SHREE H. N. SHUKLA GROUP OF COLLEGES

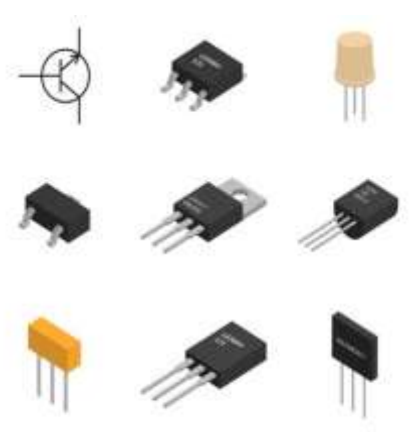
F.Y.B.Sc. SEM – II

Subject: Physics

Paper- 101

Unit -2

TRANSISTOR



- Introduction
- Transistor
- Types of BJT
- Action of transistor
- Three configuration BJT
- CE Configuration

INTRODUCTION:

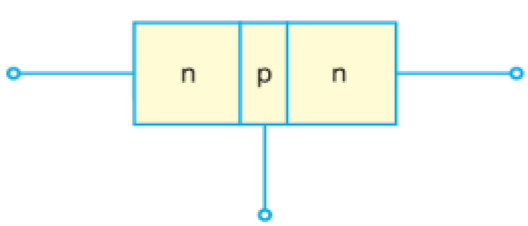
- **"W**hen a third doped element is added to a crystal diode in such a way that two *pn* junctions are formed, the resulting device is known as a *transistor*."
- The transistor—an entirely new type of electronic device—is capable of achieving amplification of weak signals in a fashion comparable and often superior to that realized by 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 58 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.

TRANSISTOR :

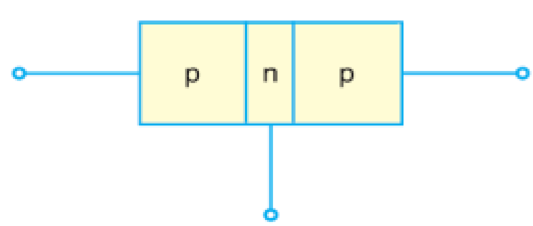
- *"A* **transistor** *consists of two pn junctions formed by *sandwiching either p-type or n-type semiconductor between a pair of opposite types. "*
- Accordingly ; there are two types of transistors, namely;

  (*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. (*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. (*ii*).



(*i*)



(*ii*)

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, one 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.

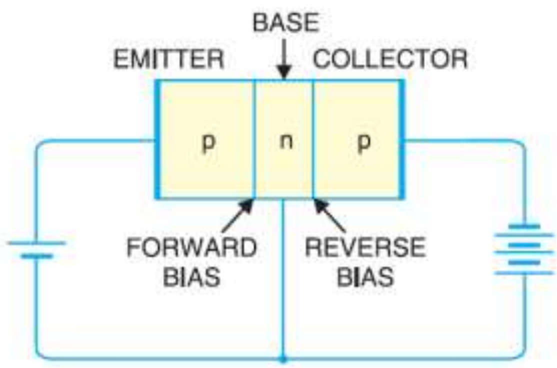
NAMING OF TRANSISTOR TERMINAL :

- 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.

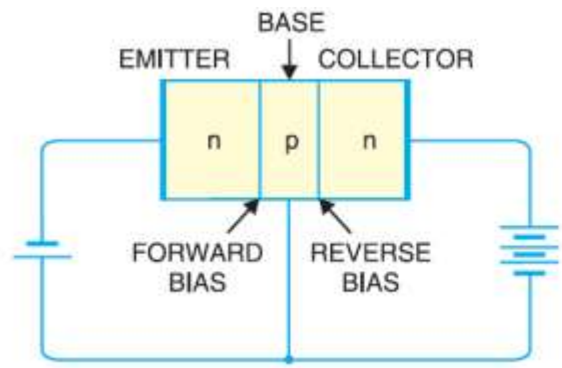
  (i) **Emitter.** The section on one side that supplies charge carriers (electrons or holes) is called the *emitter*. *The emitter is always forward biased w.r.t. base* so that it can supply a large number of *majority carriers. In Fig. (*i*), the emitter (*p*-type) of *pnp* transistor is forward biased and supplies hole charges to its junction with the base. Similarly, in Fig. (*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. (*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. (*ii*), the collector (*n*-type) of *npn* transistor has reverse bias and receives electrons.

