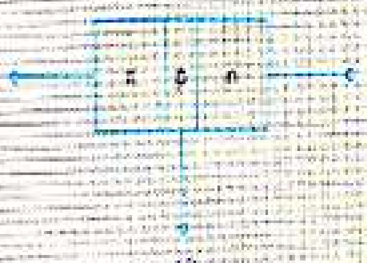
CHAPTER - 4

[TRANSISTORS]

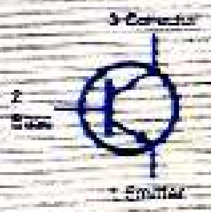
❖ INTRODUCTION:-

- **When a third doped element is added to a crystal diode in such a way that two PN junctions are formed, the resulting device is known as a Transistor.**
- **This is a new type of electronics device which can able to amplify a weak signal in a fashion comparable and often superior to that realized by vacuum tubes.**
- **A transistor consists of two PN junctions formed by sandwiching either p-type or n-type semiconductor between a pair of opposite types. Hence Transistor is classified into two types, namely: -**
    - **(i) n-p-n transistor (ii) p-n-p transistor**
- **An n-p-n transistor is composed of two n-type semiconductors separated by a thin section of p-type.**
- However, a p-n-p transistor is formed by two p-sections separated by a thin section of n-type as shown in Figure below.



(i)

(ii)



✣ NAMING: -

- A transistor has *two pn junctions*. As discussed later, one junction is forward biased and the other is reverse biased.
- The *forward biased junction* has a low resistance path whereas a *reverse biased junction* has a high resistance path.
- The weak signal is introduced in the low resistance circuit and output is taken from the high resistance circuit. Therefore, a transistor transfers a signal from a low resistance to high resistance.
- The prefix 'trans' means the signal transfer property of the device while 'istor' classifies it as a solid element in the same general family with resistors.

❖ **NAMING THE TRANSISTOR TERMINALS:-**

- **A transistor (PNP or NPN) has three sections of doped semiconductors.**
- **The section on one side is the emitter and the section on the opposite side is the collector.**
- **The middle section is called the base and forms two junctions between the emitter and collector.**

(i)Emitter: -

- The section on one side that *supplies charge carriers* (electrons or holes) is called the emitter.
- The emitter is always forward biased w.r.t. base so that it can supply a large number of majority carriers.
- The emitter (p-type) of PNP transistor is forward biased and supplies hole charges to its junction with the base. Similarly the emitter (n-type) of NPN transistor has a forward bias and supplies free electrons to its junction with the base.

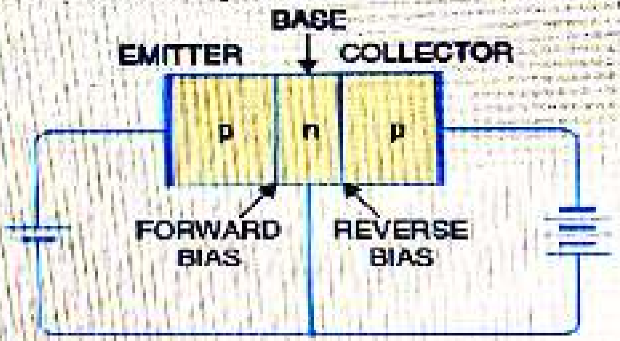
(ii) Collector: -

- The section on the other side that *collects the charges* is called the collector. The collector is always reverse biased. Its function is to remove charges from its junction with the base.
- The collector (p-type) of PNP transistor has a reverse bias and receives hole charges that flow in the output circuit. Similarly the collector (n-type) of NPN transistor has reverse bias & receives electrons.

(iii)Base: -

- The middle section which forms two PN-junctions between emitter & collector is called base.
- The base-emitter junction is forward biased, allowing low resistance for the emitter circuit.

➢ The base-collector junction is reverse biased and provides high resistance in the collector circuit.



