B.Sc. - III [Physics]

Paper – III [Solid State Electronics]

Unit – III

Title – Transistor: Current and Voltage Gain

Part – 1: Basic Concepts

By

Shri Prakash Gupta

Assistant Professor,

Department of Physics,

Harish Chandra P.G. College, Varanasi

Transistor: Current and Voltage Gain

Transistor:

When a third doped element is added to a crystal diode in a way that two p-n junctions are formed, the resulting device is known as a 'transistor'. The transistor is capable of achieving amplification of weak signals in a fashion comparable and often superior to that realized by vacuum tubes. It was invented in 1948 by J. Bardeen and W.H. Brattain of Bell Telephone Laboratories, U.S.A.

"A transistor consists of two p-n junctions formed by sandwiching either p-type or n-type semiconductor between a pair of opposite types." Accordingly, there are two types of transistors, namely:

(i) n-p-n transistor
(ii) p-n-p transistor

An npn transistor is composed of two n-types semiconductors separated by a thin section of p-type as shown in Fig.1. (i). However, a pnp transistor is formed by two p-type semiconductors separated by a thin section of n-type as shown in Fig. 1. (ii).

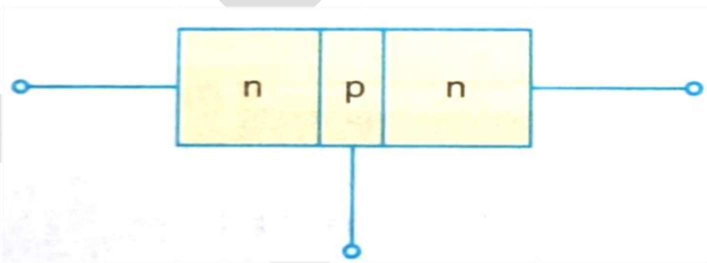


Fig.1. (i)

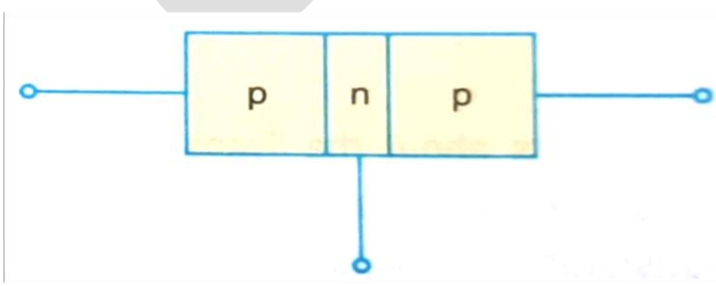


Fig.1. (ii)

In each type of transistor, the following points may be noted:

(i) There are two p-n junctions. Therefore a transistor may be regarded as a combination of two diodes connected back to back.

(ii) There are three terminals, one taken from each type of semi-conductor.

(iii) The middle section is very thin layer. This is the most important factor in the function of a transistor.

Naming the Transistor Terminals:

A transistor (pnp or npn) has three section 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.

(1) Emitter:

The section on one side that supplies charge carriers (electrons and 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. In Fig. 2 (i), the emitter (p-type) of pnp transistor is forward biased and supplies hole charges to its junction with the base. Similarly, in Fig. 2 (ii), the emitter (n-type) of npn transistor has a forward bias and supplies free electrons to its junction with base.