(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.



(*i*)



(*ii*)

TRANSISTOR ACTION :

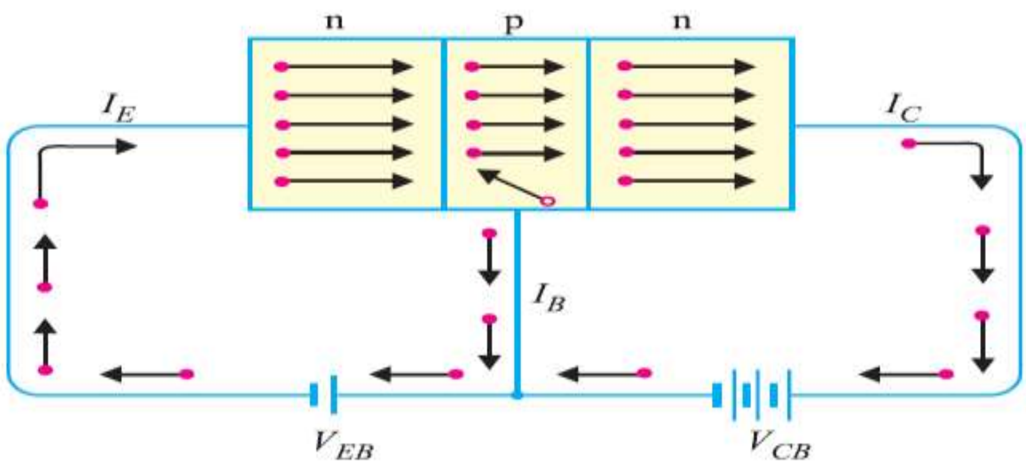
- The emitter-base junction of a transistor is forward biased whereas collector-base junction is reverse biased.

(i) Working of npn transistor :

Fig. 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 *IE*. 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 *IB*. The remainder (***more than 95%) cross over into the collector region to constitute collector current *IC*.

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

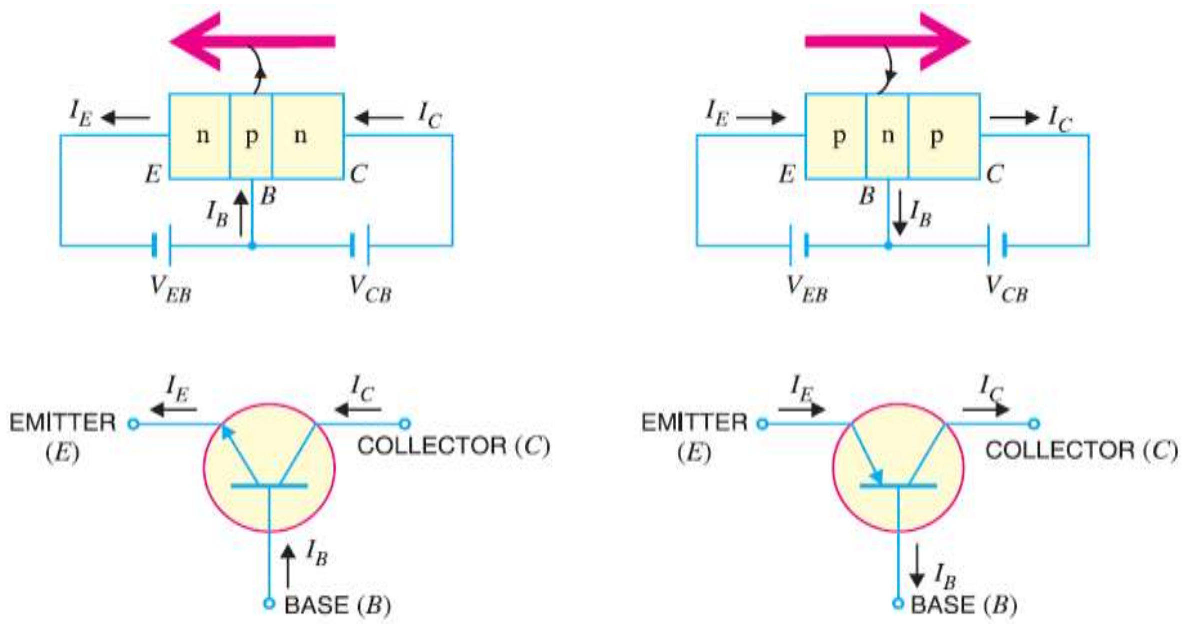
(ii) Working of pnp transistor :

