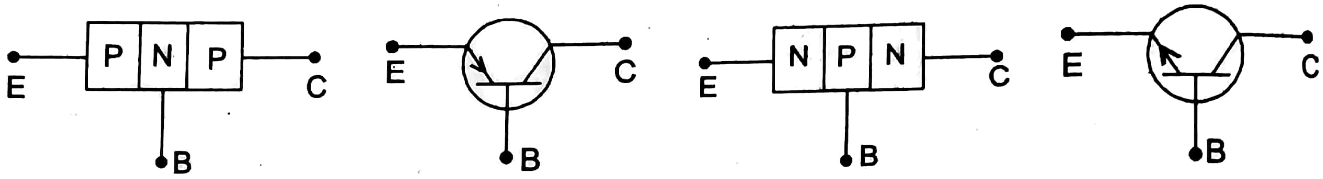
4.8 BIPOLAR JUNCTION TRANSISTORS

4.8.1 Introduction

A bipolar junction transistor is a three layer, two junction and three terminal semiconductor device. Its operation depends on the interaction of majority and minority carriers. Therefore, it is named as bipolar device. The word transistor was derived from the two word combination, (TRANsfer + reSISTOR = TRANSISTOR]. Transistor means, signals are transferred from low resistance circuit (input) into high resistance (output) circuit.

Transistor consists of two back to back PN junction joined together to form single piece of semiconductor device. The two junctions gives three region named as emitter, base and collector. There are two types of transistors such as PNP and NPN. The arrow on the emitter specifies whether the transistor is NPN type or PNP type. This arrow also indicates the direction of current flow, when the emitter base junction is forward biased. Figure 4.12 shows the circuit representation and symbols of NPN and PNP transistor.



a) PNP transistor and its symbol ***b) NPN transistor and its symbol***

Figure 4.12

Emitter

It is more heavily doped than any of other regions because, its main function is to supply majority charge carriers (either electrons or holes) to the base. The current through the emitter is emitter current. It is noted as I_E.

Base

Base is the middle section of the transistor. It separates the emitter and collector. It is very lightly doped. It is very thin as compared to either emitter or collector. The current flows through the base section is base current. It is denoted as I_B.

Collector

It forms the right hand side section of the transistor. It is shown in figure 4.12. The main function of the collector is to collect the majority charge carriers coming from the emitter and passing through the base. Generally, collector region is made physically larger than the emitter region, because it has to dissipate much greater power. Collector is moderately doped. The current flows through the collector section is collector current. It is denoted as I_C.

PNP and NPN transistors

To understand the basic operation of transistor, the following points are need to be kept in mind:

1) Emitter section is meant to provide charge carriers, therefore, it is always forward biased.

2) First letter of transistor type indicates the polarity of the emitter voltage with respect to base.

3) The main function of collector is to collect or attract those carriers through the base, hence it is always reverse biased.

4) Second letter of transistor type indicates the polarity of collector voltage with respect to the base.