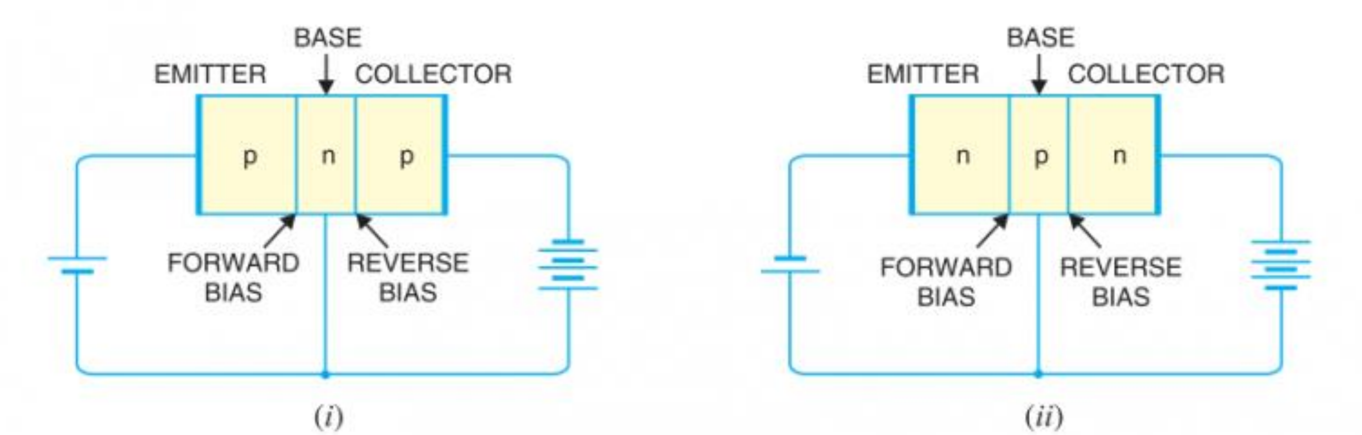


Fig. 2.

(2) 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 base. In Fig. 2(i), the collector (p-type) of pnp transistor has a reverse bias and receives hole charges that flow in the output circuit. Similarly, in Fig. 2(ii), the collector (n-type) of npn transistor has reverse bias and receives electrons.

(3) Base:

The middle section which forms two pn-junctions between the emitter and 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.

Some Facts about the Transistor:

The following facts about the transistor must be kept in mind:

- The transistor has three regions, namely; emitter, base and collector. The base is much thinner than the emitter while collector is wider than both as shown in Fig. 3.

Fig. 3.

- The emitter is heavily doped so that it can inject a large number of charge carriers (electrons or holes) into the base. The base is lightly doped and very thin; it passes most of the emitter injected charge carriers to the collector. The collector is moderately doped.
- The transistor has two pn-junctions i.e. it is like two diodes. The junction between emitter and base may be called emitter-base diode or simply the emitter diode. The junction between the base and collector may be called collector-base diode or simply the collector diode.
- The emitter diode is always forward biased whereas collector diode is always reverse biased.
- The resistance of emitter diode (forward biased) is very small as compared to collector diode (reverse biased). Therefore, forward bias applied to the emitter diode is generally very small whereas reverse bias on the collector diode is much higher.

Transistor Action:

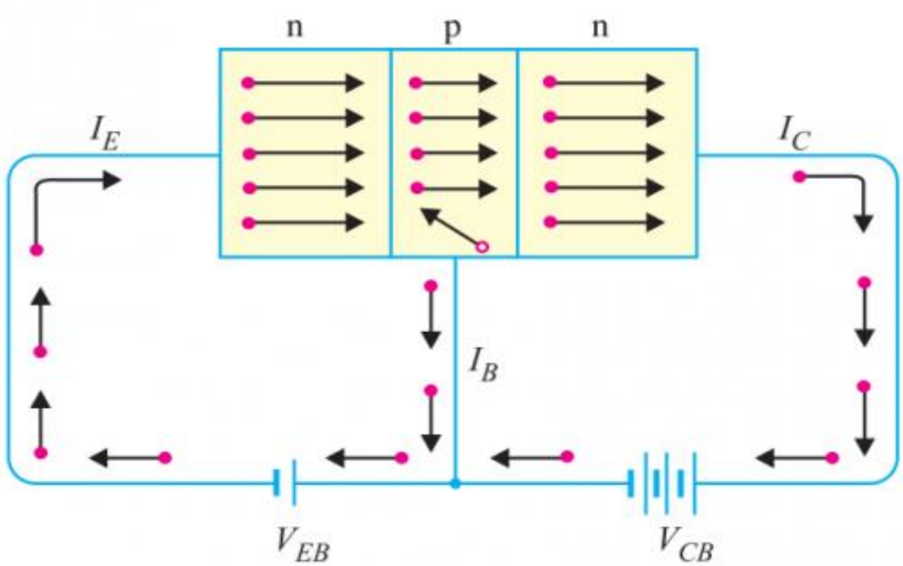
The emitter-base junction of a transistor is forward biased whereas collector-base junction is reverse biased. If we ignore the presence of emitter-base junction, then practically no current would flow in the collector circuit because of the reverse bias. However, if the emitter-base junction is also present, then forward bias on it causes the emitter current to flow. It is seen that this emitter current almost entirely flows in the collector circuit. Therefore, the current in the collector circuit depends upon the emitter current. If the emitter current is zero, then collector current is nearly zero. However, if the emitter current is 1mA, then collector current is also about 1mA. This is precisely what happens in a transistor.

