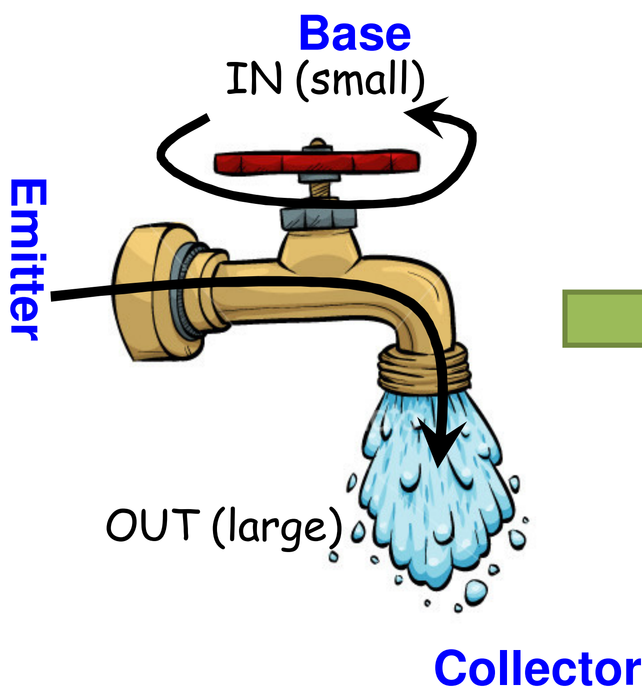
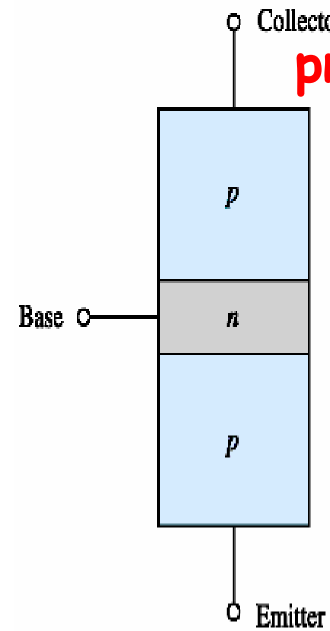
Bipolar Junction Transistors (BJTs)

Basic of transistor and amplifier action

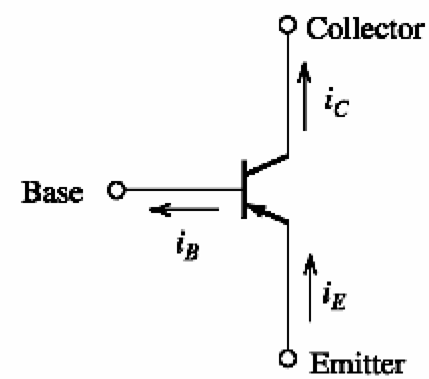
- The Transistor was invented in 1948 by John, Brattain and Shokley at Bell Laboratory in 1948 and received the Nobel prize in physics.
- It offers several advantages over tubes. No heater, smaller in size, low voltage and power, long life etc.
- Revolution of electronics devices : BJT,FET, MOSFET, UJT etc.



pnp BJT



(a) Physical structure



(b) Circuit symbol with reference directions for currents

- Output current can toggle between large and small (Switching → Digital logic; create 0s and 1s)
- Small change in 'valve' (3rd terminal) creates Large change in output between 1st and 2nd terminal (Amplification → Analog applications; Turn 0.5 → 50)

Bipolar Junction Transistors (BJTs)

- The bipolar junction transistor is a semiconductor device constructed with three doped regions.

- These regions essentially form two ‘back-to-back’ p-n junctions in the same block of semiconductor material (silicon).

- The most common use of the BJT is in linear amplifier circuits (linear means that the output is proportional to input). It can also be used as a switch (for logic circuits).

BJT Transistors

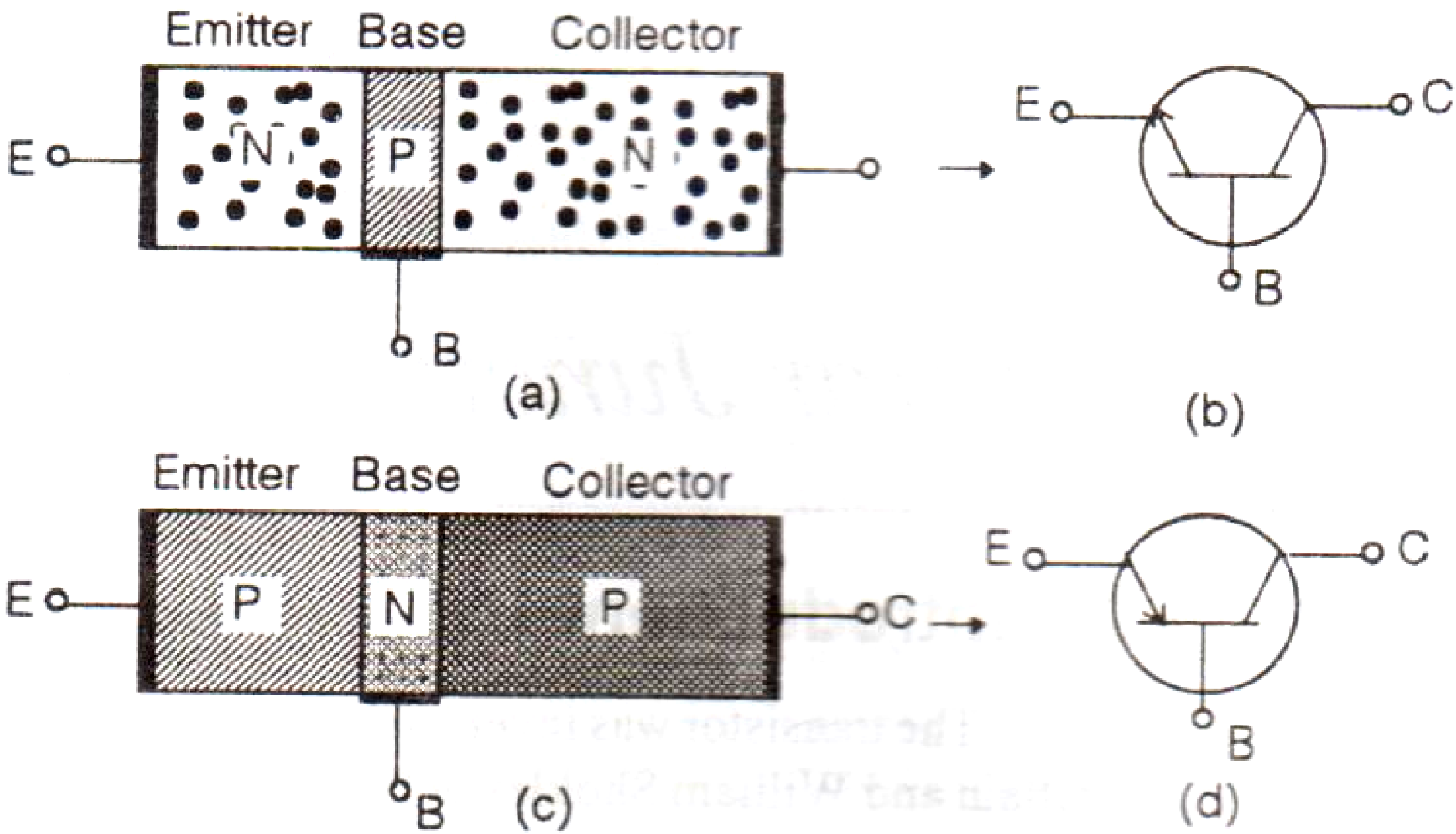
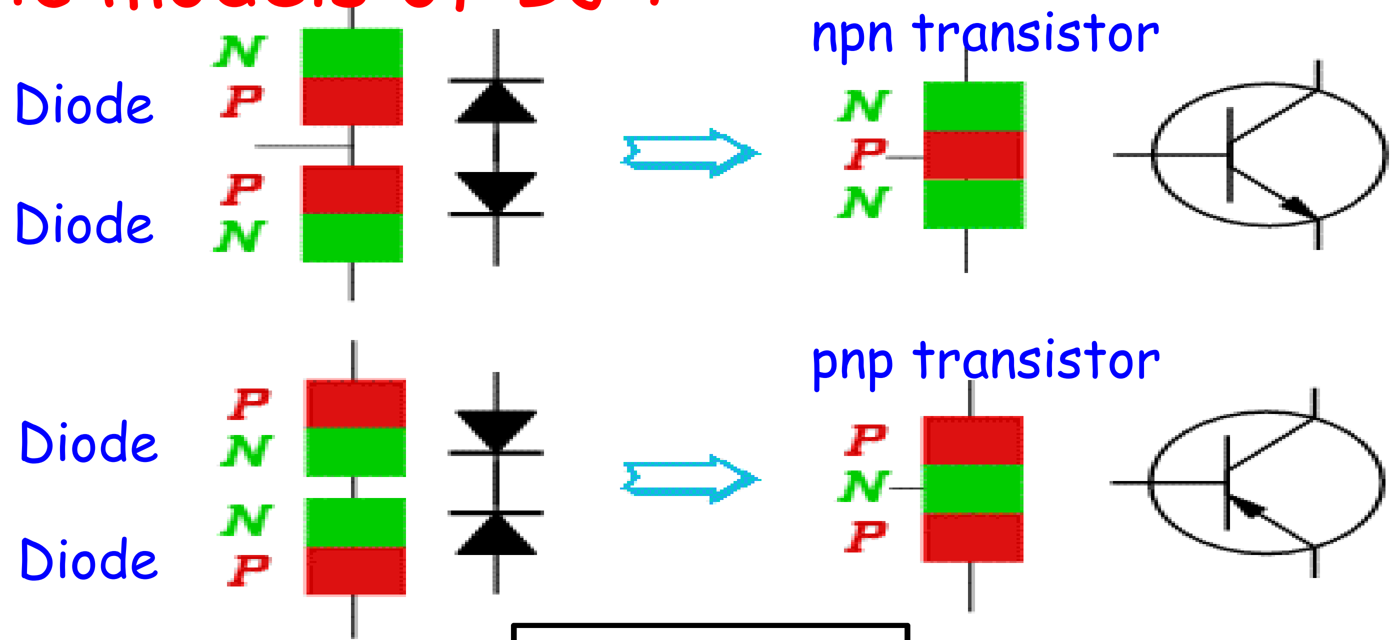