4.8.2 *Operation of PNP Transistor*

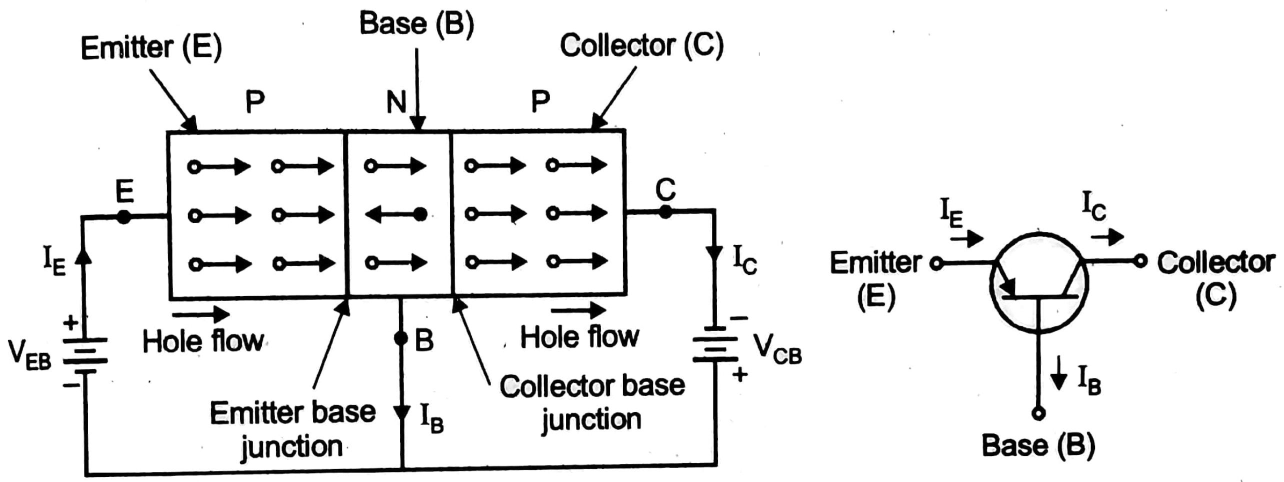


Figure 4.13

Figure 4.13 shows the connection diagram of PNP transistor. In this circuit diagram, the emitter base junction is forward biased (i.e., positive polarity of the battery is connected with 'P' type semiconductor and negative polarity of the battery is connected with 'N' type semiconductor and collector base junction is reverse biased.

The holes in the emiter are repelled by the positive battery terminal towards the PN or emitter junction. Then, the potential barrier at emitter junction is reduced. As a result of this, depletion region disappears and hence holes cross the junction and enter into N-region (base).

This constitutes the emitter current I_E. Because, the base region is thin and lightly doped, majority of the holes (about 97.5%) are able to drift across the base without meeting electrons. Only 2.5% of the holes recombine with the free electrons or N-region. This constitutes the base current I_B, which is very small. The holes which after crossing the N-P collector junction, enter the collector region. They are swept out by the negative collector voltage V_{CB}. This constitutes the collector current I_C.

The following points about transistor circuits are:

1) In a PNP transistor, majority charge carriers are holes.
2) Emitter arrow shows the direction of flow of conventional current. But electrons flows will be in the opposite direction.
3) Emitter base junction is always forward biased and collector base junction is always reverse biased.
4) The collector current is always less than the emitter current because same recombination of holes and electrons takes place.

$$I_C = I_E - I_B$$

$$I_E = I_B + I_C$$

4.8.3 *Operation of NPN Transistor*

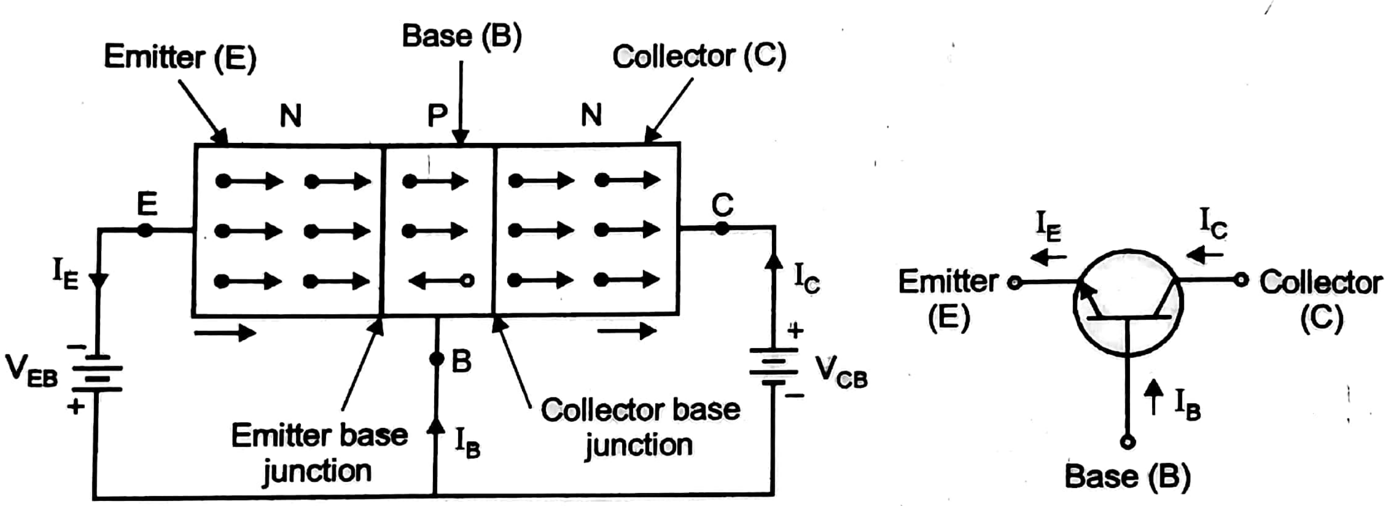


Figure 4.14

Figure 4.14 shows the connection diagram of NPN transistor. In this circuit diagram, the emitter base junction is forward biased (i.e., negative polarity of the battery is connected with 'N' type semiconductor and positive polarity of the battery is connected to with P type semiconductor) and collector base junction is reverse biased.