(i) Working of npn transistor:

Fig. 4 shows the npn transistor with forward bias to emitter-base junction and reverse bias to collector-bias junction. The forward bias causes the electron 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 remainder (more than 95%) crosses 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 the base current *i.e.*

$$I_E = I_B + I_C \ .$$

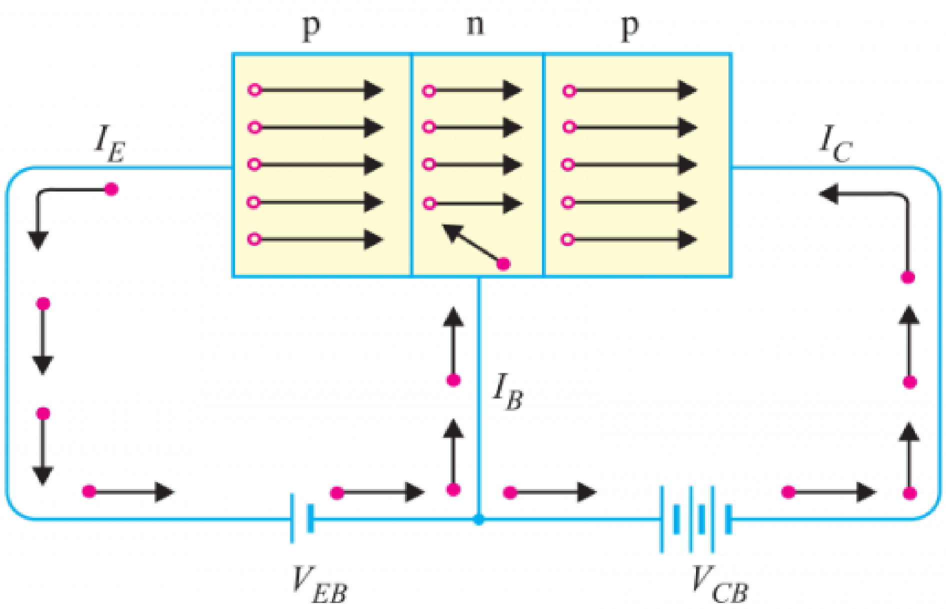


Basic connection of *npn* transistor

Fig. 4.

(ii) Working of pnp transistor:

Fig. 5 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, only a few holes (less than 5%) combine with the electrons. The remainder (more than 95%) crosses 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.



Basic connection of *pnp* transistor

Fig. 5.

Note:

There are two basic transistor types: the bipolar junction transistor (BJT) and field-effect transistor (FJT). These two transistor type types differ in both their operating characteristics and their internal construction. The term bipolar junction transistor (BJT) comes from the fact that in a bipolar transistor, there are two types of charge carriers (viz. electrons and holes) that play part in conduction. Note that bi means two and polar refers to polarities. The field-effect transistor is simply referred to as FET.

Transistor Symbols:

In the earlier diagrams, the transistors have been shown in diagrammatic form. However, for the sake of convenience, the transistors are represented by schematic diagrams. The symbols used for npn and pnp transistors are shown in Fig. 6.

