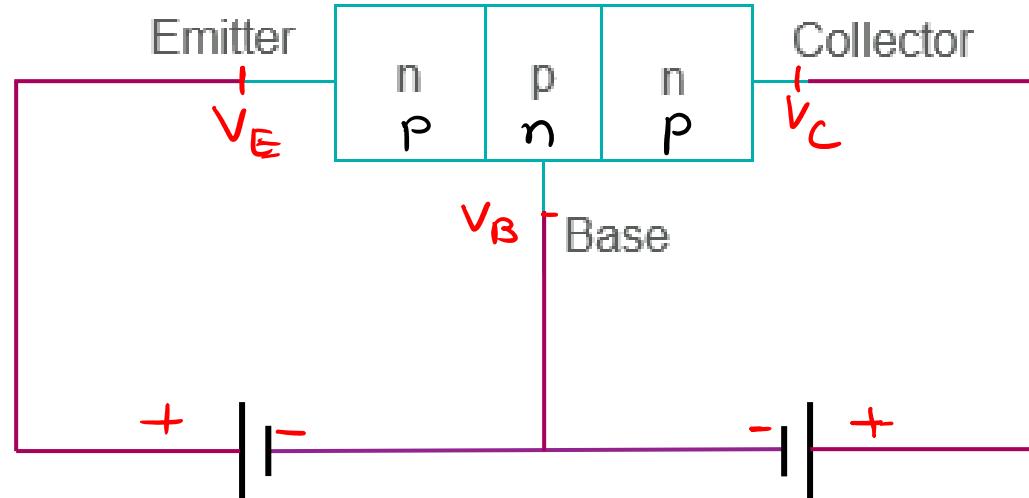
p-n-p

1> B-E :

$$V_B > V_E$$

2> C-B :

$$V_B > V_C$$



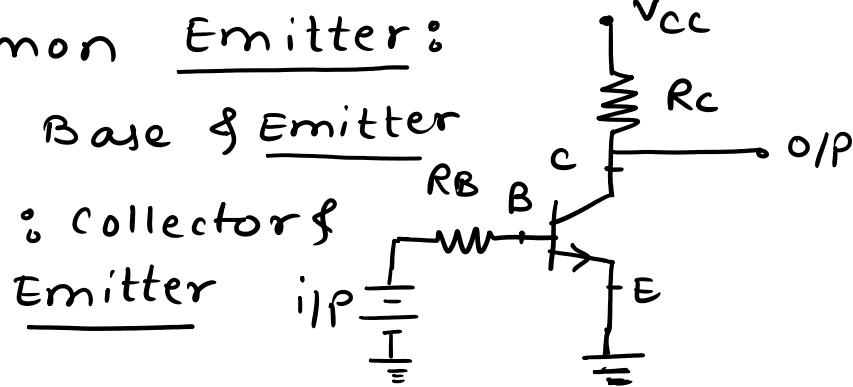
# BIPOLAR JUNCTION TRANSISTOR: CONFIGURATIONS

- Depending on which terminal is made common to input and output port there are three possible configurations of the transistor. They are as follows:
- Common Base Configuration
- Common Emitter Configuration
- Common Collector Configuration

1) Common Emitter:

Input: Base & Emitter

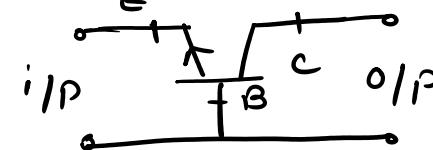
Output : collector & Emitter



2) Common Base:

Input: Emitter & Base

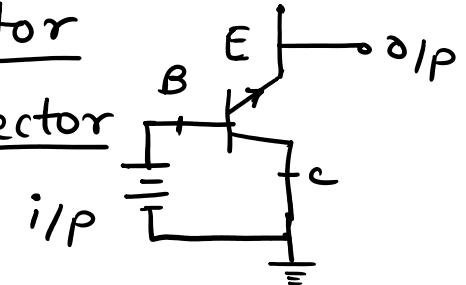
Output : collector & Base



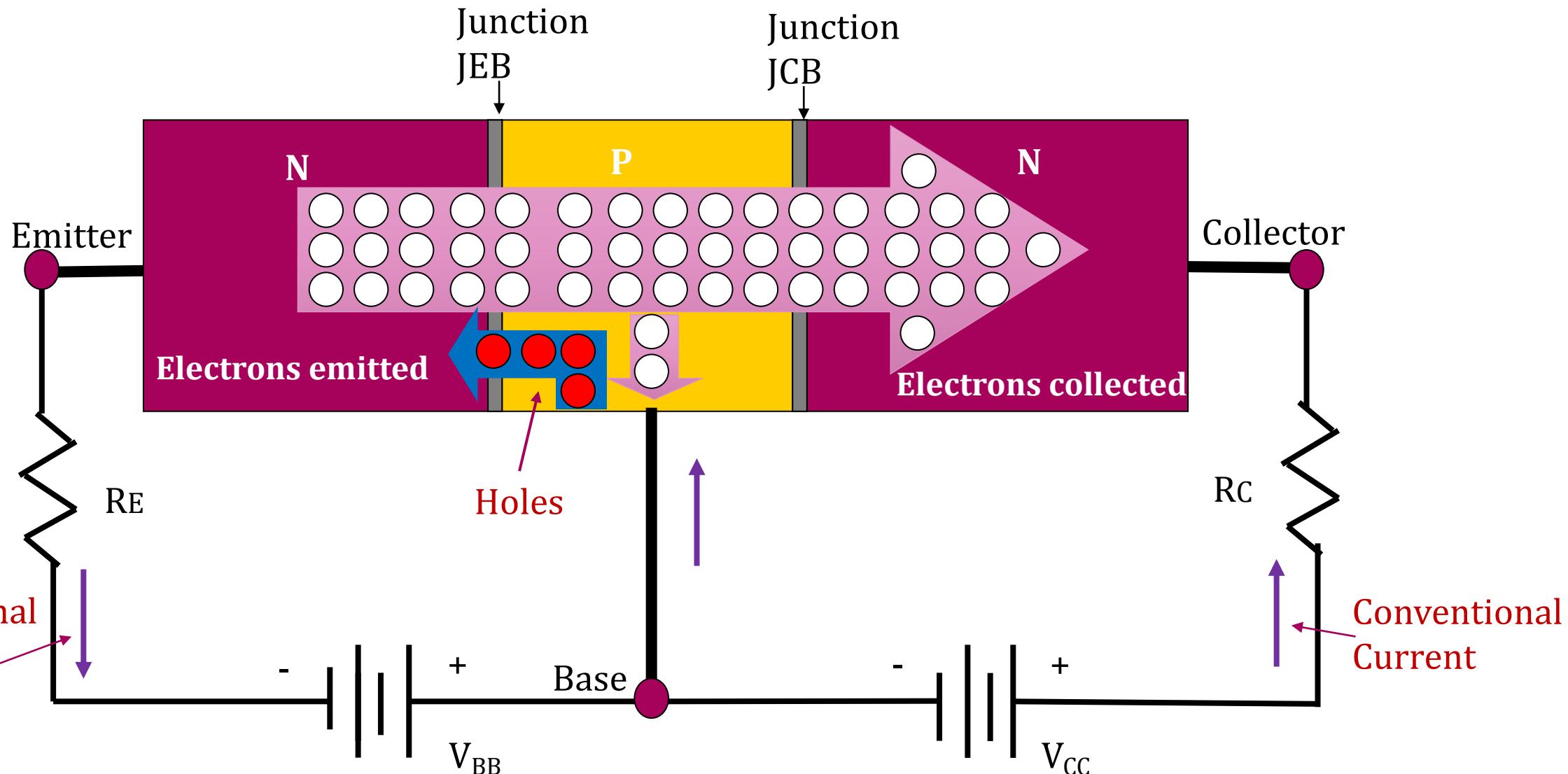
3) Common Collector:

Input : Base and collector

Output : Emitter and collector

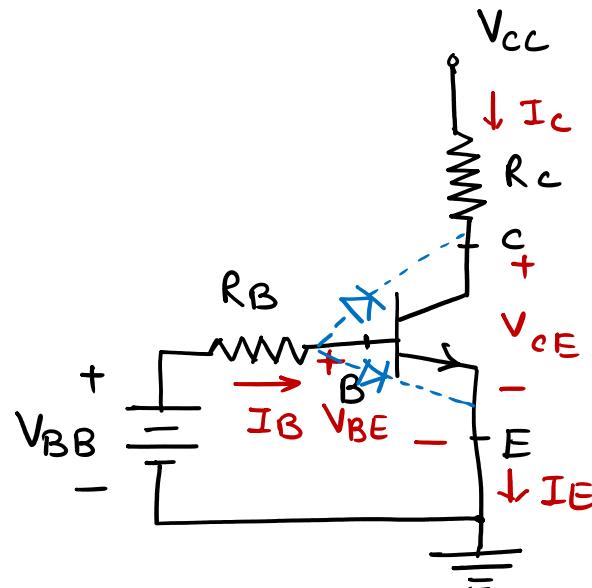


# TRANSISTOR OPERATION IN THE ACTIVE REGION N-P-N



This ppt is created as a reference material (only for the academic purpose) for the students of PICT.

It is restricted only for the internal use and any circulation is strictly prohibited.



$I_B$ : Base current (mA)

$I_C$ : Collector current (mA)

$I_E$ : Emitter current (mA)  $\rightarrow I_E = I_B + I_C$

$V_{CE}$ : C-E junction voltage

$V_{BE}$ : B-E junction voltage

$$V_{BE} = 0.7 \text{ V}$$

$$I_C = \alpha I_E \Rightarrow \alpha = I_C / I_E$$

↓  
How much percentage of  $I_E$  is flowing thr' collector

$$I_E = I_B + I_C \Rightarrow I_E \approx I_C$$

$$I_E = I_B + \alpha I_E$$

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

$$\frac{I_E}{I_B} = \frac{1}{1-\alpha}$$

$$\frac{I_C}{I_E} = \alpha \quad \& \quad \frac{I_E}{I_B} = \frac{1}{1-\alpha}$$

$$\frac{I_C}{I_B} = \frac{I_C}{I_E} \cdot \frac{I_E}{I_B} = \frac{\alpha}{1-\alpha} = \beta_{dc}$$

$\beta_{dc} = \frac{I_c}{I_B}$  = current gain of transistor

$$\boxed{\beta_{dc} = \frac{I_c}{I_B}}$$

(50 to 400)

$$\boxed{\alpha = \frac{I_c}{I_E}}$$

(0.95 to 0.99)

$$\boxed{\beta_{dc} = \frac{\alpha}{1-\alpha}}$$

$$\alpha = \frac{I_c}{I_E} = \frac{\beta I_B}{(1+\beta) I_B}$$

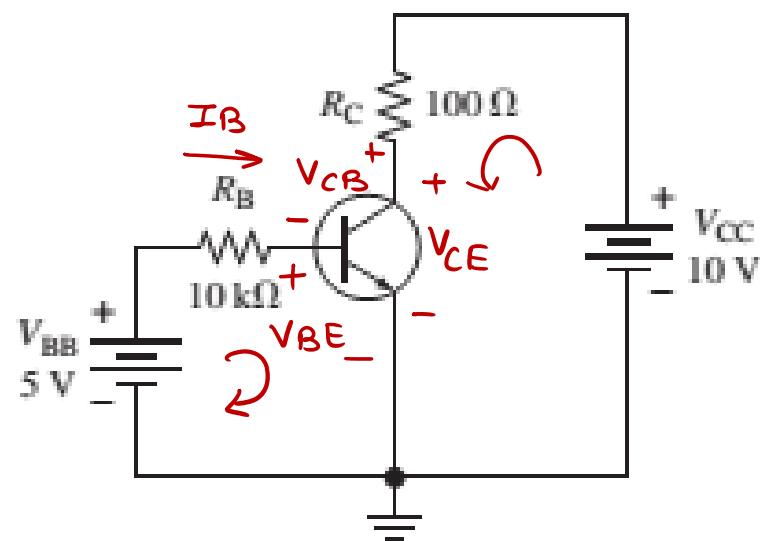
$$\boxed{\alpha = \frac{\beta}{1+\beta}}$$

$$I_E = I_c + I_B$$

$$I_E = \beta I_B + I_B$$

$$I_E = (1+\beta) I_B$$

- Determine  $I_B$ ,  $I_C$ ,  $I_E$ ,  $V_{BE}$ ,  $V_{CE}$ , and  $V_{CB}$  in the circuit of Figure. The transistor has a  $\beta_{dc} = 150$ .



