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*. The transistor—an entirely new type of electronic device—is capable of achieving amplification of weak signals in a fashion comparable and often superior to that realised by vacuum tubes. Transistors are far smaller than vacuum tubes, have no filament and hence need no heating power and may be operated in any position. They are mechanically strong, have practically unlimited life and can do some jobs better than vacuum tubes.

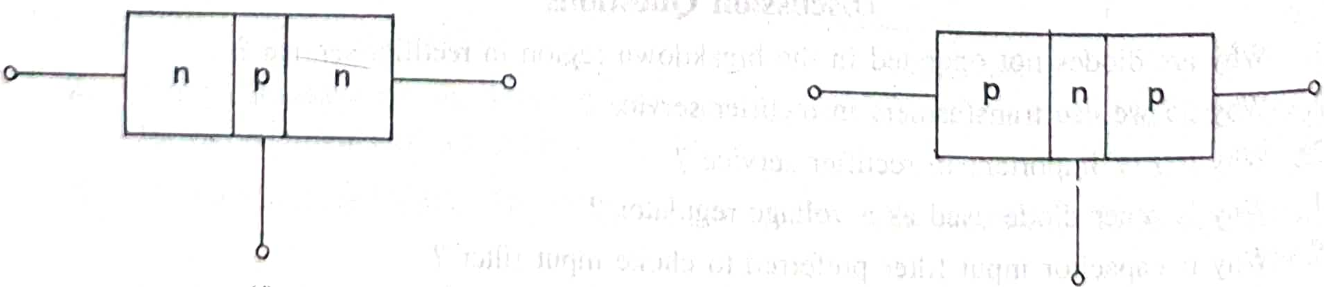
Invented in 1948 by J. Bardeen and W.H. Brattain of Bell Telephone Laboratories, U.S.A.; transistor has now become the heart of most electronic applications. Though transistor is only slightly more than 45 years old, yet it is fast replacing vacuum tubes in almost all applications. In this chapter, we shall focus our attention on the various aspects of transistors and their increasing applications in the fast developing electronics industry.

10.1 Transistor

A **transistor** *consists of two pn 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 *n-p-n* transistor is composed of two *n*-type semiconductors separated by a thin section of *p*-type as shown in Fig. 10.1 *(i)*. However, a *p-n-p* transistor is formed by two *p*-sections separated by a thin section of *n*-type as shown in Fig. 10.1 *(ii)*.



(i)   *(ii)*

Fig 10.1

* In practice, these three blocks *p*, *n*, *p* are grown out of the same crystal by adding corresponding impurities in turn.

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

(*i*) These are two *pn* junctions. Therefore, a transistor may be regarded as a combination of two diodes connected back to back.

(*ii*) There are three terminals, taken from each type of semiconductor.

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

Origin of the name "Transistor". When new devices are invented, scientists often try to devise a name that will appropriately describe the device. 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.

10.2 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. In Fig. 10.2 (*i*), the emitter (*p*-type) of *pnp* transistor is forward biased and supplies hole charges to its junction with the base. Similarly, in Fig. 10.2 (*ii*), 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. In Fig. 10.2 (*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. 10.2 (*ii*), the collector (*n*-type) of *npn* transistor has reverse bias and receives electrons.

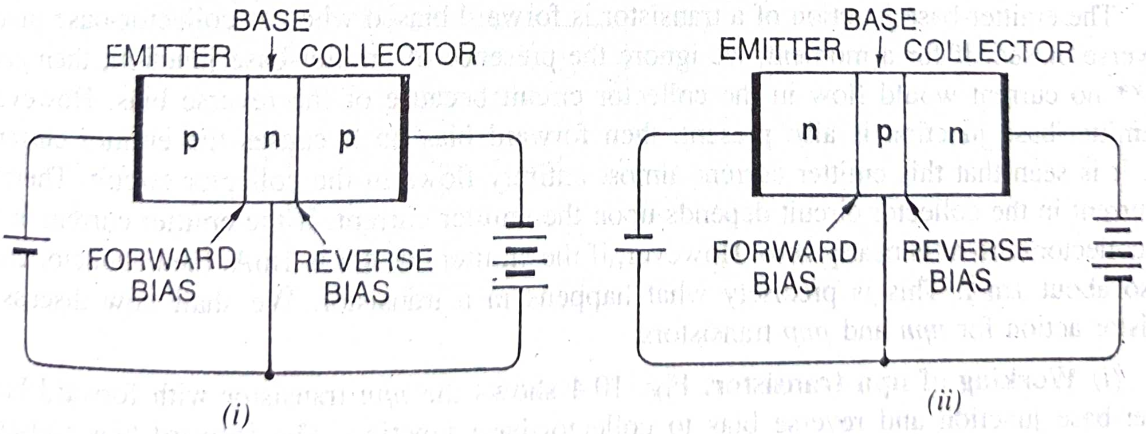


Fig. 10.2

(*iii*) **Base.** The middle section which forms two *pn*-junctions between the emitter and collector is called the *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.

