UNIT II Bipolar Junction Transistor (BJT):

Principle of Operation and characteristics – Common Emitter, Common Base, Common Collector Configurations, Operating point, DC & AC load lines, Transistor Hybrid parameter model, Determination of h-parameters from transistor characteristics, Conversion of h-parameters.

2.1 Introduction

- Transistor is a three terminal device namely Base, emitter and collector, can be operated in three configurations common base, common emitter and common collector.
- According to configuration it can be used for voltage as well as current amplification.
- The input signal of small amplitude is applied at the base to get the magnified output signal at the collector.
- The amplification in the transistor is achieved by passing input current signal from a region of low resistance to a region of high resistance.
- This concept of transfer of resistance has given the name TRANSfer-resISTOR (TRANSISTOR).

2.1.1 Types of transistors

- There are two types of transistors namely unipolar junction transistor and bipolar junction transistor.
- In unipolar transistor the current conduction is only due to one type of carriers, majority carriers.
- In bipolar transistor the current conduction is due to both the types of charge carriers, namely holes and electrons. Hence this is called Bipolar Junction Transistor (BJT).
- In BJT output current is controlled by input current and hence it is a current controlled device.

2.1.2 Types of BJT

- npn type
- pnp type

2.1.3 Advantages of BJT

- Low operating voltage.
- Higher efficiency.
- Small size and ruggedness.
- Does not require any filament power.

2.2 Construction of Bipolar Junction Transistor (BJT)

- When a transistor is formed by sandwiching a single p-region between two n-regions, as shown in the Fig. 2.1 (a), it is an n-p-n type transistor.
- The p-n-p type transistor has a single n-region between two p-regions, as shown in Fig. 2.1 (b).

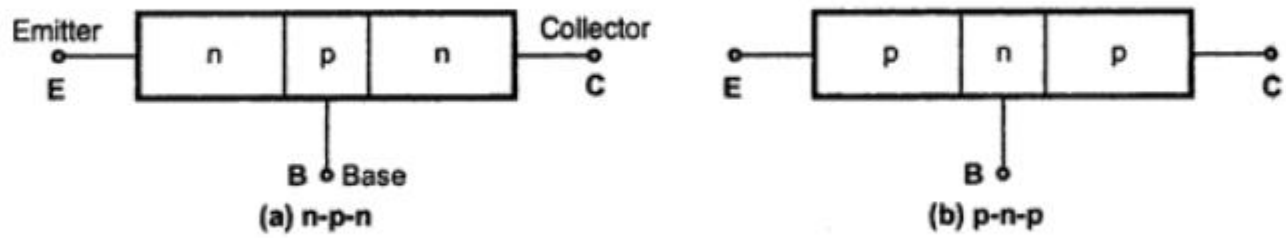


Fig. 2.1 Bipolar transistor construction

- The middle region of each transistor type is called the base of the transistor. This region is very thin and lightly doped.
- The remaining two regions are called emitter and collector. The emitter is heavily doped and collector is moderately doped.
- The collector region area is slightly more than that of emitter.

2.2.1 Biased Transistor

- In order to operate transistor properly as an amplifier, it is necessary to correctly bias the two p-n junctions with external voltages.
- Depending upon external bias voltage polarities used, the transistor works in one of the three regions, Active region, Cut-off region and Saturation region

Region	Emitter base junction	Collector base junction
Active	Forward biased	Reverse biased
Cut-off	Reverse biased	Reverse biased
Saturation	Forward biased	Forward biased

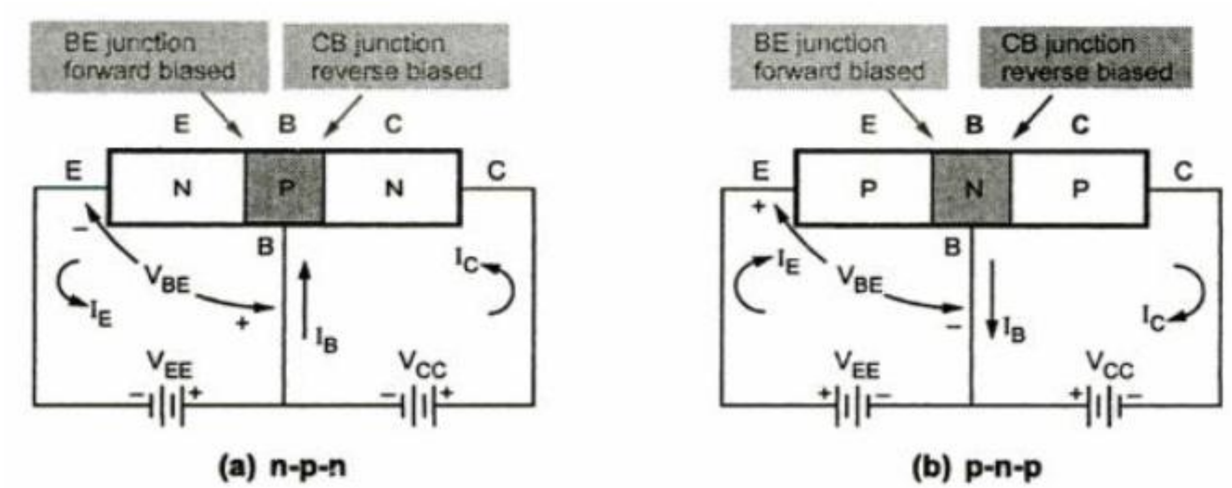


Fig. 2.2 Transistor forward-reverse bias

- To bias the transistor in its active region, the emitter base junction is forward biased while the collector base junction is reverse biased as shown in Fig. 2.2.
- The externally applied bias voltages are V_{EE} and V_{CC}, as shown in Fig. 2.2, which bias the transistor in its active region.

2.3 Operation of BJT

- The operation of the n-p-n is the same as for the p-n-p except that the roles of the electrons and holes, the bias voltage polarities, and the current directions are all reversed.

2.3.1 Operation of npn transistor

- The base to emitter junction is forward biased by the d.c source V_{EE}. Thus, the depletion region at this junction is reduced.
- The collector to base junction is reverse biased, increasing depletion region at collector to base junction as shown in Fig. 2.3.

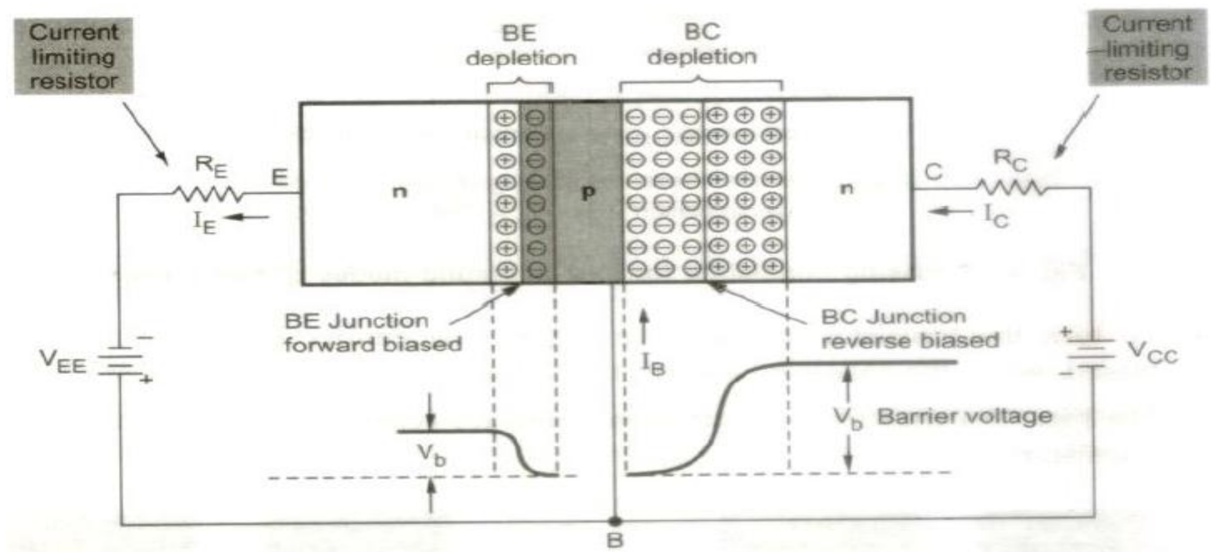


Fig. 2.3 Operation of npn transistor

- The forward biased EB junction 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 in p-region (base).
- Due to light doping, very few of the electrons injected into the base from the emitter recombine with holes to constitute base current, I_B and the remaining large number of electrons cross the base region and move through the collector region to the positive terminal of the external d.c source.
- This constitutes collector current I_C. Thus the electron flow constitutes the dominant current in an n-p-n transistor.

- Since, most of the electrons from emitter flow in the collector circuit and very few combine with holes in the base.
- Thus, the collector current is larger than the base current.

$$I_E=I_B+I_C$$

2.3.2 Operation of pnp transistor

- The p-n-p transistor has its bias voltages V_{EE} and V_{CC} reversed from those in the n-p-n transistor as shown in Fig. 2.4.

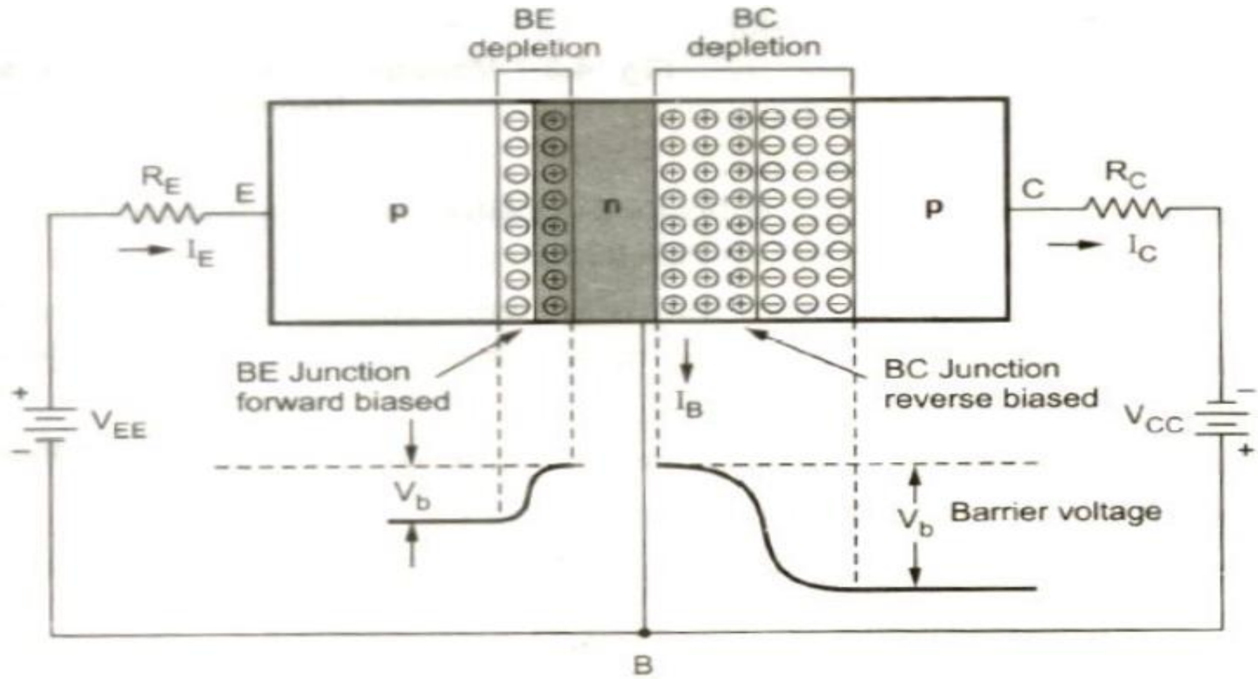


Fig. 2.4 Operation of pnp transistor

- This is necessary to forward bias the emitter base junction and reverse bias the collector base junction.
- The forward biased EB junction causes the holes in the p-type emitter to flow towards the base. This constitutes the emitter current I_E.
- As these holes flow through the n-type base, they tend to combine with electrons in n-region (base).
- As the base is very thin and lightly doped, very few of the holes injected into the base from the emitter recombine with electrons to constitute base current, I_B.
- The remaining large number of holes crosses the depletion region and move through the collector region to the negative terminal of the external d.c source.
- This constitutes collector current I_C.
- Thus the hole flow constitutes the dominant current in an p-n-p transistor.