I) Apply KVL to i/p loop,

$$V_{BB} - I_B R_B - V_{BE} = 0$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5 - 0.7}{10 \text{ k}\Omega}$$

$$\therefore I_B = 0.43 \text{ mA}$$

$$I_C = \beta_{dc} I_B = 150 \times 0.43 \times 10^{-3} = 64.5 \text{ mA}$$

$$I_E = I_B + I_C$$

$$= 64.93 \text{ mA}$$

$$V_{BE} = 0.7 \text{ V}$$

$$\text{II) } V_{CE} = V_{CB} + V_{BE}$$

$$V_{CB} = V_{CE} - V_{BE}$$

$$\therefore V_{CB} = 2.8 \text{ V}$$

II) Apply KVL to o/p loop:

$$V_{CC} - I_C R_C - V_{CE} = 0$$

$$\therefore V_{CE} = V_{CC} - I_C R_C = 10 - (64.5) \times 10^{-3} \times 100$$

$$V_{CE} = 3.55 \text{ V}$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5V - 0.7V}{10K\Omega} = 430\mu A$$

$$I_C = \beta_{DC} I_B = (150)(430\mu A) = 64.5 mA$$

$$I_E = I_C + I_B = 64.5mA + 430\mu A = 64.9mA$$

$$V_{CE} = V_{CC} + I_C R_C = 10V - (64.5mA)(100\Omega) = 10V - 6.45 = 3.55V$$

$$V_{CB} = V_{CE} - V_{BE} = 3.55V - 0.7V = 2.85V$$

- Determine the dc current gain  $\beta_{dc}$  and the emitter current  $I_E$  for a transistor where  $I_B$  50 mA and  $I_C$  3.65 mA.

$$\rightarrow I_B = 50 \text{ mA}$$

$$I_c = 3.65 \text{ mA}$$

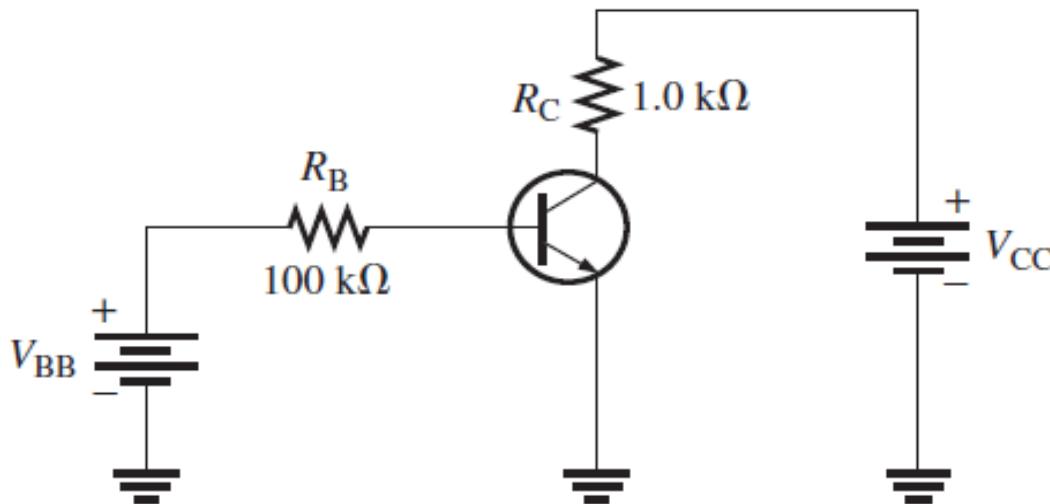
$$\beta_{dc} = \frac{I_c}{I_B} = 73$$

$$I_E = I_B + I_c = 3.7 \text{ mA}$$

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

$$\alpha = 0.986$$

A base current of  $50 \mu\text{A}$  is applied to the transistor in the following circuit, and a voltage of  $7.5$  V is dropped across  $R_C$ . Determine the  $\beta_{DC}$  of the transistor.



$$\rightarrow I_B = 50 \mu\text{A}$$

$$\beta_{DC} = \frac{I_C}{I_B}$$

To find  $I_C$ ,

voltage drop across  $R_C = 7.5$  V

$$\therefore I_C R_C = 7.5 \text{ V}$$

$$\therefore I_C = \frac{7.5}{1\text{k}\Omega} = 7.5 \text{ mA}$$

Now,

$$I_C = 7.5 \text{ mA}$$

$$\therefore \beta_{DC} = \frac{I_C}{I_B}$$

$$\therefore \beta_{DC} = 150$$

$$\& \alpha_{DC} = \frac{\beta}{1+\beta}$$

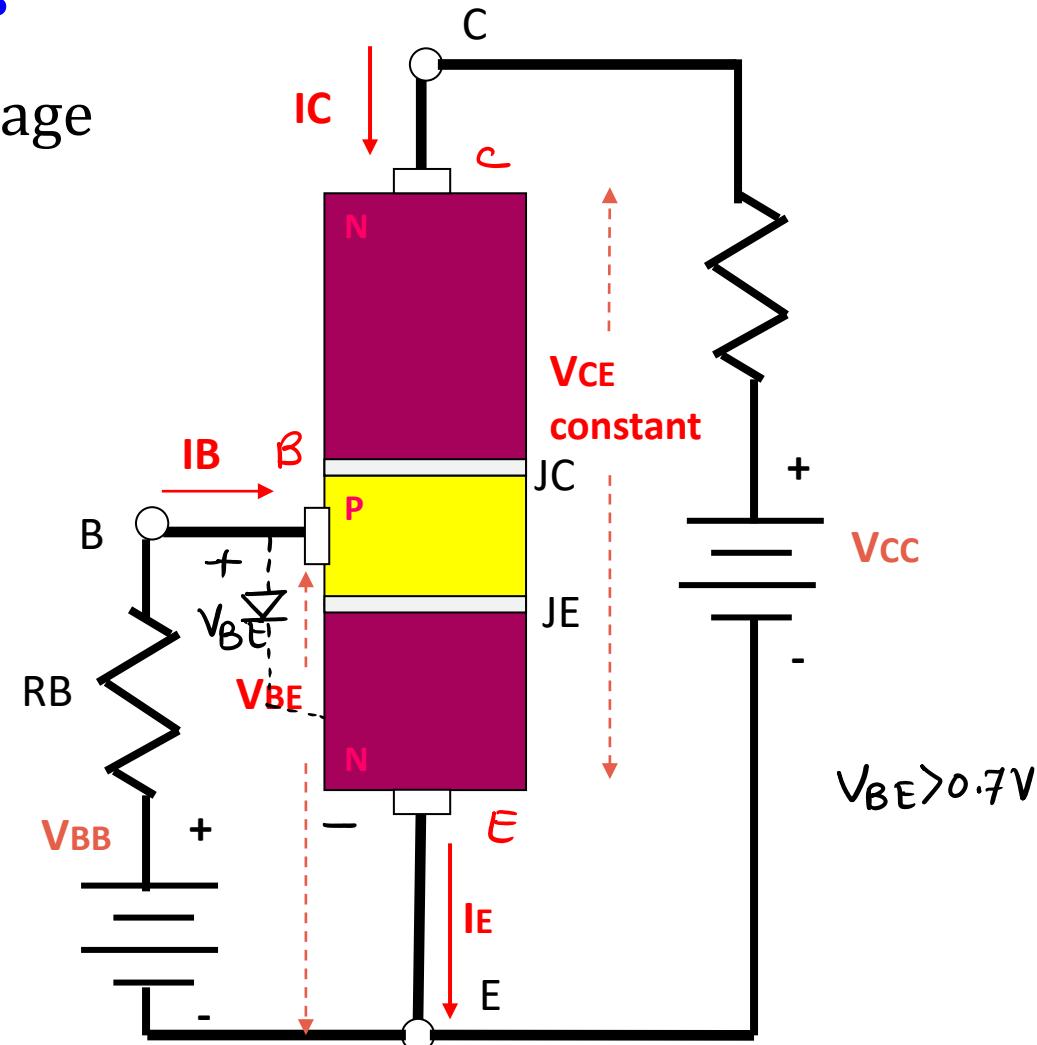
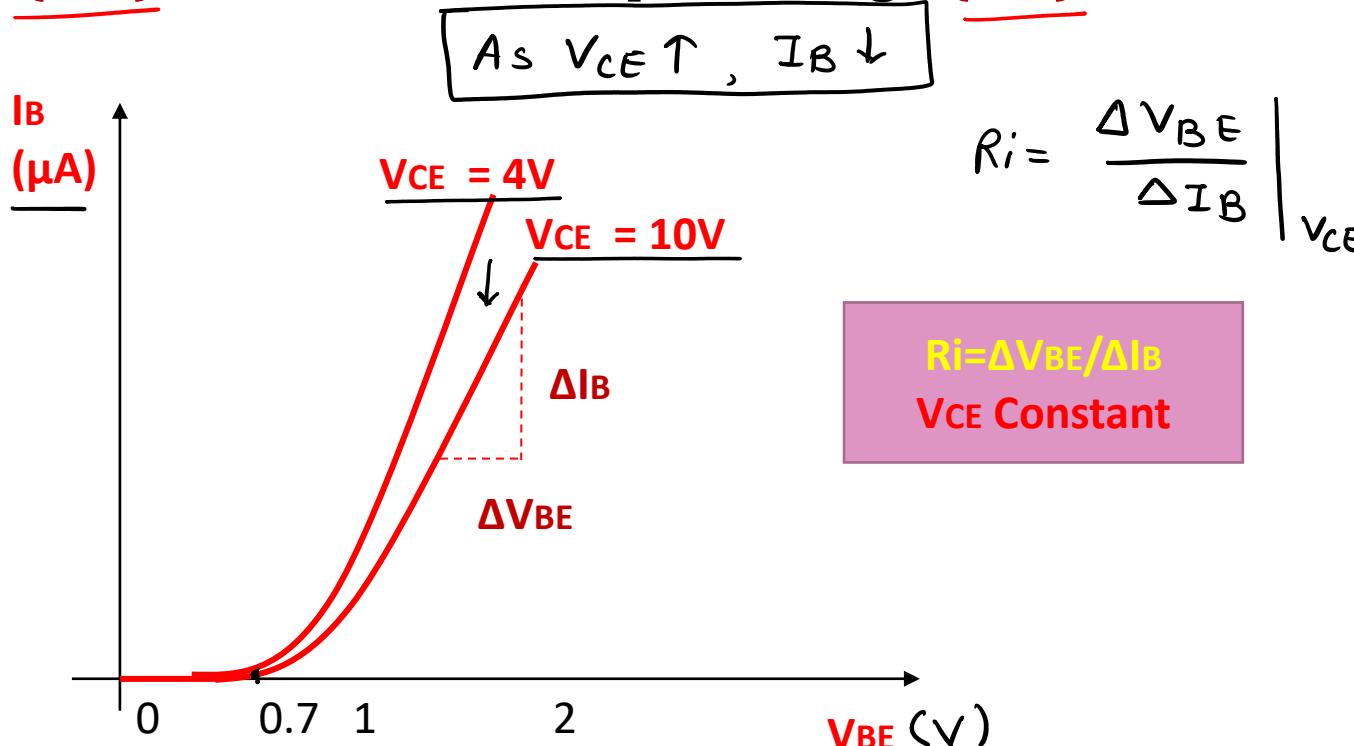
$$= 0.993$$

# CHARACTERISTICS OF A TRANSISTOR IN CE CONFIGURATION

## Input Characteristics

(Si BJT)

- It is a graph of input current ( $I_B$ ) versus input voltage ( $V_{BE}$ ) at a constant output voltage ( $V_{CE}$ ).



The value of dynamic input resistance "Ri" is low for CE.

