BIPOLAR JUNCTION TRANSISTORS

(e-content for UG)

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OBJECTIVE OF THE PRESENTATION

- This is an e-content developed for UG students of Physics Core Semester-IV (Paper Code: PHYCC410)
- The main objective is to provide the students a detailed study of the important topic " Bipolar Junction Transistors",under the paper Analog Electronics .
- This initiative has been taken by Patna University under the guidelines given by UGC.

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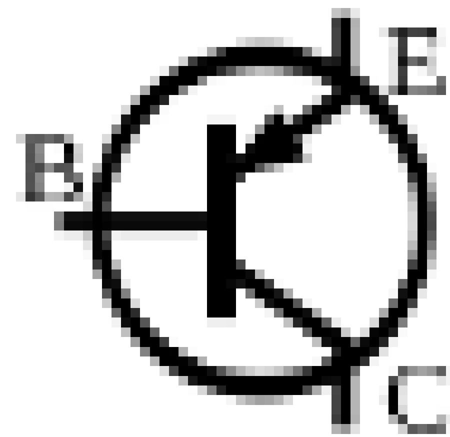
INTRODUCTION

BIPOLAR JUNCTION TRANSISTOR

- A bipolar junction transistor (bipolar transistor or BJT) is a type of transistor that uses both electrons and holes as charge carriers.
- Unipolar transistors, such as field-effect transistors, use only one kind of charge carrier. BJTs use two junctions between two semiconductor types, n-type and p-type.
- A bipolar junction transistor is a current controlled device.

BJT schematic symbols

NPN



PNP

Fig (a)

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Terminals of Transistor

- The emitter layer is heavily doped base lightly doped.
  Doping level : emitter > base > collector
- Outer layer has width much greater than those of sandwiched p or n – type material . For transistor the ratio of width of outer layer to that of sand wiched p or n – type material is (150 : 1) .
  The doping of the base layer is considerably less than that of the outer layers .
- This lower doping level decreases the conductivity of this material by limiting the number of free electrons . The term bipolar reflects the fact that holes and electrons participate in the injection process into the oppositely polarised material .

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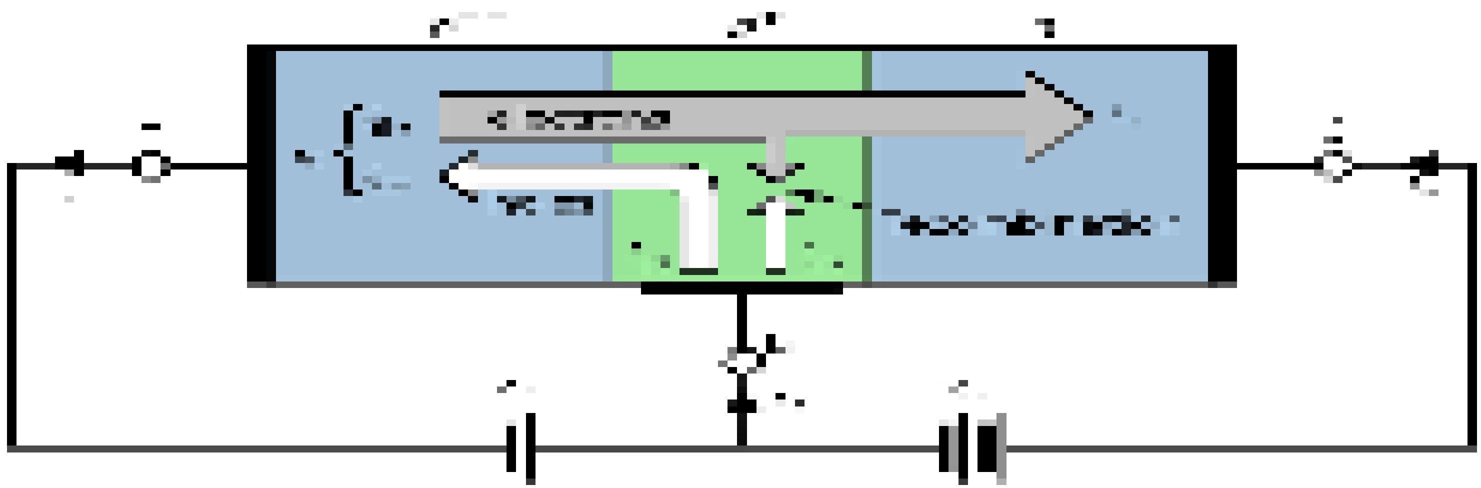
Transistor operation

- **For working of a trnasistor, base – emitter junction must be forward biased and collector base junction must be reverse biased.**



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When proper biasing is achieved, then the following condition holds:

$$I_E = I_C + I_B$$

$$I_C = I_{Cmajority} + I_{COminority}$$

Where I_E is emitter current and I_B is base current.

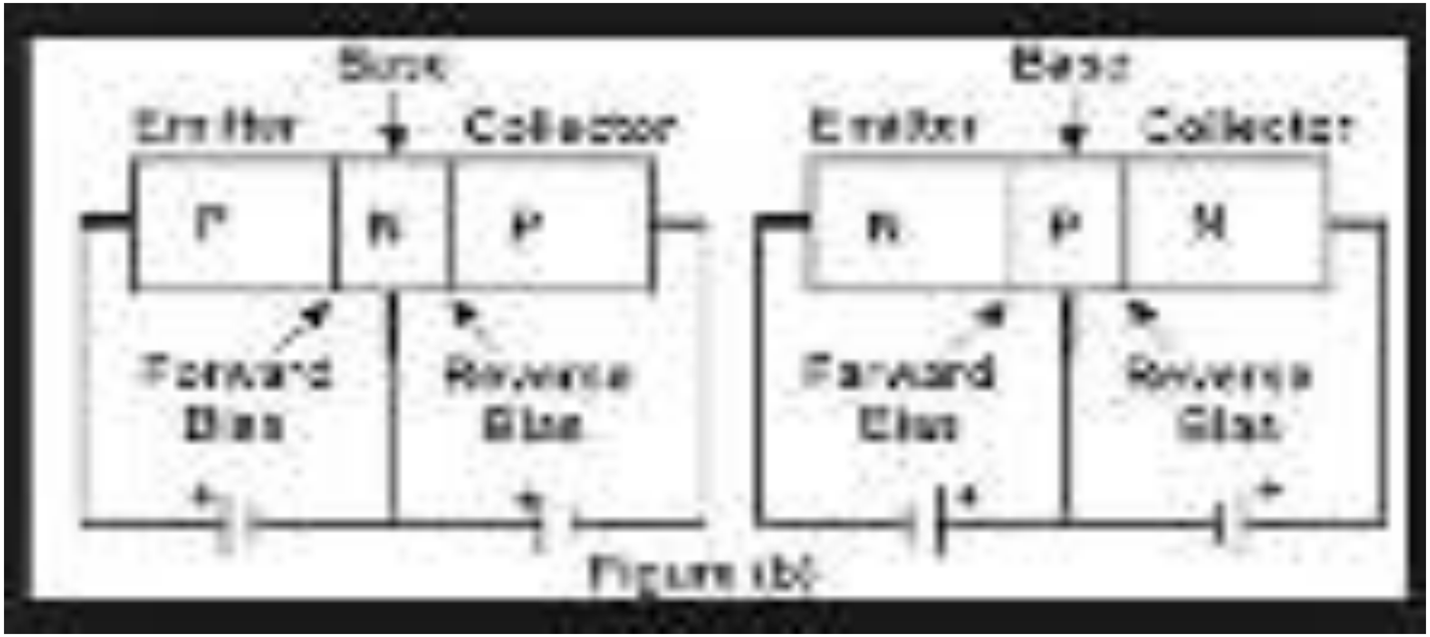
Collector current is comprised of two components, majority components and minority components.

$$I_C = I_{Cmajority} + I_{COminority}$$

where , I_{CO} = collector current with E terminal open

Transistor types: Construction

Transistor is a three layer semiconductor device categorised as npn and pnp.