2.4 Transistor Circuit Configurations

- A transistor has three terminals or leads namely emitter (E), base (B) and collector (C).
- However, when a transistor is connected in a circuit, we require four terminals i.e., two terminals for input and two for output.
- This difficulty is overcome by using one of the three terminals as a common terminal to the input and output terminals.

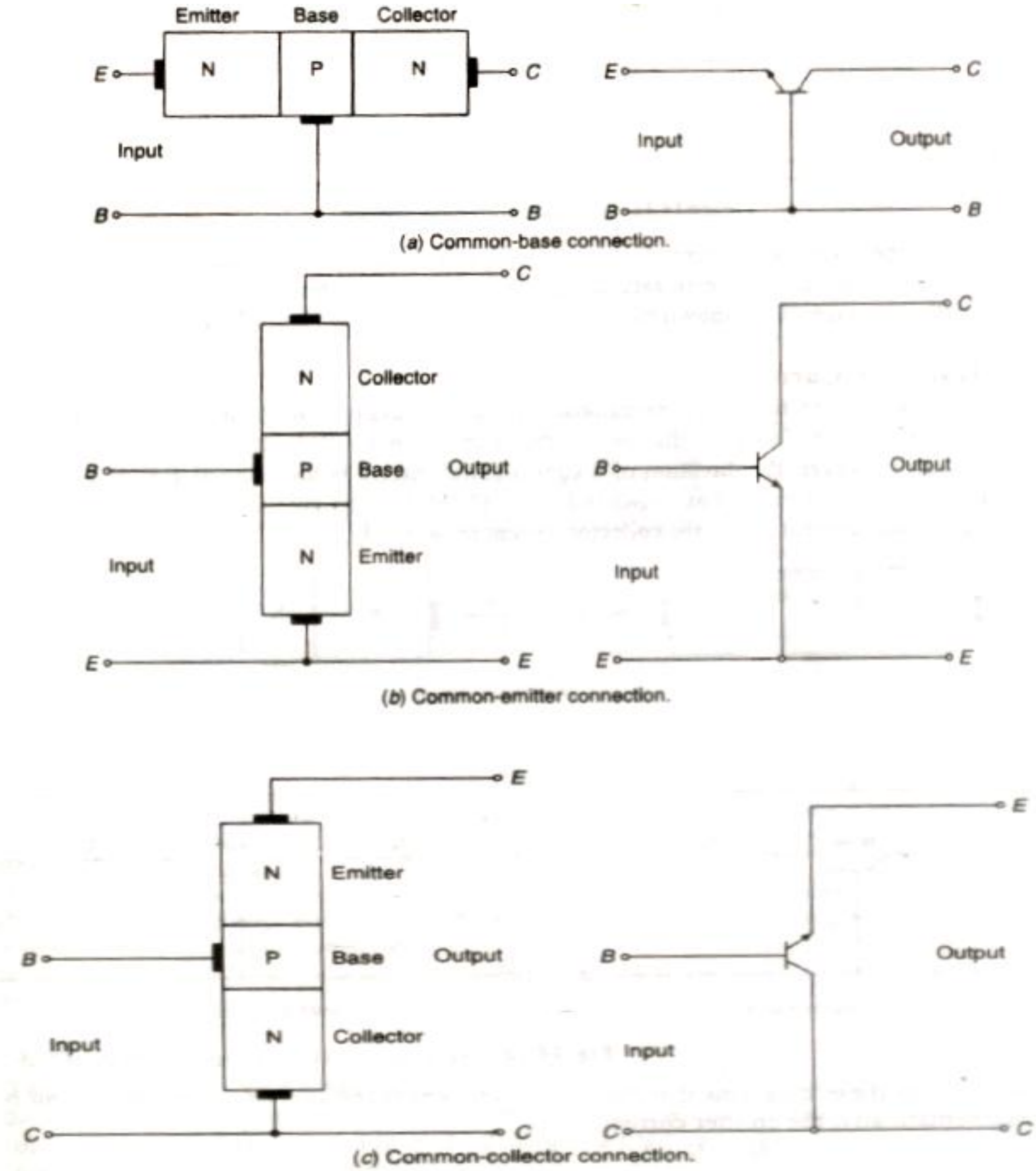


Fig. 2.5 Transistor Circuit Configurations

- Depending upon the terminals, which are used as a common terminal, the transistors can be connected in the following three different connections or configurations.
    - Common Base (CB) connection.
    - Common Emitter (CE) connection
    - Common Collector (CC) connection

Note:

- Regardless of circuit configuration, the base emitter junction is always forward biased while the collector base is always reverse biased to operate the transistor in active region.

2.5 Common Base Configuration

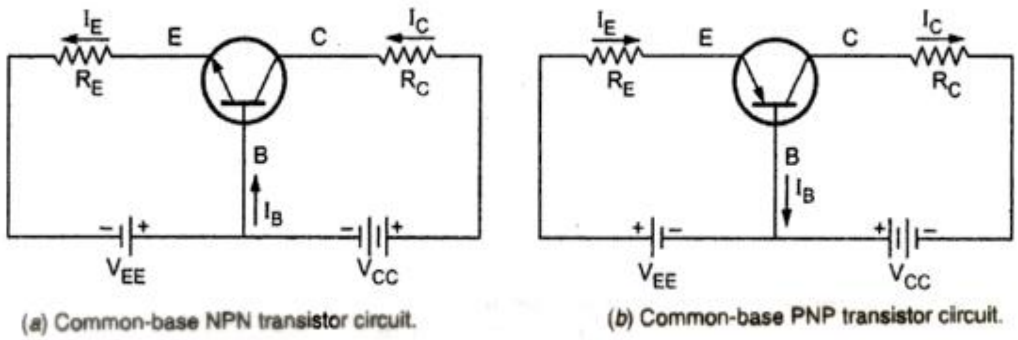


Fig. 2.6 Common Base Configuration

- Consider a transistor (either NPN or PNP) in a common base configuration as shown in Fig. 2.6 (a) or (b).
- Here the emitter current is the input current and collector current is the output current.
- The ratio of the transistor output current to the input current is called current gain of a transistor.
- Since the input current and output current may be either direct current or alternating current.
- Therefore we define two types of current gains namely d.c current gain and a.c current gain.

2.5.1 Common base d.c current gain (α)

- It is defined as the ratio of collector current (I_C) to emitter current (I_E) and is usually designated by α, α_{DC} or h_{FB}
- Mathematically, the common base d.c current gain,

$$\boxed{\alpha = \frac{I_C}{I_E}}$$

- In a transistor, the collector current is always less than the emitter current.
- Therefore current gain of a transistor in common base configuration is always less than unity.

2.5.2 Common base a.c current gain (α_0)

- It is defined as the ratio of small change in collector current (ΔI_C) to a small change in emitter current (ΔI_E) for a constant collector to base voltage (V_{CB}).
- It is designated by α_0, α_{ac} or h_{fb}.
- Mathematically, the common base a.c current gain

$$\boxed{\alpha_0 = \frac{\Delta I_C}{\Delta I_E}}$$

2.5.3 Current relations in Common Base configuration

- Hence the total collector current,

$$I_C = \alpha\, I_E + I_{CO}$$

- The above relation gives us a more accurate definition of common base current gain (α) of a transistor.

$$\alpha = \frac{I_C - I_{CO}}{I_E}$$

- Substituting the value of $I_E = I_B + I_C$ in this equation,

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

$$I_C = \alpha\,(I_B + I_C) + I_{CO}$$

$$= \alpha \cdot I_B + \alpha \cdot I_C + I_{CO}$$

$$(1-\alpha)\, I_C = \alpha \cdot I_B + I_{CO}$$

$$\boxed{I_C = \frac{\alpha \cdot I_B}{1-\alpha} + \frac{I_{CO}}{1-\alpha}}$$

Example *In a common-base connection, the emitter current is 6.28 mA and the collector current is 6.20 mA. Determine the common-base d.c. current gain.*

Solution. Given: $I_E = 6.28$ mA and $I_C = 6.20$ mA.

We know that common-base d.c. current gain,

$$\alpha = \frac{I_C}{I_E} = \frac{6.20}{6.28} = 0.987 \textbf{ Ans.}$$

Example *The common-base d.c. current gain of a transistor is 0.967. If the emitter current is 10 mA, what is the value of base current?*

Solution. Given: $\alpha = 0.967$ and $I_E = 10$ mA.

We know that common-base d.c. current gain (α),

$$0.967 = \frac{I_C}{I_E} = \frac{I_C}{10}$$

$$\therefore \quad I_C = 0.967 \times 10 = 9.67 \text{ mA}$$

We also know that emitter current (I_E),

$$10 = I_B + I_C = I_B + 9.67$$

$$\therefore \quad I_B = 10 - 9.67 = 0.33 \text{ mA } \textbf{Ans.}$$

2.5.4 Input and Output Characteristics of a Transistor in a Common Base Configuration

- Following are two important characteristics of a transistor in a common base (CB) configuration.
  - **Input characteristics**
    - These curves give the relationship between the emitter current (I_E) and the emitter to base voltage (V_{EB}) for a constant collector to base voltage (V_{CB}).

- **Output characteristics.**
    - These curves give the relationship between the collector current (I_C) and the collector to base voltage (V_{CB}) for a constant emitter current (I_E).

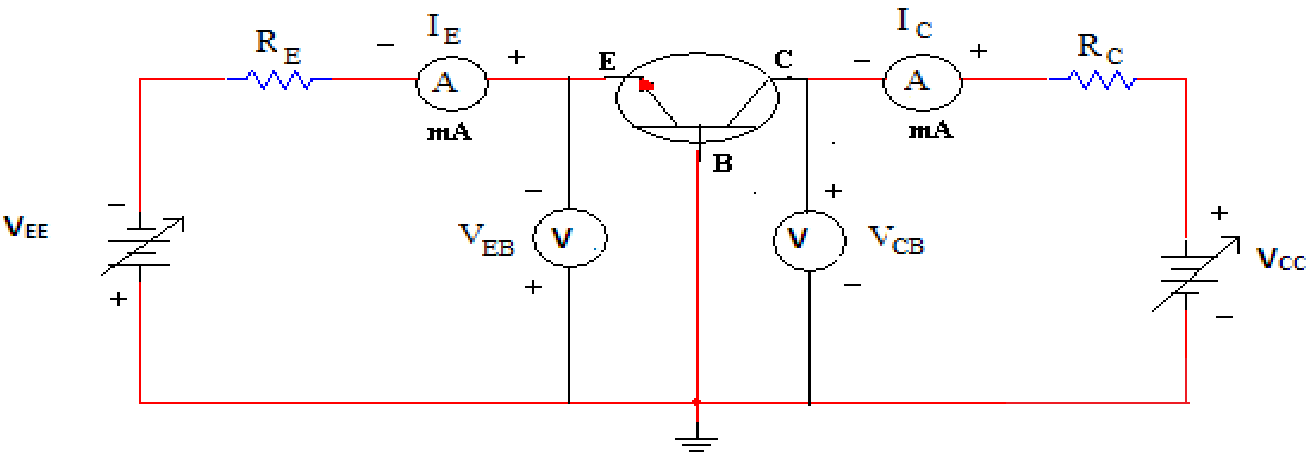


Fig. 2.7 Circuit arrangement for determining common base transistor characteristics

- In this circuit, the NPN transistor is connected in a common-base configuration.
- The d.c milli ammeters and d.c voltmeters are connected in the emitter and collector circuits of a transistor to measure the currents and voltages.

2.5.4.1 Input Characteristics of a Transistor in Common Base Configuration

- These curves may be obtained by using the circuit arrangement as shown in Fig. 2.7.
- First of all, vary the collector to base voltage (V_{CB}) to 1 V.