**As VCE increases, IB reduces.**

$$V_{CE} = V_{CB} + V_{BE}$$

$$\hookrightarrow V_{BE} = 0.7 \text{ V}$$

**As VCE increases, VCB increases.**

**As VCB increases, Depletion Region gets wider.**



$V_{CE} \uparrow$ ,  $V_{CB} \uparrow$ , As  $V_{BE}$  is constant.  
↳ C-B junction is reverse biased and reverse vtg. is increased.

As base is lightly doped, depletion layer penetrates more in Base

Effective Base Width is reduced.



Probability of recombination of electrons and holes in base region is reduced.



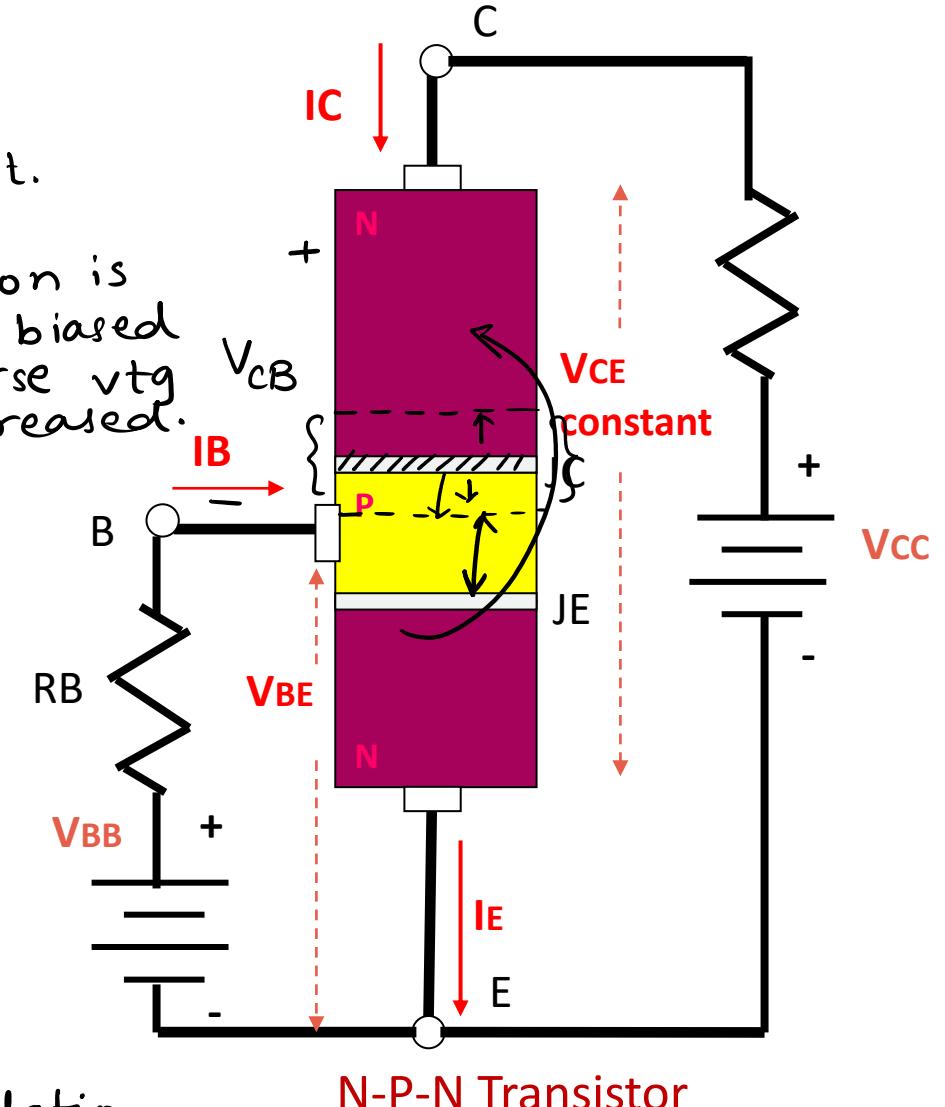
No. of holes is reduced as width is decreased.

Most of the electrons get collected at the collector terminal.



IB is reduced.

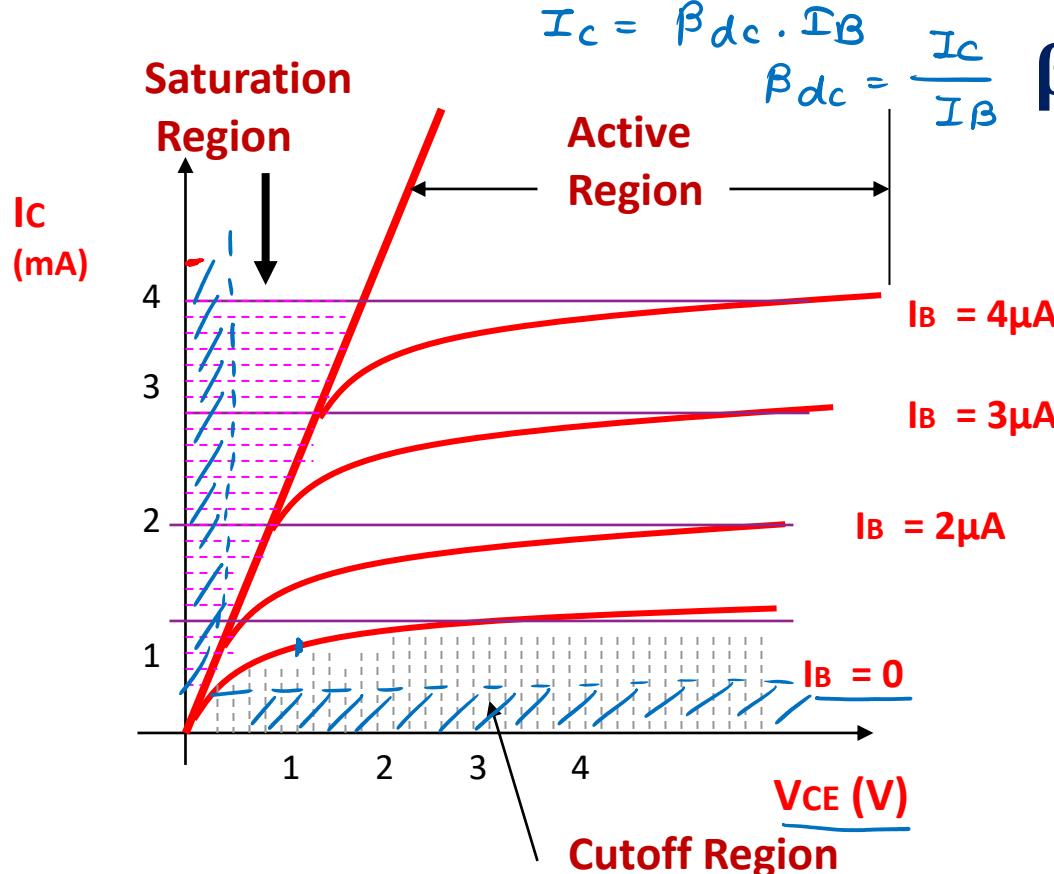
$\hookrightarrow$  Base Width Modulation



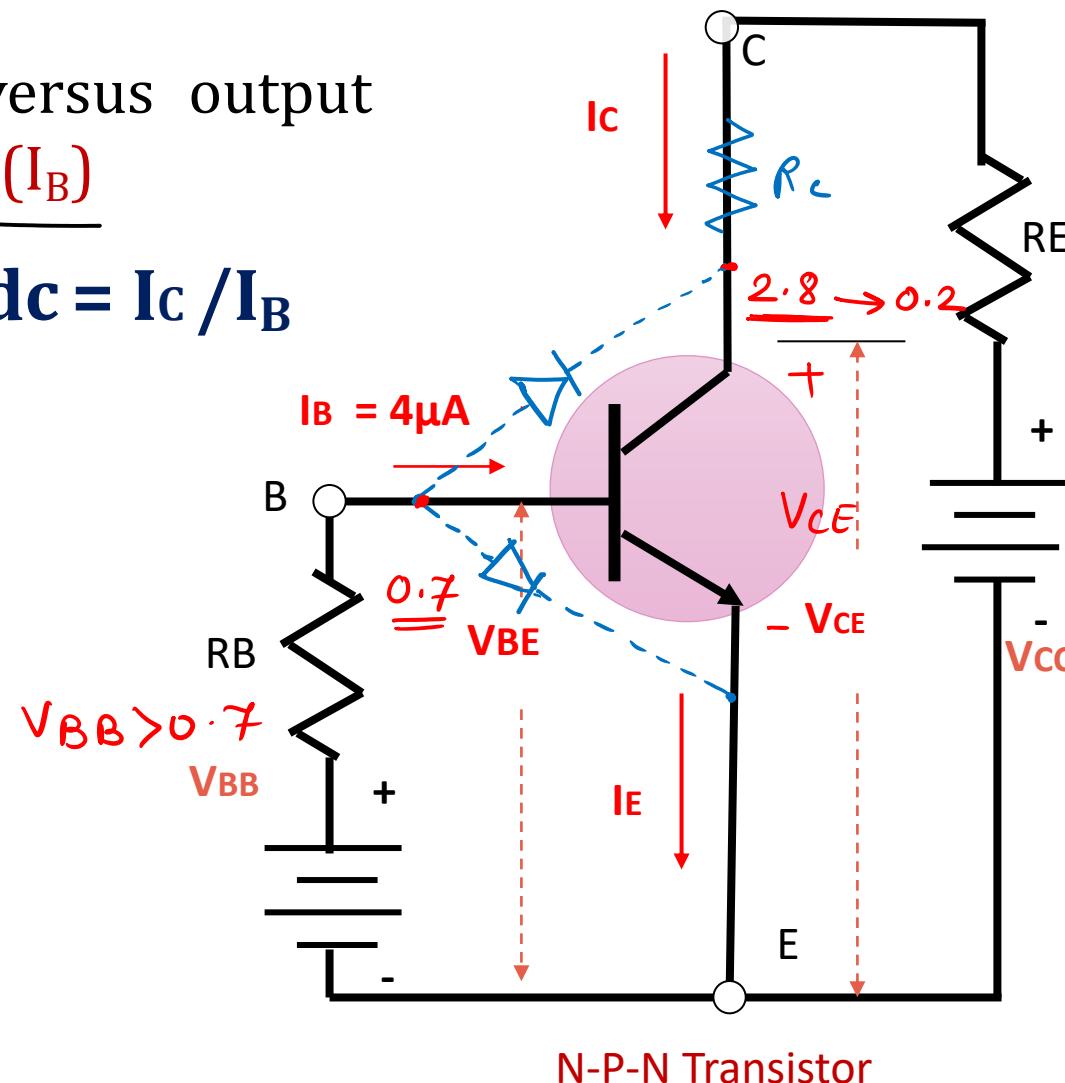
# CHARACTERISTICS OF A TRANSISTOR IN CE CONFIGURATION

## Output Characteristics

- It is a graph of output current ( $I_c$ ) versus output voltage ( $V_{CE}$ ) at a constant input current ( $I_B$ )



$$I_c = \beta_{dc} \cdot I_B \quad \beta_{dc} = \frac{I_c}{I_B} \quad \beta_{dc} = I_c / I_B$$