* Holes if emitter is *p*-type and electrons if the emitter in *n*-type.

10.3 Some Facts about the Transistor

Before discussing transistor action, it is important that the reader may keep in mind the following facts about the transistor :

(i) 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. 10.3. However, for the sake of convenience, it is customary to show emitter and collector to be of equal size.

(ii) 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.

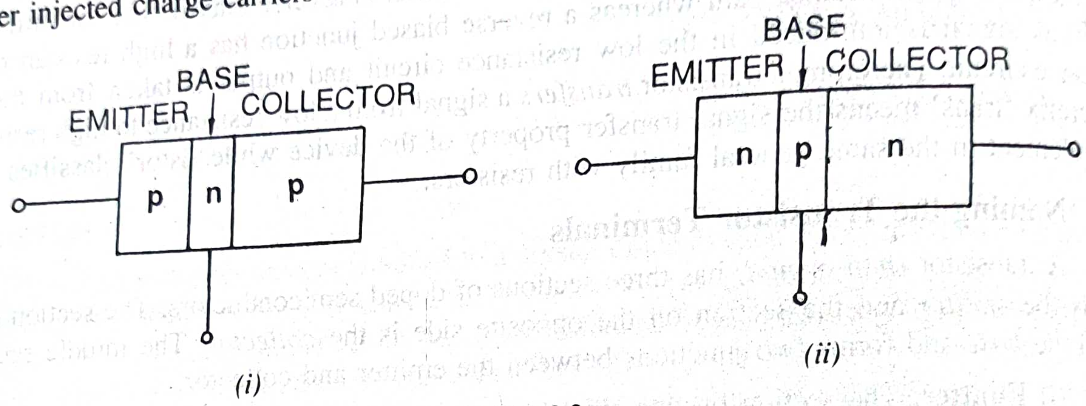


Fig. 10.3

(iii) 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 *collector diode*.

(iv) The emitter diode is always forward biased whereas collector diode is always reverse biased.

(v) 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.

10.4 Transistor Action

The emitter-base junction of a transistor is forward biased whereas collector-base junction is reverse biased. If for a moment, 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. We shall now discuss this transistor action for *npn* and *pnp* transistors.

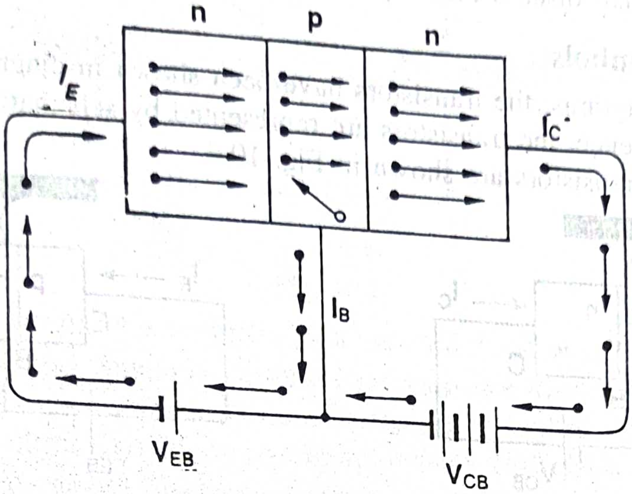
(i) **Working of npn transistor.** Fig. 10.4 shows the *npn* transistor with forward bias to emitter-base junction and reverse bias to collector-base junction. The forward bias causes the electrons in the *n*-type emitter to flow towards the base. This constitutes the emitter current I_E. As these electrons flow through the *p*-type base, they tend to combine with holes. As the base

* During transistor operation, much heat is produced at the collector junction. The collector is made larger to dissipate the heat.

** In actual practice, a very little current (a few μ A) would flow in the collector circuit. This is called collector cut off current and is due to minority carriers.