Fig. Junction transistor (a) NPN type (b) NPN transistor symbol (c) PNP type (d) PNP transistor symbol

Basic models of BJT



BJT Circuits

- **The three regions are known as the emitter, base and collector regions.**
- **Electrical connections are made to each of these regions.**

- **Most electronic devices take the signal between two input terminals and deliver from it an output signal between two output terminals.**
- **The BJT has only three terminals so one of these is usually shared (i.e. made common) between input and output circuits.**

Transistor Action

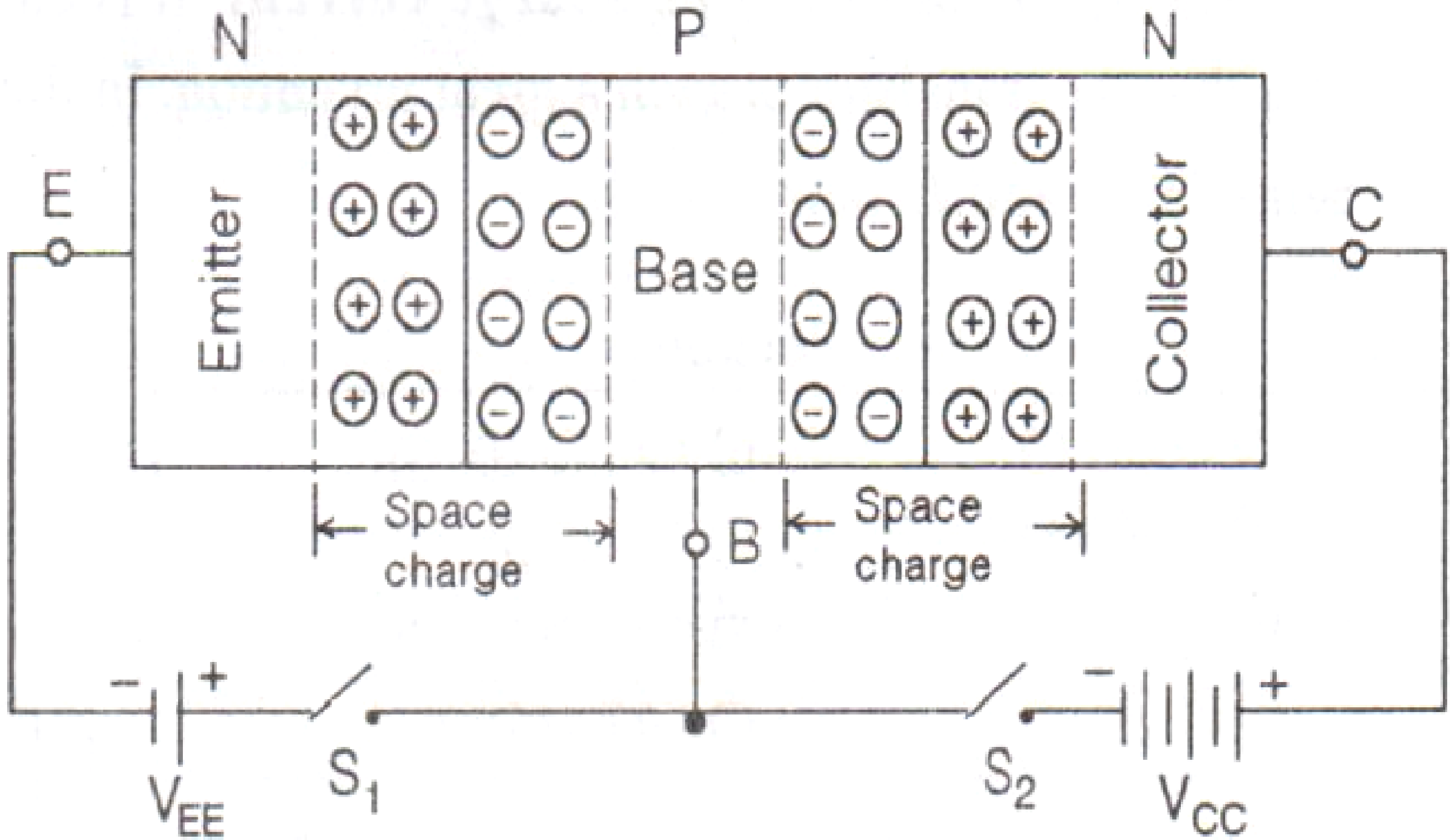


Fig. Biasing an NPN transistor for active operation

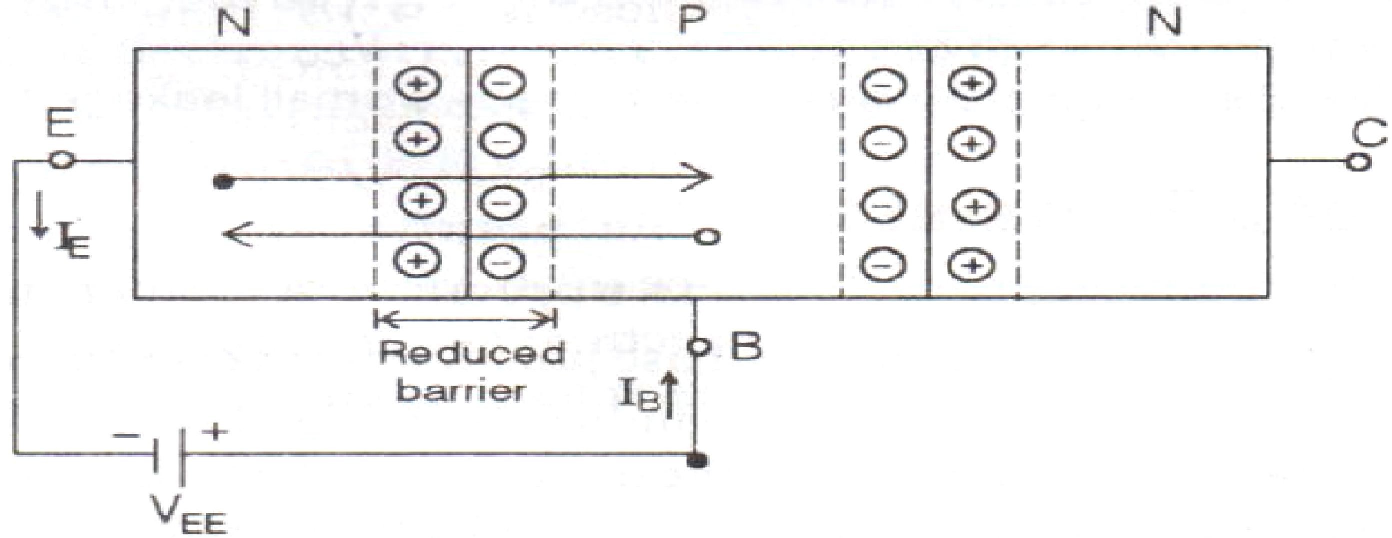


Fig. Only emitter junction is forward-biased– a large current flows

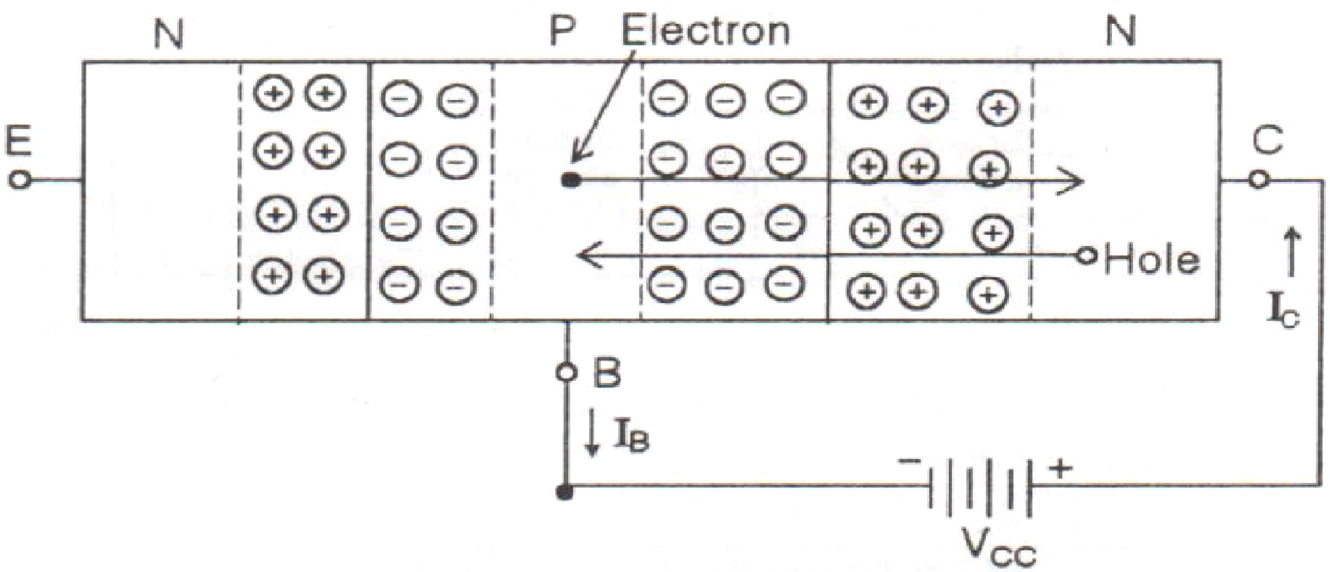


Fig. Only collector junction is reverse biased– a small leakage current flows