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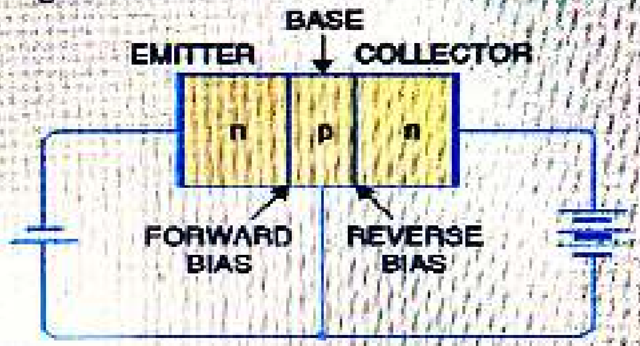
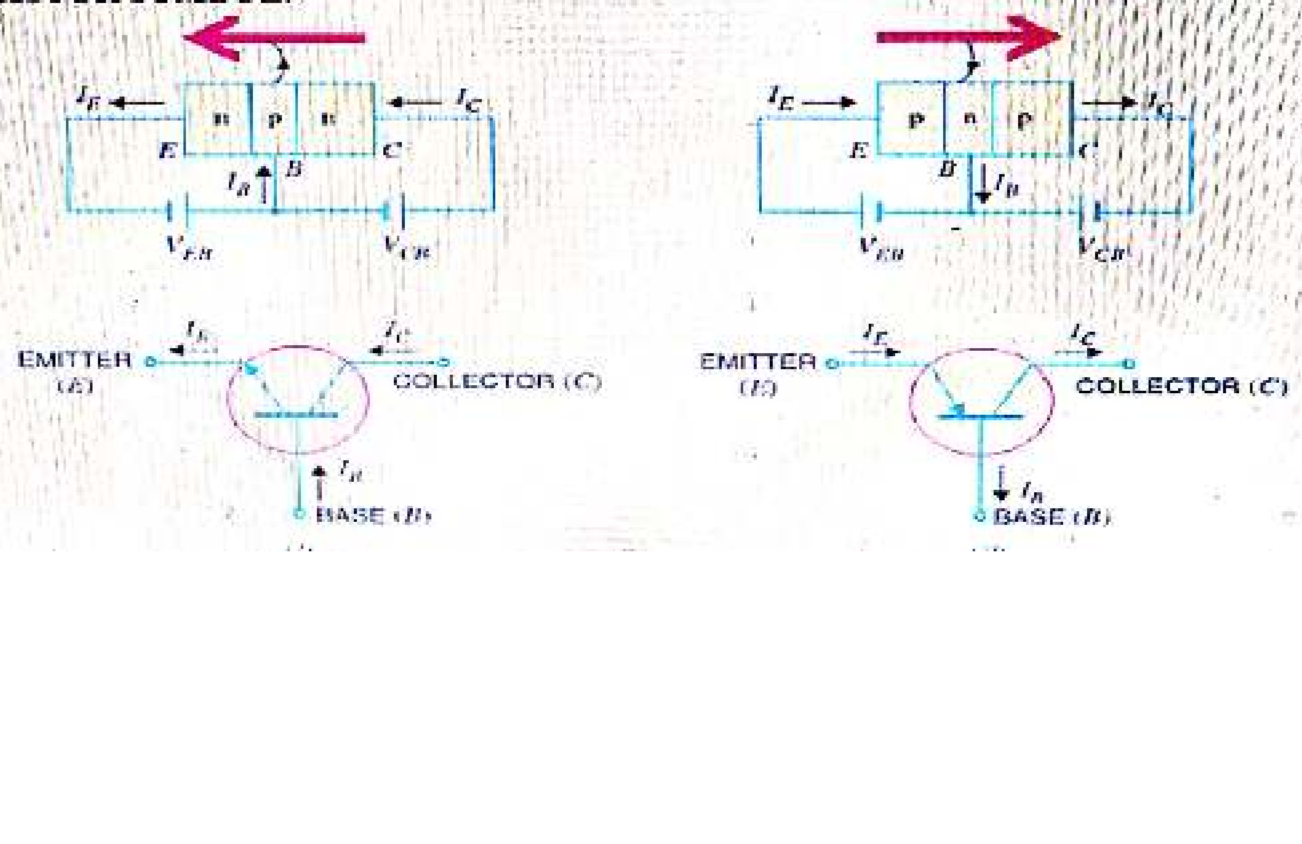