- 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 *IE*. 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 *IC*. 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 SYMBOL :

- The symbols used for *npn* and *pnp* transistors are shown in Fig.



(i) (ii)

TRANSISTOR CONNECTION :

- Accordingly; a transistor can be connected in a circuit in the following three ways :

(i) common base connection

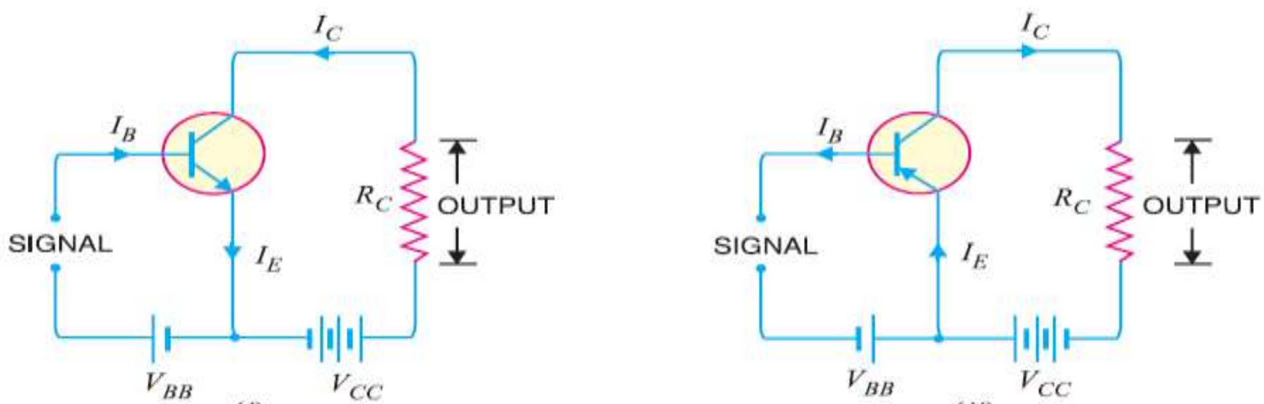
(ii) common emitter connection

(iii) common collector connection

- Each circuit connection has specific advantages and disadvantages. It may be noted here that regardless of circuit connection, the emitter is always biased in the forward direction, while the collector always has a reverse bias.

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. Fig. (*i*) shows common emitter *npn* transistor circuit whereas Fig. (*ii*) shows common emitter *pnp* transistor circuit.



(*i*) (*ii*)

1. Base current amplification factor (β). In common emitter connection, input current is I_B and output current is I_C.

The ratio of change in collector current (ΔI_C) to the change in base current (ΔI_B) is known as **base current amplification factor** *i.e.*

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

In almost any transistor, less than 5% of emitter current flows as the base current. Therefore, the value of β is generally greater than 20. Usually, its value ranges from 20 to 500. This type of connection is frequently used as it gives appreciable current gain as well as voltage gain.