The electrons in the emitter region are repelled by the negative battery terminal towards the emitter junction. The electrons crossover into the P-type base region because potential barrier is reduced due to forward bias and base region is very thin and lightly doped, most of the electrons (about 97.5%) cross over to the collector junction and enter the collector region where they are readily swept up by the positive collector voltage V_{CB}. Only 2.5% of the emitter electrons combine with the holes in the base and are lost as charge carriers.

The following points about transistor circuits are:

1) In a NPN transistor, majority charge carriers are electrons.

2) Emitter arrow shows the direction of flow of conventional current.

3) Collector current I_C is less than emitter current I_E.

The choice of NPN transistor is made more often because majority charge carriers are electrons whose mobility is much more than that of holes.

4.8.4 *Transistor Circuit Configurations*

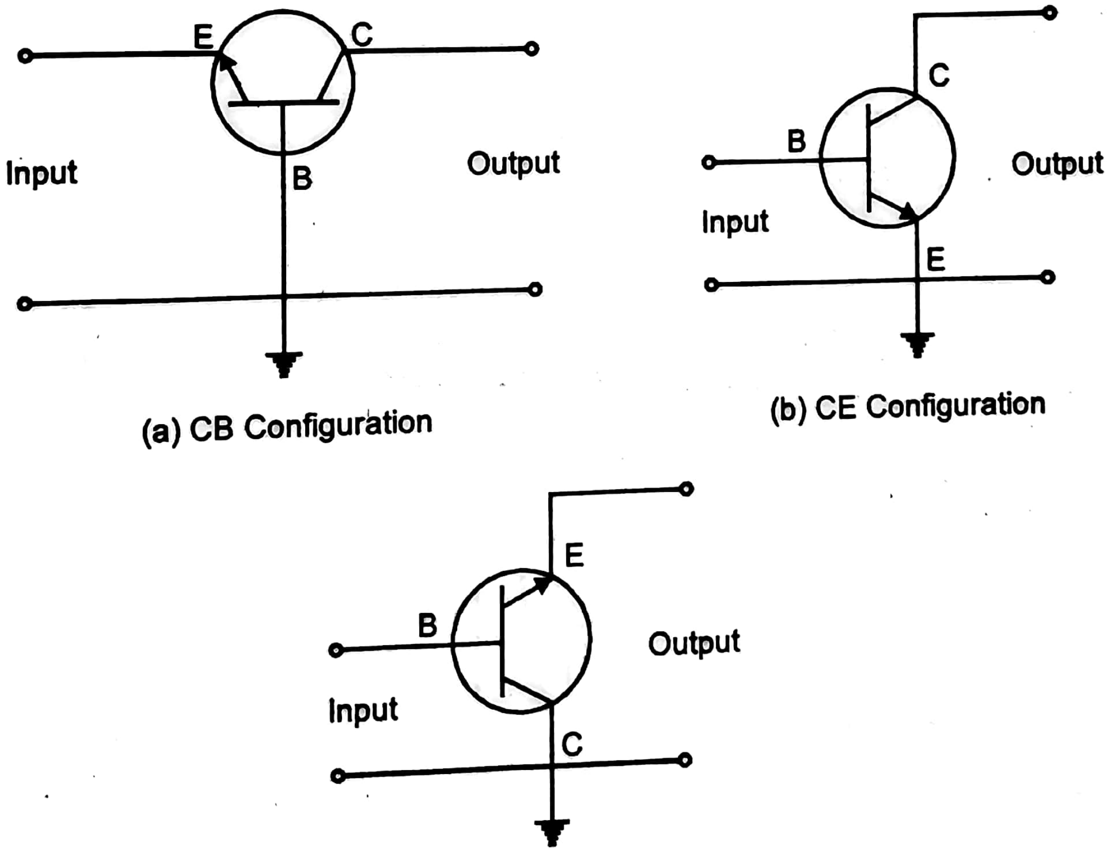
There are three terminals in a transistor such as emitter, base and collector. However, when a transistor is to be connected in a circuit, we require four terminals.

Two terminals are used for input connection and other two terminals are used for output connection. This difficulty can be overcome by making one terminal common to both input and output circuits. Accordingly, there are three types of circuit configurations.

i) Common Base (CB) configuration

ii) Common Emitter (CE) configuration

iii) Common Collector (CC) configuration



(a) CB Configuration

(b) CE Configuration

(c) CC Configuration

Figure 4.15

The term 'common' is used to denote the electrode that is common to the input and output circuits, because the common electrode is generally grounded. Figure 4.15 shows the different configurations of NPN transistor.