Working of Transistor

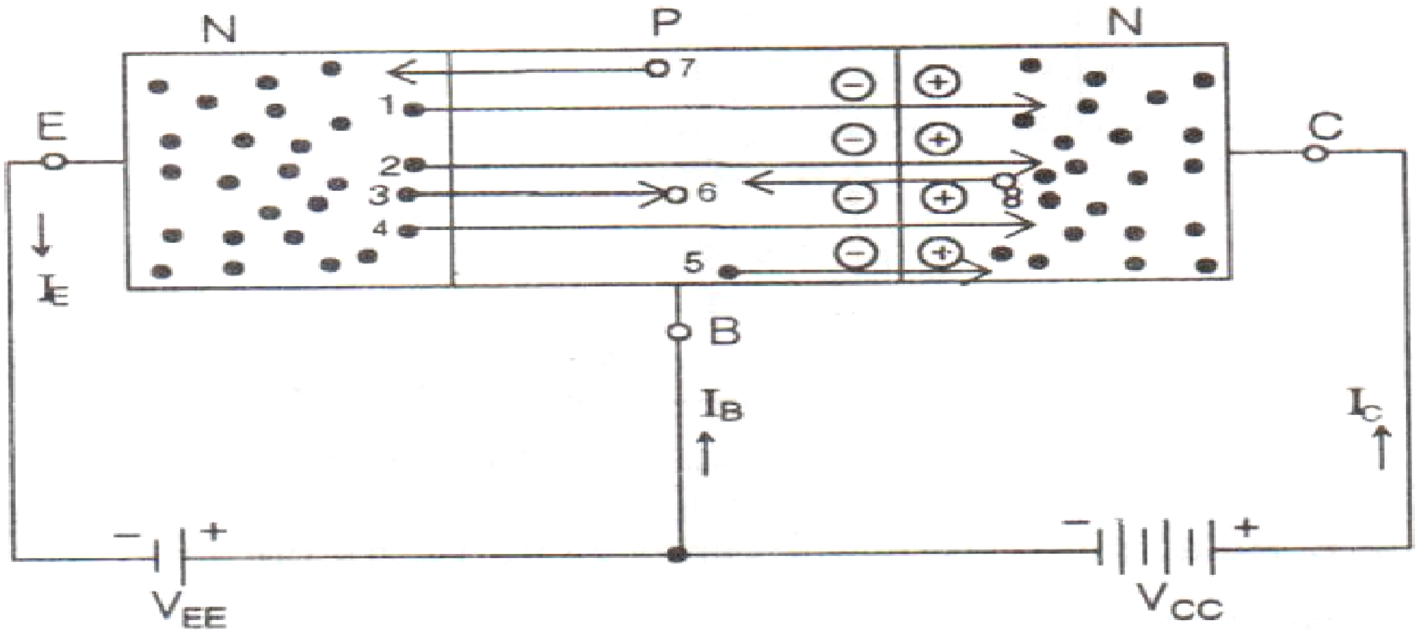


Fig. An NPN transistor biased for active opeartion

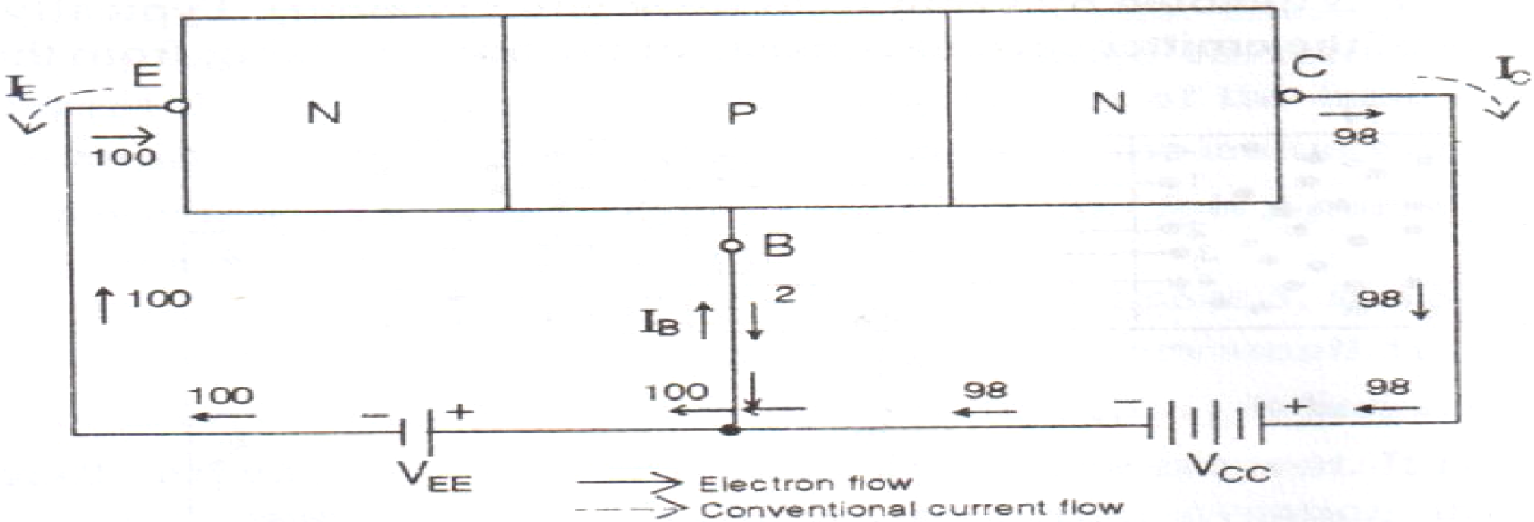


Fig. Relationship between different transistor currents

Transistor Amplifying Actions

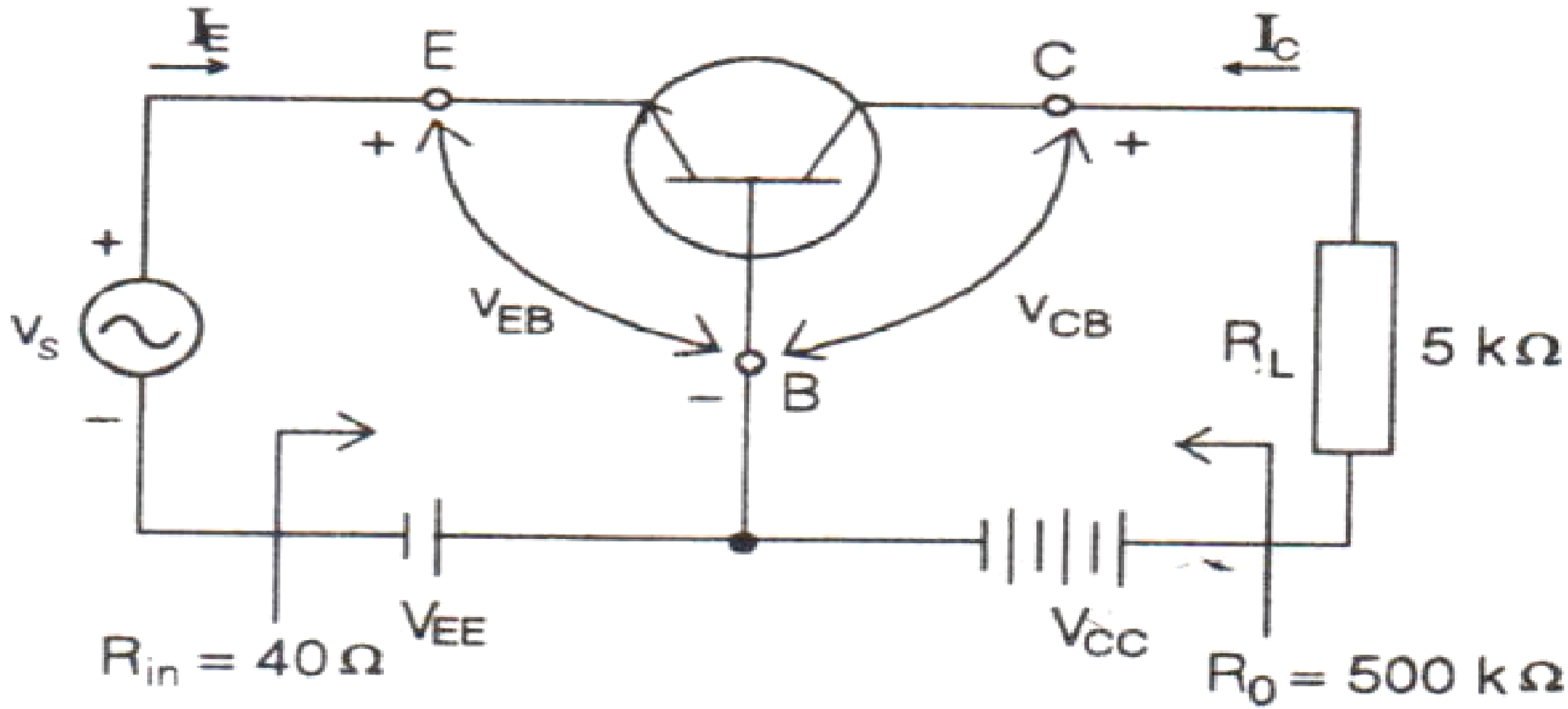


Fig. A basic amplifier in common-base configuration

The transistor's amplifying action is basically due to its capability of *transferring* its signal current from a *low resistance* circuit to *high resistance* circuit. Contracting the two terms *transfer* and *resistor* results in the name *transistor*; that is,

$$\textit{transfer} + \textit{resistor} \rightarrow \textit{transistor}$$

Types BJT Circuits

Three Types of BJT circuits configurations:

a) common base (CB)

b) common emitter (CE),

c) common collector (CC) configurations.