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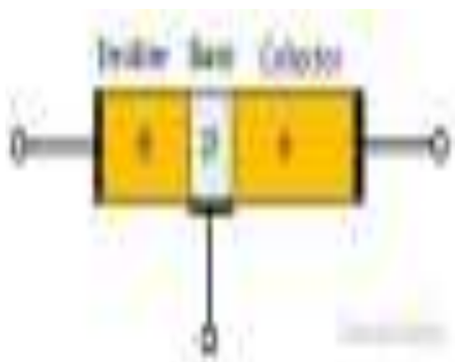
NPN Transistor

- The transistor in which one p-type material is placed between two n-type materials is known as **NPN transistor**.
- The NPN transistor **amplifies the weak signal** enter into the base and produces strong amplify signals at the collector end. In this BJT, the direction of **movement of an electron** is from **emitter to collector** region due to which the current constitutes in the transistor.
- Such type of transistor is mostly used in the circuit because their majority charge carriers are electrons which have high mobility as compared to holes.

Construction of NPN Transistor

- The NPN transistor has two diodes connected back to back. The diode on the left side is called an emitter-base diode, and the diodes on the left side are called collector-base diode. These names are given as per the name of the terminals.



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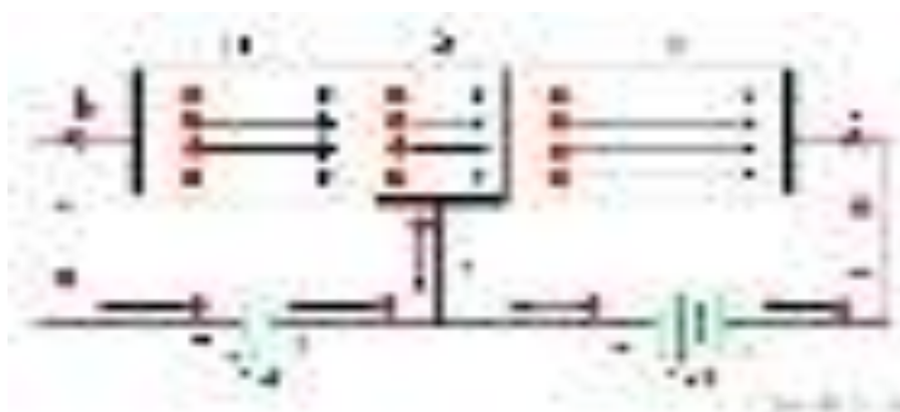
Working of NPN Transistor

- The forward biased is applied across the emitter-base junction, and the reversed biased is applied across the collector-base junction. The forward biased voltage V_{EB} is small as compared to the reverse bias voltage V_{CB}.



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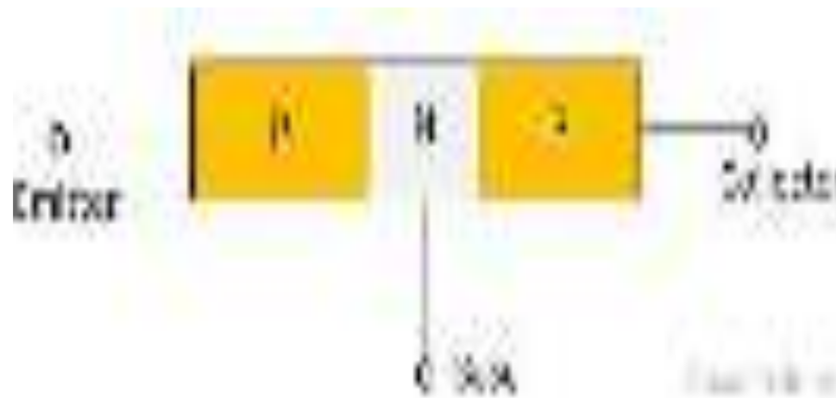
PNP Transistor

- The transistor in which one n-type material is doped with two p-type materials such type of transistor is known as PNP transistor.



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Working of PNP Transistor

- The emitter-base junction is connected in forward biased due to which the emitter pushes the holes in the base region.
- These holes constitute the emitter current. When these electrons move into the N-type semiconductor material or base, they combined with the electrons.
- The base of the transistor is thin and very lightly doped. Hence only a few holes combined with the electrons forming the base current and the remaining are moved towards the collector space charge layer.

- As CB junction is reverse biased, the holes move towards the collector , as the base allows the minority holes to move further. This constitutes the collector current due to holes moving from emitter to collector.

MODES OF OPERATION

- A transistor is a three terminal device. But in 2 port analysis we require 2 terminals for input, 2 terminals for output. So, one terminal is common to both input and output circuit.
- A transistor can be used in three modes:
  - Common emitter(CE)
  - Common base(CB)
  - Common collector (CC)
- Each circuit connection has specific advantages and disadvantages. BJT in CE mode is used as an amplifier as the gain is very high.

COMMON BASE(CB) CONFIGURATION

- Here base is grounded and it is used as the common terminal for both input and output.
- It is also called as grounded base configuration. Emitter is used as a input terminal where as collector is the output terminal.