Each circuit configuration has specific advantages and disadvantages. It may be noted here that, regardless of circuit configuration, the emitter base junction is always forward biased and collector base junction is always reverse biased.

4.8.4.1 Common Base Configuration

In this configuration, input is applied between emitter and base while output is taken from collector and base. Here, base of the transistor is common to both input and output circuits and hence, named as common base configuration. It is shown in figure 4.16.

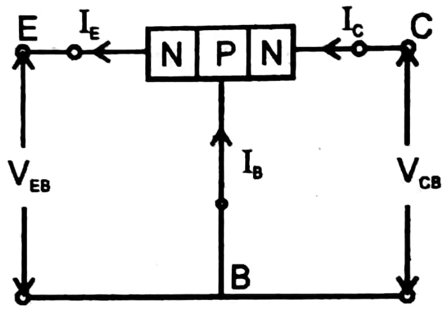


Figure 4.16 CB configuration

The two important characteristics of common base connection are:

i) Input characteristics

ii) Output characteristics

Input Characteristics

Figure 4.17 shows the circuit diagram for obtaining characteristics of CB configuration. It shows how the input current I_E varies with input voltage V_{EB} when output voltage V_{CB} is held constant. To determine the input characteristics initially, the output voltage V_{CB} is set at zero, then the input voltage V_{EB} is increased.

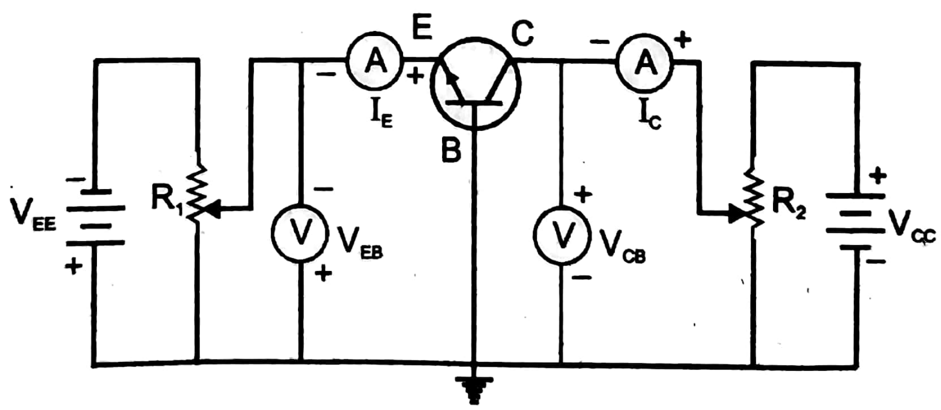


Figure 4.17 Circuit for obtaining the characteristics of CB configuration

The input characteristics is drawn between emitter current I_E and emitter-base voltage V_{EB}. The emitter current (I_E) is generally taken along Y-axis and emitter base voltage V_{EB} along X-axis. Figure 4.18 shows the input characteristics of a common base configuration. The emitter current I_E increases rapidly with small increase in emitter base voltage. This indicates the input resistance is very small. Another one, the emitter current is almost independent of collector-base voltage. This leads to the conclusion that emitter current I_E and hence collector current is almost independent of collector-base voltage V_{CB}.

This characteristics may be used to find the input resistance of the transistor. It is the ratio of change in emitter-base voltage (ΔV_{EB}) to the resulting change in emitter current (ΔI_E) at constant collector-base (V_{CB}).

i.e.,

$$\text{Input resistance} \quad R_{in} = \frac{\Delta V_{EB}}{\Delta I_E} \quad \text{at constant } V_{CB}$$

Output Characteristics

To determine the output characteristics, the emitter current I_E is kept constant, at a suitable value by adjusting the emitter-base voltage V_{EB} and varying R_2 and the output current (collector current) is measured.

The collector-base voltage (V_{CB}) is increased from zero in a number of steps and the corresponding collector current I_C is noted. This output characteristics is drawn between collector current I_C and collector-base voltage V_{CB} at constant emitter current I_E. Generally, collector current I_C is taken along Y-axis and collector-base voltage (V_{CB}) along X-axis. Figure 4.19 shows the output characteristics of CB configuration.