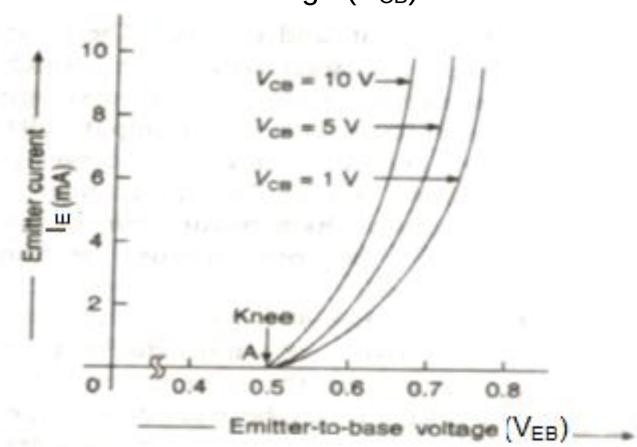


Fig. 2.8 Input characteristics of a common base transistor

- Then increase the emitter to base voltage (V_{EB}) in small suitable steps (i e., of the order of 0.1 V) and record the corresponding values of emitter current (I_E) at each step.
- Now, if we plot a graph with emitter to base voltage (V_{EB}) along the horizontal axis and the emitter current (I_E) along the vertical axis, we shall obtain a curve marked V_{CB} = 1 V as shown in Fig.2.8.
- A similar procedure may be used to obtain curves at different collector to base voltage 5 V and 10 V as shown in the figure 2.8.

- From the input characteristics the following important points are derived.
  - Up to region OA, the emitter current is negligibly small.
  - Beyond the point A, for a fixed collector to base voltage the emitter current (I_E) increases rapidly with a small increase in emitter to base voltage (V_{EB}).
  - The input characteristic may be used to determine the value of a.c input resistance.
  - Its value at any point on the curve is given by the ratio of a change in emitter to base voltage (ΔV_{EB}) to the resulting change in emitter current (ΔI_E) for a constant collector to base voltage (V_{CB}).
  - Mathematically the a.c input resistance,

$$\boxed{R_i = \frac{\Delta V_{EB}}{\Delta I_E}}$$

2.5.4.1.1 Base Width Modulation (or) Early Effect

- When reverse bias voltage V_{CB} increases, the width of depletion region also increases, which reduces the electrical base width.

2.5.4.2 Output Characteristics of a Transistor in Common Base Configuration

- These characteristics may be obtained by using the circuit shown in Fig. 2.7.

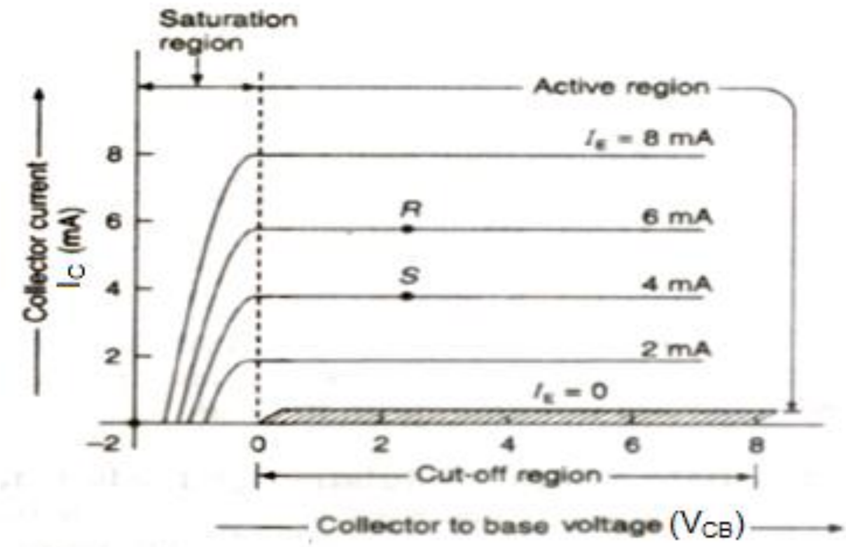


Fig. 2.9 Output characteristics of a common base transistor

- First of all, vary the emitter to base voltage (V_{EB}) to get a suitable value of emitter current (I_E) say 2 mA.
- Keeping the emitter current (I_E)constant, we increase the collector to base voltage (V_{CB}) from zero in a number of suitable steps and record the corresponding values of the collector current (I_C) at each Step.
- If we plot a graph with collector to base voltage (V_{CB}) along the horizontal axis and the collector current (I_C) along the vertical axis, we shall obtain a curve marked I_E = 2 mA as shown in Fig. 2.9.

- A similar procedure may be used to obtain the characteristics at different values of emitter current *i.e.,* I_E = 4, 6, and 8 mA.
- From the output characteristics the following important points are derived.
    - The curve may be divided into three important regions namely saturation region, active region and cut off region.

    Saturation Region

        - The saturation region is the region to the left of the vertical dashed line.
        - It may be noted that in this region, collector to base voltage (V_{CB}) is negative for a NPN transistor.
        - In this region, a small change in V_{CB} results in a large value of collector current.

    Active Region

        - The active region is the region between the vertical dashed line and the horizontal axis.
        - In the active region, the collector current is constant and is equal to the emitter current.

    Cut off Region

        - The cut off region is the region along the horizontal axis as shown by a shaded region in the figure. It corresponds to the curve marked I_E = 0.
        - The collector current flows even when the collector to base voltage (V_{CB}) is zero.
        - A small collector current flows even when emitter current (I_E) is zero.
- The collector current is practically independent of collector to base voltage (V_{CB}) in the active region.
- The output characteristic may be used to determine the value of a.c. output resistance.
- Its value at any point is given by the ratio of a change in collector to base voltage (ΔV_{CB}) to the resulting change in collector current (ΔI_C) for a constant emitter current (I_E)
- Mathematically, the a.c output resistance,

$$\boxed{R_o = \frac{\Delta V_{CB}}{\Delta I_C}}$$

2.6 Common Emitter Configuration

- Consider a transistor (either NPN or PNP) in a common emitter configuration as shown in Figure 2.10 (a) and (b).
- Here, the base current is the input current and the collector current is the output current.
- The current gain is the ratio of collector current to the base current.
- Since the base current and collector current may be direct or alternating current.
- Therefore we define two types of current gains namely d.c current gain and a.c current gains.

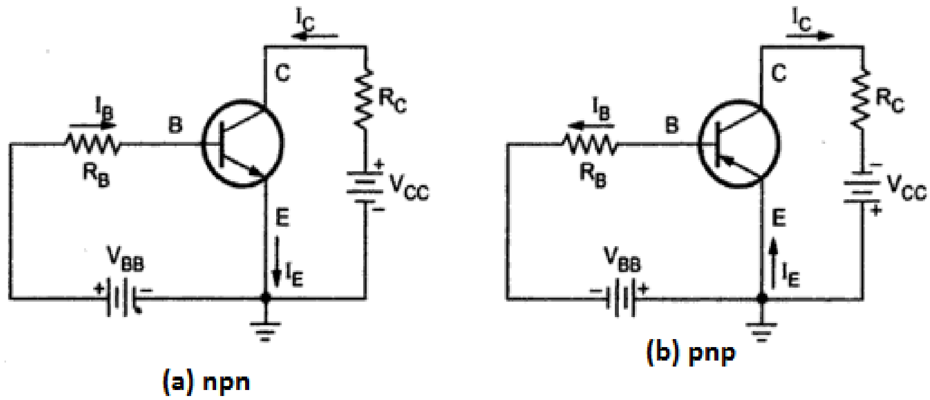


Fig. 2.10 Common Emitter Configuration

2.6.1 Common emitter d.c current gain (β)

- It is defined as the ratio of collector current (I_C) to base current (I_B) and is usually designated by β, β_{DC} or h_{FE}
- Mathematically, the common base d.c current gain,

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

- Collector current of a transistor is much larger than the base current.
- Therefore current gain β is always greater than unity.

2.6.2 Common emitter a.c current gain (β_0)

- It is defined as the ratio of small change in collector current (ΔI_C) to a small change in base current (ΔI_B) for a constant collector to emitter voltage (V_{CE}).
- It is designated by β, β_{ac} or $h_{fe.}$
- Mathematically, the common emitter a.c current gain

$$\boxed{\beta_0 = \frac{\Delta I_C}{\Delta I_B}}$$

2.6.3 Relation between current gain α and β

- We know that emitter current (I_E) of a transistor is the sum of its base current (I_B) and collector current (I_C).

$$I_E = I_B + I_C$$

- Dividing the above equation on both sides by I_C,

$$\frac{I_E}{I_C} = \frac{I_B}{I_C} + 1$$

- We have $I_C / I_E = \alpha$, $I_C / I_B = \beta$ and apply it in above equation

$$\frac{1}{\alpha} = \frac{1}{\beta} + 1 = \frac{1+\beta}{\beta}$$

$$\alpha = \frac{\beta}{\beta + 1}$$

- The above expression may be written as

$$\alpha(\beta+1) = \beta$$
$$\alpha \cdot \beta + \alpha = \beta$$
$$\alpha = \beta - \alpha \cdot \beta$$
$$= \beta(1-\alpha)$$
$$\boxed{\beta = \frac{\alpha}{1-\alpha}}$$

2.6.4 Current relations in Common emitter configuration

- The total leakage current flowing through the transistor with base open is given by

$$I_{CEO} = I_{CO} + \beta . I_{CO} = (1+\beta)\, I_{CO}$$

- The total collector current in a transistor consists of the injected current (βI_B) and the leakage current (I_{CEO}).
- Thus the total collector current is given by

$$\boxed{I_C = \beta I_B + I_{CEO} = \beta I_B + (1+\beta)\, I_{CO}}$$

Example *(a) A transistor has an α of 0.975. What is the value of β; (b) if β = 200, what is the value of α?*

Solution. Given: $\alpha = 0.975$ and $\beta = 200$

Value of β when α is 0.975

We know that

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.975}{1-0.975} = 39 \text{ Ans.}$$

Value of α when β is 200

We also know that

$$\alpha = \frac{\beta}{\beta+1} = \frac{200}{200+1} = 0.995 \text{ Ans.}$$

Example *A transistor has a typical β of 100. If the collector is 40 mA, what is the value of emitter current?*

Solution. Given: $\beta = 100$ and $I_C = 40$ mA.

We know that (β),
$$100 = \frac{I_C}{I_B} = \frac{40}{I_B}$$

$\therefore$
$$I_B = 40/100 = 0.4 \text{ mA}$$

and the emitter current,

$$I_E = I_B + I_C = 0.4 + 40 = 40.4 \text{ mA Ans.}$$

Example *A germanium transistor used in a complementary symmetry amplifier has a collector cut-off current I_{CBO} = 10 μA at a temperature of 27°C and h_{FE} = 50.*

(a) *What is the collector current, when the base current is 0.25 mA?*

(b) *Assuming h_{FE} does not increase with temperature, what would be the value of new collector current, if the transistor's temperature rises to 50°C?*

Solution. Given: $I_{CBO} = 10\ \mu A = 10 \times 10^{-6}$ A and $h_{FE}\ (= \beta) = 50$

(a) *Value of collector current when I_B = 0.25 mA (0.25 × 10^{-3} A)*

We know that collector current,

$$I_C = \beta\, I_B + (1+\beta)\, I_{CBO}$$
$$= 50 \times (0.25 \times 10^{-3}) + (1+50) \times (10 \times 10^{-6}) \text{ A}$$
$$= 13.01 \times 10^{-3} \text{ A} = 13.01 \text{ mA } \textbf{Ans.}$$

(b) *Value of new collector current if temperature rises to* 50°C

We also know that I_{CBO} doubles for every 10°C rise in temperature. Thus I_{CBO} at 50°C,

$$I_{CBO50} = I_{CBO} \times 2^{(T_2 - T_1)/10} = 10 \times 2^{(50-27)/10}\ \mu\text{A}$$
$$= 10 \times 2^{2.3} = 49.2\ \mu\text{A} = 49.2 \times 10^{-6} \text{ A}$$

∴ Collector current at 50°C,

$$I_C = \beta \cdot I_B + (1+\beta)\, I'_{CBO}$$
$$= 50 \times (0.25 \times 10^{-3}) + (1+50) \times 49.2 \times 10^{-6} \text{ A}$$
$$= 15.01 \times 10^{-3} \text{ A} = 15.01 \text{ mA } \textbf{Ans.}$$

2.6.5 Input and Output Characteristics of a Transistor in a Common Emitter Configuration

- Following are two important characteristics of a transistor in a common Emitter (CE) configuration.
  - **Input characteristics**
    - These curves give the relationship between the base current (I_B) and the base to emitter voltage (V_{BE}) for a constant collector to emitter voltage (V_{CE}).
  - **Output characteristics**
    - These curves give the relationship between the collector current (I_C) and the collector to emitter voltage (V_{CE}) for a constant base current (I_B).

