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Unit-II- Bipolar Junction Transistor (BJT)

- Bipolar Junction Transistor (BJT) symbol, Types, construction, working Principle.
- Transistor amplifier configuration: CB, CC concept, CE configuration- Input/output characteristic, Definition of α, β, γ.
- Concept of biasing, potential divider bias, Transistor as Amplifier, Transistor as a switch.

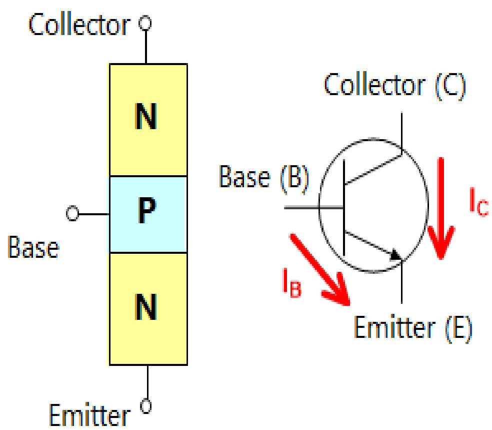
Introduction:

In 1951, William Shockley invented the first junction transistor, a semiconductor device that can amplify (enlarge) electronic signals such as radio and television signals. It is known as bipolar because both majority and minority charge carriers take part in the conduction. The word bipolar is an abbreviation for 'two polarities. The word transistor is used to represent transfer of signal through a variable resistor. The transistor has many advantages such as small size, long life, small power consumption, negligible aging effect, etc.

Symbol and Construction of BJT:

- Basically transistor consists of two back-to-back P-N junctions manufactured in a single piece of a semiconductor crystal.
- It is simply a sandwich of one type of semi-conductor material between two layers of the other type.
- BJT has three regions emitter, base and collector, Emitter is heavily doped, base is very thin lightly doped and collector is larger with moderate doping.
- BJT is of two types PNP and NPN depending upon which semiconductor material is sandwich between other type of semiconductor.
- Emitter is the left-hand section of the transistor as shown and is more heavily doped than any of the other regions. Its main function is to supply majority charge carriers (either electrons or holes) to the base.
- Base forms the middle section of the transistor. It is very thin (approximately 100m) as compared to emitter and collector and is very lightly doped.
- Collector forms the right hand side of the transistor and as the name indicates its main function is to collect majority charge carriers through the base. The size of the collector

region is larger than the emitter region. The doping of collector region is intermediate, between the heavy doping of the emitter and the light doping of the base.



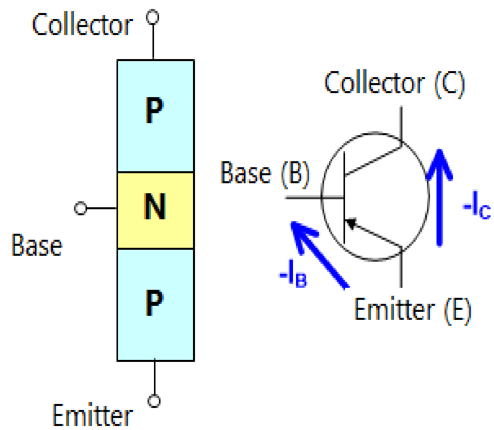


Figure (a): NPN Transistor structure & symbol   Figure (b): PNP Transistor structure & symbol

- Symbol of PNP shows arrow at emitter pointing inwards while that for NPN arrow points outwards. Arrow indicates direction of emitter current flow when emitter is forward biased.

- The transistor can be used in electronic circuits as an amplifier, a switch, or for impedance matching. Each application has its own requirements. Manufacturers develop the suitable transistors, depending upon these requirements.

- Examples:
  i. Low frequency (AF range) transistors such as 2N87, 2N88, etc.
  ii. High frequency transistors 2N 231, 2N232, etc.
  iii. High voltage transistors, for example: 2G222, 2N83, 2N1533
  iv. RF transistor suitable for frequency about 76 MHz is 2G101, 2G102, etc.
  v. High power transistors such as 2N421, 2N3229, etc.

The Working of a Transistor

For proper working of a transistor, it is essential to apply voltage of correct polarity across its two junctions. When external voltage sources are connected to the transistor, the currents start flowing through the different regions of the transistor viz. emitter current I_E, base current I_B and collector current I_C.