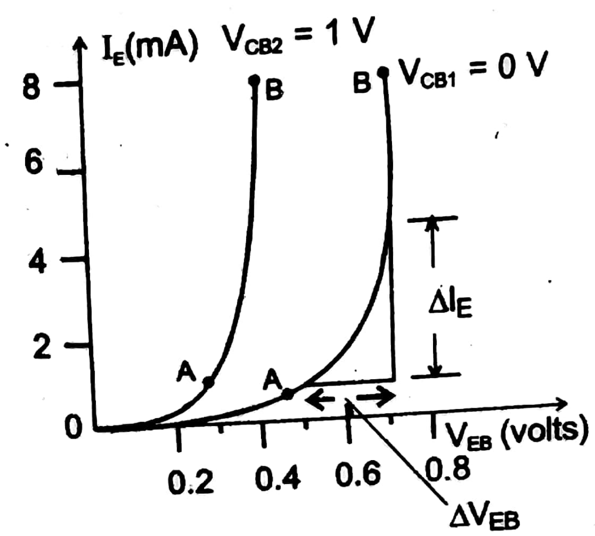


Figure 4.18 Input characteristics

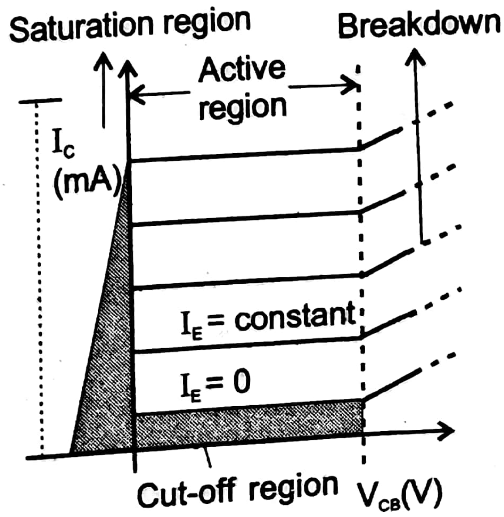


Figure 4.19 Output characteristics

The output characteristics gives us the following important points.

i) The collector current I_C varies with V_{CB} only at very low voltages (< 1 V).

ii) When the value of V_{CB} is raised abve 1-2 V, the collector current becomes constant as indicated by straight horizontal curves. It means that, now I_C is independent of collector base voltage V_{CB} and depends upon emitter current only. This is consistent with the theory that emitter current flows almost entirely to the collector terminal.

iii) A very large change in collector-base voltage produces only a tiny change in collector current. Due to this, the output resistance is very high.

iv) Output resistance is the ratio of change in collector-base voltage (ΔV_{CB}) to the resulting change in collector current (ΔI_C) at constant emitter current (I_E) i.e.,

$$\text{Output resistance } R_{out} = \frac{\Delta V_{CB}}{\Delta I_C} \text{ at constant } I_E$$

v) This characteristic may be used to find current amplification factor (α). It is defined as the ratio of change in output current (ΔI_C) to the change in input curent (ΔI_E) at constant collector-base voltage.

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \text{ at constant } V_{CB}$$

vi) The output characteristics curve may be divided into three regions. They are saturation region, active region and cut-off region.

Saturation Region: It is the region left to the vertical line. In this region, collector-base voltage V_{CB} is negative, i.e. the collector base junction is also forward biased and a small change in V_{CB} results in larger variation in collector current.

Active Region: It is the region between the veritical line to horizontal axis. In this region, the collector current is almost constant and is equal to the emitter current. In this region, the emitter-base junction is forward biased and collector-base junction is reversed biased.

Cut-off Region: It is the region along the horizontal axis shown in figure 4.19. It corresponds to the curve marked $I_E = 0$. In this region, both junctions are reverse biased. Due to this, there is no current flow in collector terminal due to majority carriers, but the current due to minority carriers will flow. This current is known as reverse saturation current.

Characteristics of CB Configuration

1) The input impedance of this configuration is low (about 100 Ω)
2) The output impedance is very high (about 1MΩ)
3) The voltage gain is medium (about 150)
4) The current gain is less than unity.
5) This configuration is mainly used for high frequency applications.

4.8.4.2 Common Emitter Configuration

In CE configuration, input is applied between base and emitter and output is taken from the collector and emitter. Here, the emitter terminal is common to both input and output circuits and hence named as common-emitter configuration. The most important characteristics of this circuit configuration are input characteristics and output characteristics.

Input Characteristics

Figure 4.20 shows the circuit diagram for common-emitter configuration. It shows how the input current I_B varies with change in input voltage V_{BE} while output voltage V_{CE} is held constant at a particular value. To begin with, collector-emitter voltage V_{CE} is maintained constant at a convenient value and then V_{BE} is increased in steps. The corresponding values of base current I_B are noted at each step. This procedure is repeated for different constant values of V_{CE}.