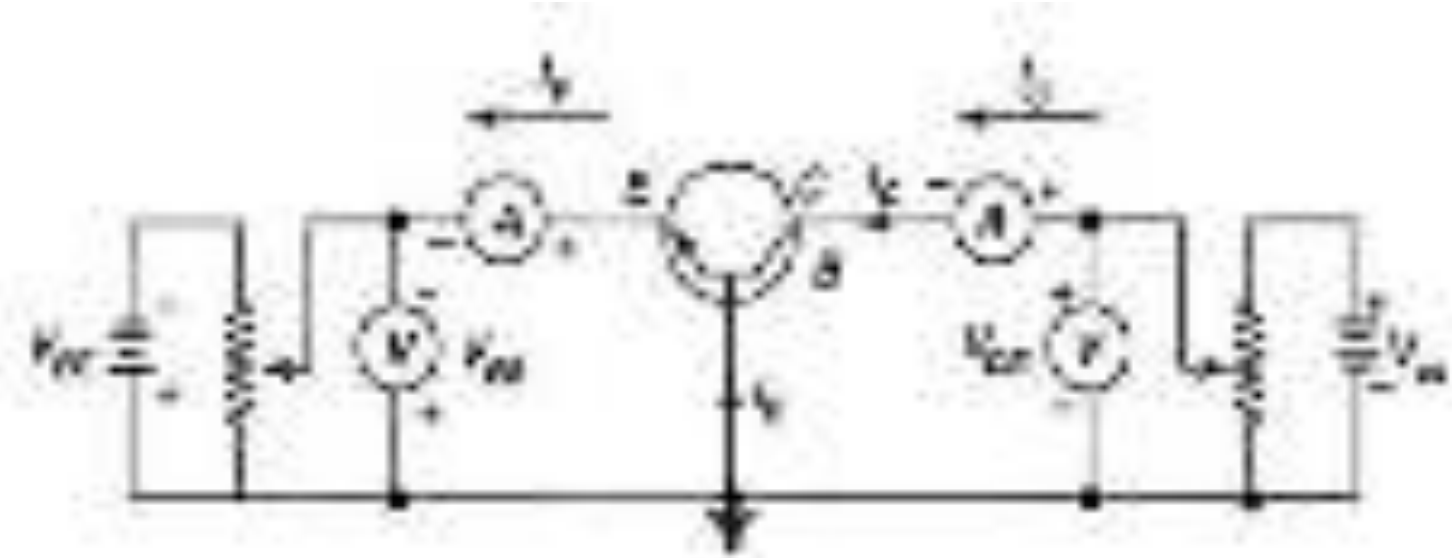

Figure 2.10 Circuit to determine CB static characteristics

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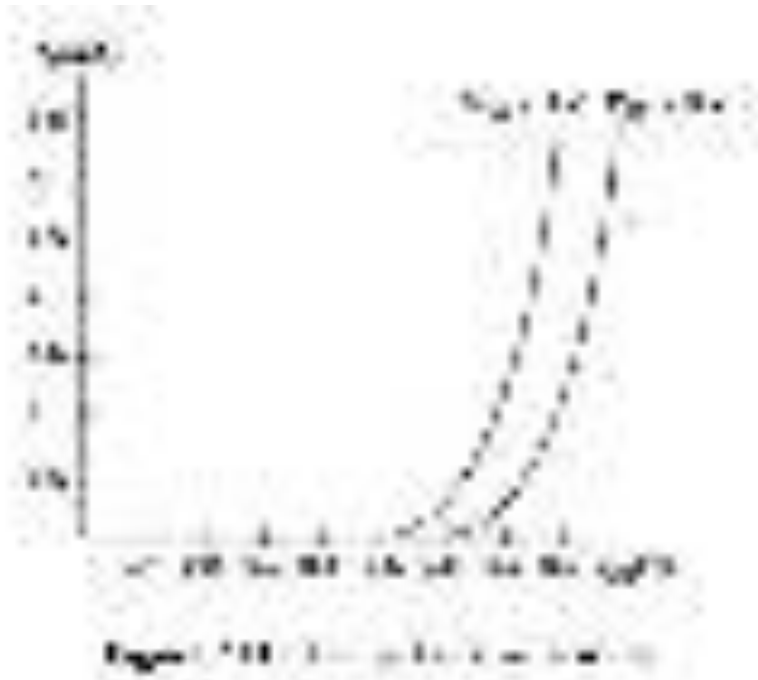
Input characteristics

- It is defined as the characteristic curve drawn between input voltage to input current whereas output voltage is constant.
- A curve is drawn between emitter current and emitter base voltage at constant collector base voltage is shown in figure .When V_{CB} is zero EB junctions is forward biased. So it behaves as a diode so that emitter current increases rapidly.

❖The curve is analogous to the forward biased diode characteristics.



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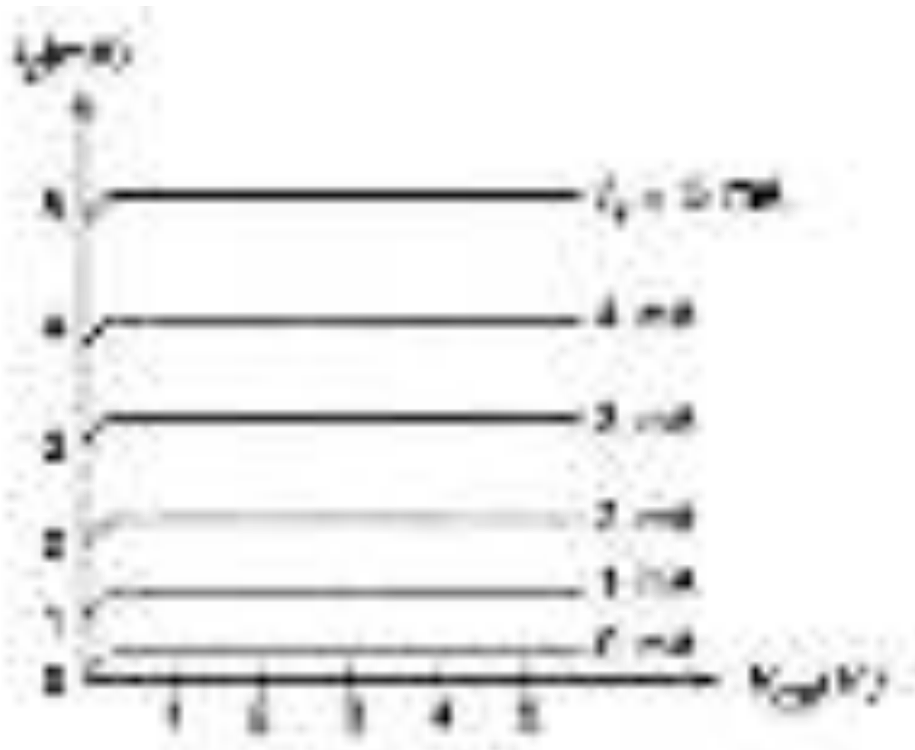
Output Characteristics

- It is defined as the characteristic curve drawn between output voltage to output current whereas input current is constant.
- To determine output characteristics, the emitter current I_E is kept constant at zero and collector current Ic is increased from zero by increasing V_{CB}.This is repeated for higher fixed values of I_E.



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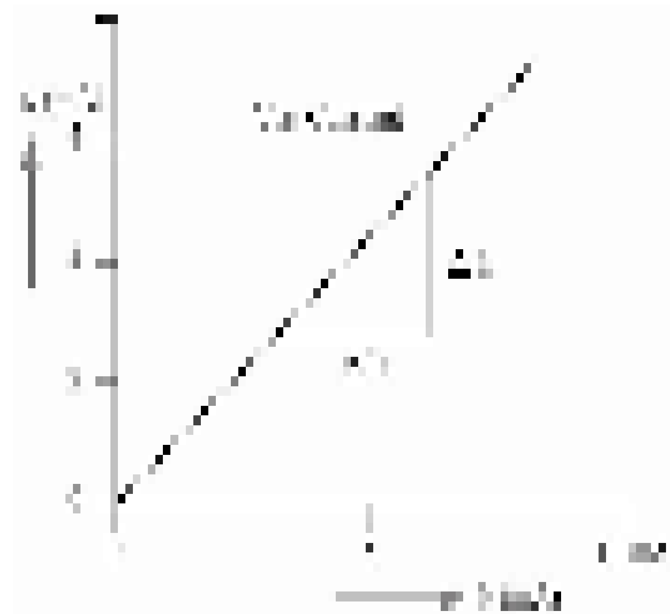
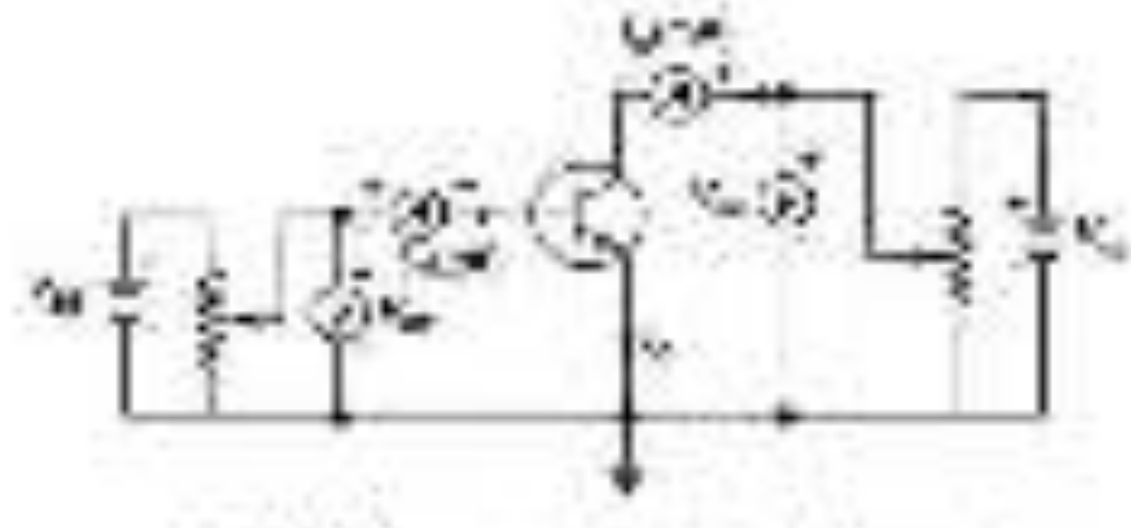
Transfer Characteristics

- It is a plot of Input versus Output current for fixed values of V_{CB}.
- It is a straight line showing linear relation with the slope giving value of Alpha.