Cut-off Region:

$$I_B = 0$$

$$I_C = \beta_{dc} \cdot I_B = 0 \rightarrow I_C R_C = 0$$

$$V_{CE} \approx V_{CC}$$

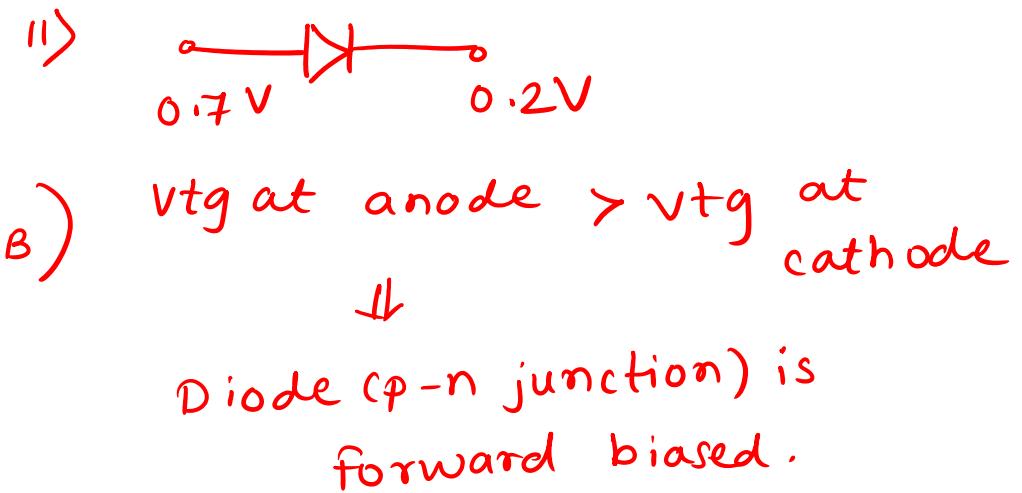
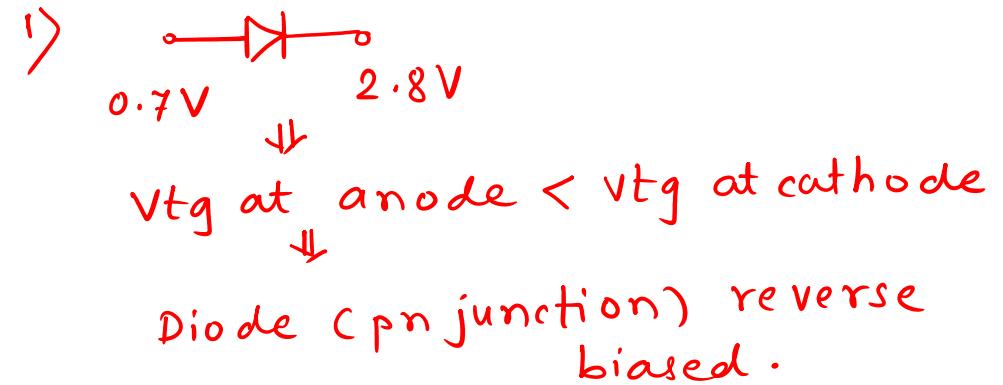
Active Region:

$$I_C = \beta_{dc} I_B$$

Saturation Region:

$$I_C \text{ is maximum } (I_{C\text{sat}}) > \cancel{\beta_{dc} I_B}$$

$$V_{CE} \approx 0.2V$$

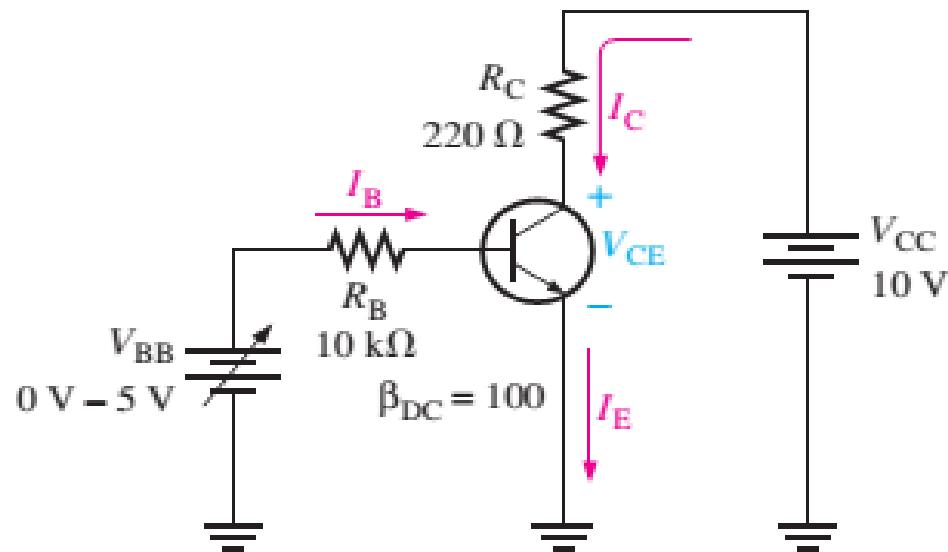


# BJT: OUTPUT CHARACTERISTICS

- Three regions of operation:
  - (1) Active region
  - (2) Cut-off regions
  - (3) Saturation region
- The Active region has collector region reverse biased and the emitter junction forward biased.
- In Cut-off region, the emitter junction is slightly reverse biased and the collector current is not totally cut-off.
- In Saturation region, both the collector and the emitter junction are forward biased.

# BJT: DC LOAD LINE

- The dc load line is the locus of  $I_C$  and  $V_{CE}$  at which BJT remains in active region i.e. it represents all the possible combinations of  $I_C$  and  $V_{CE}$  for a given amplifier.
- To draw DC load line of a transistor we need to find the Saturation Current and Cutoff Voltage.



## DC LOAD LINE

The KVL in o/p loop,

$$V_{CC} - I_C R_C - V_{CE} = 0 \quad (1)$$

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

$$\therefore I_C = \left( -\frac{1}{R_C} \right) V_{CE} + \frac{V_{CC}}{R_C}$$

$$m = -\frac{1}{R_C} ; c = \frac{V_{CC}}{R_C}$$

Put  $V_{CE} = 0$  in equ<sup>n</sup> (1),

$$V_{CC} = I_C R_C$$

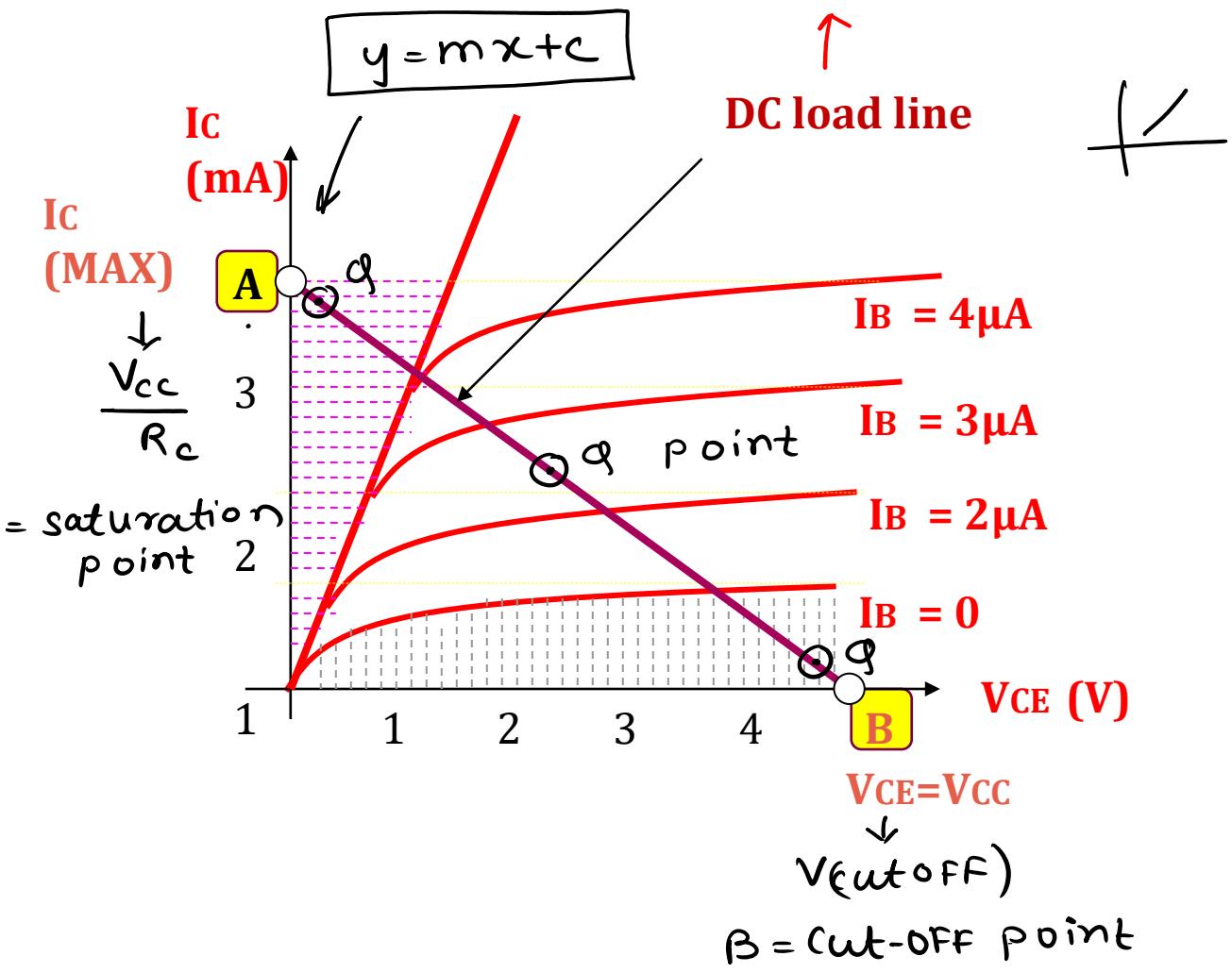
$$I_{CCsat} = \frac{V_{CC}}{R_C}$$

Put  $I_C = 0$  in equ<sup>n</sup> (1),

$$V_{CE} = V_{CC}$$

$$V_{CE(cutoff)} = V_{CC}$$

The load line is drawn under DC operating conditions (w/o applying any AC voltage).



# BJT: DC LOAD LINE

- The **saturation current** is the maximum possible current through the transistor and occurs at the point where the voltage across the collector is minimum.  
 $\uparrow I_{Ccsat}$
- The **cutoff voltage** is the maximum possible voltage across the collector and occurs at zero collector current.  
 $\uparrow V_{CEcutoff}$        $\hookrightarrow V_{CE} = 0$   
 $\downarrow I_C = 0$
- From the DC equivalent circuit by applying Kirchoff's Voltage Law (KVL) in collector loop, we get,

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

# BJT: DC LOAD LINE

$$(V_{CC}, 0) \rightarrow V_{CE} = V_{CC}$$

- **Cutoff Point** : To find the cutoff point equate the collector current to zero (in cutoff the collector current is  $I_{CO}$  which will be of micro amperes and hence can be assumed to be zero).

- In the above equation, equating  $I_C$  to zero, the cutoff point is  $(V_{CC}, 0)$ .

$$\rightarrow (0, V_{CC}/R_C) \rightarrow I_C = V_{CC}/R_C$$

- **Saturation Point** : To find the saturation point equate the collector voltage to zero (in saturation the collector voltage will be around 0.2 Volts which is small and hence can be assumed to be zero).

$$V_{CE(sat)} \approx 0.2V$$

- In the above equation, equating  $V_{CE}$  to zero the saturation point is  $(0, V_{CC}/R_C)$ .