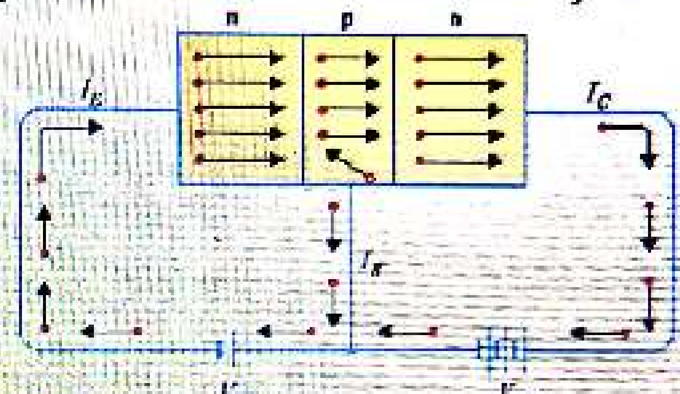
(ii)

❖ **TRANSISTOR SYMBOL:-**



❖ WORKING OF NPN TRANSISTOR (NPN): -

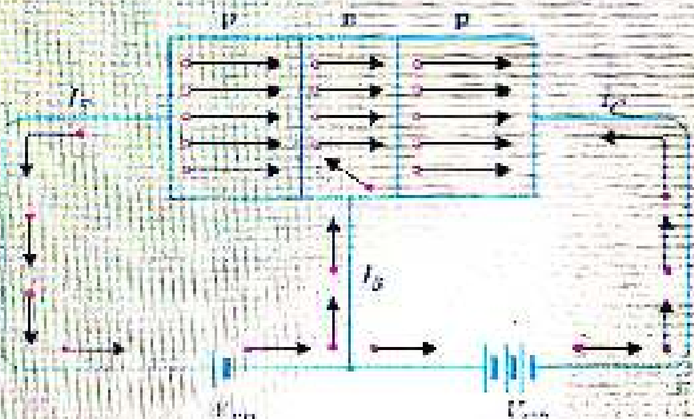
- The NPN transistor with forward bias to emitter- base junction & reverse bias to collector-base junction.
- The forward bias causes the electrons in the n-type emitter to flow towards the base.
- This constitutes the emitter current I_E. As these electrons flow through the p-type base, they tend to 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 base current I_B.
- The remainders (more than 95%) cross over into the collector region to constitute collector current I_C.
- In this way, almost the entire emitter current flows in the collector circuit.



- It is clear that emitter current is the sum of collector and base currents i.e. $I_E = I_B + I_C$

❖ WORKING OF PNP TRANSISTOR (PNP): -

- Fig. shows the basic connection of a 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 the electrons.
- As the base is lightly doped and very thin, therefore, only a few holes (less than 5%) combine with the electrons. The remainder (more than 95%) cross into the collector region to constitute collector current I_C.



- In this way, almost the 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 CONNECTIONS:-

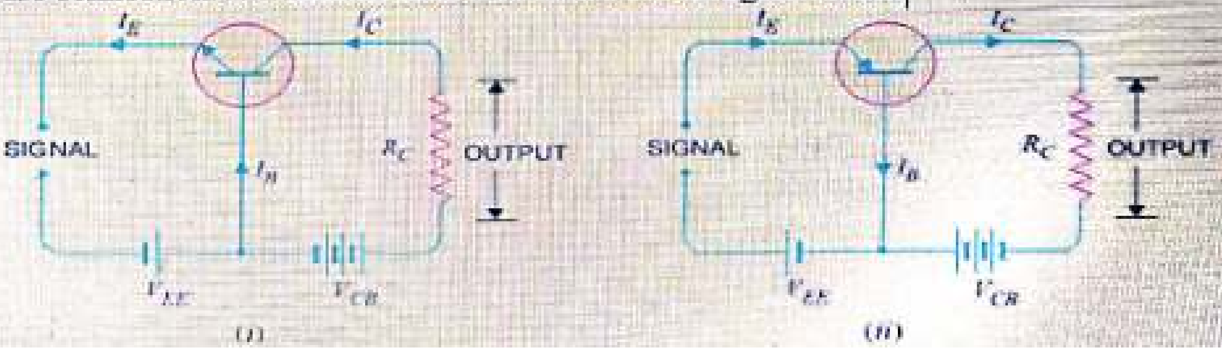
- There are three leads in a transistor such as emitter, base and collector terminals.
- However, when a transistor is to be connected in a circuit, we require **four terminals**; two for the input and two for the output.
- This difficulty is overcome by making one terminal of it in common to both input and output terminals.
- The input is fed between this common terminal and one of the other two terminals.
- The output is obtained between the common terminal and the remaining terminal.
- So a transistor can be connected in a circuit in the following ways:-