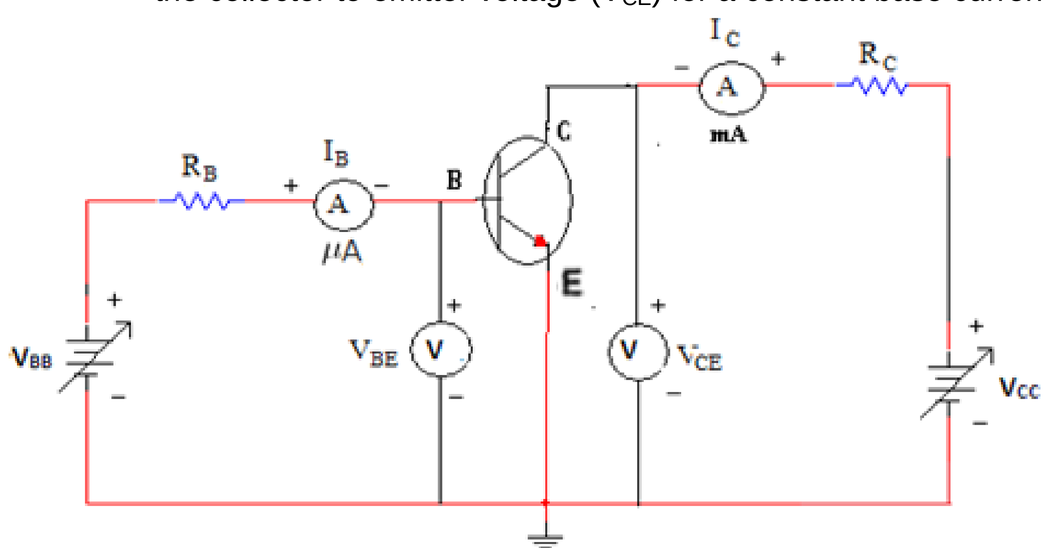


Fig. 2.11 Circuit arrangement for determining common base transistor characteristics

- In this circuit, the NPN transistor is connected in a common emitter configuration.
- The d.c milli ammeters and d.c voltmeters are connected in the base and collector circuits of a transistor to measure the voltages and currents.

2.6.5.1 Input Characteristics of a Transistor in Common Emitter Configuration

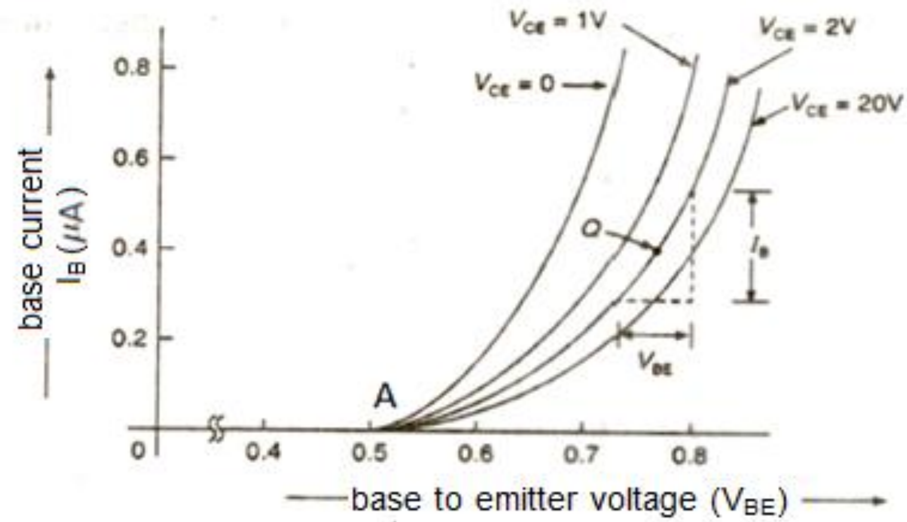


Fig. 2.12 Input characteristics of a common emitter transistor

- These curves may be obtained by using the circuit arrangement as shown in Fig. 2.11.
- First of all, vary the collector to emitter voltage (V_{CE}) to one volt.
- Then increase the base to emitter voltage (V_{BE}) in small suitable steps (i e., of the order of 0.1 V) and record the corresponding values of base current (I_B) at each step.
- Now, if we plot a graph with base to emitter voltage (V_{BE}) along the horizontal axis and the base current (I_B) along the vertical axis, we shall obtain a curve marked V_{CE} = 1 V as shown in Fig.2.12.
- A similar procedure may be used to obtain curves at different collector to emitter voltage 2 V and 20V as shown in the figure 2.12.
- From the input characteristics the following important points are derived.
  - Up to region OA, the base current is negligibly small.
  - Beyond the point A, for a fixed collector to emitter voltage the base current (I_B) increases rapidly with a small increase in base to emitter voltage (V_{BE}).
  - The input characteristic may be used to determine the value of a.c input resistance.
  - Its value at any point on the curve is given by the ratio of a change in base to emitter voltage (ΔV_{BE}) to the resulting change in base current (ΔI_B) for a constant collector to emitter voltage (V_{CE}).
  - Mathematically the a.c input resistance,

$$\boxed{R_i = \frac{\Delta V_{BE}}{\Delta I_B}}$$

2.6.5.2 Output Characteristics of a Transistor in Common Emitter Configuration

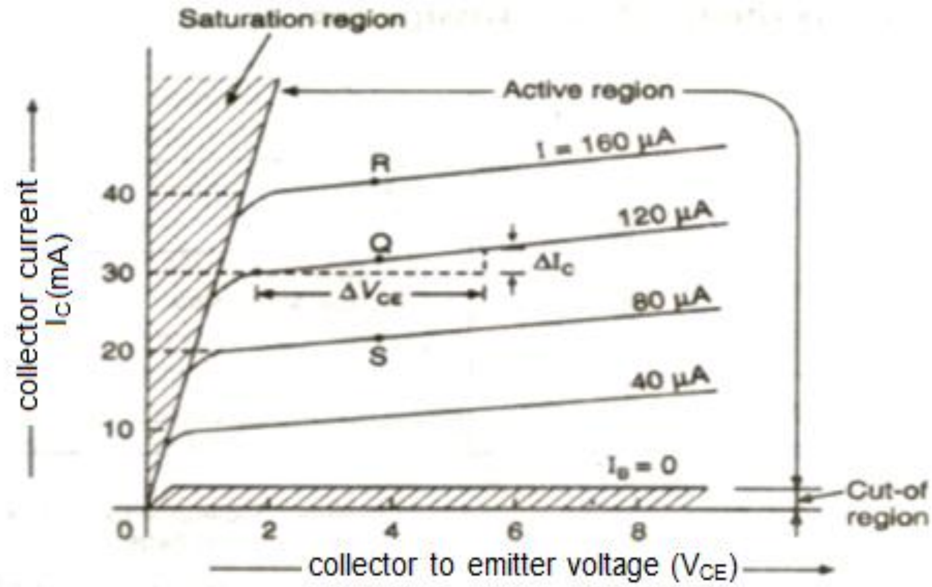


Fig. 2.13 Output characteristics of a common emitter transistor

- These characteristics may be obtained by using the circuit shown in Fig. 2.11.
- First of all, vary the base to emitter voltage (V_{BE}) to get a suitable value of base current (I_E) say 40 μA.
- Keeping the base current constant, we increase the collector to emitter voltage (V_{CE}) from zero in a number of suitable steps and record the corresponding values of the collector current (I_C) at each Step.
- If we plot a graph with collector to emitter voltage (V_{CE}) along the horizontal axis and the collector current (I_C) along the vertical axis, we shall obtain a curve marked I_B = 40 μA as shown in Fig. 2.13.
- A similar procedure may be used to obtain the characteristics at different values of emitter current *i.e.,* I_B = 80, 120 and 160 μA.
- From the output characteristics the following important points are derived.
  - The output characteristics may be divided into three important regions namely saturation region, active region and cut-off region.
  - The saturation and cut-off regions are shown by the shaded areas, while the active region is the region between the saturation and cut off region.
  - As the collector to emitter voltage (V_{CE}) is increased above zero, the collector current (I_C) increases rapidly to a saturation value, depending upon the value of base current.
  - When collector to emitter voltage (V_{CE}) is increased further, the collector current I_C slightly increases.
  - The collector current (I_C) is zero, when the base current (I_B) is zero. Under this condition the transistor is said to be cut off.
  - The characteristic may be used to determine the common emitter transistor a.c output resistance.

➢ Its value at any given operating point *Q* is given by the ratio of a change in collector to emitter voltage (ΔV_{CE}) to the resulting change in collector current (ΔI_C) for a constant base current.

➢ Mathematically, the a.c output resistance,

$$\boxed{R_o = \frac{\Delta V_{CE}}{\Delta I_C}}$$

2.7 Common Collector Configuration

- The Fig. 2.14 shows the common collector configuration.

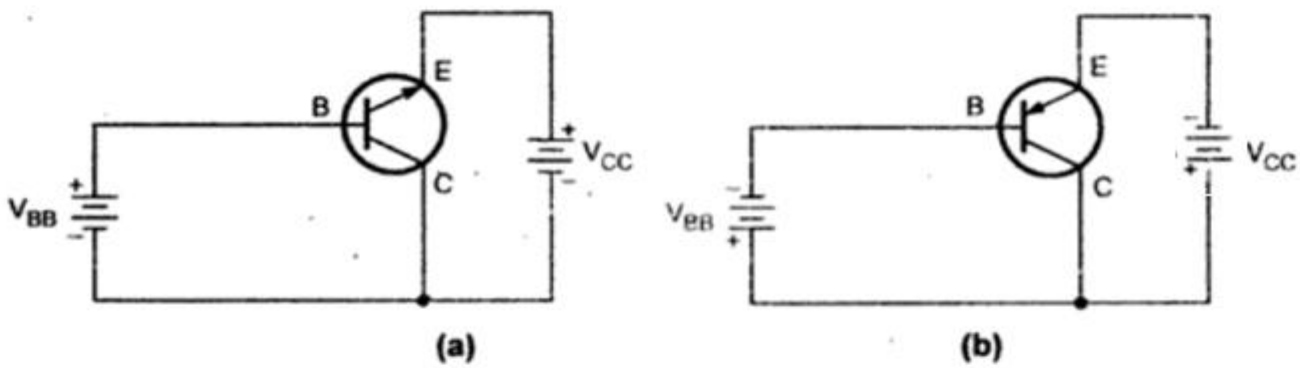


Fig. 2.14 Common collector configurations

- In this configuration input is applied between base and collector, and output is taken from emitter and collector.
- Here, collector of the transistor is common to both input and output circuits, and hence the name common collector configuration.
- Common collector connections for both n-p-n and p-n-p transistors are shown in Fig. 2.14 (a) and (b) respectively.

2.7.1 Common collector d.c current gain (ϒ)

- It is defined as the ratio of emitter current (I_E) to base current (I_B) and is usually designated by ϒ, $ϒ_{DC}$ or h_{FC}
- Mathematically, the common current d.c current gain,

$$\boxed{\gamma = \frac{I_E}{I_B}}$$

- Emitter current of a transistor is much larger than the base current.
- Therefore current gain ϒ is always greater than unity.