Relation between β and α. A simple relation exists between β and α. This can be derived as follows :

$$\beta = \frac{\Delta I_C}{\Delta I_B} \quad ...(i)$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \quad ...(ii)$$

Now $I_E = I_B + I_C$

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

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

Substituting the value of ΔI_B in exp. (*i*), we get,

$$\beta = \frac{\Delta I_C}{\Delta I_E - \Delta I_C} \quad ...(iii)$$

Dividing the numerator and denominator of R.H.S. of exp. (*iii*) by ΔI_E, we get,

$$\beta = \frac{\Delta I_C / \Delta I_E}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} = \frac{\alpha}{1-\alpha} \qquad \left[\because \ \alpha = \frac{\Delta I_C}{\Delta I_E}\right]$$

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

It is clear that as α approaches unity, β approaches infinity. In other words, the current gain in common emitter connection is very high. It is due to this reason that this circuit arrangement is used in about 90 to 95 percent of all transistor applications.

2. Expression for collector current. In common emitter circuit, I_B is the input current and I_C is the output current.

We know $I_E = I_B + I_C$ ...(*i*)

and $I_C = \alpha I_E + I_{CBO}$ ...(*ii*)

From exp. (*ii*), we get, $I_C = \alpha I_E + I_{CBO} = \alpha (I_B + I_C) + I_{CBO}$

or $I_C (1-\alpha) = \alpha I_B + I_{CBO}$

or
$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO} \quad ...(iii)$$

From exp. (*iii*), it is apparent that if $I_B = 0$ (*i.e.* base circuit is open), the collector current will be the current to the emitter. This is abbreviated as I_{CEO}, meaning collector-emitter current with base open.

$\therefore$
$$I_{CEO} = \frac{1}{1-\alpha} I_{CBO}$$

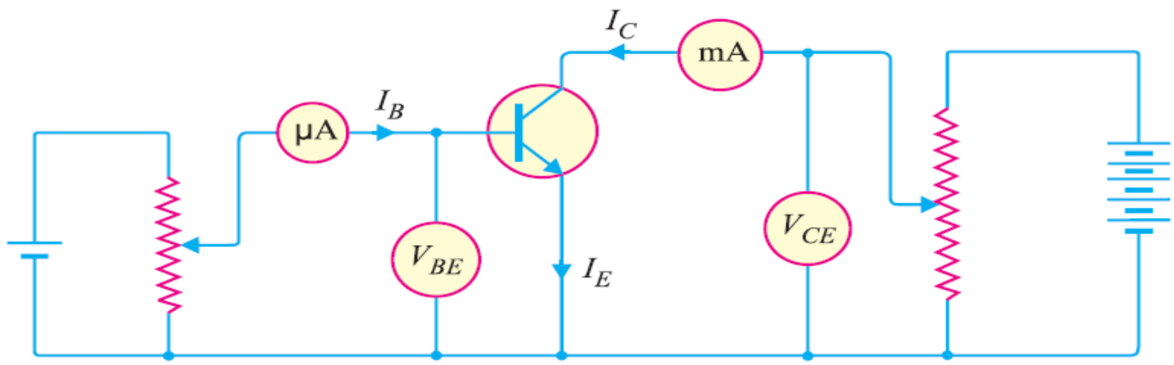
Substituting the value of $\frac{1}{1-\alpha} I_{CBO} = I_{CEO}$ in exp. (*iii*), we get,

$$I_C = \frac{\alpha}{1-\alpha} I_B + I_{CEO}$$

or
$$I_C = \beta I_B + I_{CEO} \qquad \left(\because \beta = \frac{\alpha}{1-\alpha}\right)$$

CHARACTERISTIC CE CONNECTION :

- The important characteristics of this circuit arrangement are the *input characteristics* and *output characteristics.*