A BJT has two junctions, namely emitter-base or simply emitter junction and collector-base junction or collector junction. Junction can be forward bias or reverse bias. Depending upon this transistor is operated either in cutoff, active or either saturation,

There are three ways in which the junctions can be biased.

i. Both the junctions can be forward biased. Under this condition a large current can flow through the two junctions/diodes and transistors can work as a low resistance device and said to be in ON condition.

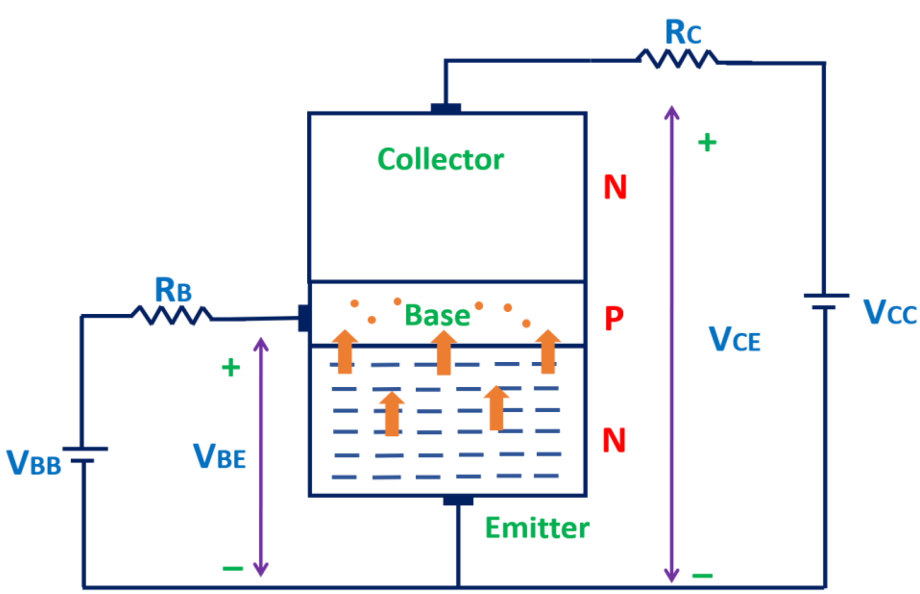
ii. Both the junctions can be reverse biased and very small current flows through the circuit. The transistor is said to be in OFF condition.

iii. One junction, normally emitter junction, is forward biased and other junction, i.e., collector junction is reverse biased.

Different modes of operation of BJT

Emitter-Base Junction	Collector-Base Junction	Operating region
Reverse biased	Reverse biased	Cut-off
Forward biased	Reverse biased	Active
Forward biased	Forward biased	Saturation

Working of NPN Transistor:



The BE junction is forward bias and the CB is a reverse bias junction. The width of the depletion region of the CB junction is higher than the BE junction. The forward bias at the BE junction decreases the barrier potential and produces electrons to flow from the emitter to the base and the base is a thin and lightly doped it has very few holes and less amount of electrons from the emitter about 2% it recombine in the base region with holes and from the base terminal it will flow out. This initiates the base current flow due to the combination of electrons and holes. The leftover large number of electrons will pass the reverse bias collector junction to initiate the collector current. By using KCL we can observe the mathematical equation

$$\mathbf{I_E = I_B + I_C}$$

The base current is very less as compared to emitter and collector current

$$\mathbf{I_E \sim I_C}$$

As the base current is much smaller than the collector current, $I_B << I_C$

- The ratio of the de collector current to the dc emitter current is called dc alpha (α_{dc}) of the transistor.

$$\alpha_{dc} = I_C / I_B$$

Since the collector current almost equals the emitter current, the dc alpha is slightly less than 1.

- The ratio of dc collector current to the dc base current is called the dc beta (β_{dc}) of a transistor.