  (i) Common Base connection (ii) Common Emitter connection (iii) Common Collector connection

(i)Common Base Connection

In this circuit arrangement, input is applied between emitter and base and output is taken from collector and base.

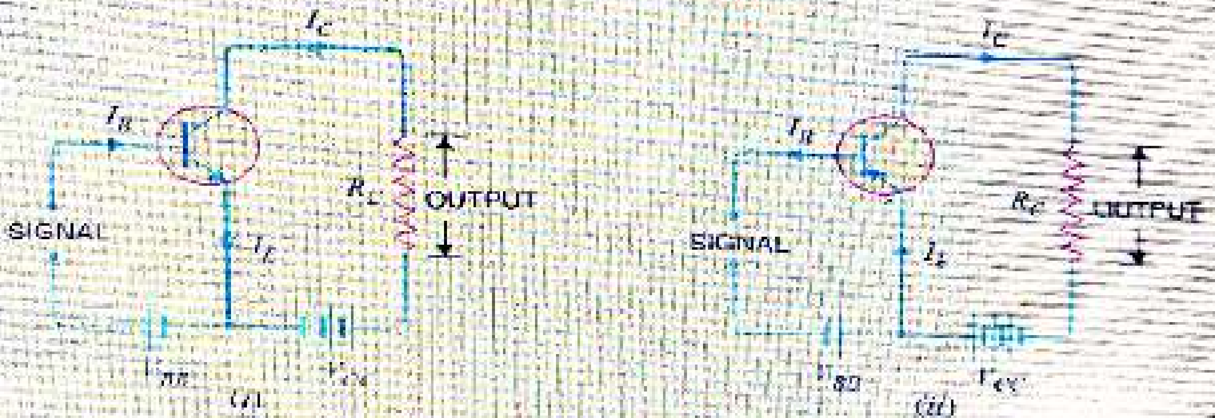
Here, base of the transistor is common to both input and output circuits and hence the name Common Base connection. A Common Base NPN and PNP in figure below.



(ii) Common Emitter Connection

In this circuit arrangement, input is applied between base and emitter and output is taken from the collector and emitter.

Here, emitter of the transistor is common to both input and output circuits and hence the name Common Emitter connection. A Common Emitter NPN and PNP transistor circuit is shown in figure below.



(iii) Common Collector Connection

In this circuit arrangement, input is applied between base and collector while output is taken between the emitter and collector.

Here, collector of the transistor is common to both input and output circuits and hence the name Common Collector connection. A Common Collector NPN and PNP in figure below

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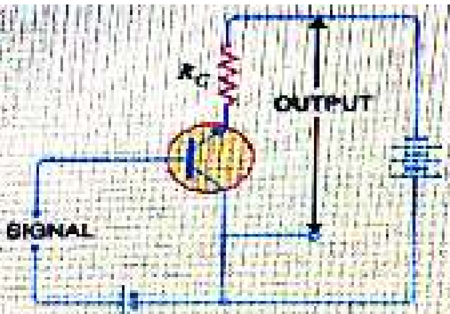
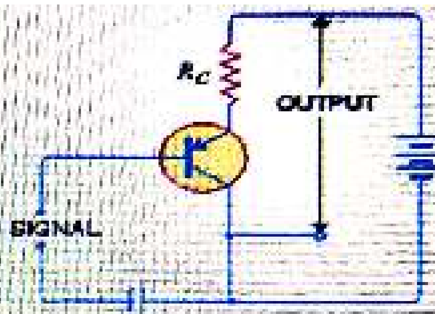