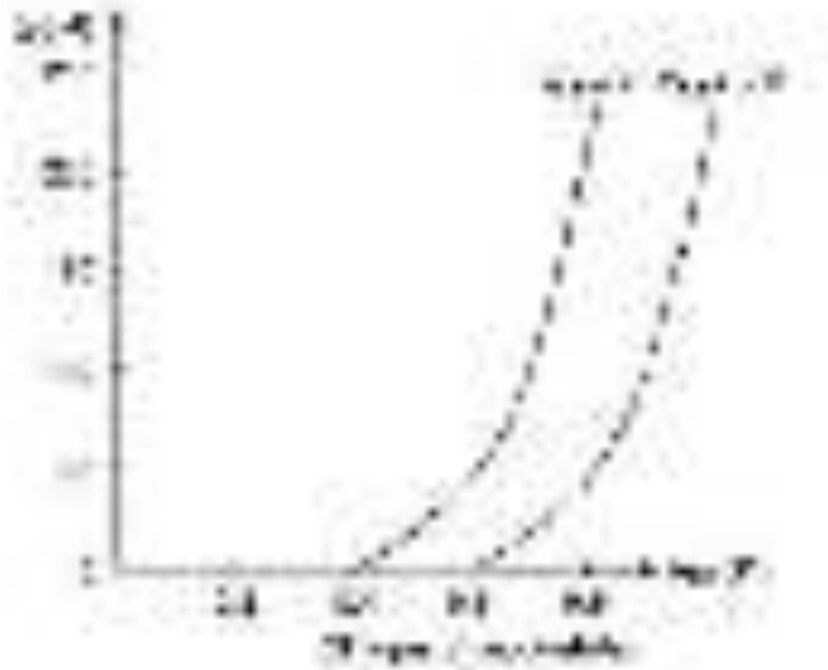
COMMON EMITTER (CE) CONFIGURATION

- In common emitter configuration, emitter is grounded and it is used as the common terminal for both input and output. Base is used as a input terminal whereas collector is the output terminal.



Input Characteristics

- It is defined as the characteristic curve drawn between input voltages to input current whereas output voltage is constant.
- A curve is drawn between base current and base emitter voltage at constant collector base voltage is shown. Here the base width decreases. So curve moves right as V_{CE} increases.



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Output Characteristics

- It is defined as the characteristic curve drawn between output voltage to output current whereas input current is constant.
- From the characteristic it is seen that for a constant value of I_B, I_c is independent of V_{CB} and the curves are parallel to the axis of V_{CE}.

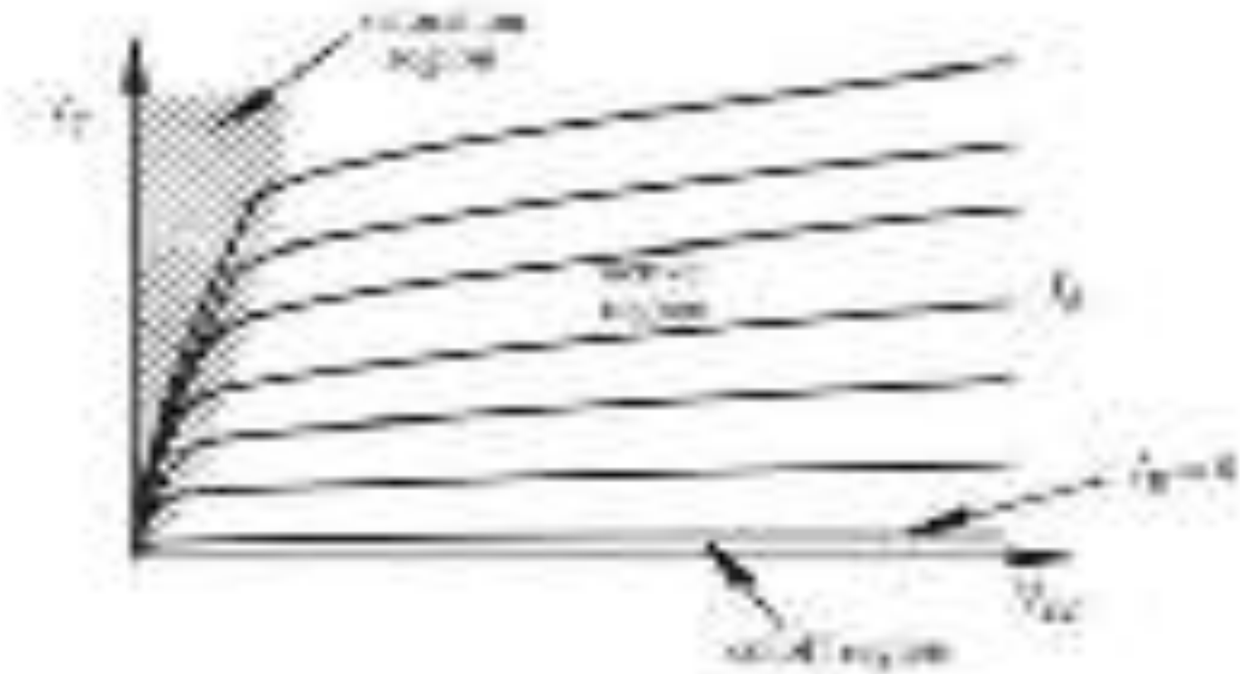

Figure 2.15 CE output Characteristics

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Analysis of Output Characteristics

Active region	Saturation region	Cut-off region
• I_E increased, I_C increased • BE junction forward bias and CB junction reverse bias • Refer to the graph, $I_C \approx I_E$ • I_C not depends on V_{CB} • Suitable region for the transistor working as amplifier.	• BE and CB junction is forward bias • Small changes in V_{CB} will cause big different to I_C • The allocation for this region is to the left of $V_{CB}=0V$	• Region below the line of $I_E=0A$ • BE and CB is reverse bias • No current flow at collector, only leakage current.

TRANSISTOR IN ACTIVE REGION

- In this region, the transistor is operated because it offers a linear curve with gain stability.
- Active region is one in which base emitter junction is forward biased and base collector junction is reverse biased.

TRANSISTOR IN SATURATION REGION

- Saturation is one in which both emitter base and base collector junctions of the transistor are forward biased.
- In this region high current flows through the transistor , as both junctions of the transistor are forward biased and bulk resistance offered is very much less .
- Transistor in saturation region is considered as one state in digital logic.
- A transistor is said to be in saturation if and only if
  - $\beta = I_C/I_B$

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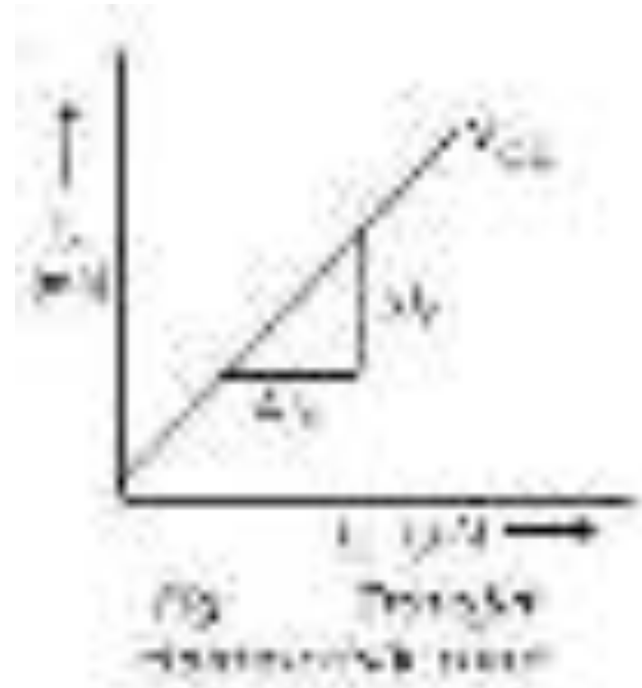
TRANSISTOR IN CUT-OFF REGION

- In this region both junctions of the transistor are reverse biased. Hence transistor in cut-off does not conduct any current except for small reverse saturation currents that flow across junctions.
- In cut-off condition emitter current is zero and the collector current consists of small reverse saturation currents.
- Transistor when used as switch is operated in cut-off on condition and saturation regions which corresponds to switch off an on condition respectively.