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

The dc beta is also known as the current gain because a small base current produces much larger collector current. Thus

$$\beta_{dc} >> 1 \text{ as } I_C >> I_B$$

Relation between α and β

According to definition of dc alpha and dc beta as,

$$\beta_{dc} = I_C/I_B \text{ and } \alpha_{dc} = I_C/ I_B$$

We know that, $\mathbf{I_E = I_B + I_C}$

Therefore $I_B = I_E - I_C$

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

or

$$\beta = \alpha/1- \alpha$$

Simplifying above equation,

$$\beta\ (1- \alpha) = \alpha$$

or $$\beta = \alpha\ (1+\beta)$$

Therefore $$\alpha = \beta/ 1+\beta$$

Transistor Amplifier Configuration:

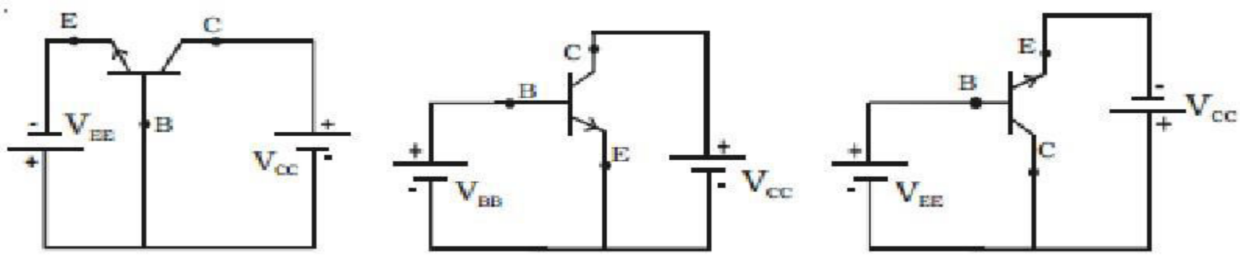
In transistor amplifier, input signal to be amplified is applied across two terminals while output is taken across two terminals. Transistor is a three terminal device. So one terminal is common to input and output. Depending upon which terminal is common, there are three configurations of transistor amplifier.

i. Common-Base (CB)

ii. Common-Emitter (CE)

iii. Common-Collector (CC)

The term common is used to denote the electrode that is common to the input and output. The common terminal is generally grounded. Therefore these modes of operations are also referred as grounded base, grounded emitter and grounded collector. The figure shows all three configurations for NPN transistors.



(a) CB mode (b) CE mode (c) CC mode

Fig Three modes of transistor circuit

Common Base (CB) Configuration:

In CB configuration, the input signal is applied between the emitter and the base whereas output is taken out from the collector and the base. Here emitter current I_E is the input current and collector current Ic is the output current. The dc alpha (α_{dc}) is the current gain in CB configuration. It is also called as the forward current transfer ratio. The CB configuration is rarely used for audio-frequency circuits because its current gain is less than unity. Typically values of α_{dc} range from 0.95 to 0.99. But voltage gain may be from 50 to 2000. CB configuration is useful for high frequency operations. The common base configuration is used primarily to match a very low source impedance (approximately 20 ohms) to high load impedance (100 KΩ and up).

Common Emitter (CE) Configuration:

The CE (common-emitter) is the most popular of all the three configurations. In CE configuration, input signal is applied between the base and the emitter and output signal is taken out from the collector and the emitter. I_B is the input current while I_C is the output current. β_{dc} is the current gain in CE configuration. In this configuration, current gain as well as voltage gain is very high. Therefore it has the highest power gain, of all the three and is often used as an amplifier.

Common Collector (CC) Configuration:

In CC configuration, the input signal is applied between the base and the collector and output signal is taken out from emitter-collector circuit. Here I_B is the input current. I_E is the output current. The current gain of the circuit is

$$\Gamma = I_E/ I_B = I_E/I_C \times I_C/ I_B = (1/\alpha) \times \beta = (1+\beta)$$

It means that output current is $(1 + \beta)$ times the input current.

The voltage gain of CC configuration approaches unity. Therefore this configuration is not used as a voltage amplifier.

But current gain is high. Therefore it can be used as power amplifier.

Main use of CC configuration is for impedance matching.

Parameter Information for CB, CE, CC Configurations.