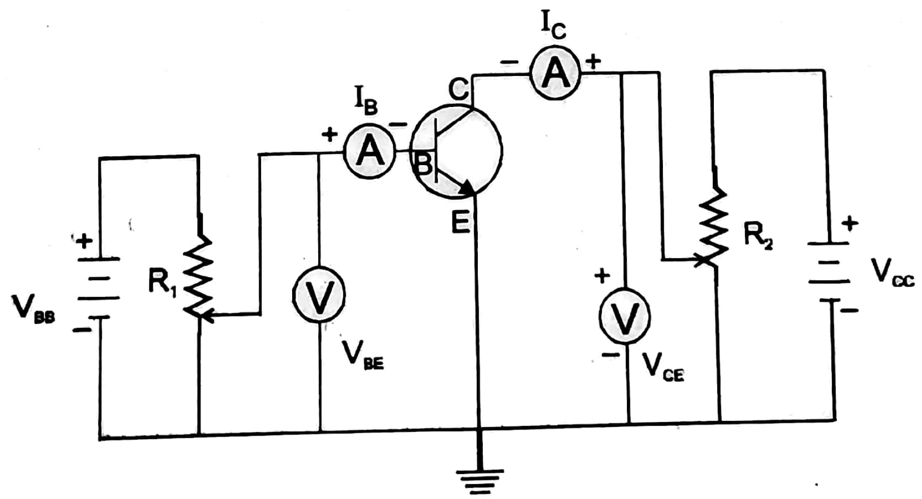


Figure 4.20 Circuit for CE configuration

This input characteristics is drawn between base current I_B and base-emitter voltage V_{BE} at constant collector-emitter voltage V_{CE}. Here, the base current I_B is taken along Y-axis and base-emitter voltage V_{BE} along X-axis. Figure 4.21 shows the input characteristics of CE configuration.

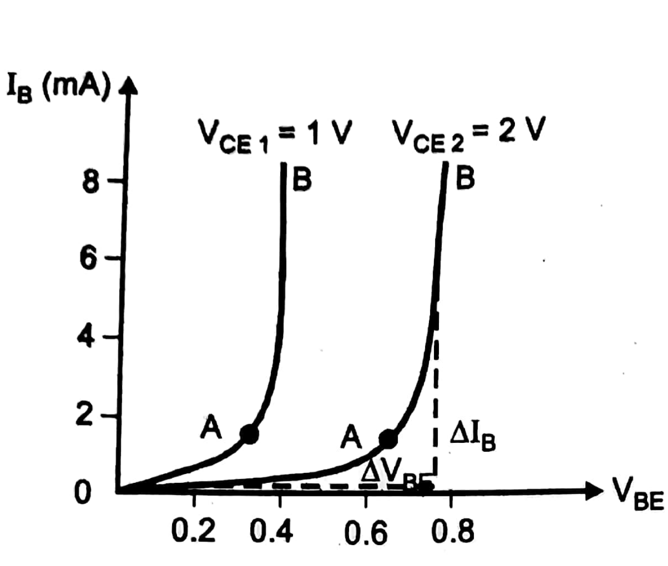


Figure 4.21 Input characteristic

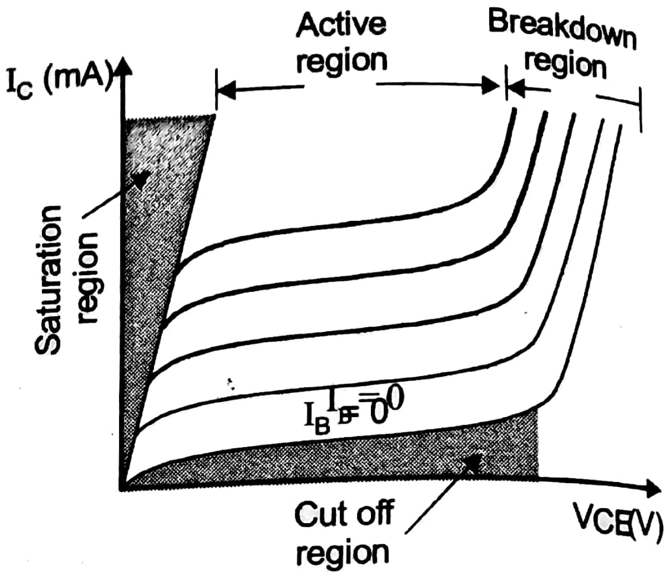


Figure 4.22 Output characterisics

The input characteristics gives us the following points.

i) If the input voltage (V_{BE}) is less than threshold or knee voltage, below which the base current is very small. The value of knee voltage is 0.7 V for silicon and 0.3 V for germanium transistor. The knee voltage means the voltage at which conduction starts. i.e., input current (base current) increases. This characteristics is similar to the forward biased diode curve.

ii) As compared to CB arrangement, I_B increases less rapidly with V_{BE}. Therefore input resistance of a CE configuration is higher than that of CB configuration.

iii) The input resistance of this configuration is the ratio of change in base-emitter voltage (ΔV_{BE}) to the resulting change in base current (ΔI_B) at constant V_{CE}.

$$R_{in} = \frac{\Delta V_{BE}}{\Delta I_B} \text{ at constant } V_{CE}$$

The value of input resistance for this configuration is of the order of a few hunderd ohms.