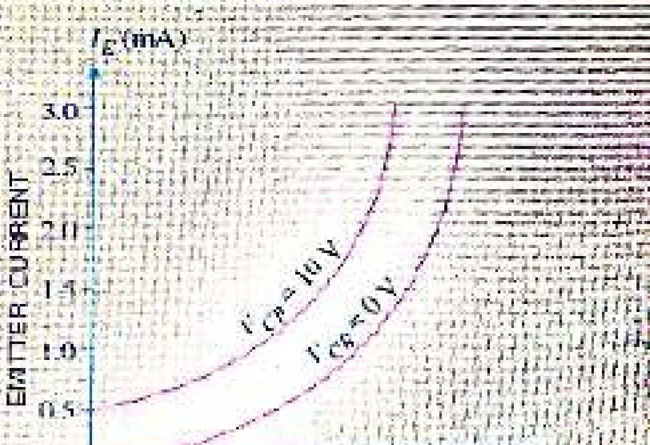
❖ TRANSISTOR CHARACTERISTICS:-

1) Characteristics of Common Base Connection

- The complete electrical behavior of a transistor can be described by stating the interrelation of the various currents and voltages.
- These relationships can be conveniently displayed graphically and the curves thus obtained are known as the characteristics of transistor.
- The most important characteristics of common base connection are **input characteristics and output characteristics.**

A) Input Characteristics:-

- It is the curve between emitter current I_E & emitter-base voltage V_{BE} at constant collector-base voltage V_{CB}.
- The emitter current is generally taken along y-axis and emitter-base voltage along x-axis. Fig. Shows the input characteristics of a typical transistor in CB arrangement.
- The following points may be noted from these characteristics :
  - ♣ The emitter current I_E increases rapidly with small increase in emitter-base voltage V_{EB}. It means that input resistance is very small.



- The emitter current is almost independent of collector base voltage V_{CB}. This leads to the conclusion that emitter current (and hence collector current) is almost independent of collector voltage.

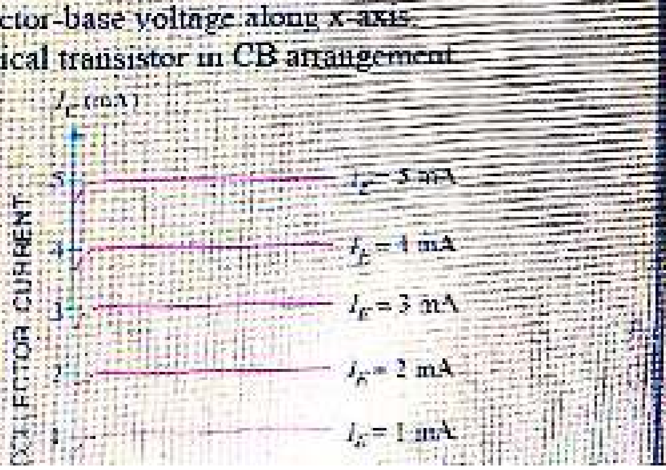
- **Input Resistance:** - It is the ratio of change in emitter base voltage (ΔV_{EB}) to the resulting change in emitter current (ΔI_E) at constant collector-base voltage (V_{CB}) i.e.

$$\text{Input resistance, } r_i = \frac{\Delta V_{BE}}{\Delta I_E} \text{ at constant } V_{CB}$$

- In fact, input resistance is the opposition offered to the signal current. As a very small V_{EB} is sufficient to produce a large flow of emitter current I_E, thus, input resistance is quite small, of the order of a few ohms.

B) Output Characteristics:-

- It is the curve between collector current I_C & collector base voltage V_{BC} at constant emitter current I_E.
- Generally, collector current is taken along y-axis and collector-base voltage along x-axis.
- The fig. shows the input and output characteristics of a typical transistor in CB arrangement.
- The following points may be noted from characteristics :
  - The collector current I_C varies with V_{CB} only at very low voltages (< 1V). The transistor is never operated in this region.
  - When the value of V_{CB} is raised above 1 – 2 V, the collector current becomes constant as indicated by straight horizontal curves. It means that now I_C is independent of V_{CB} and depends upon I_E only. This is consistent with the theory that the emitter current



flows almost entirely to the collector terminal. The transistor is always operated in this region.

- A very large change in collector-base voltage produces only a tiny change in collector current. This means that output resistance is very high.