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%) 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.*

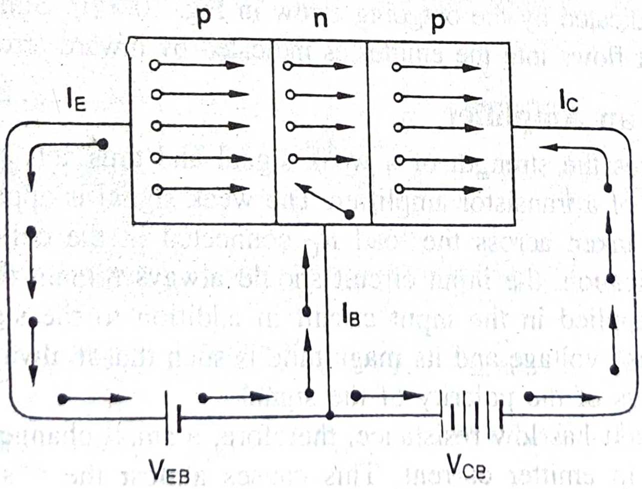
$$I_E = I_B + I_C$$



Basic connection of *npn* transistor

Fig. 10.4

(ii) **Working of pnp transistor.** Fig. 10.5 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, 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.



Basic connection of *pnp* transistor

Fig. 10.5

* The electrons which combine with holes become valence electrons. Then as valence electrons, they flow down through holes and into the external base lead. This constitutes base current I_B.

** The reasons that most of the electrons from emitter continue their journey through the base to collector to form collector current are : *(i)* The base is lightly doped and very thin. Therefore, there are a few holes which find enough time to combine with electrons. *(ii)* The reverse bias on collector is quite high and exerts attractive forces on these electrons.

Importance of transistor action. 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. We shall discuss the amplifying property of transistor later in this chapter.

10.5 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. 10.6.

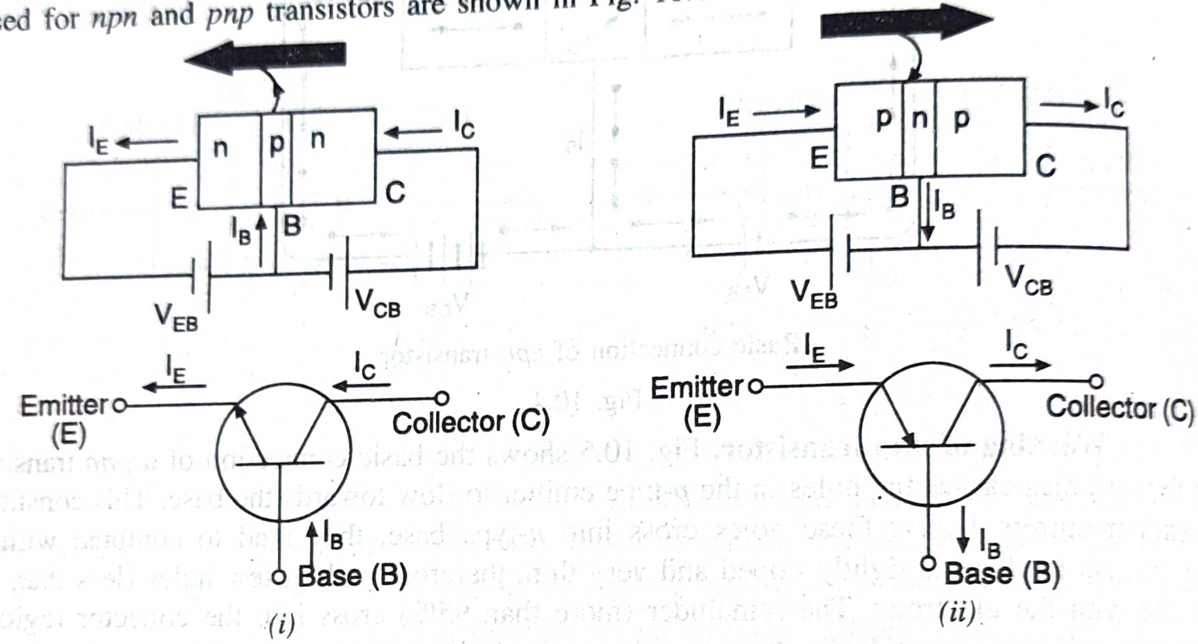


Fig. 10.6

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 arrow in Fig. 10.6 *(i)*. Similarly, for *pnp* connection, the conventional current flows into the emitter as indicated by inward arrow in Fig. 10.6 *(ii)*.