- $(V_{CC}, 0)$  is cut off point where transistor enters in to cut off region from active region and  $(0, V_{CC}/R_C)$  is saturation point where the transistor enters saturation region

# **BJT: Q POINT**

## **Q point or quiescent or operating point of BJT**

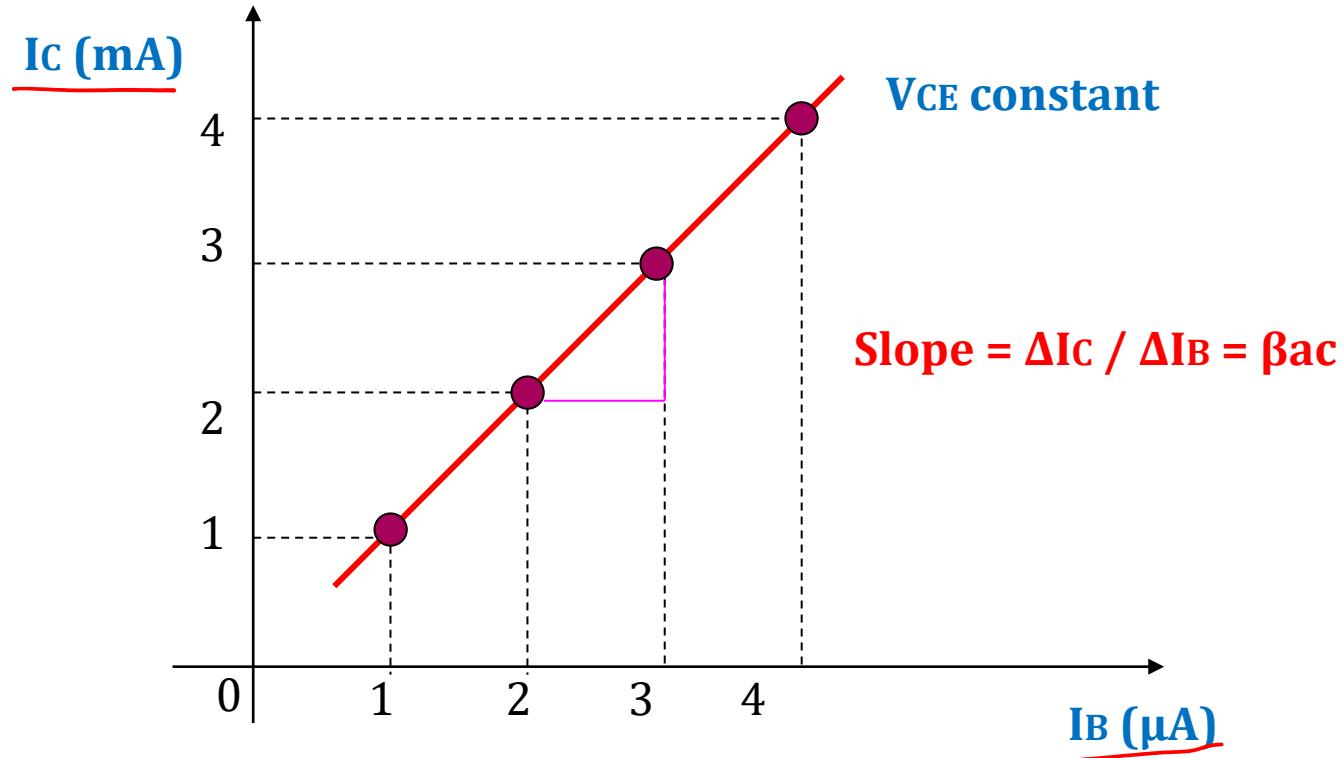
- Q-point is the operating point of the transistor ( $I_{CQ}, V_{CEO}$ ) at which it is biased.
- The concept of Q-point is used when transistor act as an amplifying device and hence is operated in active region of input output characteristics.

# BJT: SIGNIFICANCE OF Q-POINT

- Normally the signals which are to be amplified will be of the order milli volts or less. If these signals are directly inputted to the amplifier, they will not get amplified as transistor needs voltages greater than cut in voltages for it to be in active region.
- Transistor acts as amplifier only in active region of operation . So, appropriate DC voltages and currents should be established through BJT by external sources so that BJT operates in active region and superimpose the AC signals to be amplified.
- The DC voltage and current are so chosen that the transistor remains in active region for entire AC signal excursion. All the input AC signals variations happen around Q-point.
- Q-point is generally taken to be the intersection point of load line with the output characteristics of the transistor.
- There can be infinite number of intersection points, but Q-point is selected in such a way that irrespective of AC input signal swing the transistor remain in active region.

# CHARACTERISTICS OF A TRANSISTOR IN CE CONFIGURATION

## Transfer Characteristics



$$I_c = \beta_{dc} \cdot I_B$$

$$\beta_{dc} = \frac{I_c}{I_B}$$

$$\beta_{ac} = \Delta I_c / \Delta I_B$$

$$\beta_{dc} = I_c / I_B$$

V<sub>CE</sub> constant

# COMPARISON OF CONFIGURATIONS

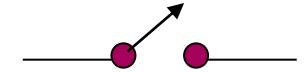
Sr. No.	Parameter	CB	CE	CC
1	Common terminal between input and output	Base	Emitter	Collector
2	Conduction Angle	0 °	180 °	0 °
3	Input Current	I <sub>E</sub>	I <sub>B</sub>	I <sub>B</sub>
4	Output Current	I <sub>C</sub>	I <sub>C</sub>	I <sub>E</sub>
5	Current Gain	$\alpha_{DC} = I_C/I_E$ Less than one	$\beta_{DC} = I_C/I_B$ High	$\gamma = I_E/I_B$ High
6	Input Voltage	V <sub>eb</sub>	V <sub>be</sub>	V <sub>bc</sub>
7	Output Voltage	V <sub>cb</sub>	V <sub>ce</sub>	V <sub>ec</sub>
8	Current Gain	Less than unity	High	High
9	Input Resistance	Very low (20Ω)	Low (1KΩ)	High (500kΩ)
10	Output Resistance	Very high (1M)	High (40kΩ)	Low (50Ω)
11	Application	As Preamplifier	Audio Amplifier	Impedance Matching
12	Voltage Gain	Medium	Large	Less than 1

# TRANSISTOR BIASING

What is meant by dc biasing of a transistor ?

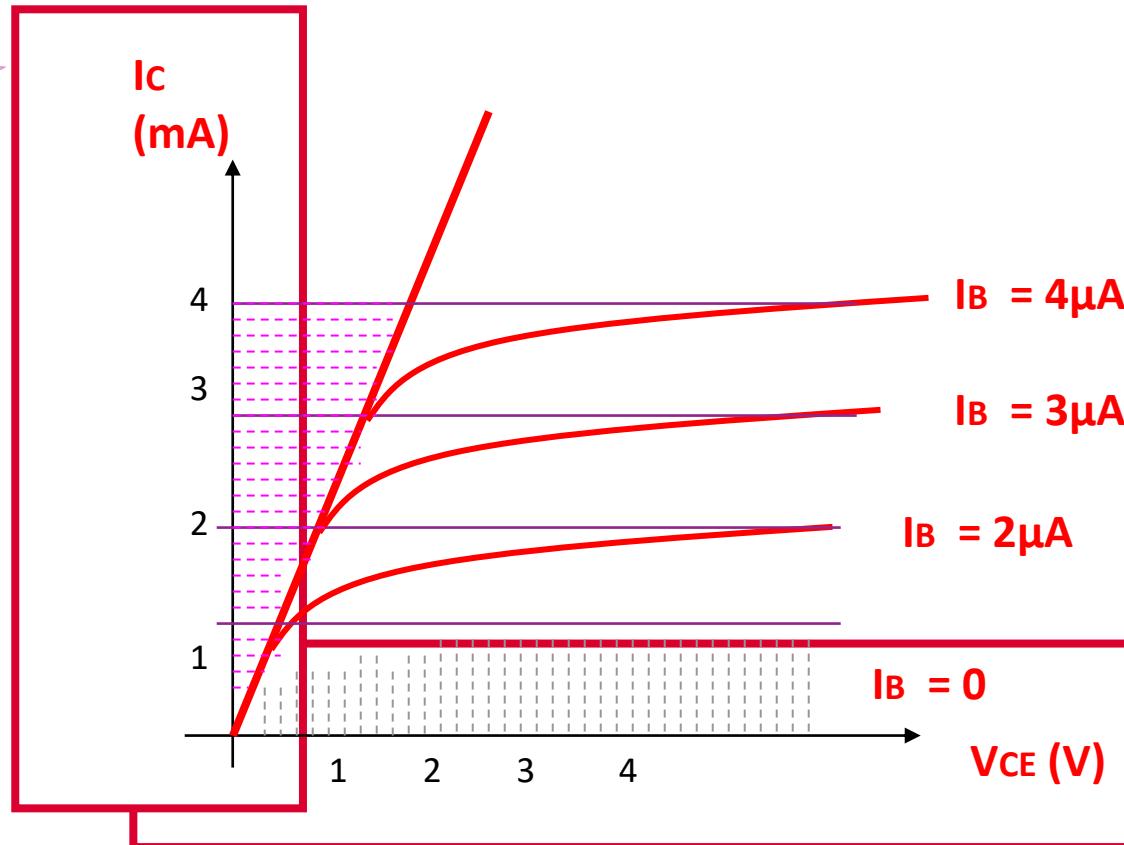
- Depending on the application, a transistor is to be operated in any of the three regions of operation namely cutoff, active and saturation region.
- To operate the transistor in these regions the two junctions of a transistor should be forward or reverse biased.

# TRANSISTOR BIASING FOR DIFFERENT APPLICATIONS

Sr. No.	Region of Operation	Base Emitter Junction	Collector Base Junction	Application
1	Cutoff Region	Reverse Biased	Reverse Biased	Transistor Is OFF  → open switch
2	Saturation Region	Forward Biased	Forward Biased	Transistor Is ON  → closed switch
3	Active Region	Forward Biased	Reverse Biased	Amplifier

# OUTPUT CHARACTERISTICS OF BJT

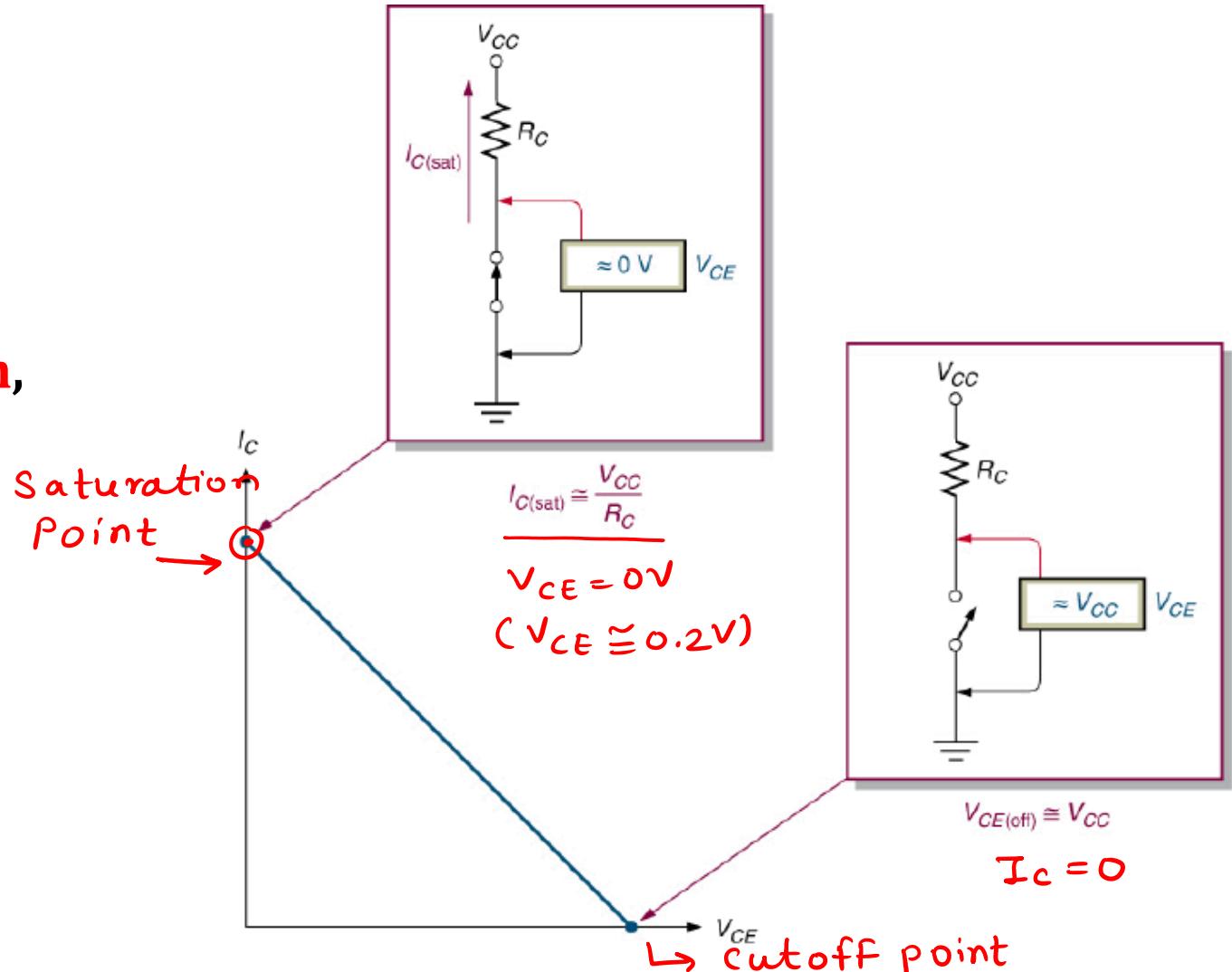
Saturation Region



Cut-off Region

# BJT AS A SWITCH

- When operated in **Saturation Region**, the BJT acts as a **Closed Switch**.
- When operated in **Cut-off Region**, the BJT acts as an **Open Switch**.