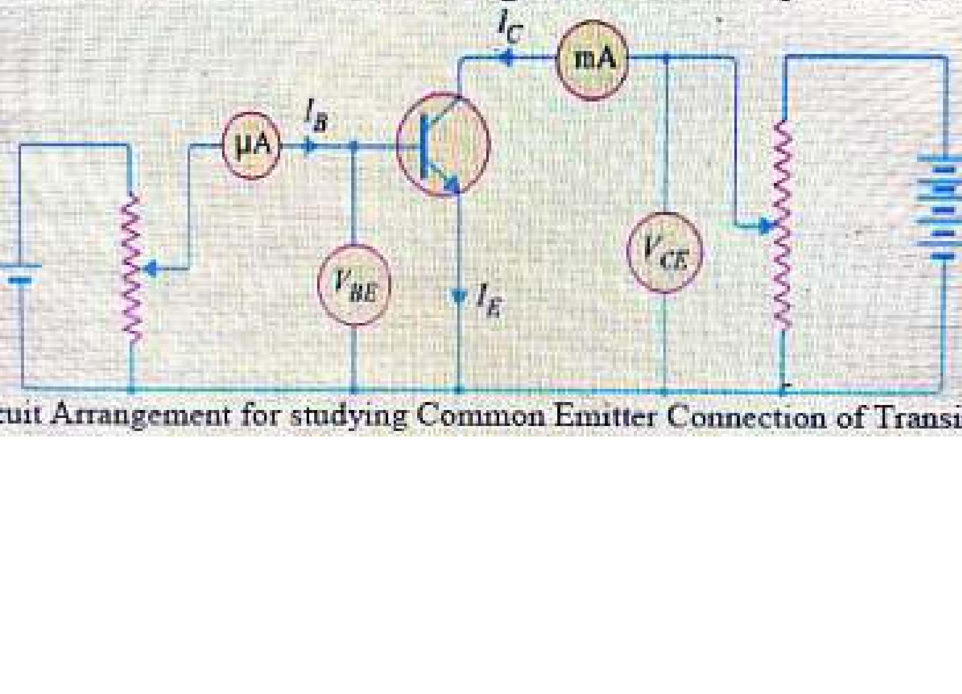
➢ **Output Resistance:** - It is the ratio of change in collector-base voltage (ΔV_{CB}) to the resulting change in collector current (ΔI_C) at constant emitter current i.e.

$$\text{Output resistance, } r_o = \frac{\Delta V_{CB}}{\Delta I_C} \text{ at constant } I_E$$

➢ The output resistance of CB circuit is very high, of the order of several tens of kilo-ohms.

2) Characteristics of Common Emitter Connection:-

➢ The important characteristics of this circuit arrangement are the input characteristic and output characteristic.



(Circuit Arrangement for studying Common Emitter Connection of Transistor)

(Circuit Arrangement for studying Common Emitter Connection of Transistor)

A) Input Characteristics:-

- It is the curve between base current IB & base-emitter voltage VBE at constant collector-emitter vo[ltage] V_{CE}. The input characteristics of a CE connection can be determined by the circuit shown in Fig. Keeping V_{CE} constant (Let 10 V), note the base current I_B for various values of V_{BE}.
- Then plot the readings obtained on the graph, taking I_B along y-axis and V_{BE} along x-axis. This gives the input characteristic at V_{CE} = 10V as shown in Fig.

- The following points may be noted from the characteristics :
  - The characteristic resembles that of a forward biased diode curve. This is expected since the base-emitter section of transistor is a diode and it is forward biased.
  - As compared to CB arrangement, I_B increases less rapidly with V_{BE}. Therefore, input resistance of a CE circuit is higher than that of CB circuit.
- **Input Resistance:** – It is the ratio of change in base-emitter voltage (ΔV_{BE}) to the change in b[ase] current (ΔI_B) at constant V_{CE}. The value of input resistance for CE circuit is of the order of a hundred ohms

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B) **Output Characteristics: -**

- It is the curve between collector current I_C and collector-emitter voltage **V_{CE} at constant base current I_B.**
- The output characteristics of CE circuit can be drawn with the help of above circuit arrangement in Fig.
- Keeping the base current I_B fixed at some value say, 5 μA, note the collector current I_C for various values of V_{CE}.
- Then plot the readings on a graph, taking I_C along y-axis and V_{CE} along x-axis.
- This gives the output characteristic at I_B = 5 μA as shown in Fig. The test can be repeated for I_B = 10 μA to obtain the new output characteristic as shown in Fig.
- Following similar procedure, a family of output characteristics can be drawn as shown in Fig.