Output Characteristics

It is the curve between collector current I_C and collector-emitter voltage V_{CE} at constant base current I_B. For obtaining this curve, first base current I_B is set to a convenient value and maintained constant. Then, collector-emitter voltage V_{CE} is increased from zero in steps, collector current I_C being noted at each step. Next, V_{CE} is reduced to zero, and I_B is increased to another convenient value and maintained constant and then V_{CE} is increased from zero in steps, I_C being noted at each step. In this way a family of curves is obtained.

The following points may be noted from the characteristics:

1) From this curve, V_{CE} increases from zero to contain voltage, collector current I_C rapidly increases. This region is called saturation region. It is shown in figure 4.22. After this, collector current I_C becomes almost constant and independent of V_{CE}. This value of V_{CE} upto which collector current I_C changes is called the knee voltage.

2) When $I_B = 0$, a small amount of collector current flows. It is called reverse saturation current (I_{CEO}). Since, the main collector current is zero, the transistor is said to be in cut-off region.

3) It may be noted that, if V_{CE} is increased continuously then depletion region in CB junction is increased, so that I_C increases and operates the transistor in active region. It is shown in figure 4.41.

4) Further increase in V_{CE} causes avalanche breakdown in CB junction. As a result of this, enormous I_C will flow and the transistor enter into breakdown region. It is shown in figure 4.22.

5) This characteristics can be used to find current gain β. It is defined as the ratio of change in output current (ΔI_C) to the change in input current (ΔI_B).

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

6) Output resistance is also found from this characteristics. It is defined as the ratio of change in collector-emitter voltage (ΔV_{CE}) to resulting change in collector current (ΔI_C) at constant I_B.

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

Characteristics of CE Configuration

1) The input impedance is low (about 750 Ω).
2) The output impedance is high (about 45 kΩ).
3) The voltage gain is high (about 500).
4) The current gain is high.
5) This configuration is mainly used for audio frequency applications.

4.8.4.3 Common Collector Configuration

In this configuration, collector terminal is common to both input and output. Here, input signal is applied between base and collector terminal and output signal is taken out from emitter-collector terminal.

Characteristics of CC Configuration

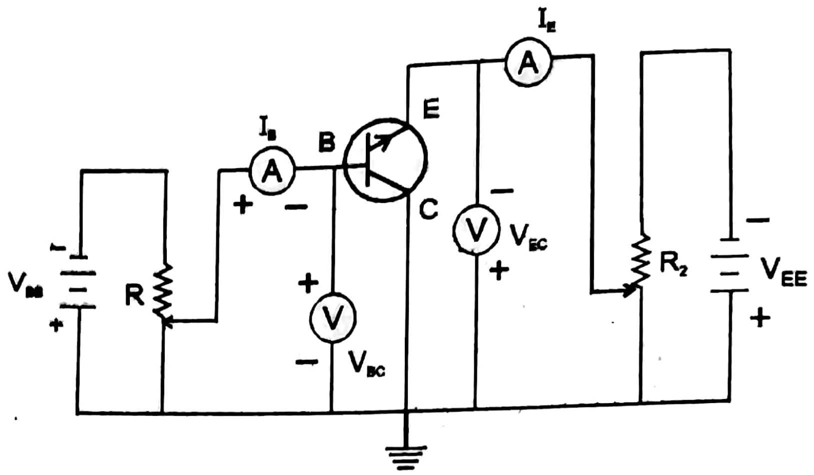


Figure 4.23 Circuit for CC configuration

Figure 4.23 shows the circuit arrangement for common collector configuration. To determine the output characteristics, the base current I_B is kept constant, at a suitable value by adjusting the base collector voltage and varying R_2 and the output current (emitter current (I_E)) is measured. We know that the CE output characteristics are plotted as I_C Vs V_{CE}.

Since I_C is approximately equal to I_E, common collector characteristics is identical to CE configuration. Figure 4.25 shows the output characteristics of CC configuration. From this characteristics, we can find the output resistance (R_{out}).