# CIRCUIT DIAGRAM FOR BJT AS SWITCH

i) Transistor in cut-off region:

When  $V_{BB} < 0.7V$   
→ B-E junction is OFF.

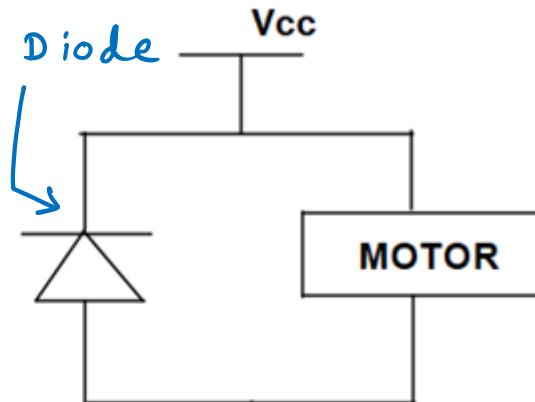
$$\therefore I_B = 0$$

$$\therefore I_C = \beta_{dc} \cdot I_B = 0$$

∴ Motor is OFF.

(Transistor acts as open switch.)

Freewheeling Diode



ii) Transistor in saturation region:

When  $V_{BB} > 0.7V$

→ B-E junction is Fwd biased.

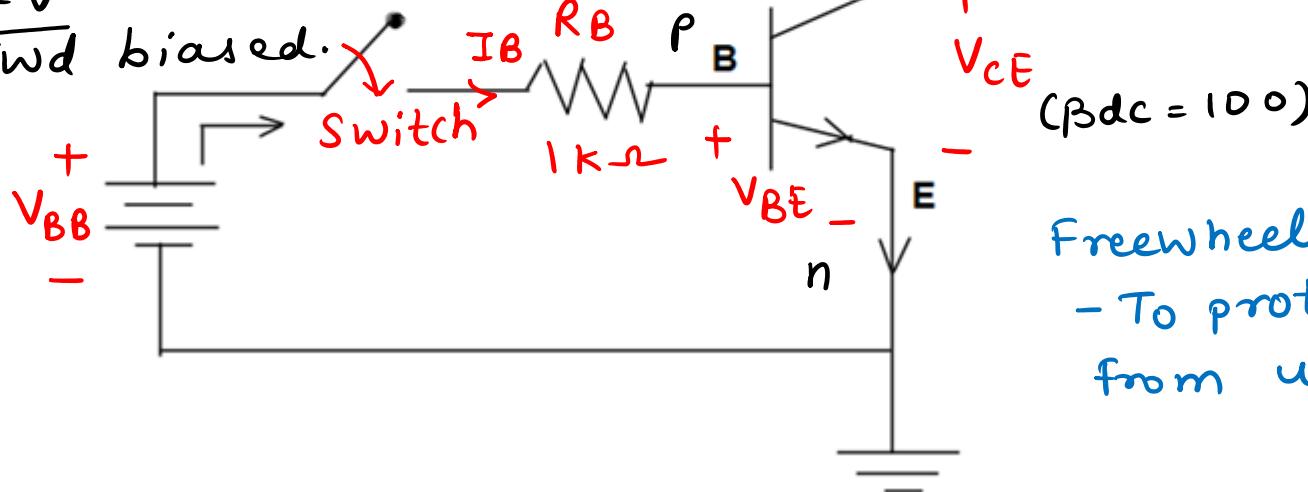
$$V_{BB} = 3V$$

$$\therefore I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

$$= \frac{3 - 0.7}{1k\Omega}$$

$$= \frac{2.3}{1k\Omega}$$

$$\therefore I_B = 2.3mA$$



$$I_C = \beta_{dc} \cdot I_B$$

$$= 100 (2.3 \times 10^{-3})$$

$$\therefore I_C = 230mA$$



Collector current  
will drive DC motor



Motor is ON.



Transistor acts  
as a closed sw.

Freewheeling Diode:

- To protect the opamp device  
from unwanted vtg spikes.

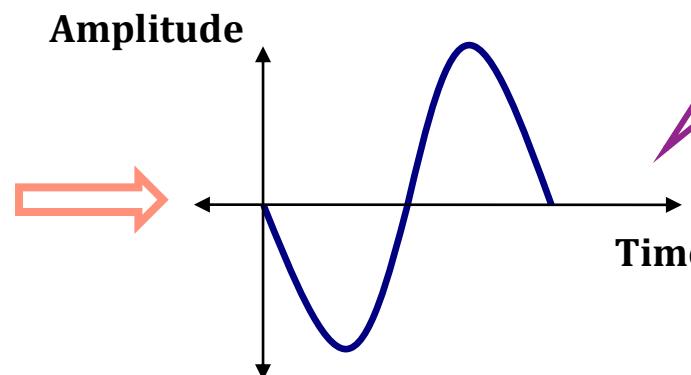
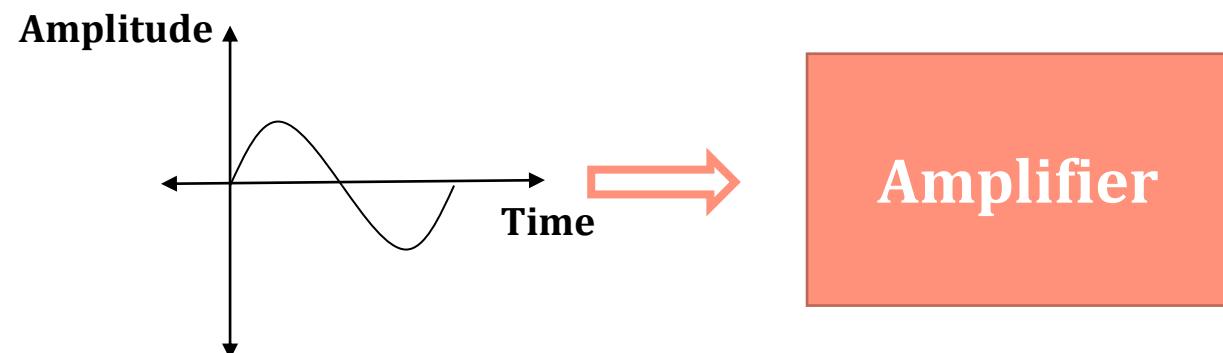
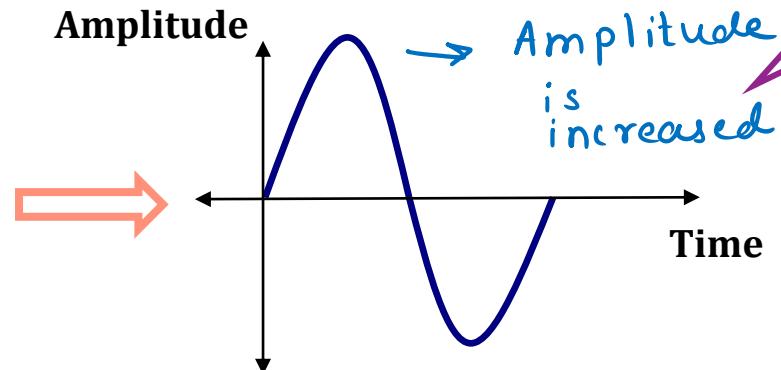
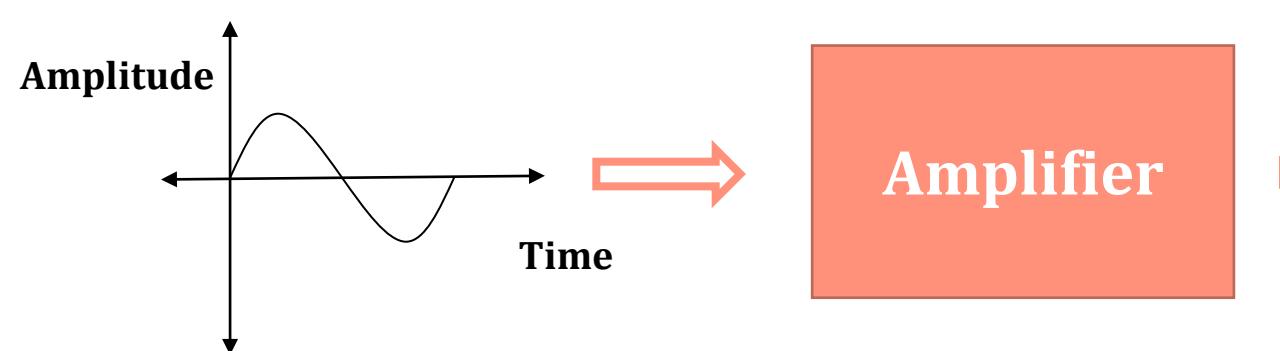
# TRANSISTOR AS A SWITCH...

- An ideal transistor switch would have infinite circuit resistance between the Collector and Emitter when turned “fully-OFF” resulting in zero current flowing through it and zero resistance between the Collector and Emitter when turned “fully-ON”, resulting in maximum current flow.
- But, when the transistor is turned “OFF”, small leakage currents flow through the transistor and when fully “ON” the device has a low resistance value causing a small saturation voltage ( $V_{CE}$ ) across it. Even though the transistor is not a perfect switch, in both the cut-off and saturation regions the power dissipated by the transistor is at its minimum.

# TRANSISTOR AS A SWITCH...

- For the Base current to flow, the Base input terminal must be made more positive than the Emitter by increasing it above the 0.7 volts needed for a silicon device. By varying this Base-Emitter voltage VBE, the Base current is also altered and which in turn controls the amount of Collector current flowing through the transistor.
- When maximum Collector current flows the transistor is said to be Saturated. The value of the Base resistor determines how much input voltage is required and corresponding Base current to switch the transistor fully "ON".

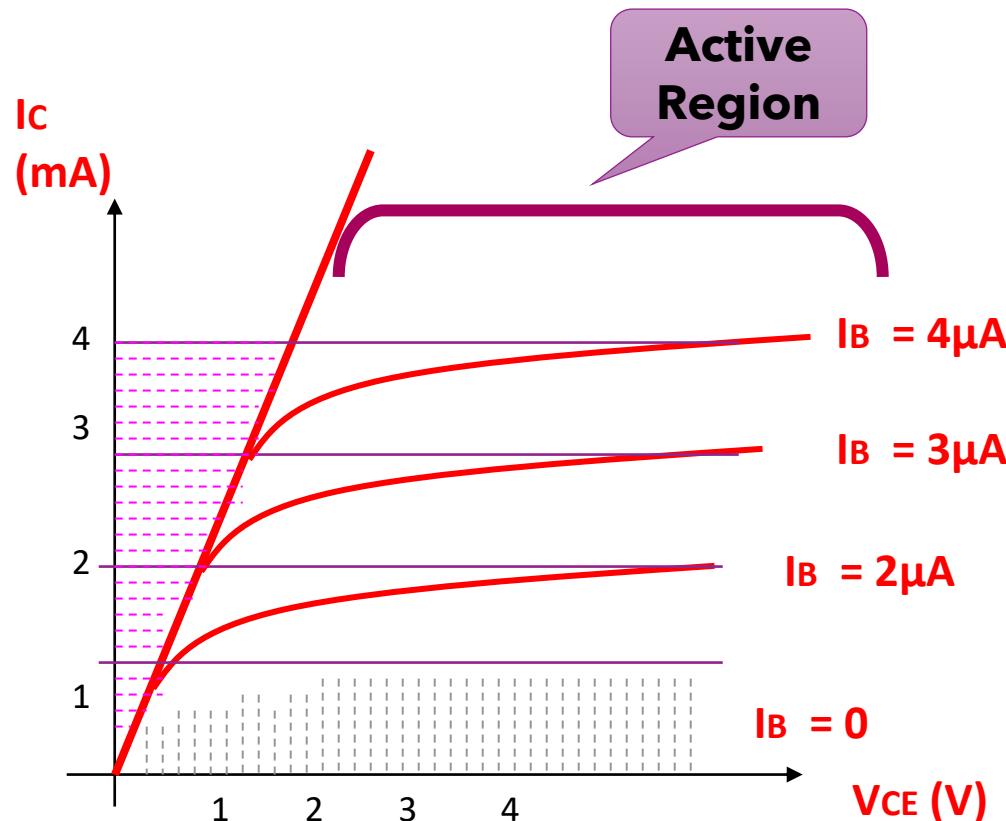
# AMPLIFICATION ??