- The following points may be noted from the characteristics:
  - (i) The collector current I_C varies with V_{CE} for V_{CE} between 0 and 1V only. After this, I_C becomes almost constant & independent of V_{CE}.
  - This value of V_{CE} upto which I_C changes with V_{CE} is called the knee voltage (V_{knee}). The transistors are always operated in the region above knee voltage.
  - (ii) Above knee voltage, I_C is almost constant. However, a small increase in I_C with increasing V_{CE} is caused by the collector depletion layer getting wider and capturing a few more majority carriers before electron-hole combinations occur in the base area.
  - (iii) For any value of V_{CE} above knee voltage, the collector current I_C is approximately equal to $\beta \times I_B$
- **Output Resistance:** - It is the ratio of change in collector-emitter voltage (ΔV_{CE}) to the change in collector current (ΔI_C) at constant I_B i.e. Output resistance, $r_o = \frac{\Delta V_{CE}}{\Delta I_C}$ at constant I_B
- It may be noted that whereas the output characteristics of CB circuit are horizontal, they have noticeable slope for the CE circuit.
- Therefore, output resistance of CE circuit is less than that CB circuit. Its value is of the order of 50 kΩ.

3) Characteristics of Common Collector Connection:-

- In a Common Collector circuit connection the load resistor connected from emitter to ground, so the collector tied to ground even though the transistor is connected in a manner similar to the CE connection.
- Hence there is no need for a set of common-collector characteristic to choose the parameters of the circuit. The output characteristic of the CC configuration is same as CE configuration.
- For CC Connection the output characteristic are plot of I_E versus V_{CE} for a constant value of I_B.
- There is an almost unnoticeable change in the vertical scale of I_C of the CE connection if I_C is replaced by I_E for CC connection.
- The input circuit of CC connection, the CE characteristic is sufficient to obtain the required information.
- Hence Common Collector circuit connection is known as **Emitter Follower**.

❖ CURRENT AMPLIFICATION FACTORS: - (It is the ratio of output current to input current)

1) Common Base Connection:-

In a common base connection, the input current is the Emitter Current I_E and output current is the Collector Current I_C.

Hence the ratio of change in collector current to the change in emitter current at constant collector-base voltage V_{CB} is known as current amplification factor for CB Connection and is denoted as α **(Alpha).**

♣ Practical values of α in commercial transistors range from 0.9 to 0.99.

2) Common Emitter Connection:-

In a common emitter connection, the input current is the Base Current I_B and output current is the Collector Current I_C.

Hence ratio of change in collector current (I_C) to the change in base current (I_B) at constant collector-emitter voltage V_{CE} is known as current amplification factor for CE Connection and denoted as β **(Beta).**

♣ Usually, its value ranges from 20 to 500.

3) Common Collector Connection:-

In a common collector connection, the input current is the Emitter Current I_B and output current is the Emitter Current I_E.

Hence the ratio of change in emitter current to the change in base current at constant V_{CC} is known as current amplification factor for CC Connection and is denoted as γ (Gamma).

♣ This circuit provides about the same current gain as the common emitter circuit as $\Delta I_E \approx \Delta I_C$.

❖ RELATION AMONG DIFFERENT CURRENT AMPLIFICATION FACTORS:-

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

1) Relation between α and β :-

♣ As, $\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{\Delta I_C}{\Delta I_E - \Delta I_C} = \frac{\Delta I_C/\Delta I_E}{1 - \Delta I_C/\Delta I_E} = \frac{\alpha}{1-\alpha}$ ➔ As, $\alpha = \frac{\Delta I_C}{\Delta I_E} = \frac{\Delta I_C}{\Delta I_B + \Delta I_C} = \frac{\Delta I_C/\Delta I_B}{1 + \Delta I_C/\Delta I_B} = \frac{\beta}{1+\beta}$