2.7.2 Common collector a.c current gain ($ϒ_0$)

- It is defined as the ratio of small change in emitter current (ΔI_E) to a small change in base current (ΔI_B) for a constant collector to emitter voltage (V_{CE}).
- It is designated by ϒ, $ϒ_{ac}$ or $h_{fc.}$

- Mathematically, the common collector a.c current gain

$$\boxed{\gamma_0 = \frac{\Delta I_E}{\Delta I_B}}$$

2.7.3 Current Relations in CC Configuration

- In CC configuration, I_B is the input current and the I_E is the output current.
- Now I want to relate the output current I_E with the input current I_B.
- We have $I_E = I_B + I_C$ --- (1)
- Also we have, $I_C = \alpha I_E + I_{CBO}$ and apply this I_C value in equation (1)

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

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

$$I_E = \frac{1}{1-\alpha_{dc}} I_B + \frac{1}{1-\alpha_{dc}} I_{CBO} \qquad \text{... (2)}$$

- We have $\beta_{dc} = \alpha_{dc} / 1\text{-}\alpha_{dc}$
- Add 1 to both the sides of above equation

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

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

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

- Apply the above value in equation (2), we get

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

- Neglect the leakage current I_{CBO} then

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

$$\boxed{\frac{I_E}{I_B} = (1 + \beta_{dc})} \qquad \text{... (3)}$$

- From the above equation we conclude that, current gains of CE and CC are nearly same.

Example : *If $\beta = 100$, $I_{CBO} = 10\ \mu A$ and $I_B = 80\ \mu A$. Find I_E.*

Solution : We know that,

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

$$= (1+100) \times 80 \times 10^{-6} + (1+100) \times 10 \times 10^{-6}$$

$$= \mathbf{9.09\ mA}$$

Example : *If $\alpha = 0.98$, $I_{CBO} = 10\ \mu A$ and $I_B = 100\ \mu A$. Find I_E.*

Solution : We know that, $\beta = \dfrac{\alpha}{1-\alpha}$

$$\therefore \quad \beta = \frac{0.98}{1-0.98} = 49$$

Current I_E can be given as,

$$I_E = (1+\beta)\, I_B + (1+\beta)\, I_{CBO}$$

$$= (1+49) \times 100 \times 10^{-6} + (1+49) \times 10 \times 10^{-6} = 5.5\ \text{mA}$$

2.7.4 Input and Output Characteristics of a Transistor in a Common Collector Configuration

- Following are two important characteristics of a transistor in a common Collector (CC) configuration.
  - **Input characteristics**
    - These curves give the relationship between the base current (I_B) and the base to collector voltage (V_{BC}) for a constant emitter to collector voltage (V_{EC}).
  - **Output characteristics**
    - These curves give the relationship between the emitter current (I_E) and the emitter to collector voltage (V_{EC}) for a constant base current (I_B).

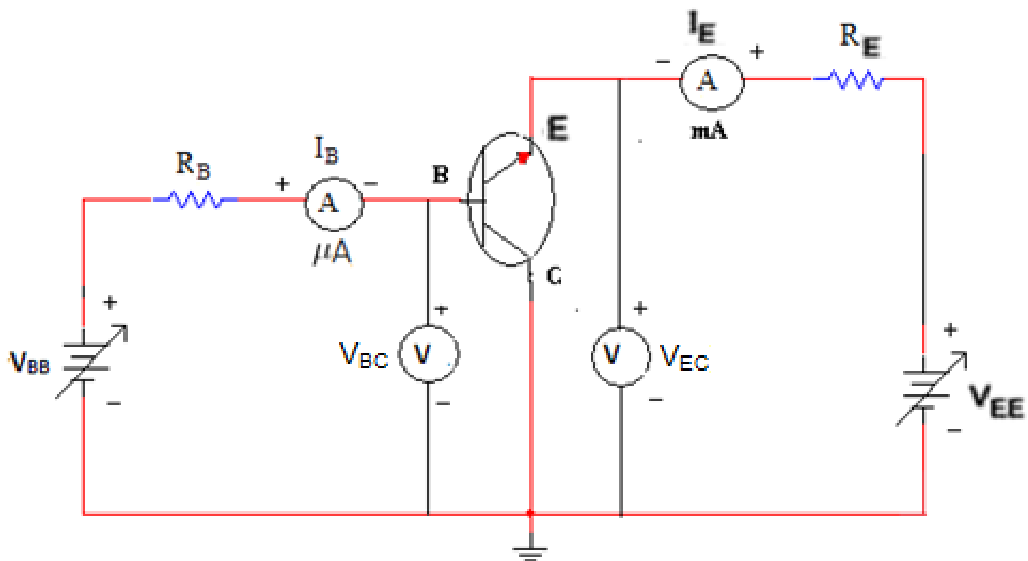


Fig. 2.15 Circuit arrangement for determining common collector transistor characteristics

2.7.4.1 Input Characteristics of a Common Collector Configuration

- It is the graph of input current I_B versus input voltage V_{BC} at constant V_{EC}.
- The base current is taken along Y-axis and collector base voltage V_{BC} is taken along X-axis.
- Fig. 2.16 shows the input characteristics of a typical transistor in common collector configuration.

- The common collector input characteristics are quite different from either common base or common emitter input characteristics.
- This difference is due to the fact that the input voltage V_{BC} is largely determined by the level of emitter to collector voltage V_{EC}.

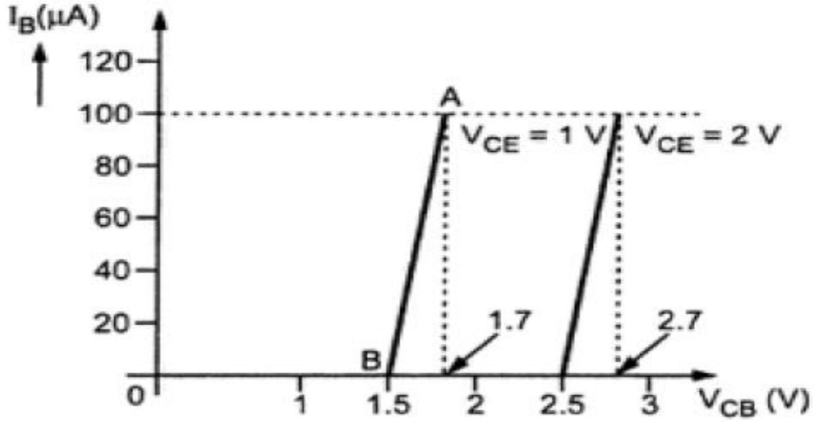


Fig. 2.16 Input characteristics of transistor in CC configuration

2.7.4.2 Output Characteristics of a Common Collector Configuration

- It is the curve between emitter current I_E and collector to emitter voltage V_{CE} at constant base current I_B.
- The emitter current is taken along Y-axis and collector to emitter voltage along X-axis.
- Fig. 2.17 shows the output characteristics of a typical transistor in common collector configuration.

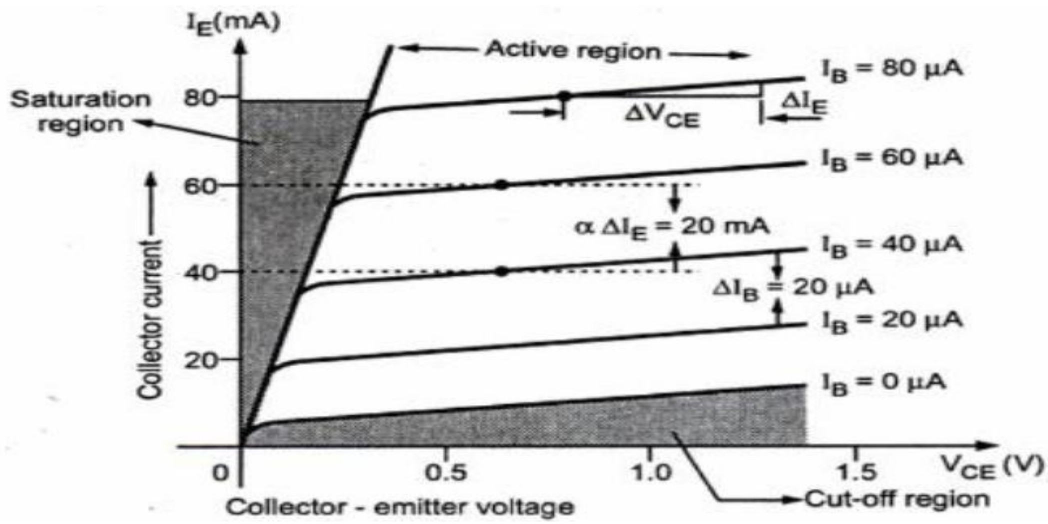


Fig. 2.17 Output characteristics of the transistor In CC configuration

- Since, I_C is approximately equal to I_E, the common collector output characteristics are practically similar to those of the common emitter output characteristics.

Example : *In a certain n-p-n common-collector circuit, V_E = 4.4 V, V_{CE} = 6 V and V_{CC} = 12 V. Determine V_C and V_B.*

Solution : Fig. shows common collector circuit.

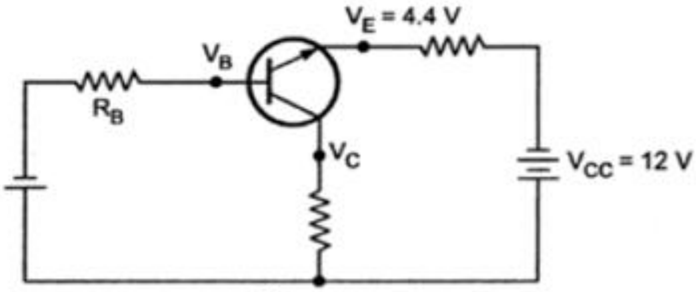


Fig.

$$V_B = V_E + 0.7\,V = 4.4 + 0.7\,V$$
$$= 5.1\,V$$
$$V_C = V_{CC} - V_E - V_{CE}$$
$$= 12 - 4.4 - 6\,V = 1.6\,V$$

2.8 Why CE Configuration is widely used in Amplifier Circuits?

- The CE configuration is the only configuration which provides both voltage gain as well as current gain greater than unity.
- In a common emitter circuit, the ratio of output resistance to input resistance is small, may range from 10 Ω to 100 Ω. This makes configuration an ideal for coupling between various transistor stages.

2.9 Comparison of Transistor Configurations

Sr. No.	Characteristic	Common Base	Common Emitter	Common Collector
1.	Input resistance (R_i)	Very low (20 Ω)	Low (1 kΩ)	High (500 kΩ)
2.	Output resistance (R_o)	Very high (1 MΩ)	High (40 kΩ)	Low (50 Ω)
3.	Input current	I_E	I_B	I_B
4.	Output current	I_C	I_C	I_E
5.	Input voltage applied between	Emitter and Base	Base and Emitter	Base and Collector
6.	Output voltage taken between	Collector and Base	Collector and Emitter	Emitter and Collector
7.	Current amplification factor	$\alpha_{dc} = \frac{I_C}{I_E}$	$\beta_{dc} = \frac{I_C}{I_B}$	$\frac{I_E}{I_B}$
8.	Current gain (A_i)	Less than unity	High (20 to few hundreds)	High (20 to few hundreds)
9.	Voltage gain (A_v)	Medium	Medium	Less than unity
10.	Applications	As a input stage of multistage amplifier	For audio signal amplification	For impedance matching

2.10 Biasing

- In order to operate transistor in the desired region we have to apply external d.c voltages of correct polarity and magnitude to the two junctions of the transistor. This is known as biasing of the transistor.
- The d.c voltages are used to bias the transistor.

2.10.1 Need for Biasing

- To operate the transistor in the desired region.
- To get the output signal power always greater than input signal power.

2.11 Operating point or Quiescent point

- A point which establish a certain current and voltage conditions, while biasing a transistor.
- The operating point must be stable for proper operation of the transistor.
- However, the operating point shifts with changes in transistor parameters such as β, I_{CO} and V_{BE}.
- As transistor parameters are temperature dependent, the operating point also varies with changes in temperature.

2.11.1 Selection of Operating Point

- The operating point can be selected at three different positions on the dc load line: near saturation region, near cut-off region or at the center, i.e. in the active region.
- The selection of operating point will depend on its application.
- When transistor is used as an amplifier, the Q point should be selected at the center of the dc load line to prevent any possible distortion in the amplified output Signal.
- This is well understood by going through following cases.

2.11.1.1 Case 1: Operating point near saturation region

- Biasing circuit is designed to fix a Q-point at point P which is very near to the saturation region is shown in Fig. 2.18.