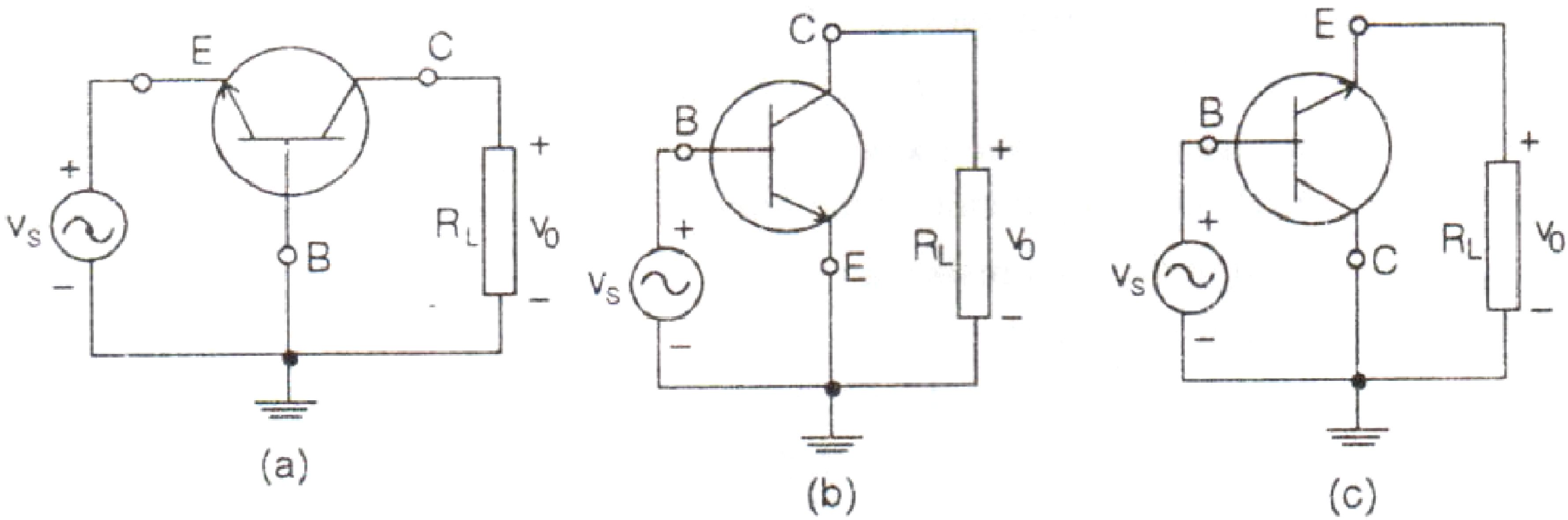


Fig. Three configurations in which a transistor may be connected

Common Base (CB) Configuration

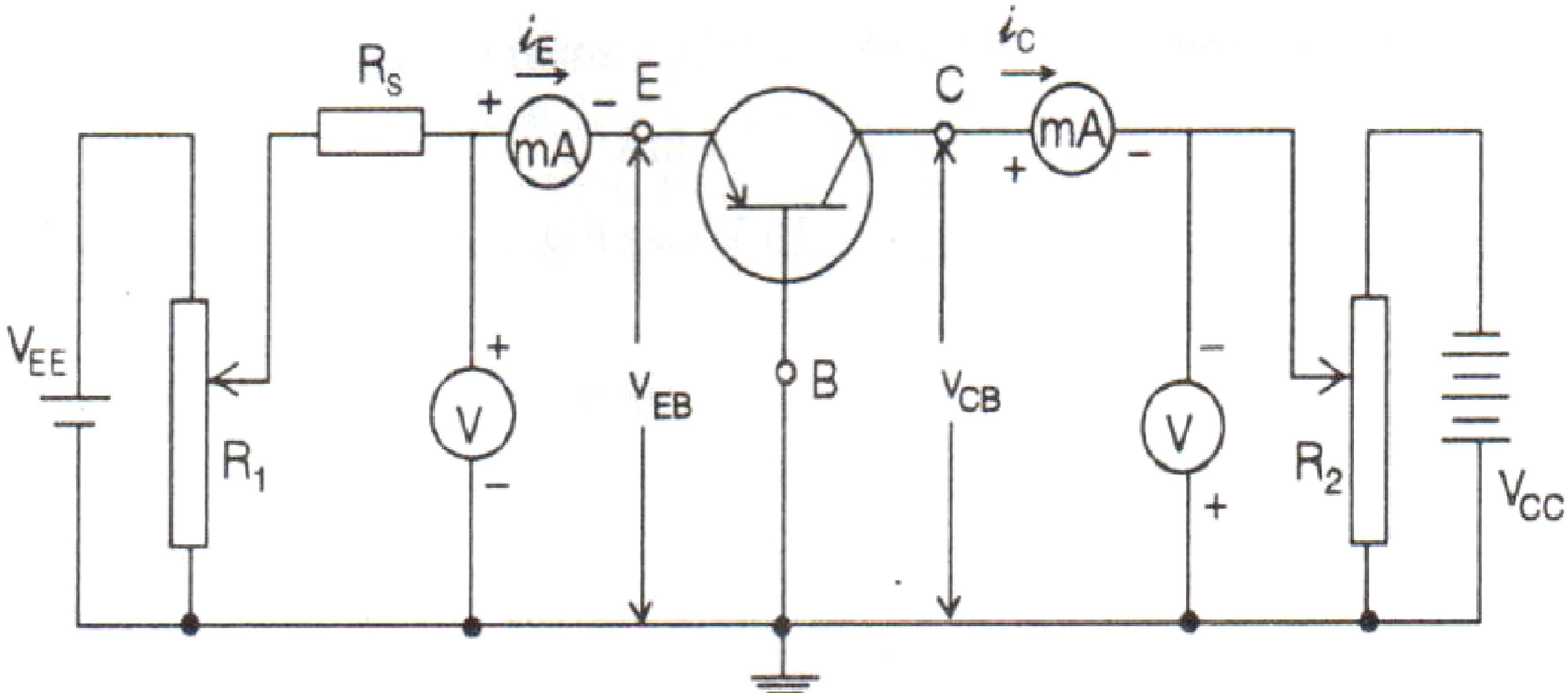


Fig. Circuit arrangement for determining the static characteristics of a PNP transistor in CB configuration

Mode of Operation of Transistor

Cut-off:

- If the Emitter-base junction (the one controlling the current) is not forward biased, then the transistor is said to be in cut-off.
- A small amount of current will still flow, usually negligible

Saturation:

- If the Base-collector junction sees so much current flow that it is no longer forward biased, then the device will no longer behave as described.

Breakdown:

- If a high enough voltage is applied, the transistor junctions will break down, and a high current can flow.