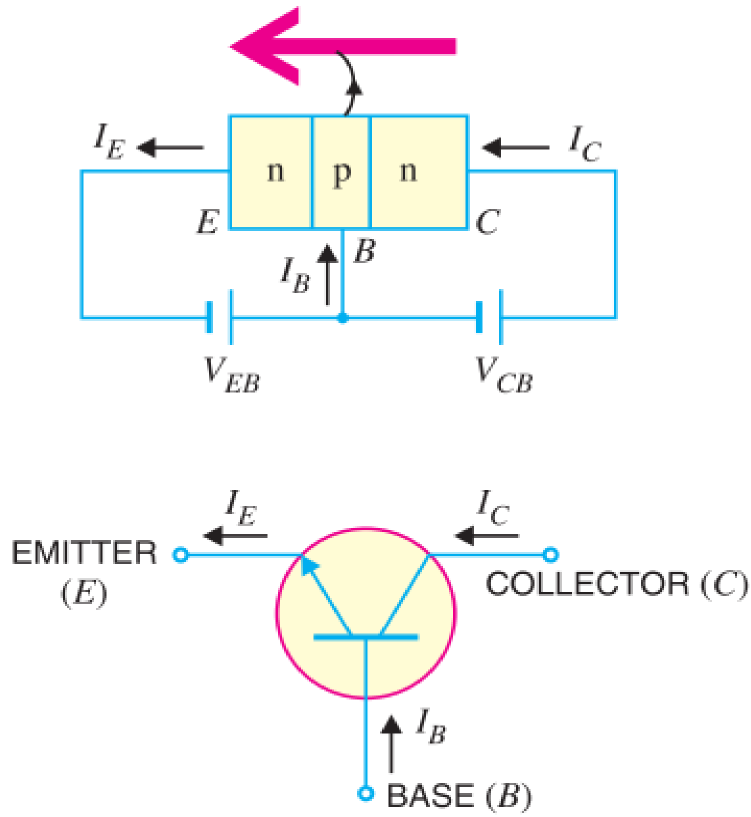


Fig. 6.(i): The schematic diagram of npn transistor.

Note that emitter is shown by an arrow which indicates the direction of conventional current flow with forward bias. For npn connection, it is clear that conventional current flows out of the emitter as indicated by the outgoing arrowin Fig. 6(i). Similarly, for pnp connection, the conventional current flows into the emitter as indicated by inward arrow in Fig. 6(ii).

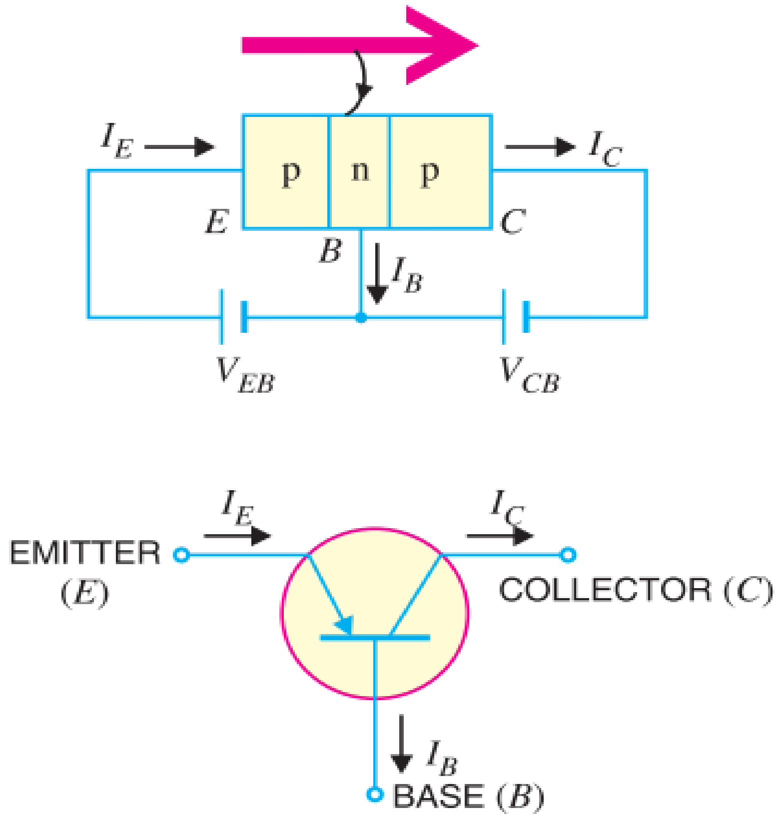


Fig. 6(ii): The schematic diagram of pnp transistor.