2) Relation between α and γ :-

♣ As, $\gamma = \frac{\Delta I_E}{\Delta I_B} = \frac{\Delta I_E}{\Delta I_E - \Delta I_C} = \frac{\Delta I_E/\Delta I_E}{1 - \Delta I_C/\Delta I_E} = \frac{1}{1-\alpha}$ ➔ As, $\alpha = \frac{\Delta I_C}{\Delta I_E} = \frac{\Delta I_E - \Delta I_B}{\Delta I_E} = \frac{\Delta I_E/\Delta I_B - 1}{\Delta I_E/\Delta I_B} = \frac{\gamma - 1}{\gamma}$

3) Relation between β and γ :-

♣ As, $\gamma = \frac{\Delta I_E}{\Delta I_B} = \frac{\Delta I_B + \Delta I_C}{\Delta I_B} = \frac{\Delta I_B}{\Delta I_B} + \frac{\Delta I_C}{\Delta I_B} = 1 + \beta$ ➔ As, $\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{\Delta I_E - \Delta I_B}{\Delta I_B} = \frac{\Delta I_E}{\Delta I_B} - \frac{\Delta I_B}{\Delta I_B} = \gamma - 1$

4) Relation between α, β and γ:-

♣ As, $\beta = \frac{\alpha}{1-\alpha} = \alpha \times \frac{1}{1-\alpha} = \alpha \times \gamma$

$\therefore \beta = \alpha \times \gamma$

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

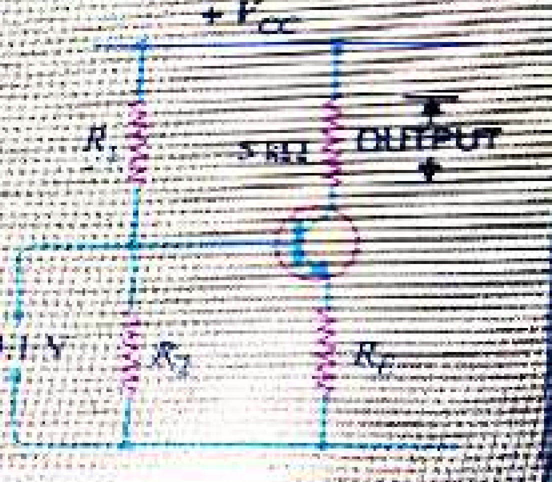
❖ COMPARISON OF TRANSISTOR CONNECTIONS:-

S. No.	Characteristic	Common base	Common emitter	Common collector
1.	Input resistance	Low (about 100 Ω)	Low (about 750 Ω)	Very high (about 750 kΩ)
2.	Output resistance	Very high (about 450 kΩ)	High (about 45 kΩ)	Low (about 50 Ω)
3.	Voltage gain	about 150	about 500	less than 1
4.	Applications	For high frequency applications	For audio frequency applications	For impedance matching
5.	Current gain	No (less than 1)	High (β)	Appreciable

❖ AMPLIFIER:-

- ➢ The device which increases the strength of a weak signal is known as *Amplifier*. This can achieve by use of Transistor. It may be classified according to the number of stage of amplification, Such as:-
- ✓ **Single Stage Transistor Amplifier:** - When only one transistor with associated circuitry is used for amplifying a weak signal, the circuit is known as *Single Stage Transistor Amplifier*.
- ✓ **Multi stage Transistor Amplifier:** When a transistor circuit containing more than one stage of amplification is known as *Multi stage Transistor Amplifier*.

➢ SINGLE STAGE TRANSISTOR AMPLIFIER:-



- ➢ A single stage transistor amplifier has one transistor, bias circuit and other auxiliary components.
- ➢ When a weak A.C. signal is given to the base of transistor, a small base current starts flowing.
- ➢ Due to transistor action, a much larger (β times the base current) current flows through the collector load R_C.
- ➢ As the value of R_C is quite high (usually 4-10 kΩ), therefore, a large voltage appears across R_C.
- ➢ Thus, a weak signal applied in the base circuit appears in amplified form in the collector circuit.
- ➢ It is in this way that a transistor acts as an amplifier.

[Transistor as an Amplifier]