Sr.No.	Parameter	CC	CB	CE
1	Common terminal	Collector	Base	Emitter
2	Input current	I_B	I_E	I_B
3	Output current	I_E	I_C	I_C
4	Current gain	β (>>1)	α(<1)	β (>>1)
5	Voltage gain	<1	Medium-150	High-500
6	Input resistance	High	Low	High-Medium
7	Output resistance	Low	Very high	High
8	Application	For impedance matching	Input stage for a multistage amplifier	Audio signal application

Input-Output Characteristics of common emitter (CE) configuration

The three important characteristics of a transistor in any mode are (i) input characteristics (ii) output characteristics and (iii) transfer characteristics.

(i) Input characteristics

- Input characteristic curve is drawn between the base current (I_B) and voltage between base and emitter (V_{BE}), when the voltage between collector and emitter (V_{CE}) is kept constant at a particular value.
- V_{BE} is increased in suitable equal steps and corresponding base current is noted. The procedure is repeated for different values of V_{CE}.
- I_B values are plotted against V_{BE} for constant V_{CE}. The input characteristic thus obtained is shown in Fig.
- The input impedance of the transistor is defined as the ratio of small change in base - emitter voltage to the corresponding change in base current at a given V_{CE}.

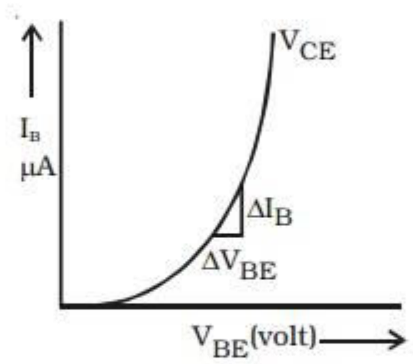


Fig *Input characteristics*

∴ Input impedance, $r_1 = (\Delta V_{BE}/\Delta I_B)_{VCE}$

- The input impedance of the transistor in CE mode is very high.

(ii) Output characteristics

- Output characteristic curves are drawn between I_C and V_{CE}, when I_B is kept constant at a particular value.

- The base current I_B is kept at a constant value, by adjusting the base emitter voltage V_{BE}. V_{CE} is increased in suitable equal steps and the corresponding collector current is noted. The procedure is repeated for different values of I_B.
- Now, I_c versus V_{CE} curves are drawn for different values of I_B. The output characteristics thus obtained are represented in Fig.
- The three regions of the characteristics can be discussed as follows :
    i. Saturation region: The initial part of the curve (ohmic region, OA) is called saturation region. (i.e) the region in between the origin and knee point. (Knee point is the point, where Ic is about to become a constant).
    ii. Cut off region: There is very small collector current in the transistor, even when the base current is zero (I_B = 0). In the output characteristics, the region below the curve for I_B = 0 is called cut off region. Below the cut off region, the transistor does not function.
    iii. Active region: The central region of the curves is called active region. In the active region, the curves are uniform. In this region, E-B junction is forward biased and C-B junction is reverse biased.

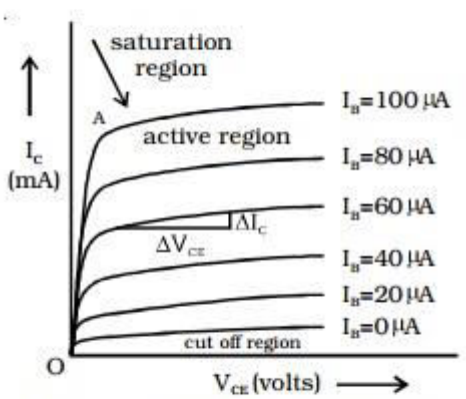
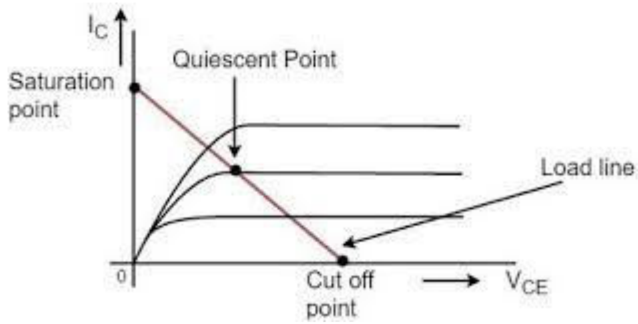


Fig . Output characteristics

- The output impedance r_o is defined as the ratio of variation in the collector emitter voltage to the corresponding variation in the collector current at a constant base current in the active region of the transistor characteristic curves.
- Output impedance, $r_o = (\Delta V_{CE}/ \Delta I_C)I_B$
- The output impedance of a transistor in CE mode is low.