Input CB Characteristics

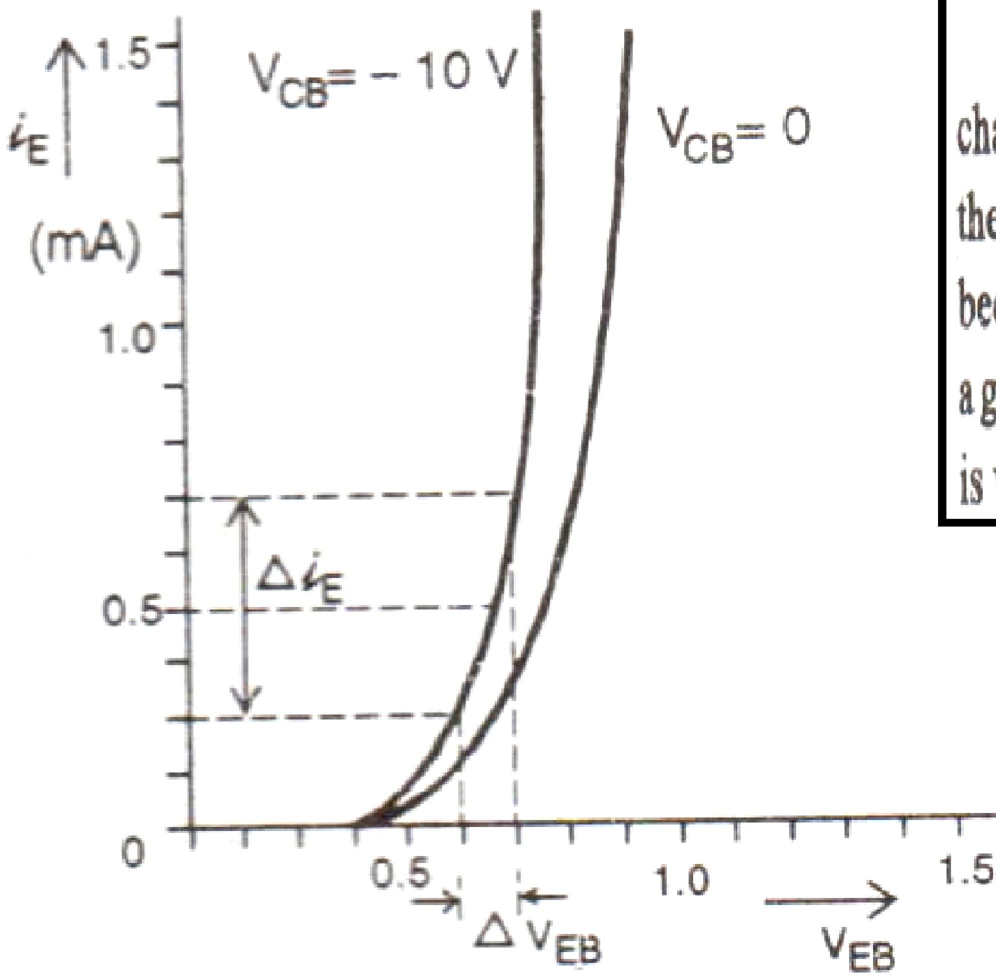


Fig. Common-base input characteristics for a typical PNP silicon transistor

For a given value of V_{CB}, the curve is just like the diode characteristic in forward-bias region. Here, the emitter-base is the *PN*-junction diode which is forward-biased. This junction becomes a better diode as V_{CB} increases. That is, there will be a greater i_E for a given v_{EB} as V_{CB} increases, although the effect is very small.

Dynamic Input Resistance

$$r_i = \left. \frac{\Delta v_{EB}}{\Delta i_E} \right|_{V_{CB}=\text{const.}}$$

Output CB Characteristics

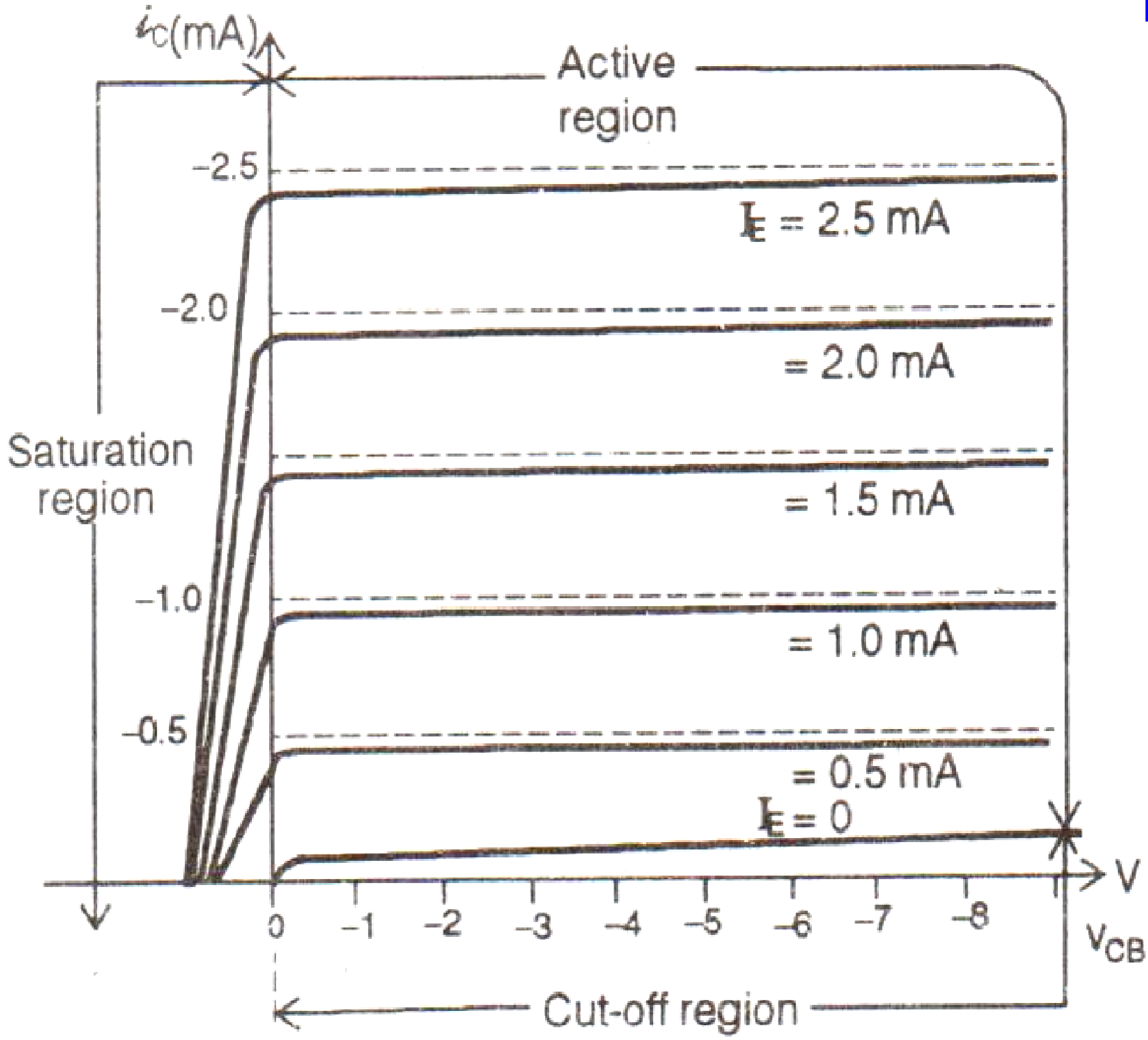


Fig. Common-base output characteristics for a PNP transistor

Dynamic Output Resistance :