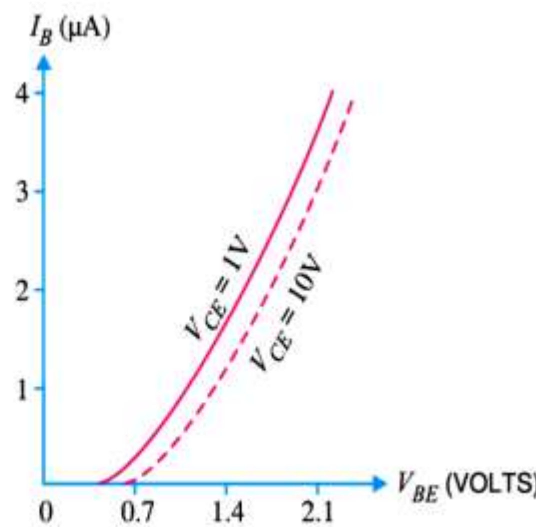


1. Input characteristic. *It is the curve between base current I_B and base-emitter voltage V_{BE} at constant collector-emitter voltage V_{CE}.*

The input characteristics of a *CE* connection can be determined by the circuit shown in Fig. 8.29. Keeping V_{CE} constant (say at 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. 8.30. Following a similar procedure, a family of input characteristics can be drawn. The following points may be noted from the characteristics :

(*i*) 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.

(*ii*) 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.



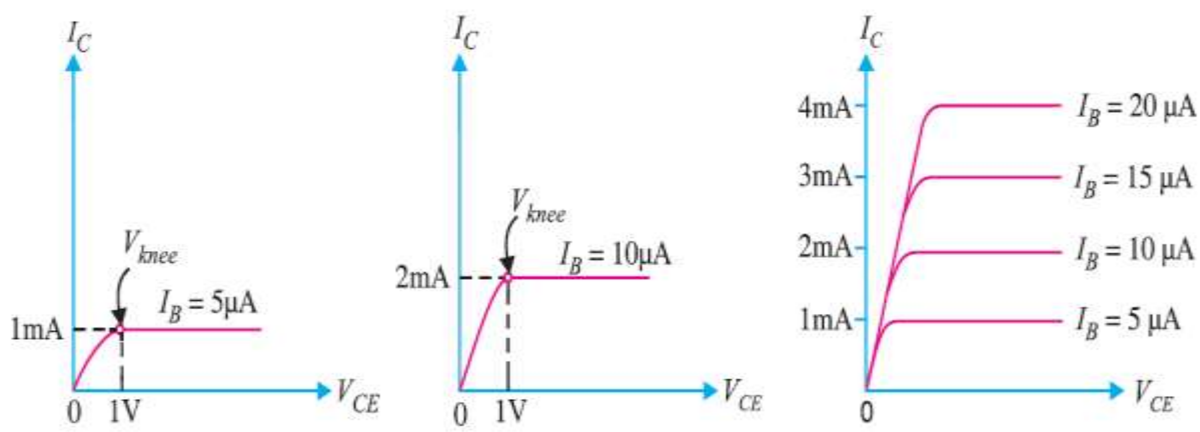
Input resistance. It is the ratio of change in base-emitter voltage (ΔV_{BE}) to the change in base current (ΔI_B) at constant V_{CE} *i.e.*

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

The value of input resistance for a *CE* circuit is of the order of a few hundred ohms.

2. Output characteristic :

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



(*i*) (*ii*) (*iii*)

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, collector current becomes *almost* constant and independent of V_{CE}. This value of V_{CE} upto which collector current 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.*

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

It may be noted that whereas the output characteristics of *CB* circuit are horizontal, they have noticeable slope for the *CE* circuit. Therefore, the output resistance of a *CE* circuit is less than that of *CB* circuit. Its value is of the order of 50 kΩ.

COMPARISON OF TRANSISTOR CONNECTION :

The comparison of various characteristics of the three connections is given below in the tabular form.

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