Transistors operate in the active region when they are used as amplifiers. The saturation and cut off regions are useful in digital circuits, when transistors are used as switches. In saturation, transistor conducts. Therefore it is considered as closed switch and in cutoff it acts as an open switch.

Operating Regions of Transistor:



Cut off region:

The point where the load line intersects the $I_B = 0$ curve is known as cut off. At this point, $I_B = 0$ and only small collector current (i.e. collector leakage current (CEO) exists. At cut off, the base-emitter junction no longer remains forward biased and normal transistor action is lost.

The collector-emitter voltage is nearly equal to VCC i.e. VCE (cut off) = VCC

This is the region in which transistor tends to behave as an open switch. The transistor has the effect of its collector and base being opened. The collector, emitter and base currents are all zero in this mode of operation.

The transistor operates in cutoff region when both the emitter and collector junctions are reverse biased. As in cutoff region, the collector current, emitter current and base currents are nil, we can write as

$$IC=IE=IB=0$$

Where IC = collector current, IE = emitter current, and IB = base current.

(ii) Saturation. The point where the load line intersects the IB = IB(sat) curve is called saturation. At this point, the base current is maximum and so is the collector current. At saturation, collector-base junction no longer remains reverse biased and normal transistor action is lost.

$I_{Cmax} = I_{C\ sat} = V_{CC}/R_C$

If base current is greater than IB(sat), then collector current cannot increase because collector-base junction is no longer reverse-biased.

This is the region in which transistor tends to behave as a closed switch. The transistor has the effect of its collector and Emitter being shorted. The collector and Emitter currents are maximum in this mode of operation.

The transistor operates in saturation region when both the emitter and collector junctions are forward biased. As it is understood that, in the saturation region the transistor tends to behave as a closed switch, we can say that,

IC=IE

Where IC = collector current and IE = emitter current.

(iii) Active region. The region between cut off and saturation is known as active region. In the active region, collector-base junction remains reverse biased while base-emitter junction remains forward biased. Consequently, the transistor will function normally in this region.

This is the region in which transistors have many applications. This is also called as **linear region**. A transistor while in this region, acts better as an **Amplifier**.

This region lies between saturation and cutoff. The transistor operates in active region when the emitter junction is forward biased and collector junction is reverse biased. In the active state, collector current is β times the base current, i.e.,

$$IC=\beta IB$$

Where,

IC = collector current

β = current amplification factor

IB = base current

Quiescent Point:

Q point or the operating point of a device, also known as a bias point, or quiescent point is the steady-state DC voltage or current at a specified terminal of an active device such as a diode or transistor with no input signal applied.

Also, the Q Point is the relationship between the diode forward voltage and current defined by the device characteristic. Consequently, there is only one point on the dc load line where the diode voltage and current are compatible with the circuit conditions.

In other words, this operating point (Q point) is the intersection where the optimum forward voltage and forward current converge, and it is also the point where the diode operates at its optimum.

Biasing concept for Transistor:

Transistor Biasing is the process of setting a transistors DC operating voltage or current conditions to the correct level so that any AC input signal can be amplified correctly by the transistor.

Biasing is required for establishment and stability of Q-point. If the transistor is not biased correctly, it would work inefficiently and produce distortion in the output signal.

There are various methods for providing bias for a transistor

i. Fixed bias: The biasing current I_B is provided by connecting fixed resistor of value R_B, in between Vcc and base of transistor. It is not a very satisfactory method because bias voltages and currents do not remain constant during transistor operation.

ii. Base bias with emitter feedback: In this biasing, resistor of R_E value is connected from emitter of transistor to ground. This circuit achieves good stability of dc operating point against changes in β with the help of emitter resistor, which causes degeneration to take place.

iii. Base bias with collector feedback: It is also known as collector-to-base bias or collector feedback bias. It provides better bias stability.

iv. Potential divider bias: It is most widely used in linear discrete circuits because it provides good bias stability.