$$r_o = \frac{\Delta v_{CB}}{\Delta i_C}\Bigg|_{I_E = \text{const.}}$$

The α_{dc} of the transistor:

$$\alpha_{dc} = \frac{I_C}{I_E}$$

The α_{ac} Current gain of the transistor:

$$h_{fb} \quad \text{or} \quad = \frac{\Delta i_C}{\Delta i_E}\Bigg|_{V_{CB} = \text{const.}}$$

(*i*) The collector current I_C is approximately equal to the emitter current I_E. This is true only in the active region, where collector-base junction is reverse-biased.

(*ii*) In the active region, the curves are almost flat. This indicates that i_C (for a given I_E) increases only slightly as v_{CB} increases. Is it not what happens in a constant current source ? The transistor characteristic (in *CB* configuration) is similar to that of the current source. It means that the transistor should have high output resistance (r_0).

(*iii*) As v_{CB} becomes positive (the collector-base junction becomes forward-biased), the collector current i_C (for a given I_E) sharply decreases. This is the saturation region. In this region, the collector current does not depend much upon the emitter current.

(*iv*) The collector current is not zero when $I_E = 0$. It has a very small value. This is the reverse leakage current I_{CO}. The conditions that exist when $I_E = 0$ for *CB* configuration is shown in Fig. The notation most frequently used for I_{CO} is I_{CBO}, as indicated in the figure. In this notation, the subscript C_{BO} means that it is the current between the collector and base when the third terminal (the emitter) is open. Mind you, the current I_{CBO} is like the reverse saturation current for a diode. This too is temperature sensitive. At room temperature, the typical values of I_{CBO} ranges from 2 μA to 5 μA for germanium transistors, and 0.1 μA to 1 μA for silicon transistors.

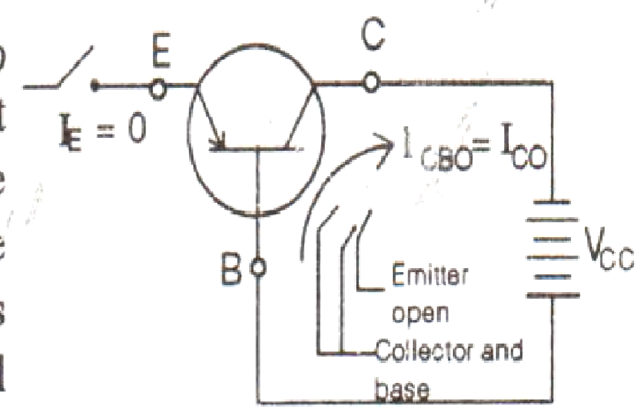


Fig. Reverse leakage current in CB configuration

Common Emitter (CE) Configuration

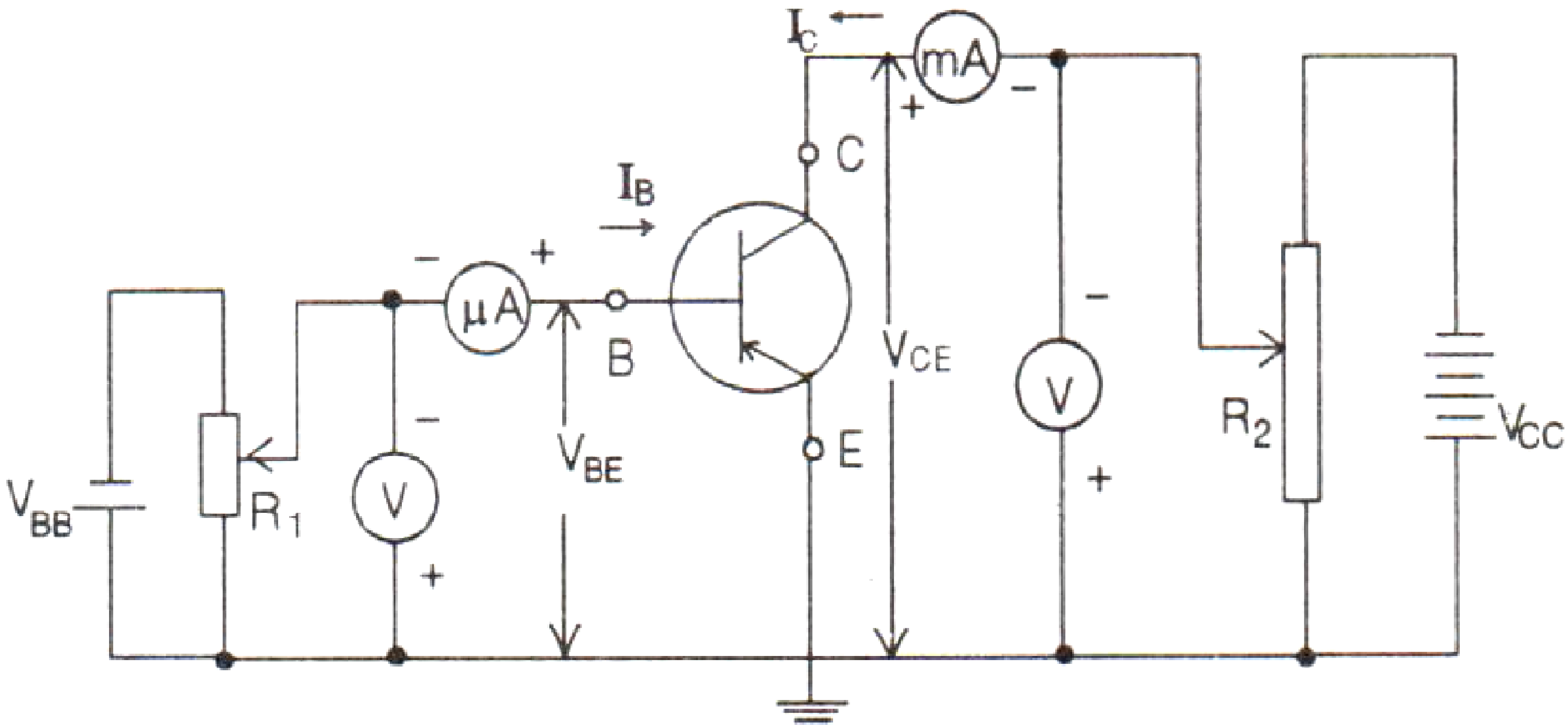


Fig. Circuit arrangements for determining the static characteristics of a PNP transistor, in ce configuration