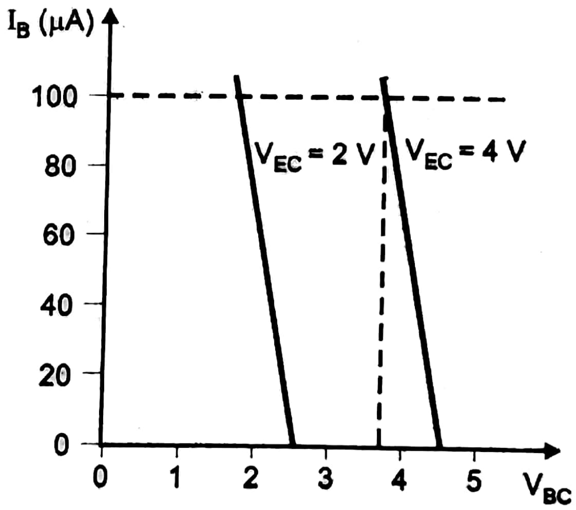


Figure 4.24 Input characteristics

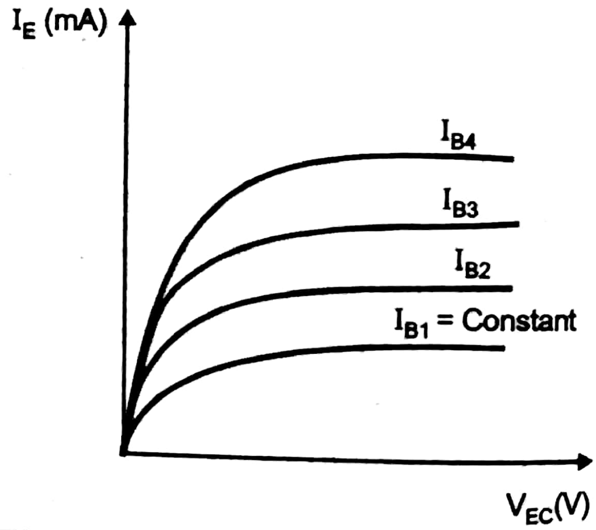


Figure 4.25 Output characteristics

It is defined as the ratio of change in collector-emitter voltage (ΔV_{EC}) to the resulting change in emitter current (ΔI_E) at constant base current (I_B).

$$R_{out} = \frac{\Delta V_{EC}}{\Delta I_E} \text{ at constant } I_B$$

This characteristics may be used to find current amplification factor (γ). It is defined as the ratio of change in output current (ΔI_E) to the change in input current (ΔI_B) at constant V_{CE}.

$$\gamma = \frac{\Delta I_E}{\Delta I_B} \quad \text{at constant } V_{CE}$$

Input Characteristics

The common collector input characteristics are different from CB and CE configuration. The difference is due to the fact the input voltage V_{BC} is largely determined by the level of emitter-collector voltage V_{EC}. This is because when the transistor is biased on, V_{BE} remains around 0.7 V, for Silicon transistor (and 0.3 V for Ge transistor) and V_{EC} may be much larger than 0.7 V. From the circuit diagram 4.23,

$$V_{EC} = V_{BC} + V_{BE}$$

$$V_{BE} = V_{EC} - V_{BC}$$

Suppose V_{EC} = 2 V at I_B = 100 μA and V_{BE} = 0.7 V, then $V_{BC} \approx 1.3$ V. Then V_{EC} is maintained constant at 2 volts while the input voltage V_{BC} is increased to 1.5 V then V_{BE} reduced to 0.5 V. Since V_{BE} is reduced, I_B is also reduced from 100 μA to zero.

Figure 4.24 shows the input characteristics of CC configuration. In this curve, V_{EC} is maintained constant. At particular value of V_{BC}, base current value is noted. Then increasing V_{BC}, the base current I_B reduces out and reaches to zero. From this curve, we can find the input resistance R_{in},

$$R_{in} = \frac{\Delta V_{BC}}{\Delta I_B} \text{ at constant } V_{EC}$$

Characteristics of CC Configuration

1) The input impedance is high (about 750 kΩ).
2) The output impedance is low (about 50 Ω).
3) The voltage gain is less than 1.
4) The current gain is high.
5) This configuration is mainly used for impedance matching.

4.8.4.4 Comparison of Transistor Configurations

Characteristics	*CB*	*CE*	*CC*
Input Impedance	Low (about 100 Ω)	Low (about 750 Ω)	High(about 750 kΩ)
Output Impedance	Very high (about 1 MΩ)	High (about 45 kΩ)	Low (about 50 Ω)
Voltage Gain	About 150 (Medium)	About 500 (Medium)	Less than 1
Current Gain	Less than unity	High	High
Application	For high frequency application	For audio frequency application	For impedance matching