Transistor Circuit as an Amplifier:

"A transistor raises the strength of a weak signal and thus acts as an amplifier." The input circuit (i.e. emitter-base junction) has low resistance because of forward bias whereas output circuit (i.e. collector-base junction) has high resistance due to reverse bias. As we have seen, the input emitter current almost entirely flows in the collector circuit. Therefore, a transistor transfers the input signal current from a low-resistance circuit to a high-resistance circuit. This is the key factor responsible for the amplifying capability of the transistor.

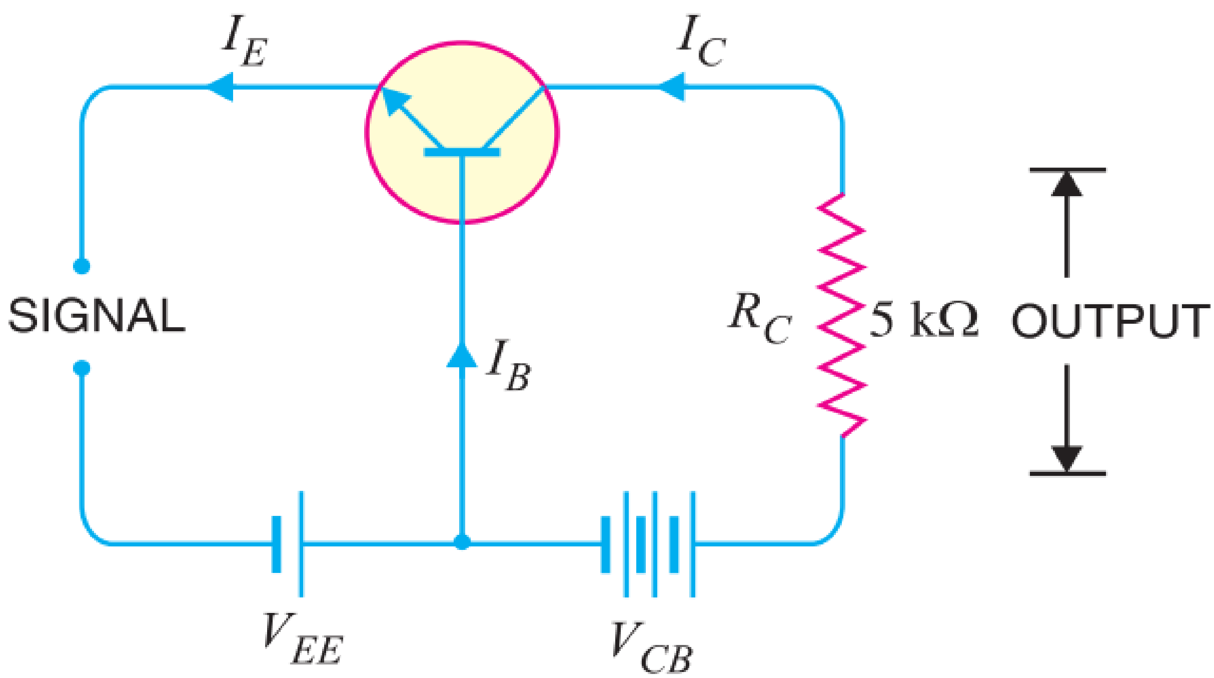
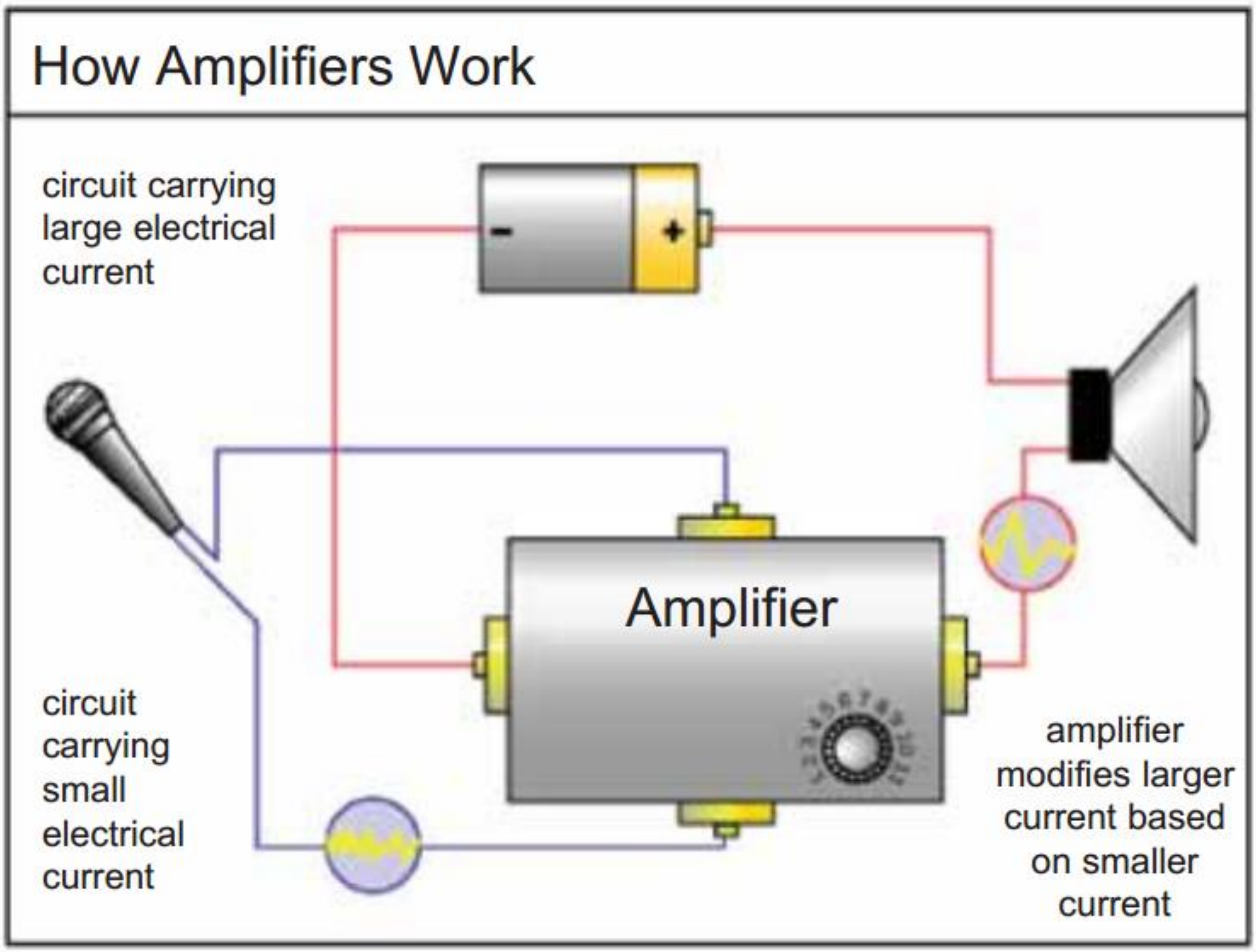


Fig. 7 : Transistor Circuit as an Amplifier

Fig.7 shows the basic circuit of a transistor amplifier. The weak signal is applied between emitter-base junction and output is taken across the load R_C connected in the collector circuit. In order to achieve faithful amplification, the input circuit should always remain forward biased. To do so, a d. c. voltage V_{EE} is applied in the input circuit in addition to the signal as shown. This d. c. voltage is known as bias voltage and its magnitude is such that it always keeps the input circuit forward biased regardless of the polarity of the signal.

As the input circuit has low resistance, therefore, a small change in signal voltage causes an appreciable change in emitter current. This cause almost the same change in collector current due to transistor action. The collector current flowing through a high load resistance R_C produces a large voltage across it. Thus, a weak signal applied in the input circuit appears in the amplified form in the collector circuit. It is in this way that a transistor acts as an amplifier.



Comments: The basic amplifying action is produced by transferring a current from a low-resistance to a high-resistance circuit. Consequently, the name transistor is given to the device by combining the two terms given in magenta letters below:

Transfer + Resistor → Transistor

References:

(i) Principles of Electronics by V.K. Mehta and Rohit Mehta.

(ii) Solid State Electronics by J.P. Agarwal.

———ӜӜӜӜ———