Input CE Characteristics

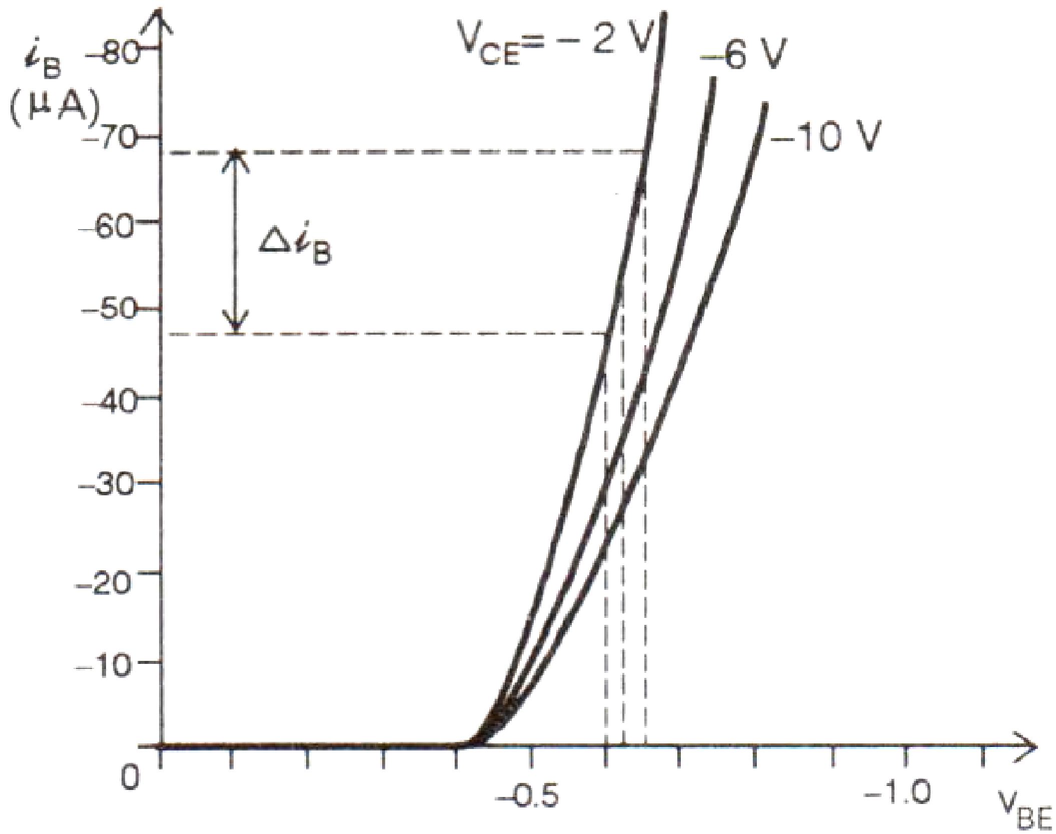


Fig. Common-emitter input coniguration characteristics of a PNP transistor

Dynamic Input Resistance

$$r_i = \left.\frac{\Delta v_{BE}}{\Delta i_B}\right|_{V_{CE} = \text{const.}}$$

Output CE Characteristics

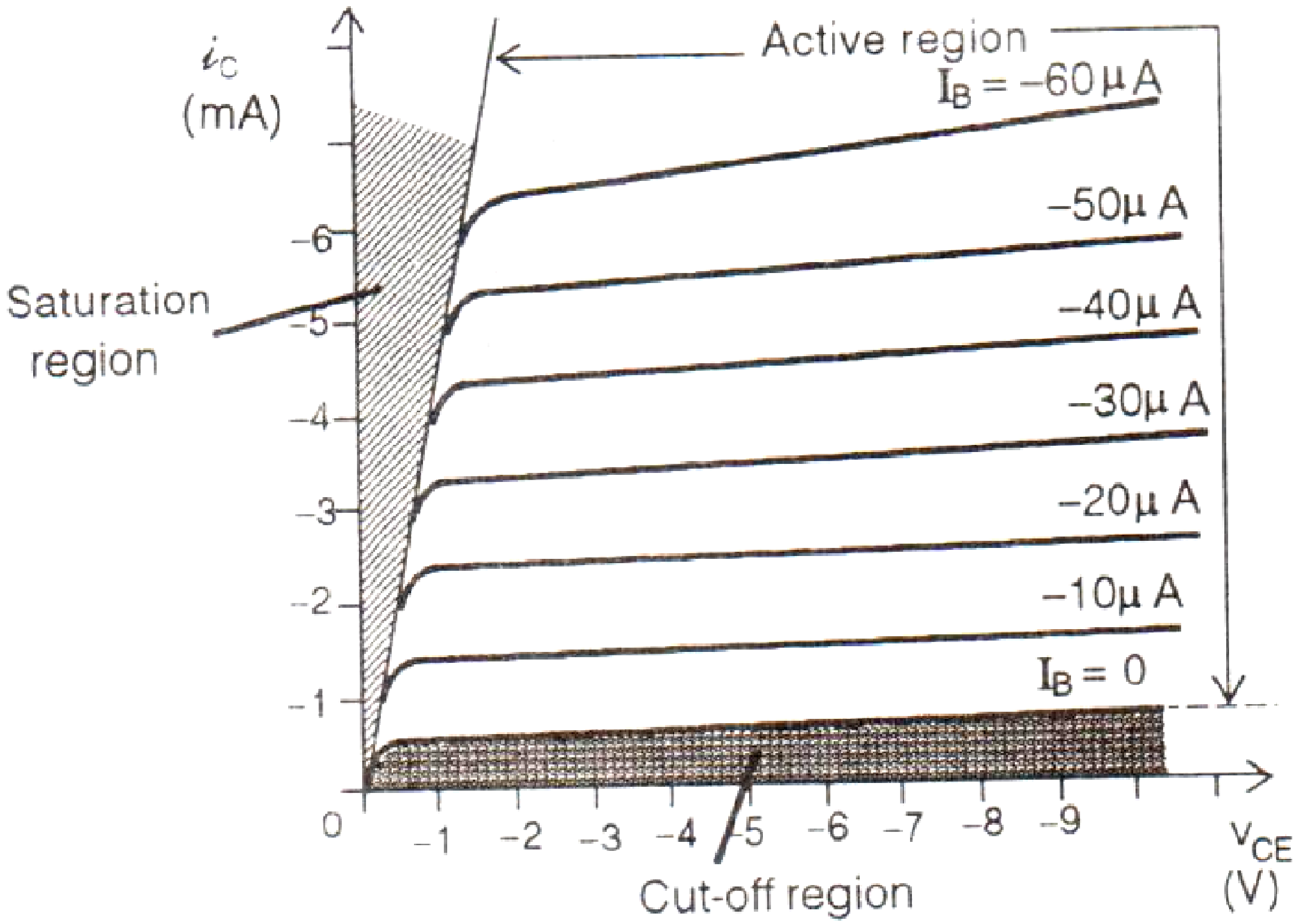


Fig. Common-emitter output characteristics of a PNP transistor

Common Collector (CC) Configuration

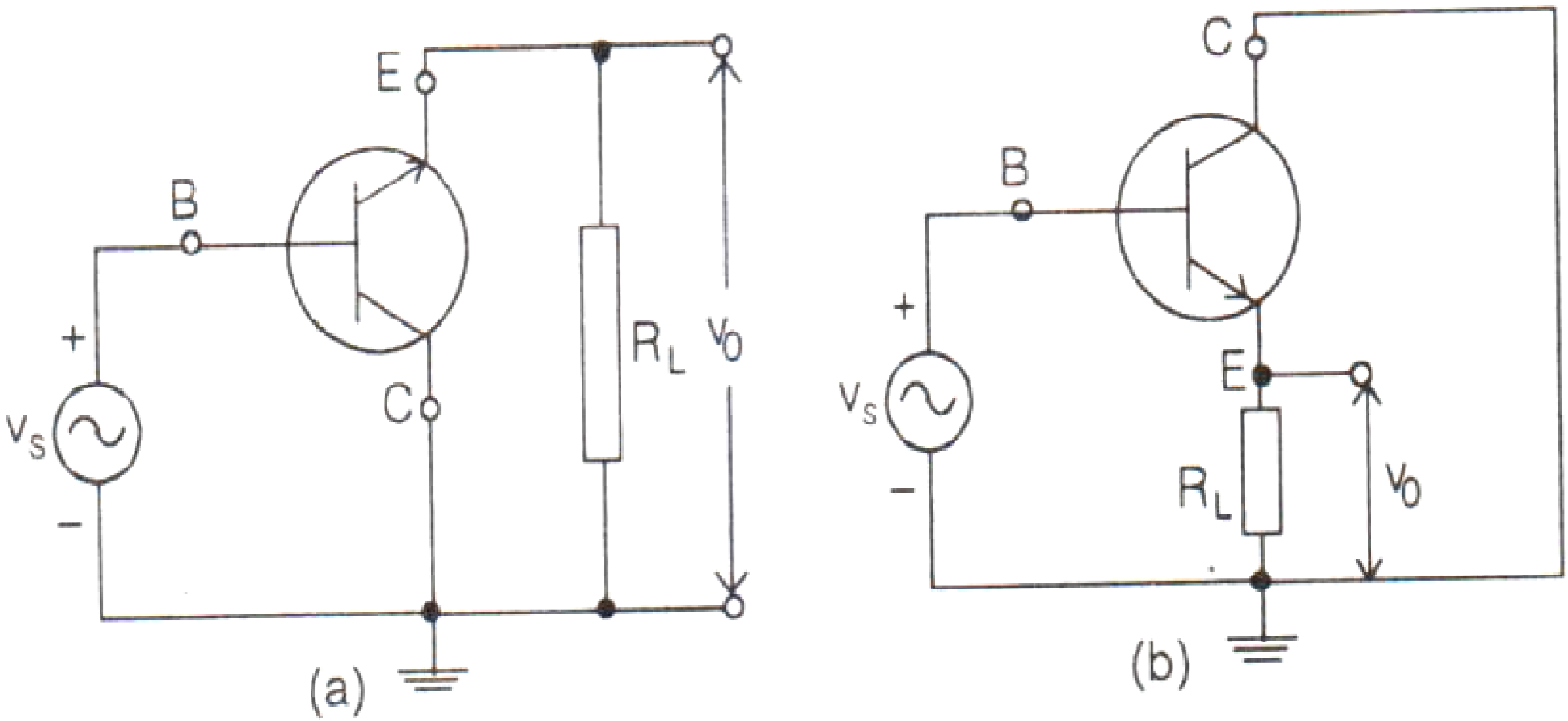


Fig. Transistor connected in CC configuration

Current Relation in CE Configuration

Current in the NPN transistor

$$I_E = I_C + I_B \qquad (1)$$

$$I_C = \alpha_{dc} I_E + I_{CBO} \qquad (2)$$

Out put current I_c related to Input Current I_B

$$I_C = f(I_B) \qquad (3)$$

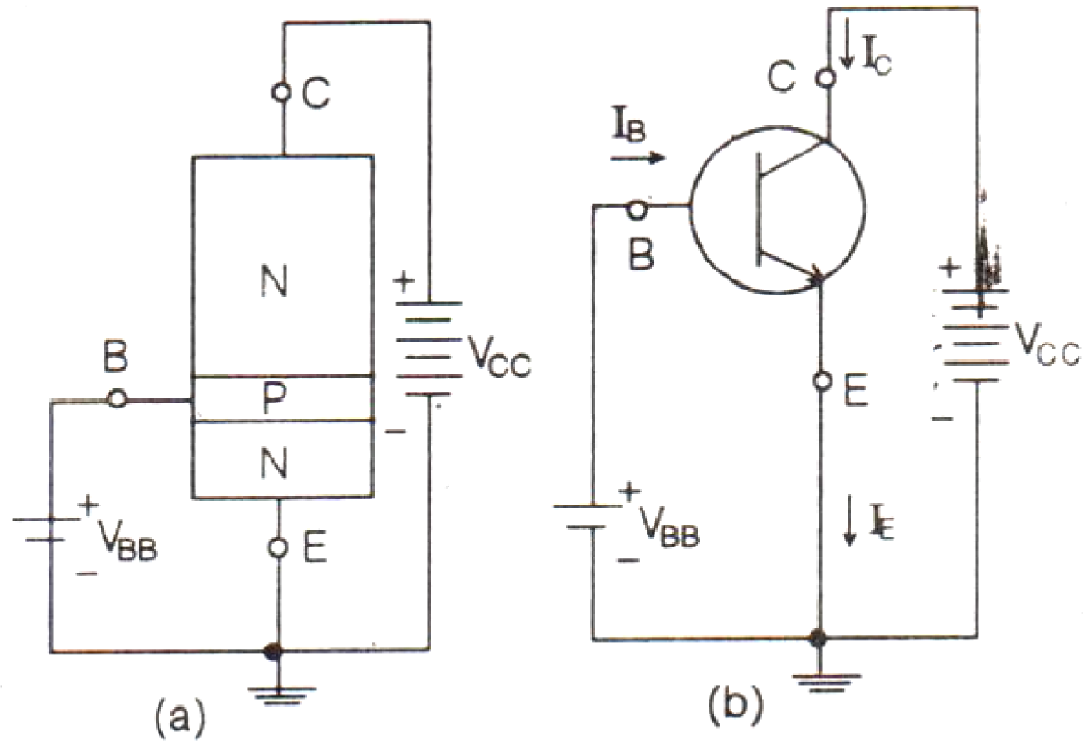


Fig. FR biasing of an NPN transistor in common emitter (CE) configuration

From (1) and (2) Eq:

$$I_C = \alpha_{dc}(I_C + I_B) + I_{CBO} \qquad (4)$$

$$(1 - \alpha_{dc})I_C = \alpha_{dc} I_B + I_{CBO}$$

$$I_C = \frac{\alpha_{dc}}{1-\alpha_{dc}} I_B + \frac{1}{1-\alpha_{dc}} I_{CBO} \qquad (5)$$

$$\beta_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}} \quad (6)$$

$$I_{CEO} = \frac{I_{CBO}}{1-\alpha_{dc}} \quad (7)$$

$$I_C = \beta_{dc} I_B + I_{CEO} \quad (8)$$

This equation states that I_C is equal to β_{dc} multiplied by the input current I_B, plus a leakage current I_{CEO}. This leakage current is the current which would flow between the collector and emitter, if the third terminal (base) were open.

If we solve Eq. for β_{dc}, we obtain

$$\beta_{dc} = \frac{I_C - I_{CEO}}{I_B}$$

If I_{CEO} is very small compared to I_C (as is the case usually) then

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

Thus, β_{dc} is the ratio of dc collector current to dc base current.

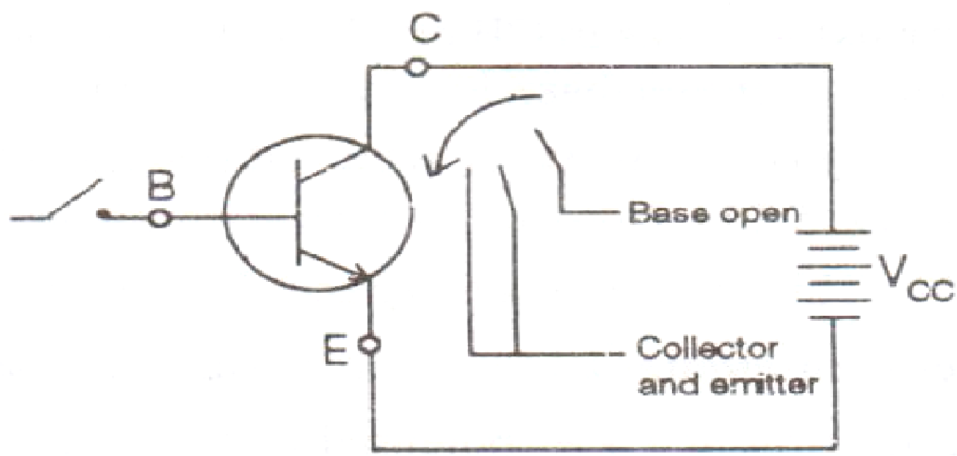