10.6 Transistor as an Amplifier

A transistor raises the strength of a weak signal and thus acts as an amplifier. Fig. 10.7 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 causes almost the **same change in collector

* It may be recalled that biasing is also necessary in vacuum tube amplifiers for faithful amplification (see Chapter 5). The reader may find the detailed discussion on transistor biasing in Chapter 11.

** The reason is as follows. The collector-base junction is reverse biased and has a very high resistance--of the order of mega ohms. Thus collector-base voltage has little effect on the collector current. This means that a large resistance R_C can be inserted in series with collector without disturbing the collector current relation to the emitter current *viz.* $I_C = \alpha I_E + I_{CBO}$. Therefore, collector current variations caused by a small base-emitter voltage fluctuations result in voltage changes in R_C that are quite high—often hundreds of times larger than the emitter-base voltage.

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.

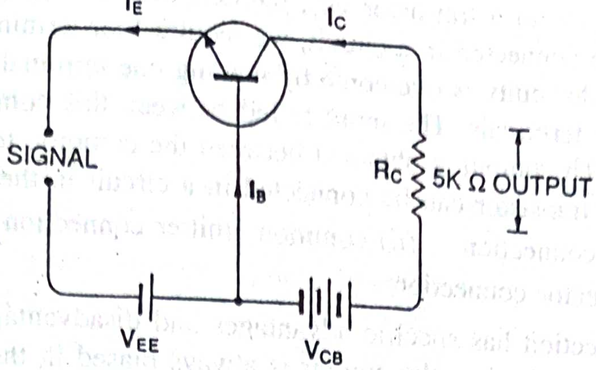


Fig. 10.7

Illustration. The action of a transistor as an amplifier can be made more illustrative if we consider typical circuit values. Suppose collector load resistance $R_C = 5K\Omega$. Let us further assume that a change of 0.1V in signal voltage produces a change of 1mA in emitter current. Obviously, the change in collector current would also be approximately 1mA. This collector current flowing through collector load R_C would produce a voltage = 5 KΩ × 1 mA = 5V. Thus, a change of 0.1V in the signal has caused a change of 5V in the output circuit. In other words, the transistor has been able to raise the voltage level of the signal from 0.1V to 5V *i.e.* voltage amplification is 50.

Example 10.1 *A common base transistor amplifier has an input resistance of 20Ω and output resistance of 100 kΩ. The collector load is 1kΩ. If a signal of 500 mV is applied between emitter and base, find the voltage amplification. Assume α_{ac} to be nearly one.*

Solution

*Fig. 10.8 shows the conditions of the problem. Note that output resistance is very high as compared to input resistance. This is not surprising because input junction (base to emitter) of the transistor is forward biased while the output junction (base to collector) is reverse biased.

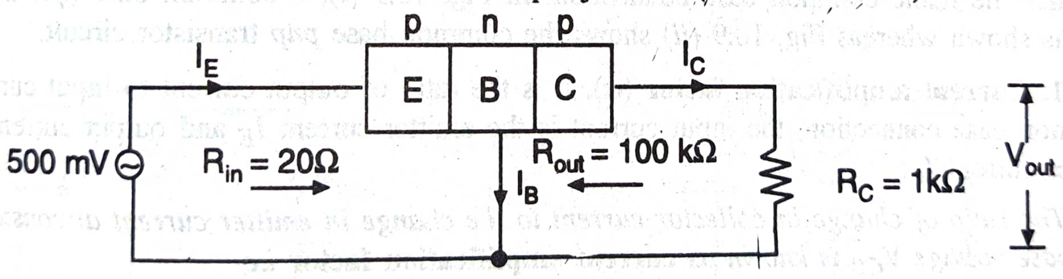


Fig. 10.8

Input current, $I_E = \dfrac{\text{Signal}}{R_{in}} = \dfrac{500\ mV}{20\ \Omega} = 25\ mA$. Since α_{ac} is nearly 1, output current $I_C = I_E = 25\ mA$. Output voltage, $V_{out} = I_C R_C = 25\ mA \times 1k\Omega = 25V$

$$\therefore \text{ Voltage amplification, } A_v = \frac{V_{out}}{\text{signal}} = \frac{25V}{500\ mV} = \mathbf{50}$$

Comments. The reader may note that basic amplifying action is produced by transfering 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 bold letters below :

*The d.c. biasing is omitted in the figure because our interest is limited to amplification.