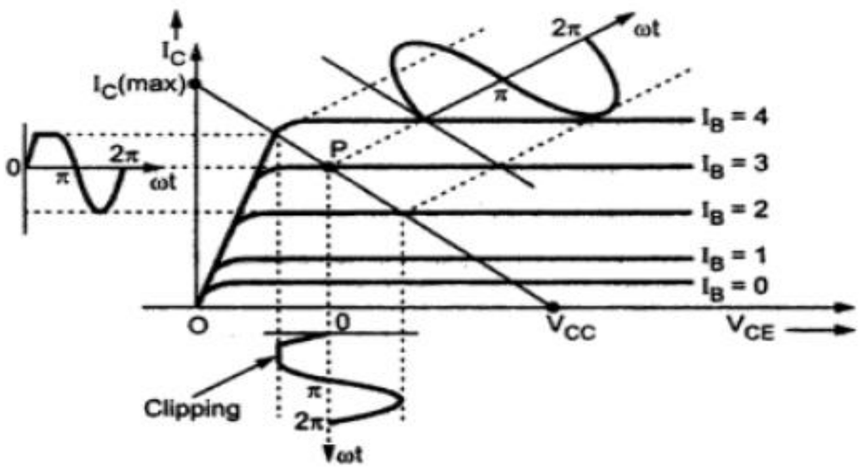


Fig. 2.18 Operating point near saturation region gives clipping at the positive peaks

- Collector current is clipped at the positive half cycle.
- Therefore, point P is not a suitable operating point.

2.11.1.2 Case 2: Operating point near cut-off region

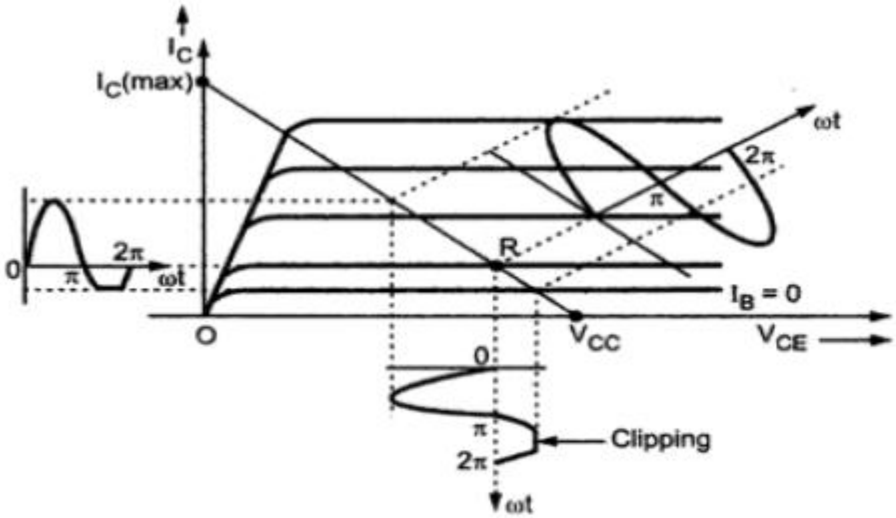


Fig. 2.19 Operating point near cut-off region gives clipping at the negative peaks

- Biasing circuit is designed to fix a Q-point at point R which is very near to the cut-off region is shown in Fig. 2.19.
- The collector current is clipped at the negative half cycle.
- So, point R is also not a suitable operating point.

2.11.1.3 Case 3: Operating point at the centre of the active region

- Biasing circuit is designed to fix a Q-point at point Q as shown in Fig. 2.20.
- The output signal is sinusoidal waveform without any distortion.
- Thus point Q is the best operating point.

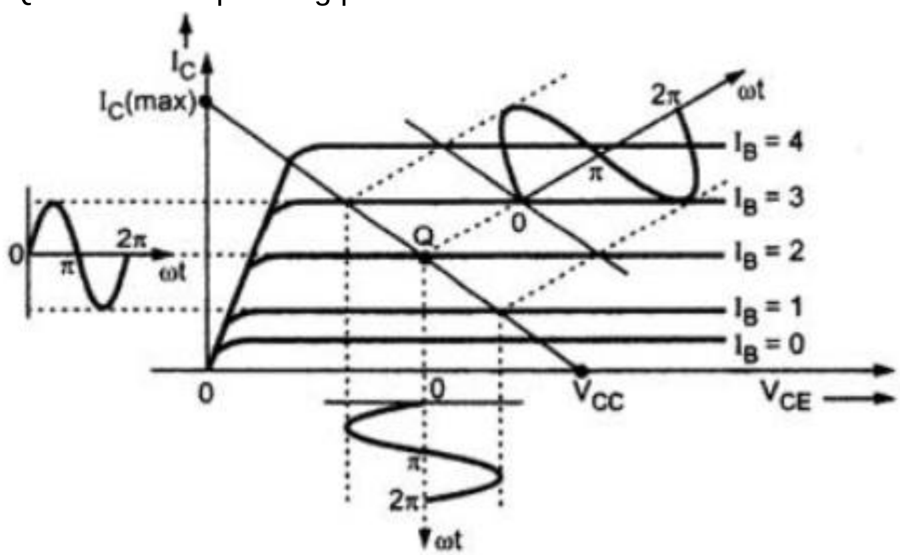


Fig. 2.20 Operating point at the centre of the active region is most suitable

2.12 DC Load line

- The line drawn between two points I_C and V_{CE} is called as DC load line.
- Consider a common emitter circuit shown in the Fig. 2.21.
- The transistor in the Fig.2.21 is biased with a common supply such that the base emitter junction is forward biased and the collector base junction is reverse biased.

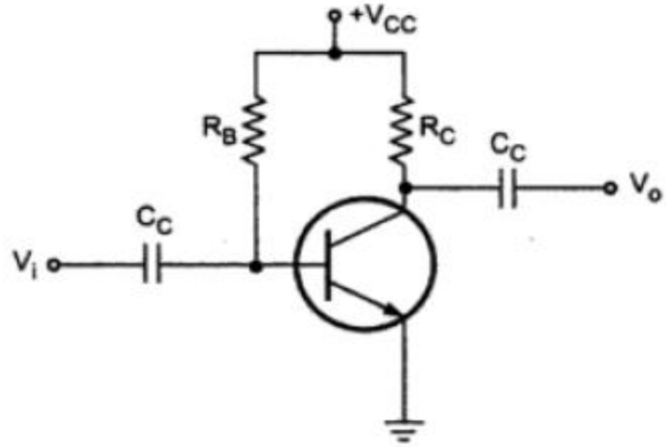


Fig. 2.21 Common emitter amplifier

- Coupling capacitor C_C act as a DC blocking element.
- Input side coupling capacitor C_C couples AC input signal to the base of the transistor.
- Output side coupling capacitor C_C couples AC output signal of the transistor to the load.

2.12.1 DC analysis

- To find dc analysis ac signal is equal to zero and the capacitors are open circuited.
- Therefore, DC equivalent circuit for common emitter amplifier is shown in the Fig. 2.22.

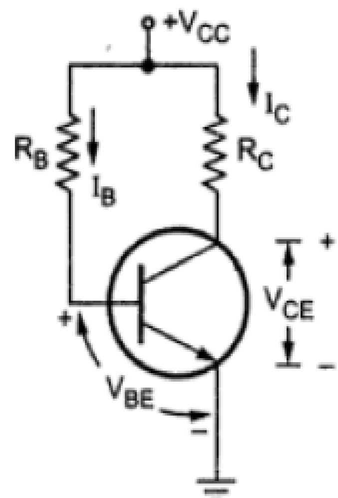


Fig. 2.22 DC equivalent circuit of figure 2.21

- Applying Kirchhoff's voltage law to the base circuit of Fig. 2.22, we get

$$V_{CC} - I_B R_B - V_{BE} = 0$$

$$\therefore \quad \boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B}} \quad \text{---- (1)}$$

As $V_{CC} >> V_{BE}$, $$\boxed{I_B = \frac{V_{CC}}{R_B}}$$

Where

I_B is the base current

- Applying Kirchhoff's voltage law to the collector circuit shown in the Fig. 2.22, we get

$$V_{CC} - I_C R_C - V_{CE} = 0$$

$$V_{CC} = I_C R_C + V_{CE}$$

$$\boxed{V_{CE} = V_{CC} - I_C R_C} \quad \text{---- (2)}$$

$$\boxed{I_C = \frac{V_{CC} - V_{CE}}{R_C}} \quad \text{---- (3)}$$

Where

$I_C R_C$ is the voltage drop across R_C

V_{CE} is the collector to emitter voltage.

- From the above collector current equation, we get

$$\boxed{I_C = \left[-\frac{1}{R_C}\right] V_{CE} + \frac{V_{CC}}{R_C}} \quad \text{---- (4)}$$

- From the equation number 4, we can draw a straight line on the graph of I_C versus V_{CE} which is having slope - $1/R_C$ and Y-intercept V_{CC}/R_C.
- Apply I_C=0 (transistor is in cut off region) in the equation number 4, we get

$$\boxed{V_{CE}=V_{CC}} \text{ (Point A)}$$

- Apply V_{CE}=0 (transistor is in saturation region) in the equation number 4, we get

$$\boxed{I_C=V_{CC}/R_C} \text{ (Point B)}$$

- The Fig. 2.23 shows the output characteristics of a common emitter configuration with DC load line drawn between points A and B.

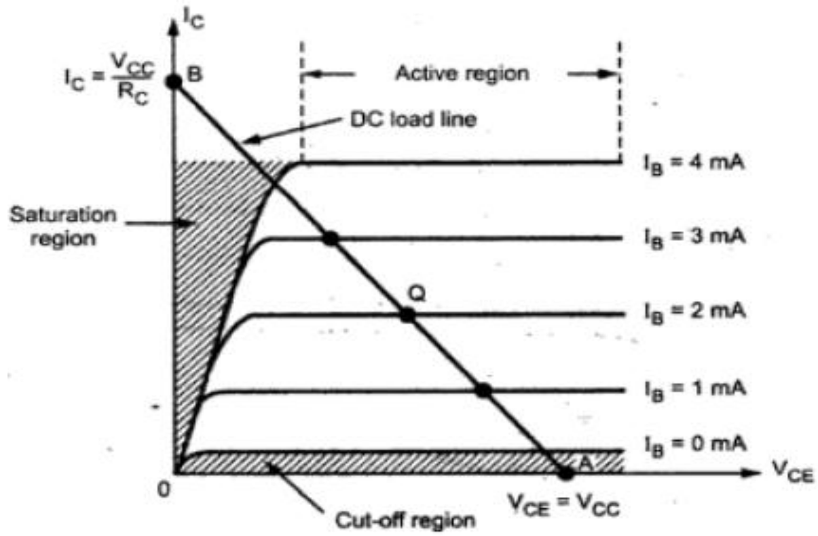


Fig. 2.23 Common emitter output characteristics with dc load line

2.13 A.C. Load Line

- The AC load line is a straight line with a slope equal to the AC impedance facing the nonlinear device.
- Consider a common emitter amplifier circuit as shown III Figure 2.24.

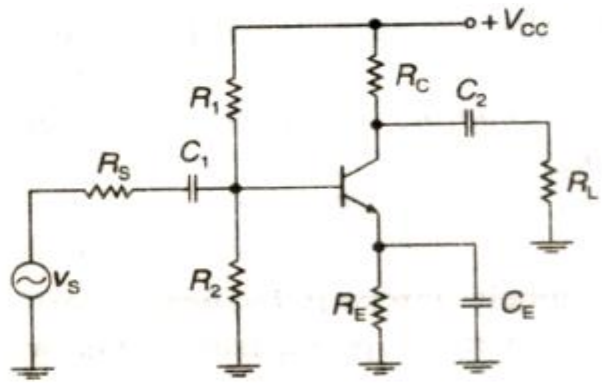


Fig. 2.24 Common emitter amplifier circuit

2.13.1 AC analysis

- To find ac analysis d.c signal is equal to zero and the capacitors are short circuited.
- Figure 2.25 shows the ac equivalent circuit of the common emitter amplifier.