Transfer Characteristics

- From the transfer characteristic curve, we can obtain the value of Current Amplification factor β



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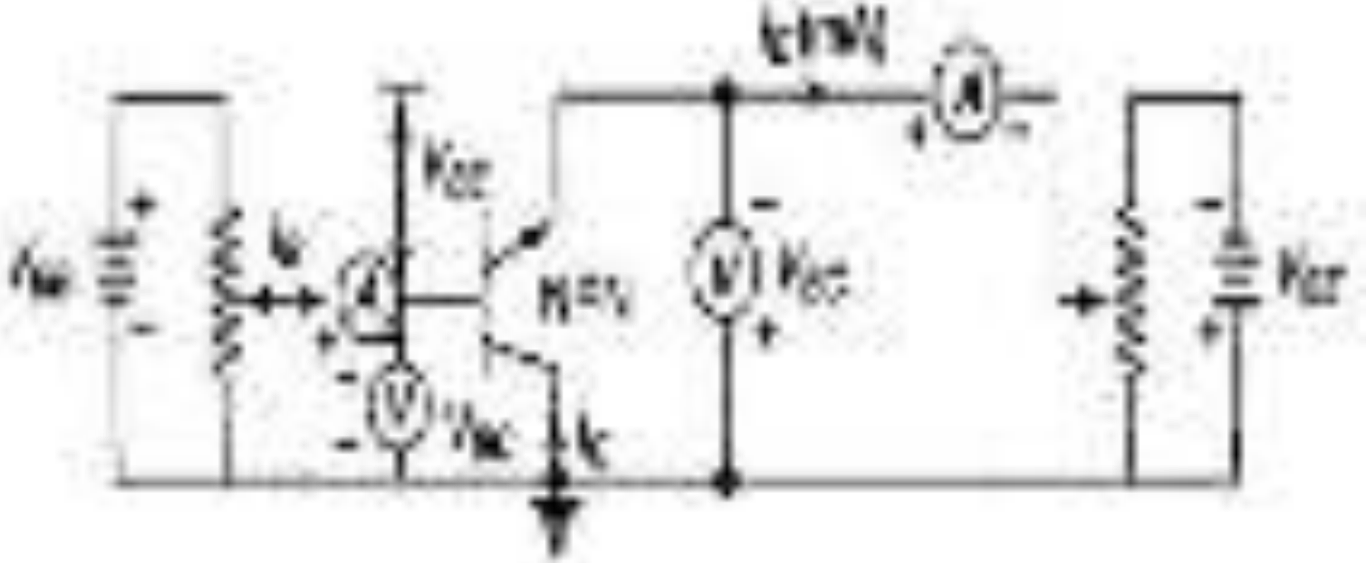
COMMON COLLECTOR (CC) CONFIGURATION

- In common collector configuration circuit is shown in figure. Here collector is grounded and it is used as the common terminal for both input and output.
- It is also called as grounded collector configuration.
- Base is used as a input terminal whereas emitter is the output terminal.



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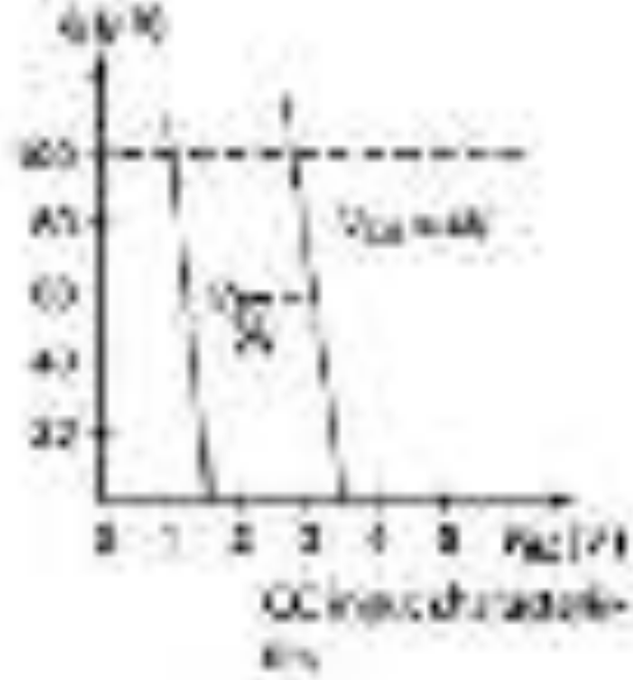
Input Characteristics

- It is defined as the characteristic curve drawn between input voltage to input current whereas output voltage is constant.
- To determine input characteristics, the emitter base voltage V_{EB} is kept constant at zero and base current I_B is increased from zero by increasing V_{BC}.This is repeated for higher fixed values of V_{CE}. A curve is drawn between base current and base emitter voltage at constant collector base voltage is shown.



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Output Characteristics

- It is defined as the characteristic curve drawn between output voltage to output current whereas input current is constant.
- From the characteristic it is seen that for a constant value of I_B, I_E is independent of V_{EB} and the curves are parallel to the axis of V_{EC}.

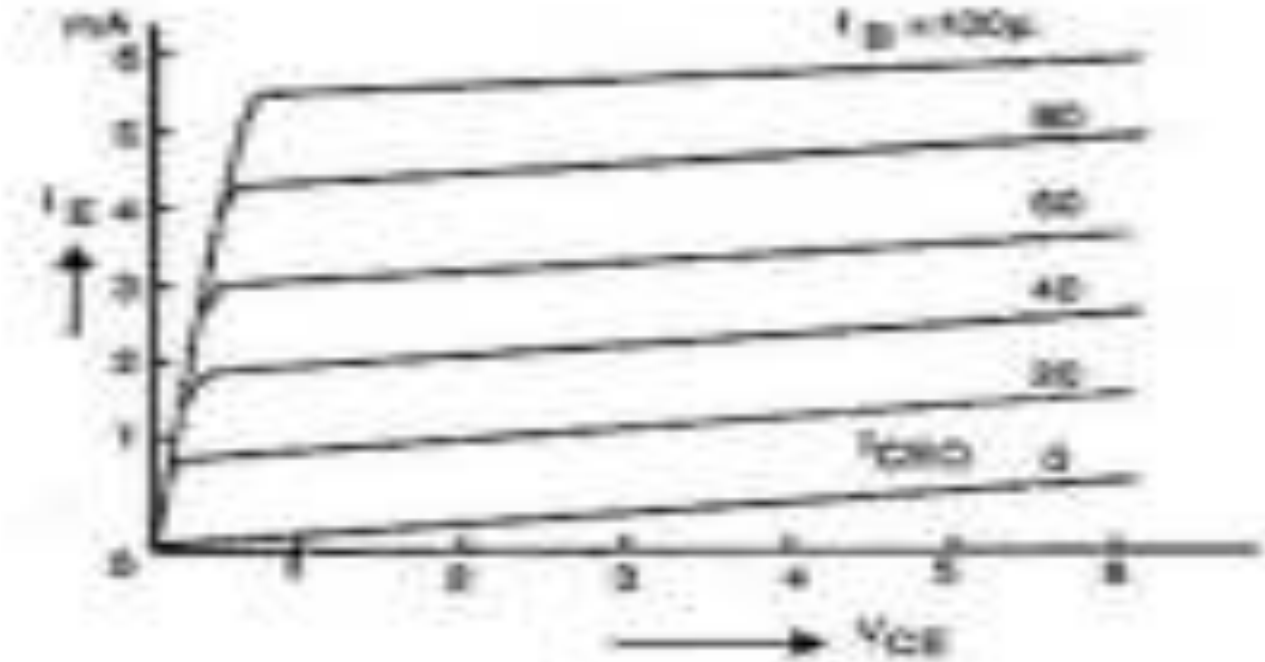

Figure 2.18 CC output characteristics

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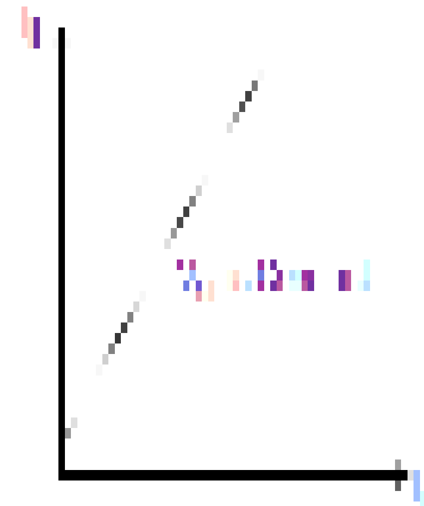
Transfer Characteristics

- It is a plot of input current I_B versus output current I_E for fixed value of V_{CE}.
- Its slope gives the value of current amplification factor γ.