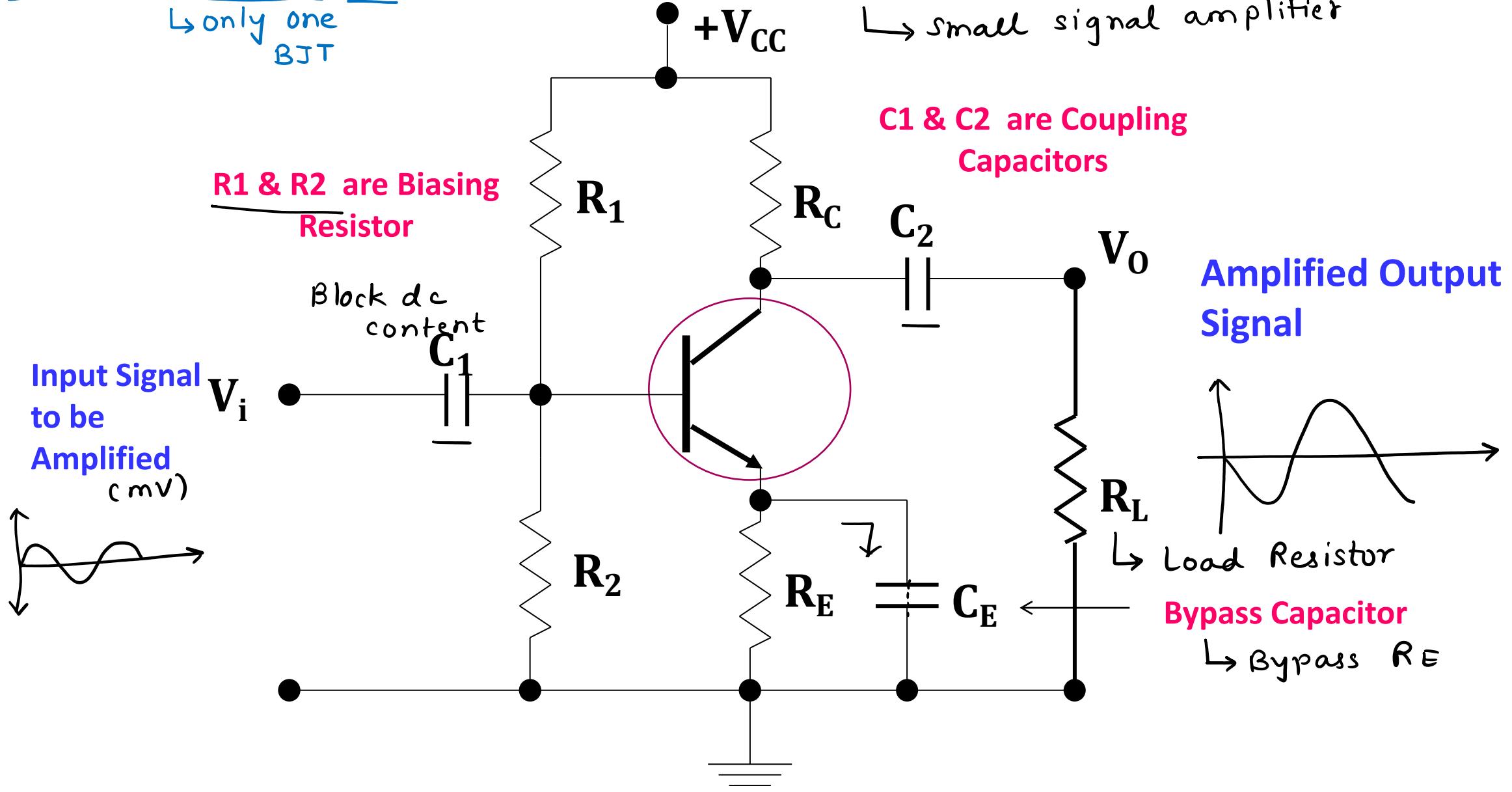
# APPLICATION OF BJT AS AN AMPLIFIER...

The common emitter (CE) configuration is widely used as a basic amplifier as it has both voltage and current amplification.

# OUTPUT CHARACTERISTICS OF BJT



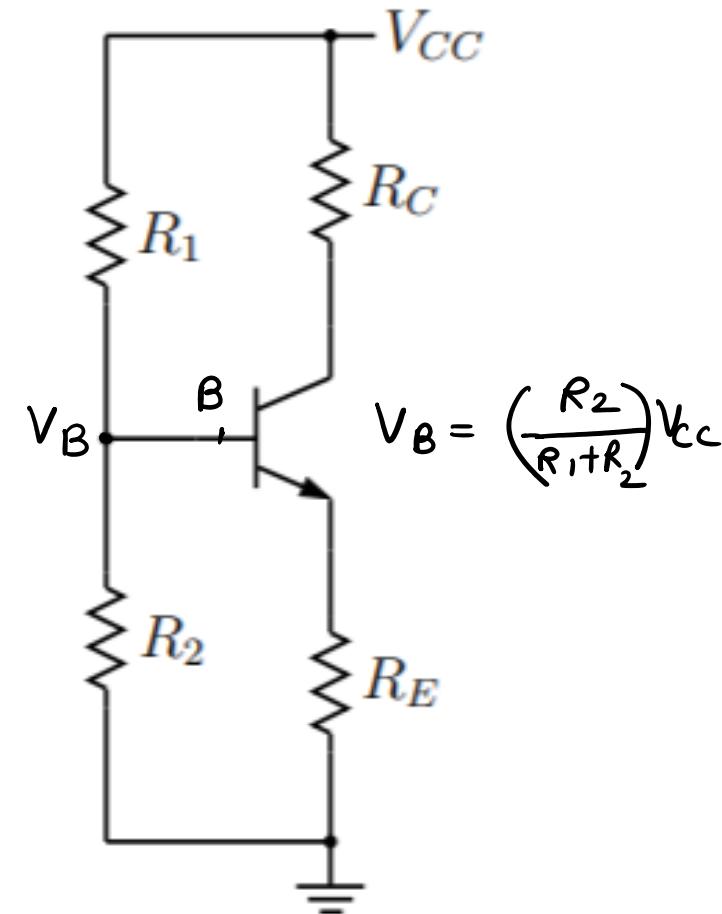
# SINGLE STAGE RC COUPLED AMPLIFIER (CE)



# TRANSISTOR BIASING: VOLTAGE DIVIDER

↳ 'q' point stability

- The term 'Bias' refers to the DC conditions (currents and voltages) inside the amplifier circuit.
- This method of biasing the transistor greatly reduces the effects of varying Beta, ( $\beta$ ) by holding the Base bias at a constant steady voltage level allowing for best stability. The quiescent Base voltage ( $V_B$ ) is determined by the potential divider network formed by the two resistors,  $R_1$ ,  $R_2$  and the power supply voltage  $V_{CC}$  as shown with the current flowing through both resistors.



## Transistor Bias Voltage:

$$V_B = V_{cc} \frac{R_2}{R_1 + R_2} \longrightarrow \text{voltage divider rule}$$

## Beta Value:

Beta is also referred to as  $h_{FE}$  which is the transistors forward current gain in the common emitter configuration. Beta has no units as it is a fixed ratio of the two currents,  $I_c$  and  $I_b$  so a small change in the Base current will cause a large change in the collector current.

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

## AMPLIFIER COUPLING CAPACITORS

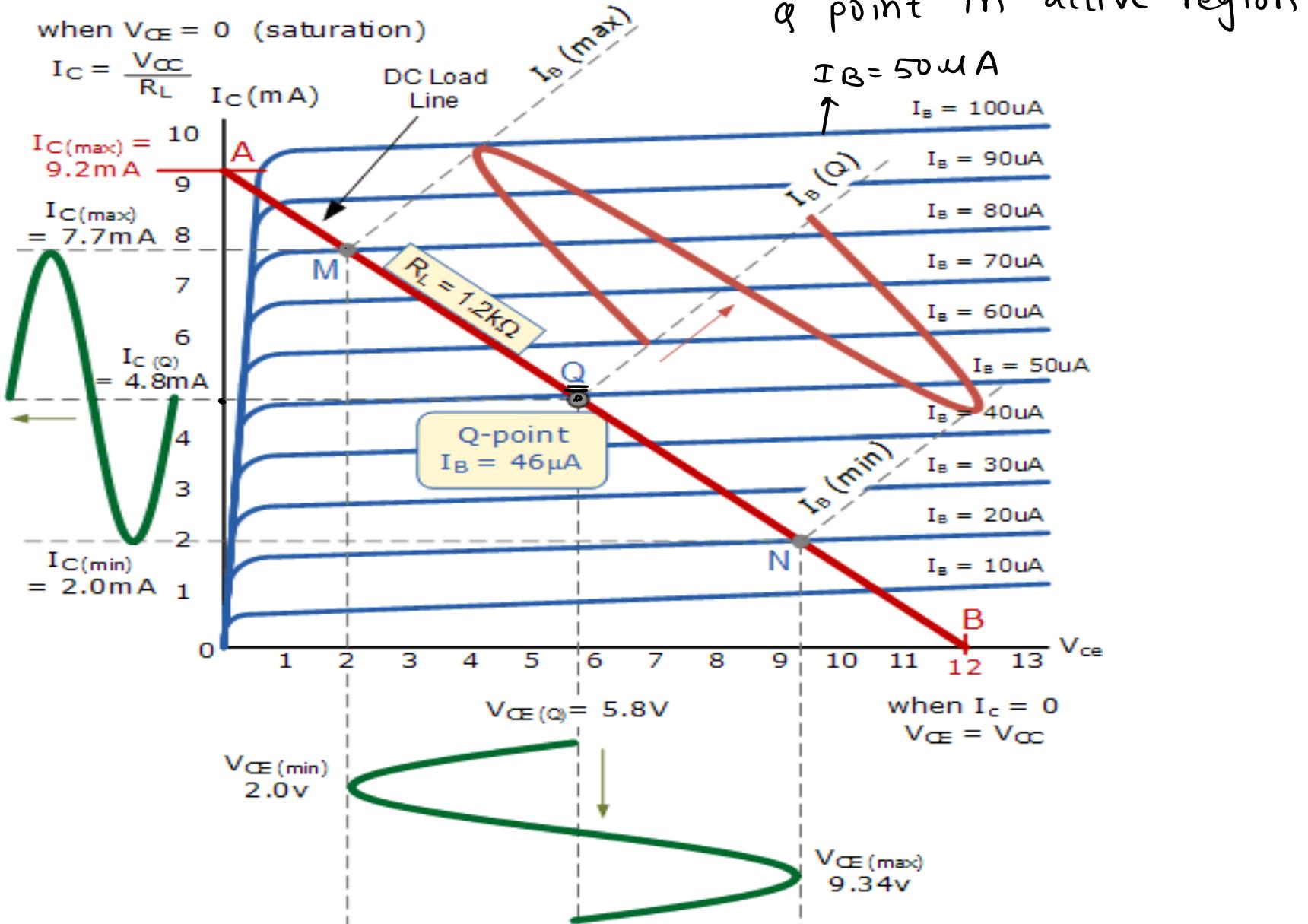
$$\rightarrow X_C = \frac{1}{2\pi f C} ; X_C = \infty \text{ for DC.}$$
$$\hookrightarrow f = 0$$