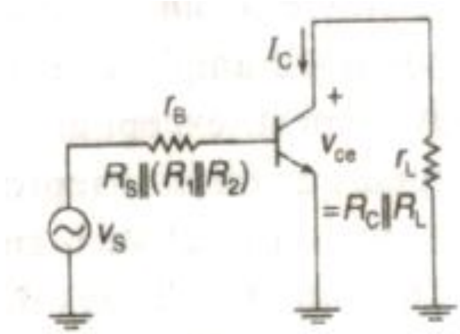


Fig. 2.25 A.C. equivalent of Common emitter amplifier circuit

- From the above figure, the resistance driving the base,

$$r_B = R_S \,||\, (R_1 \,||\, R_2)$$

- a.c. load resistance seen by the collector

$$r_L = R_C \,||\, R_L$$

- Now summing up the voltages around the collector loop of the a.c. equivalent circuit,

$$v_{ce} + i_c \cdot r_L = 0$$

$$i_c = -\frac{v_{ce}}{r_L} \qquad \ldots (i)$$

where i_c = A.C. collector current,

v_{ce} = A.C. collector-to-emitter voltage,

- Now let

I_{CQ} = The d.c. collector current at Q-point

V_{CEQ} = The d.c. collector-emitter voltage at Q-point.

$I_{C\,(sat)}$ = The d.c. saturation current, and

$V_{CE\,(cut\text{-}off)}$ = The d.c. cut-off voltage.

- Then the a.c collector current,

$$i_c = \Delta I_C = I_C - I_{CQ}$$

- The a.c collector-to-emitter voltage

$$v_{ce} = \Delta V_{CE} = V_{CE} - V_{CEQ}$$

- Substituting the values of i_c and v_{ce} in equation (i),

$$I_C - I_{CQ} = -\frac{V_{CE} - V_{CEQ}}{r_L} = -\frac{V_{CE}}{r_L} + \frac{V_{CEQ}}{r_L}$$

$$I_C = I_{CQ} + \frac{V_{CEQ}}{r_L} - \frac{V_{CE}}{r_L} \qquad \ldots (ii)$$

- The above equation is an equation of a straight line called ac load line.
- We know that when the transistor goes into saturation, the collector-to-emitter voltage (V_{CE}) becomes zero.
- In that case, the equation (ii) may be written as

$$\boxed{I_C = I_{CQ} + \frac{V_{CEQ}}{r_L} = I_{C\,(sat)}}$$

- The above expression gives the upper end of the ac load line.
- Similarly, when the transistor goes into cut-off, the collector current (I_C) becomes zero.
- In that case, the equation (ii) may be written as

$$0 = I_{CQ} + \frac{V_{CEQ}}{r_L} - \frac{V_{CE}}{r_L}$$

$$= I_{CQ} + \frac{V_{CEQ}}{r_L} - \frac{V_{CE\,(cut\text{-}off)}}{r_L} \quad \ldots(\because V_{CE} = V_{CE\,(cut\text{-}off)} \text{ at } I_C = 0)$$

$$\boxed{V_{CE\,(cut\text{-}off)} = V_{CEQ} + I_{CQ} \cdot r_L}$$

- The above equation gives us the lower end of ac load line.
- By joining the upper and lower ends, we get a complete ac load line as shown in Figure 2.26.

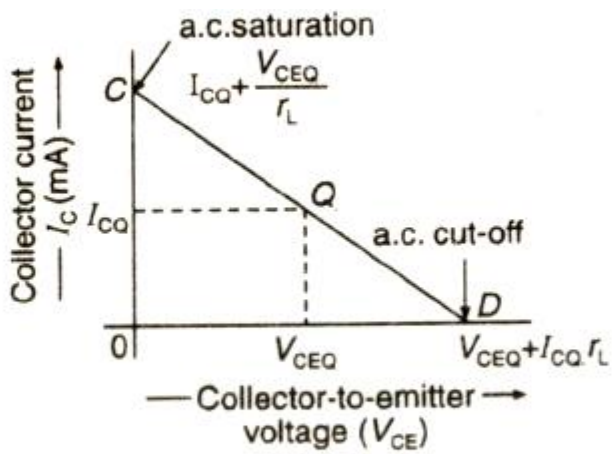


Fig. 2.26 A.C. load line

2.14 BJT Small Signal Model

- A transistor model is a combination of circuit elements, which deals the actual behavior of a transistor under specific operating condition.
- The transistor behavior is different at low frequencies and high frequencies.
- At low frequencies the reactance's of junction capacitances of the transistor are very high and can be ignored.
- But this is not the case at high frequencies.
- Therefore, we use different transistor models to analyze the transistor at low and high frequencies. At low frequencies we use hybrid equivalent model and at high frequencies we use hybrid π model.

2.15 BJT Hybrid model (or) h parameter model

- The equivalent circuit of a transistor can be drawn using hybrid model.
- The parameters which are used in hybrid model called as hybrid parameters (or) h-parameters.
- These are generally used to determine amplifier characteristic parameters such as voltage gain, input and output resistances.
- The hybrid parameters give very accurate results in transistor amplifier circuit analysis.

2.15.1 Benefits of h-parameters

- Real numbers at audio frequencies.
- Easy to measure.
- Can be obtained from the transistor static characteristic curves.
- Convenient to use in circuit analysis and design.
- Most of the transistor manufacturers specify the h-parameters.

2.15.2 The h-parameters of a Linear Circuit

- Figure 2.27 (a) shows a model of any linear device or a circuit.
- This device or a circuit is represented by a box and has four terminals i.e., two-terminals 1-1' for input and two-terminals 2-2' for output.
- The behavior of this circuit is specified by two voltages and two currents.

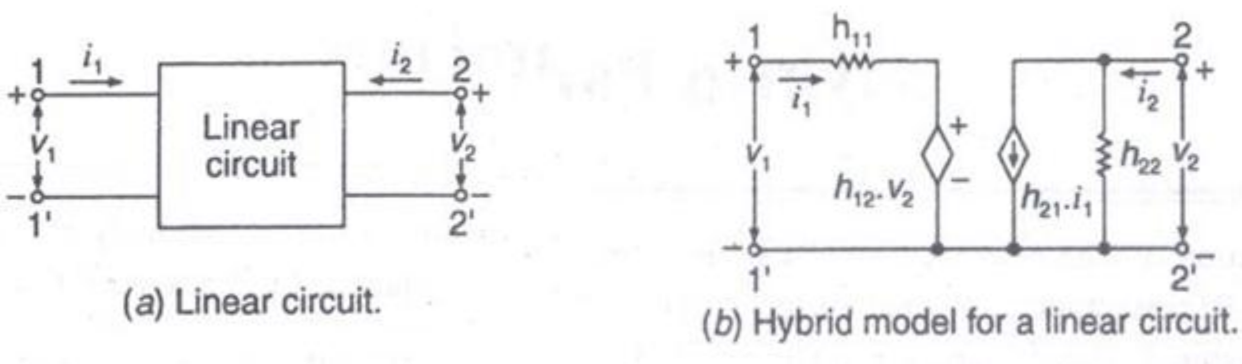


Fig. 2.27 Linear Circuit and its Hybrid model

- Two voltages are the input voltage (V_1) and the output voltage (V_2).
- The two currents are the input current (i_1) and output current (i_2).
- The linear circuit may be replaced by an equivalent circuit as shown in Figure 2.27 (b).
- The equivalent circuit is called hybrid model of a linear circuit.
- In such a circuit, the input voltage and the output current may be related in terms of the input current and output voltage by the following two equations.

$$v_1 = h_{11} \cdot i_1 + h_{12} \cdot v_2 \qquad \text{... } (i)$$

$$i_2 = h_{21} \cdot i_1 + h_{22} \cdot v_2 \qquad \text{... } (ii)$$

where

v_1 = Input voltage, v_2 = Output voltage,

i_1 = Input current, i_2 = Output current,

h_{11}, h_{12}, h_{21} and h_{22} = The hybrid or h-parameters.

- The equations (i) and (ii) have been obtained by applying Kirchoff's Voltage Law to the input and output circuits of the hybrid model shown in figure 2.27 (b).
- Thus a linear circuit has a set of four h-parameters namely h_{11}, h_{12}, h_{21} and h_{22}.

2.15.3 Determination and Meaning of h-parameters

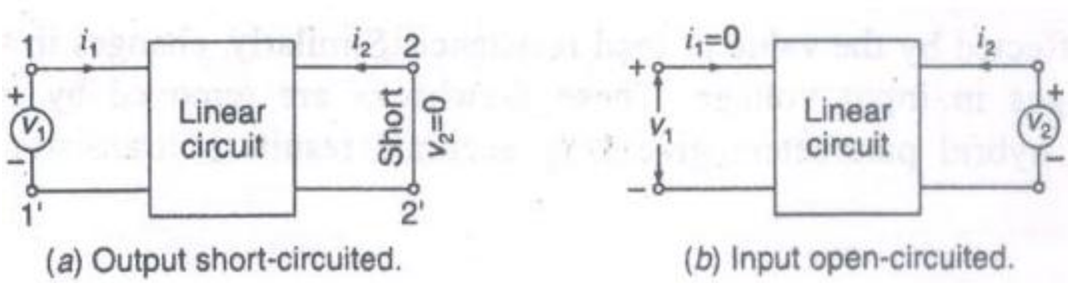


Fig. 2.28 Determination of h parameters

2.15.3.1 Determination of h_{11} and h_{21}

- These are determined by short-circuiting the output terminals of a given circuit as shown in Figure 2.28 (a).
- A short-circuit at the output terminals makes the voltage V_2 equal to zero.
- We know that the input voltage is given by the relation,

$$v_1 = h_{11} \cdot i_1 + h_{12} \cdot v_2$$

- Substituting the value of v2 (equal to zero) in the above equation, the input voltage,

$$v_1 = h_{11} \cdot i_1$$

$$\boxed{h_{11} = v_1/i_1}$$

- Similarly, we know that the output current is given by the relation,

$$i_2 = h_{21} \cdot i_1 + h_{22} \cdot v_2$$

- Again substituting the value of v2 (equal to zero) in the above equation, the output current,

$$i_2 = h_{21} \cdot i_1$$

$$\boxed{h_{21} = i_2/i_1}$$

2.15.3.2 Determination of h_{21} and h_{22}

- These are determined by open circuiting the input terminals of a given circuit as shown in Fig. 2.28 (b).
- An open circuit, at the input terminals makes the input current (i_1) equal to zero.
- We also know that the input voltage is given by the relation

$$v_1 = h_{11} \cdot i_1 + h_{12} \cdot v_2$$

- Substituting the value of i1 (equal to zero) in the above equation, the input voltage,

$$v_1 = h_{12} \cdot v_2$$

$$\boxed{h_{12} = v_1/v_2}$$

- Similarly, we know that the output current is given by the relation,

$$i_2 = h_{21} \cdot i_1 + h_{22} \cdot v_2$$

- Again substituting the value of i1 (equal to zero) in the above equation, the output current,

$$i_2 = h_{22} \cdot v_2$$

$$\boxed{h_{22} = i_2/v_2}$$

2.15.4 Another Representation for h-parameters

- Sometimes, it is more convenient to represent the parameters h_{11}, h_{12}, h_{21} and h_{22} as h_i h_r, h_f and h_o respectively.
- In other words