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PARAMETERS CB/CE/CC

Property	CB	CE	CC
Input resistance	Low (about 100 Ω)	Moderate (about 750 Ω)	High (about 750 kΩ)
Output resistance	High (about 450 kΩ)	Moderate (about 45 kΩ)	Low (about 25 Ω)
Current gain	1	High	High
Voltage gain	About 150	About 500	Less than 1
Phase shift between input & output voltages	0 or 360°	180°	0 or 360°
Applications	for high frequency circuits	for audio frequency circuits	for impedance matching

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Common Base Connection

- Current amplification factor (α) :

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

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

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

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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}.

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

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.

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

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

$$r_o = \frac{\Delta V_{CB}}{\Delta I_C}$$

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

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

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

$$I_E = I_B + I_C$$

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

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

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

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

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

Input and Output Resistance of common emitter conf.

- **Input Resistance:** The ratio of change in emitter-base voltage to the change in base current is called Input Resistance.

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

- **Output Resistance:** The ratio of change in collector-emitter voltage to the change in collector current is called Output Resistance.

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

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TRANSISTOR LOAD LINE ANALYSIS

- The load line analysis of transistors means , for the given value of collector-emitter voltage , we find the value of collector current.
- For drawing the DC load line , we need to know its cut off and saturation point.
- The DC load represents the desirable combinations of the collector current and collector-emitter voltage.
- DC load line is straight line joining the cut off and saturation point.
- Let us consider a CE NPN transistor circuit shown in the figure given , when no input signal is applied.

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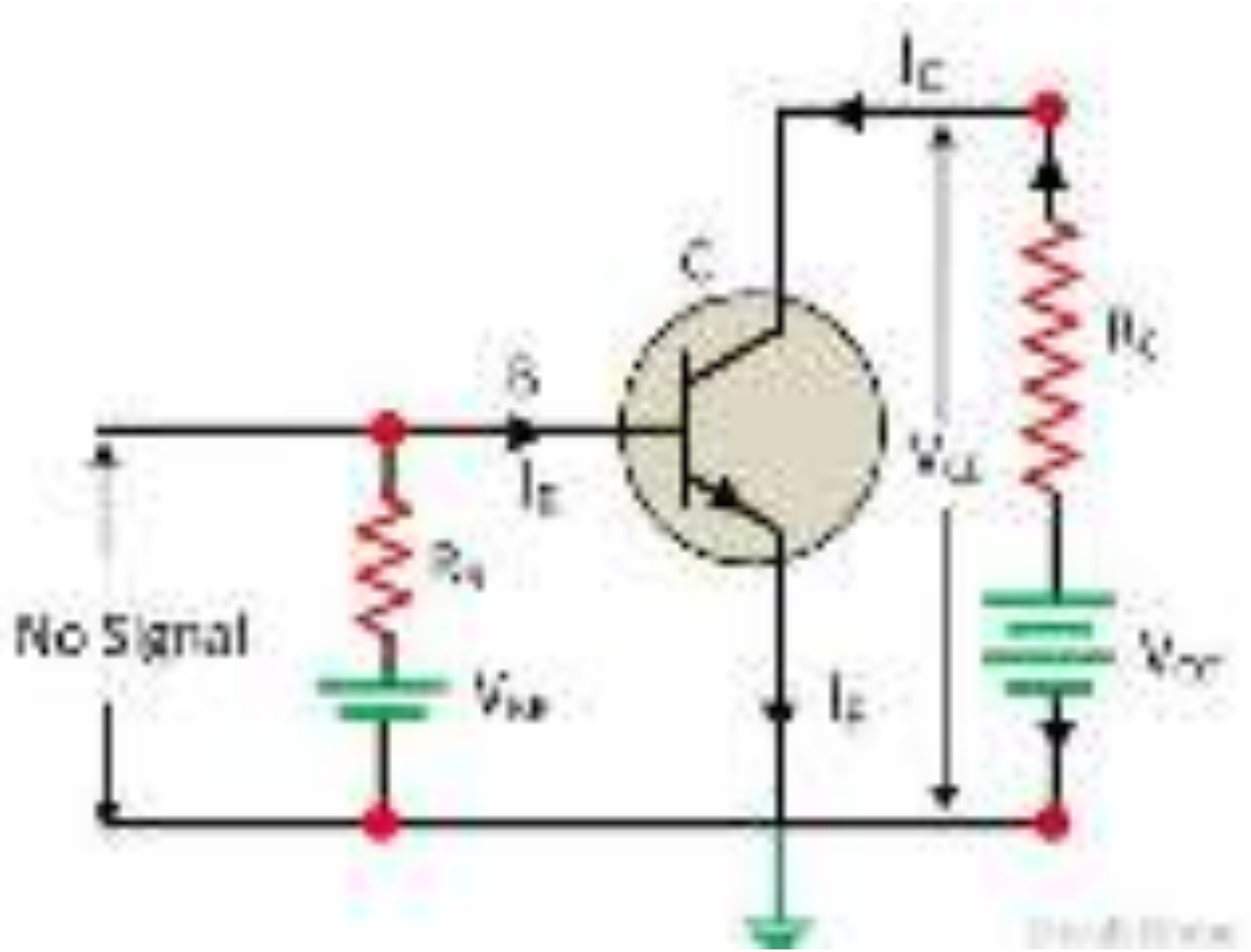
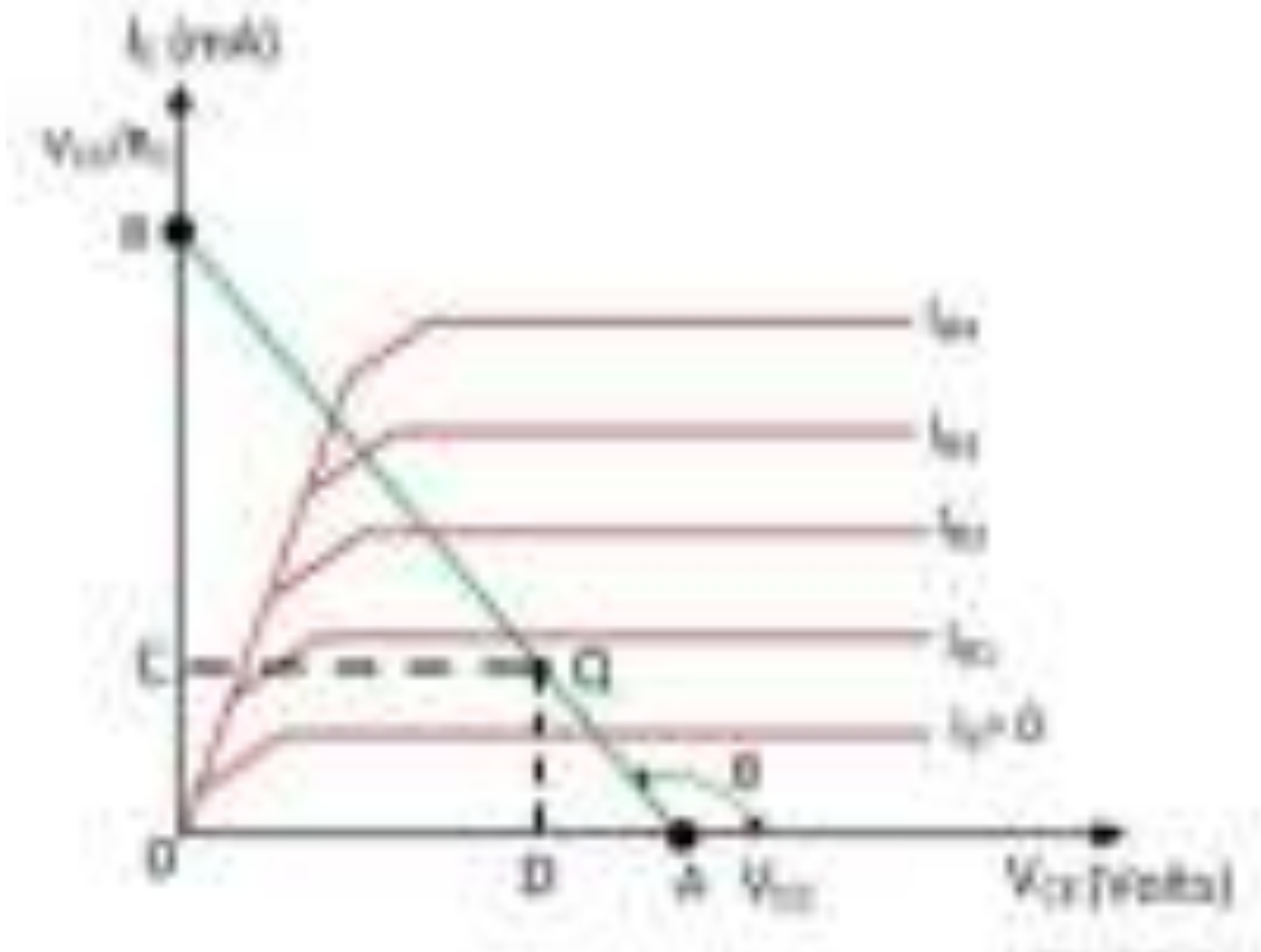