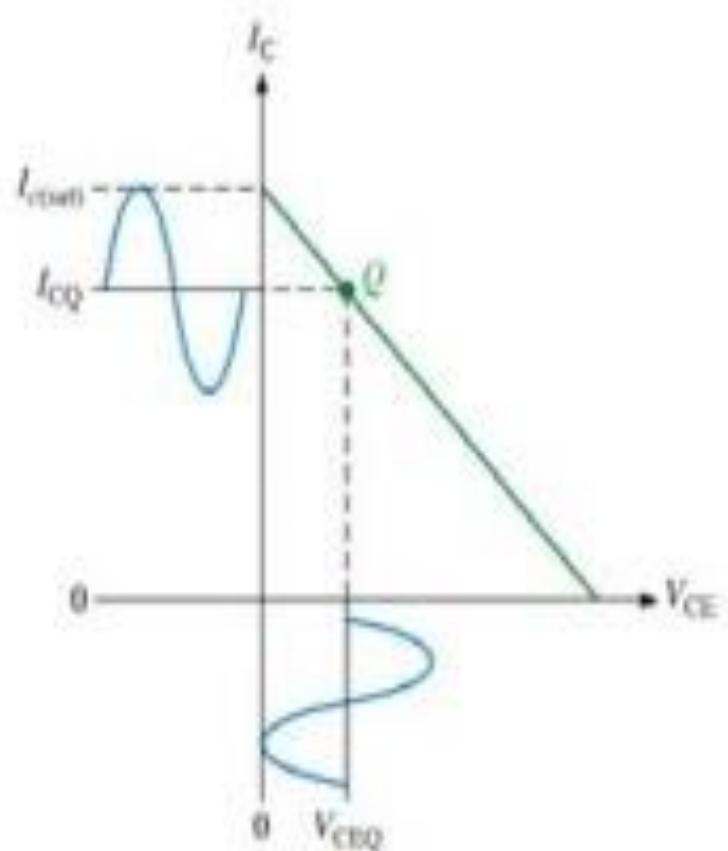
- In Common Emitter Amplifier circuits, capacitors C<sub>1</sub> and C<sub>2</sub> are used as Coupling Capacitors to separate the AC signals from the DC biasing voltage. This ensures that the bias condition set up for the circuit to operate correctly is not affected by any additional amplifier stages, as the capacitors will only pass AC signals and block any DC component.
- The output AC signal is then superimposed on the biasing of the following stages. Also, a bypass capacitor, C<sub>E</sub> is included in the Emitter leg circuit.
- This capacitor is effectively an open circuit component for DC biasing conditions, which means that the biasing currents and voltages are not affected by the addition of the capacitor maintaining a good Q-point stability.

# AMPLIFIER COUPLING CAPACITORS

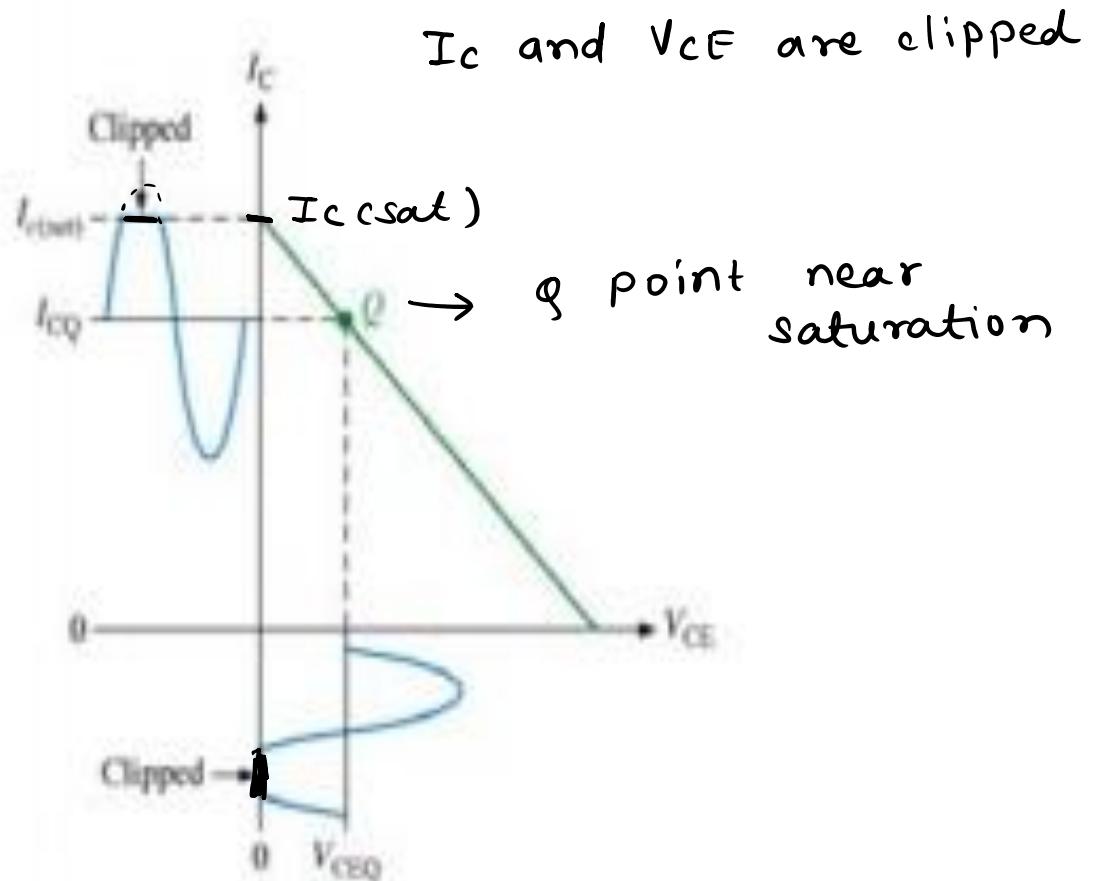
- However, this parallel connected bypass capacitor effectively becomes a short circuit to the Emitter resistor at high frequency signals due to its reactance. Thus, only  $RL$  plus a very small internal resistance acts as the transistors load increasing voltage gain to its maximum.
- Generally, the value of the bypass capacitor,  $CE$  is chosen to provide a reactance of at most,  $1/10$ th the value of  $RE$  at the lowest operating signal frequency.

$$I_C = 4.8 \text{ mA}$$



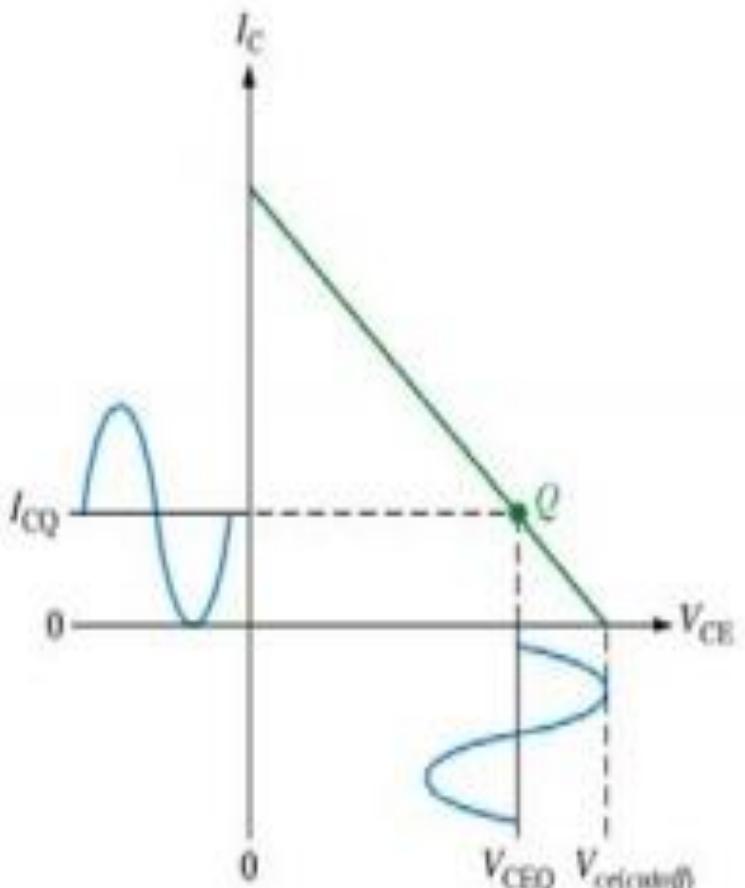


(a) Amplitude of  $V_{ce}$  and  $I_c$  limited by saturation

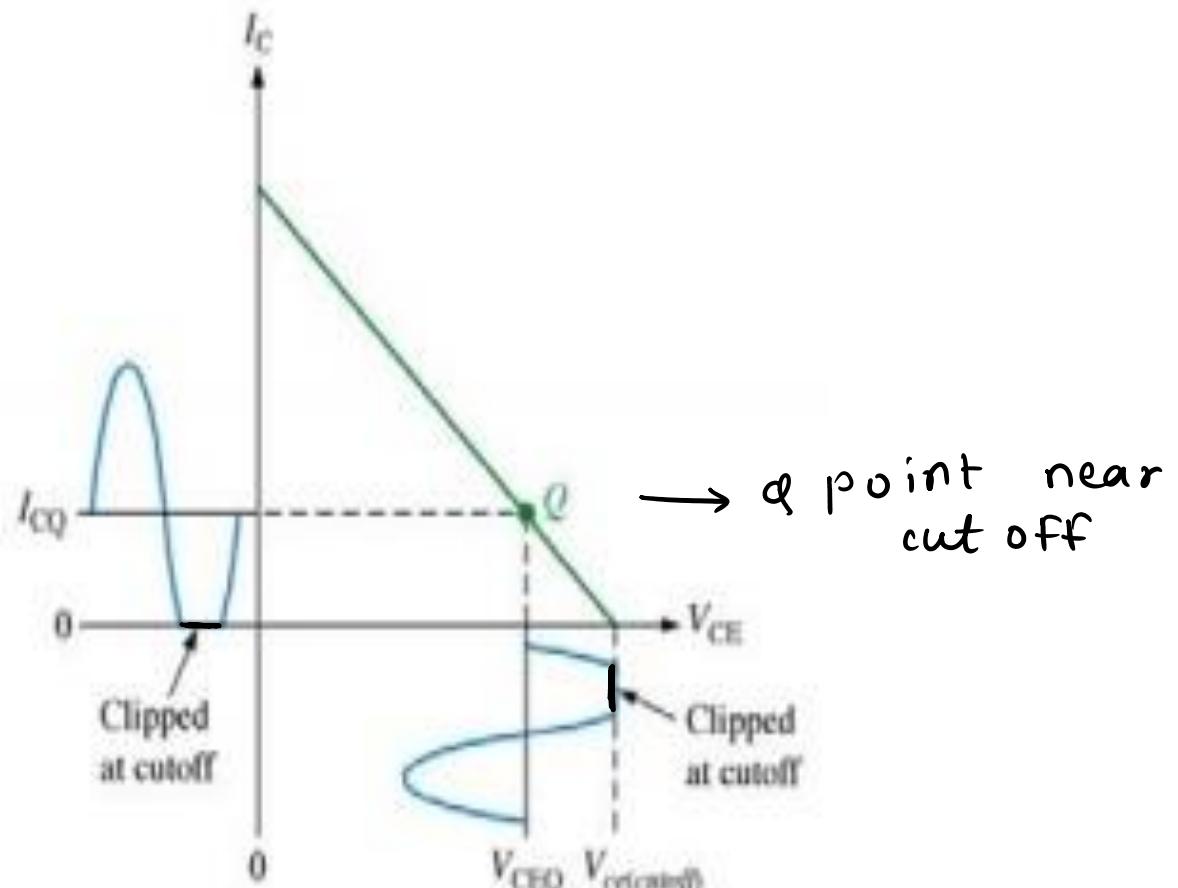


(b) Transistor driven into saturation by a further increase in input amplitude

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(a) Amplitude of  $V_{ce}$  and  $I_c$  limited by cutoff



(b) Transistor driven into cutoff by a further increase in input amplitude

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# **Acknowledgements**

- 1. Electronic Devices, Thomas L. Floyd**
- 2. Web Resources**

# **THANK YOU..**