Fig. Reverse leakage current in CE configuration

Current Relation in CC Configuration

In CC base current is Input current and emitter current is output current:

$$I_E = f(I_B)$$

To find the functional relation:

$$I_E = I_B + I_C \qquad \text{and} \qquad I_C = \alpha_{dc} I_E + I_{CBO}$$

Collector terminal is common terminal, so eliminate the *Ic from relation*:

$$I_E = I_B + \alpha_{dc} I_E + I_{CBO}$$

or

$$(I - \alpha_{dc}) I_E = I_B + I_{CBO}$$

$$I_E = \frac{1}{1-\alpha_{dc}} I_B + \frac{1}{1-\alpha_{dc}} I_{CBO}$$

Since

$$\frac{1}{1-\alpha_{dc}} = \beta_{dc} + 1$$

Therefore,

$$I_E = (\beta_{dc} + 1) I_B + (\beta_{dc} + 1) I_{CBO}$$

If we neglect the leakage current I_{CBO}, then

$$I_E = (\beta_{dc} + 1) I_B \qquad \text{or} \qquad \frac{I_E}{I_B} = (\beta_{dc} + 1)$$

Features of Common Base

- Current gain of approximately 1 (alpha)
- Low input impedance (due to low current gain)
- High output impedance (Base screens collector)
- High voltage gain (if input impedance matched)
- Works with a low gain transistor (beta)
- Good HF & bandwidth as falling beta with frequency matters less.

Features of Common Emitter

- High voltage gain
- High current gain
- Medium input impedance due to high current gain
- High output impedance. For HF capacitive loading will need to be resonated reducing bandwidth.
- Bad HF & bandwidth as falling beta with frequency reduces gain.

Comparison Between the Three Configurations

Property	CB	CE	CC
Input resistance	Low (about 100 Ω)	Moderate (about 750 Ω)	High (about 750 kΩ)
Output resistance	High (about 450 kΩ)	Moderate (about 45 Ω)	Low (about 25 Ω)
Current gain	1	High	High
Voltage gain	About 50	About 500	Less than 1
Phase shift between input and output voltages	0 or 360°	180°	0° or 360°
Application	For high frequency circuits	For audio frequency circuits	For impedance matching