I
C
B
No Signal

The DC load line curve of the previous circuit is shown here:



CUT OFF & SATURATION POINTS

- $V_{CC} = I_C R_C + V_{CE}$
- Therefore $I_C = V_{CC}/R_C - V_{CE}/R_C$

TWO PARTICULAR CASES

- **1)** when $I_C = 0$, $V_{CE} = V_{CC}$

  It gives the cut off point A.
- **2)** when $V_{CE} = 0$, $I_C = V_{CC}/R_C$

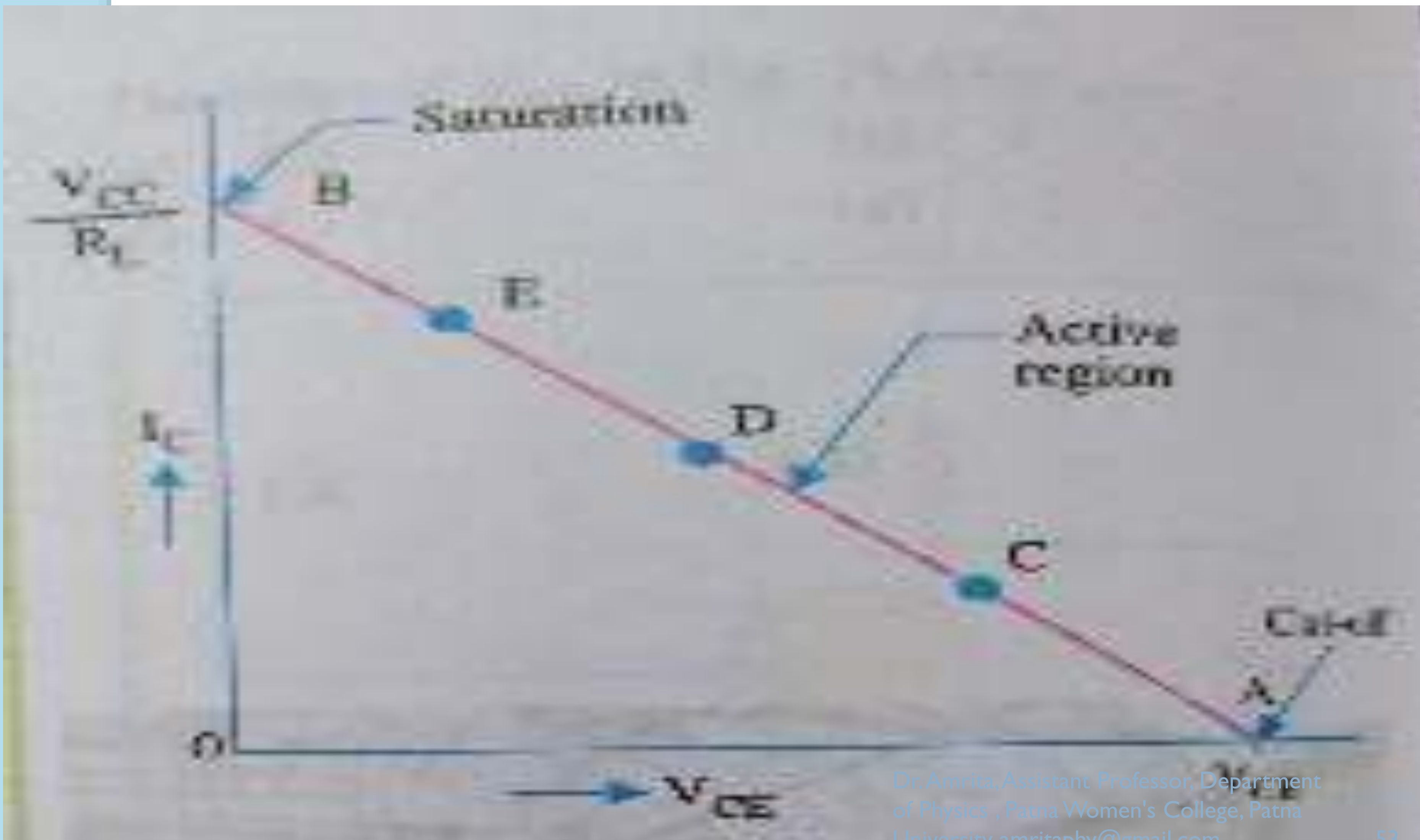
  It gives the saturation point.

Q- point or Operating Point

- A point on the DC load line , which represents the value of I_C and V_{CE} that exist in a transistor circuit when no input signal is applied.
- It is also known as the DC operating point or working point.
- The best position for this point is midway between cut-off and saturation point where

$$V_{CE} = 1/2V_{CC}$$

FIGURE INDICATING Q-POINT



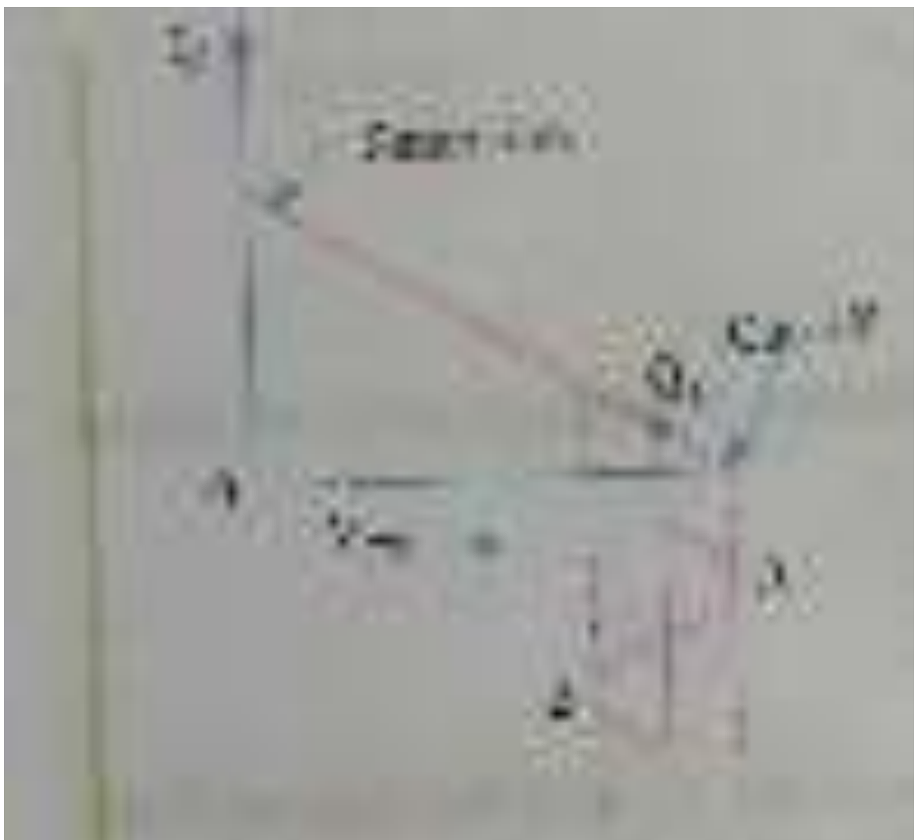
Q-POINT AND MAXIMUM UNDISORTED OUTPUT

- Position of the Q-point on the DC load line determines the maximum signal that we can get from the circuit before clipping occurs.

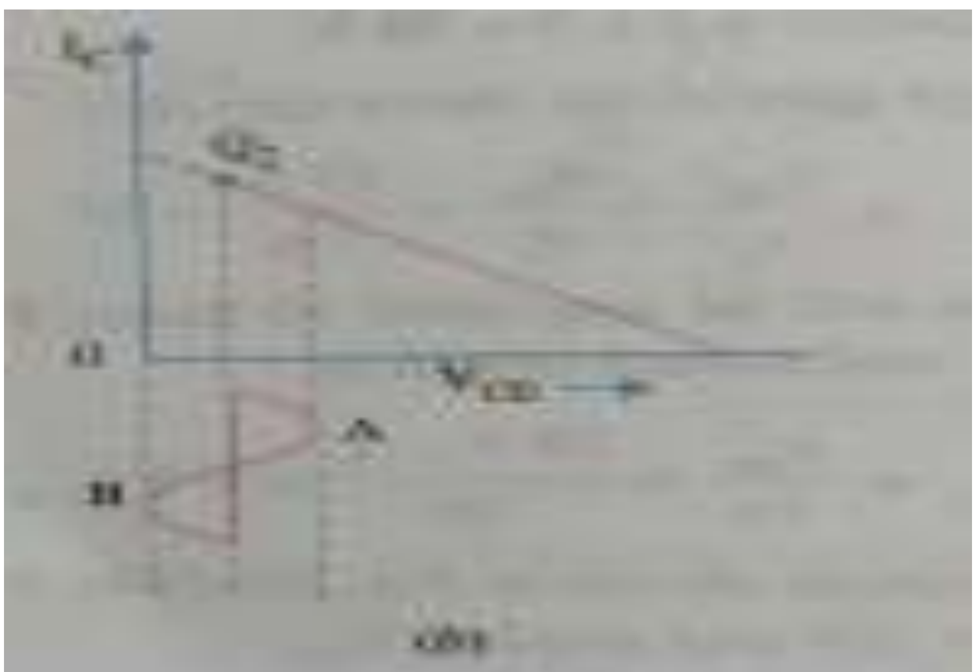
THE THREE CASES

- 1) When Q-point Q_1 is located near cut-off point , signal first starts to clip at A. it is called cut-off clipping because the positive swing of the signal drives the transistor to cut-off.

- As seen from the given figure , maximum swing is = $I_{CQ}R_{AC}$



- 2) When Q-point Q_2 is located near saturation point , then clipping first starts at B as shown.
- The maximum negative swing = V_{CEQ}



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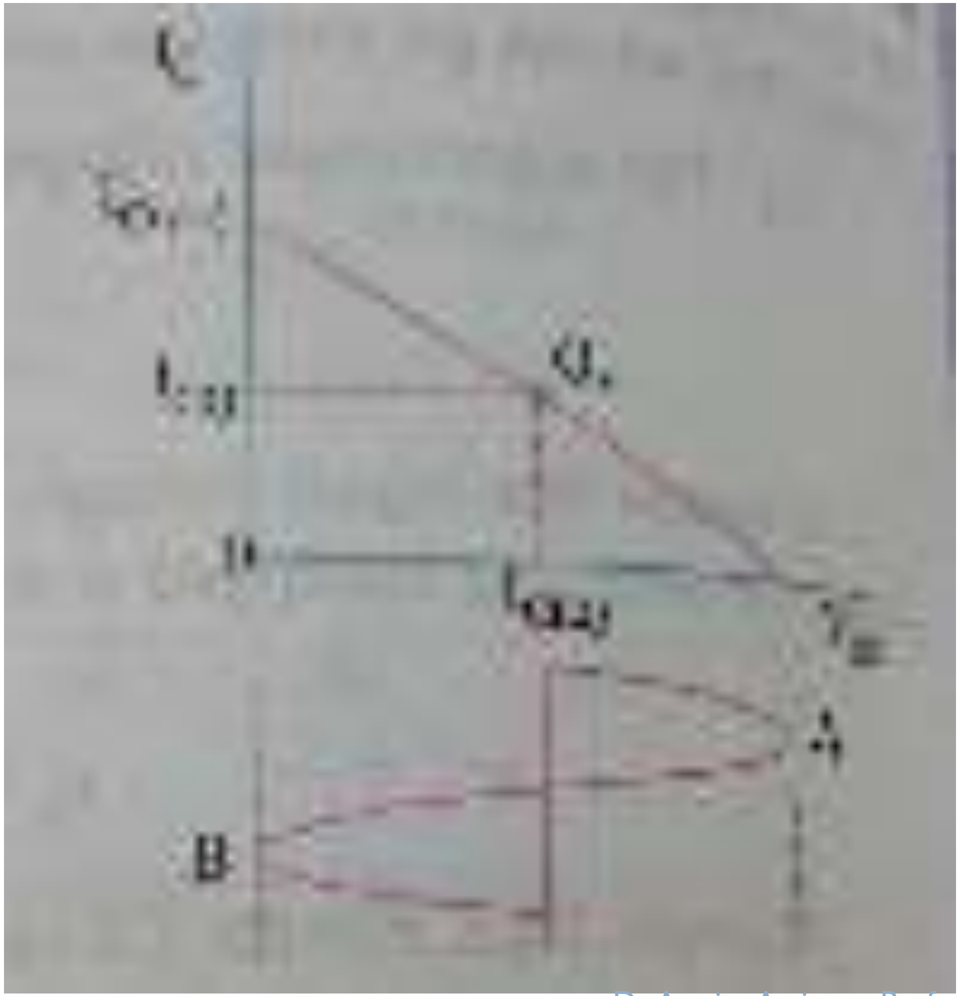
- 3)When Q-point Q_3 is located at the centre of the load line , in this condition , we get the maximum possible output signal.
- The point Q_3 gives the optimum Q-point
- The maximum undistorted signal = $2V_{CEQ}$
- Q point is also known as quiesent point or silent point because it is the point where the transistor is silent ie. There is no a.c. signal.

IDEAL OPERATING POINT IN ACTIVE REGION



APPLICATIONS OF BJT

- BJTs can be used as amplifiers or switches.
- This ability gives them many applications in electronic equipment such as computers, televisions, mobile phones.
- These are also commonly used in audio amplifiers, industrial control, and radio transmitters.
- It serves as the fundamental unit in design of Integrated Circuits.

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Thank You