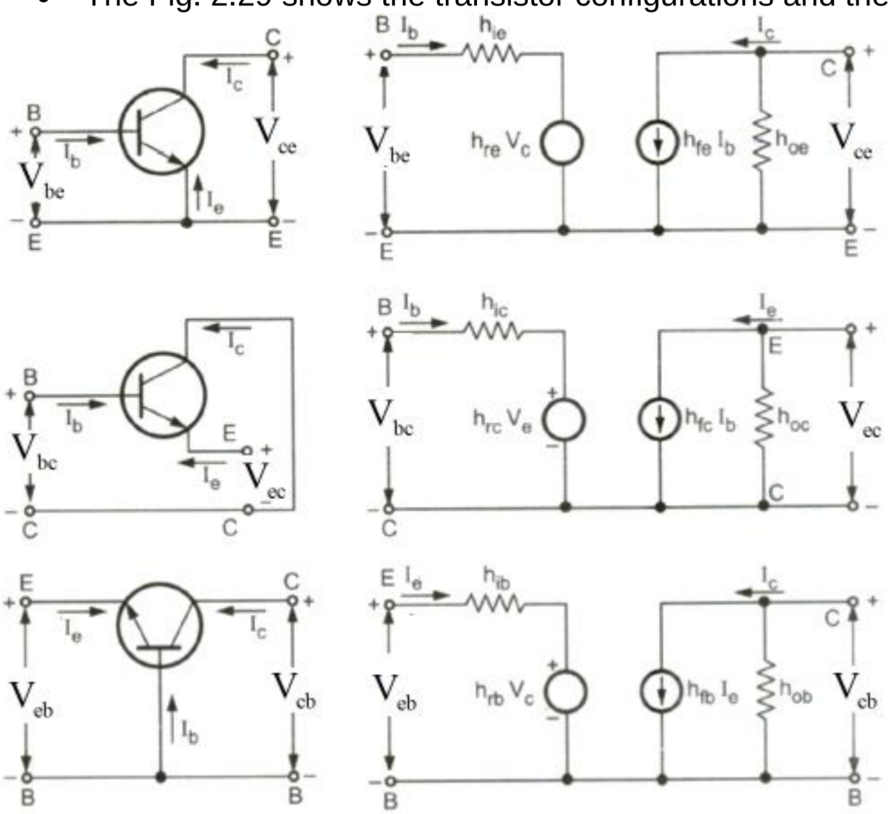
$$\begin{aligned}
h_i &= h_{11} = \text{Input resistance with output shorted,} \\
h_r &= h_{12} = \text{Reverse voltage gain with input open,} \\
h_f &= h_{21} = \text{Forward current gain with output shorted,} \\
h_o &= h_{22} = \text{Output conductance with input open.}
\end{aligned}$$

i = Input $\qquad r$ = Reverse

f = Forward $\qquad o$ = Output

2.15.5 Transistor configurations and their hybrid models

- The basic circuit of hybrid model is same for all the three configurations, only parametType equation here.ers are different.
- The Fig. 2.29 shows the transistor configurations and their hybrid models.



CE

$$V_{be} = h_{ie} I_b + h_{re} V_{ce}$$
$$I_c = h_{fe} I_b + h_{oe} V_{ce}$$

CC

$$V_{bc} = h_{ic} I_b + h_{rc} V_{ec}$$
$$I_e = h_{fc} I_b + h_{oc} V_{ec}$$

CB

$$V_{eb} = h_{ib} I_e + h_{rb} V_{cb}$$
$$I_c = h_{fb} I_e + h_{ob} V_{cb}$$

Fig. 2.29 Transistor configurations and their hybrid models

- The circuits and equations in Fig. 2.29 are valid for either an n-p-n or p-n-p transistor and are independent of the type of load or method of biasing.

2.16 Determination of h-parameters from Transistor Characteristics

- Let us consider common emitter configuration. Its functional relationship can be defined from the below equations.

$$V_{be} = f_1\,(I_b\,,V_{ce})$$

$$I_c = f_2\,(I_b\,,V_{ce})$$

2.16.1 Determination of h_{ie} and h_{re} from Input Characteristic Curves

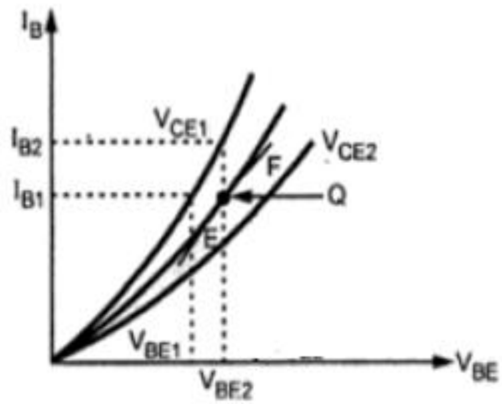


Fig. 2.30 Input characteristics curve for the common emitter transistor configuration

- The input characteristic curves give the relationship between input voltage V_{BE} and the input current I_B for different values of output voltage V_{CE}.
- Fig. 2.30 shows typical input characteristic curves for the common emitter transistor configuration.
- The parameter h_{ie} can be obtained as the change in the base voltage, V_{BE2} - V_{BE1}, divided by the change in the base current, I_{B2} - I_{B1}, for a constant collector voltage at the quiescent point, Q.
- The slope of the line EF, drawn tangent to the input characteristic curve at the point Q gives h_{ie}.

$$h_{ie} = \left.\frac{\Delta V_{BE}}{\Delta I_B}\right|_{V_{CE}\,\text{constant}} = \frac{V_{BE2} - V_{BE1}}{I_{B2} - I_{B1}}$$

- The parameter h_{re} can be obtained as the change in base voltage, V_{BE2} – V_{BE1}, divided by the change in collector voltage, V_{CE2} – V_{CE1}, for a constant base current I_B, at the quiescent point Q.

$$h_{re} = \left.\frac{\Delta V_{BE}}{\Delta V_{CE}}\right|_{I_B\,\text{constant}} = \frac{V_{BE2} - V_{BE1}}{V_{CE2} - V_{CE1}}$$

2.16.2 Determination of h_{fe} and h_{oe} from output Characteristic Curves

- The output characteristic curves give the relationship between output current I_C and output voltage V_{CE} for different values of input current I_B.

- Fig. 2.31shows typical output characteristic curves for the common emitter transistor configuration.

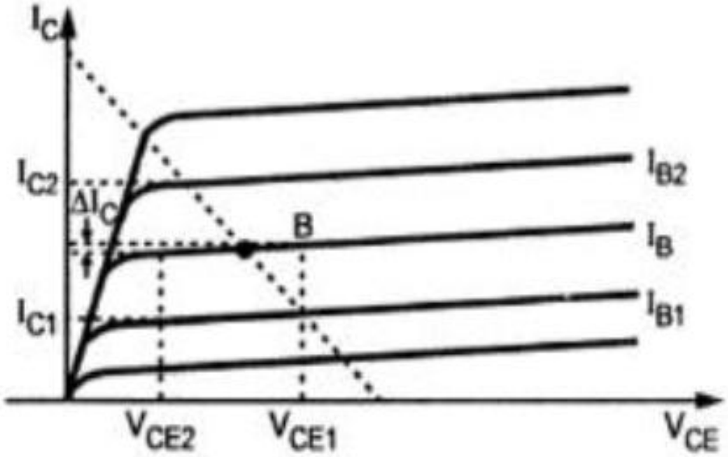


Fig. 2.31 Output characteristics curve for the common emitter transistor configuration

- It is the ratio of change in collector current I_C taken around the quiescent point Q to the corresponding change in the base current I_B, for constant value of output voltage V_{CE} at the Q-point.

$$h_{fe} = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE\,constant}} = \frac{I_{C2} - I_{C1}}{I_{B2} - I_{B1}}$$

- The parameter h_{oe} can be obtained as the change in the collector current, I_{C2} – IC1 divided by the change in the collector voltage, V_{CE2} – V_{CE1} for a constant base current at the quiescent point Q.

$$h_{oe} = \left.\frac{\Delta I_C}{\Delta V_C}\right|_{I_{B\,constant}} = \frac{I_{C2} - I_{C1}}{V_{CE2} - V_{CE1}}$$

2.17 Conversion of h-parameters

- Some transistor manufacturers provide only the four CE hybrid parameters while others provide CB h-parameters.
- Sometimes, for a specific purpose, it becomes necessary to convert one set of h parameters in one configuration to another set in another configuration.
- The conversion formulas can be obtained using the definitions of the parameters involved and Kirchhoff's laws.

2.17.1 Conversion of CE h parameter to the CB h parameter

- For this purpose first the CB hybrid model is drawn as shown in Fig. 2.32 (a) and then it is redrawn in CE configuration, as shown in Fig. 2.32 (b).
- The latter corresponds in every detail to the former except that the emitter terminal E is made common to the input and output ports.

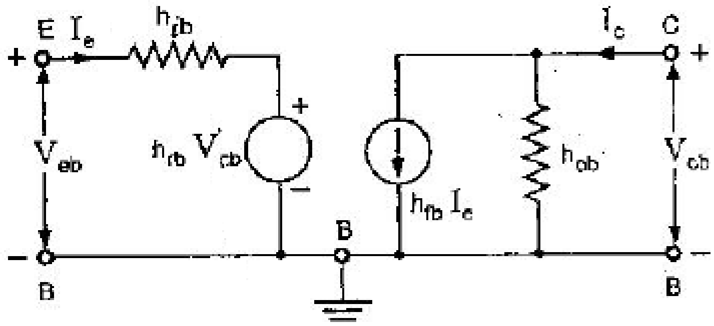


Fig. 2.32 (a) h parameter model CB Configuration

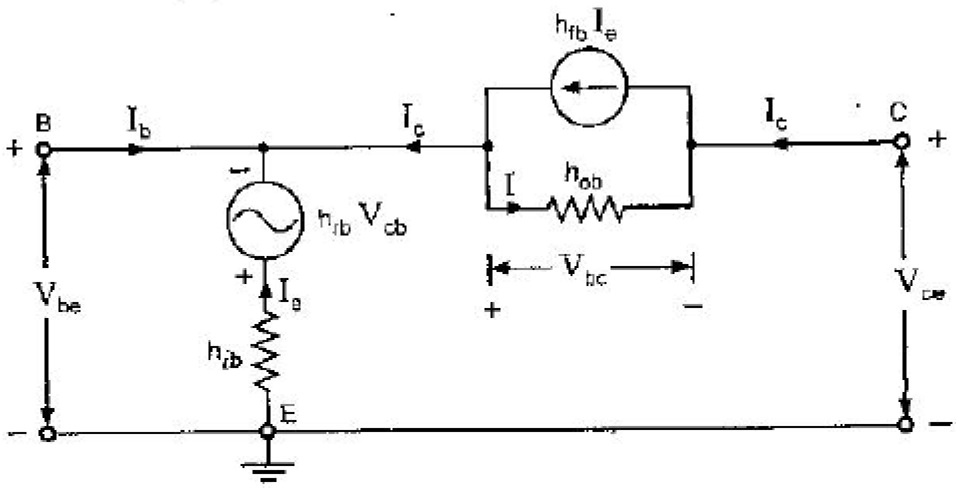


Fig. 2.32 (b) Circuit of Fig. 2.32 (a) redrawn in CE Configuration

2.17.1.1 To find h_{re}

- By definitions using figure 2.32(b)

$$h_{re} = \left.\frac{V_{be}}{V_{ce}}\right|_{I_b=0} = \left.\frac{V_{bc}+V_{ce}}{V_{ce}}\right|_{I_b=0} = 1 + \left.\frac{V_{bc}}{V_{ce}}\right|_{I_b=0} \quad \text{--- (1)}$$

- From the figure 2.32(b), if $I_b = 0$, then

$$I_c = -I_e \quad \text{--- (2)}$$

- From the output side of figure 2.32(b), we can write I as

$$h_{fb}I_e = I + I_c$$

$$I = h_{fb}I_e - I_c \quad \text{---- (3)}$$

- Apply the value of I_C in equation (2) to equation (3), we will get

$$I = h_{fb}I_e - (-I_e)$$

$$I = (1 + h_{fb})I_e \quad \text{---- (4)}$$

- From the figure 2.32(b), we have

$$I = h_{ob}V_{bc} \quad \text{--- (5)}$$

- Compare equation (4) with equation (5) and find I_e

$$I_e = \frac{h_{ob} V_{bc}}{1 + h_{fb}} \quad \text{--- (6)}$$

- Applying Kirchhoff's voltage law to the output mesh of Fig. 10.12 (b), we have

$$h_{ib}\, I_e + h_{rb}\, V_{cb} + V_{bc} + V_{ce} = 0 \quad \text{--- (7)}$$

- Apply I_e value in equation (6) into equation (7)

$$\frac{h_{ib}\, h_{ob}}{1 + h_{fb}}\, V_{bc} - h_{rb}\, V_{bc} + V_{bc} + V_{ce} = 0$$

$$\frac{V_{bc}}{V_{ce}} = \frac{-(1 + h_{fb})}{h_{ib}\, h_{ob} + (1 - h_{rb})(1 + h_{fb})} \quad \text{--- (8)}$$

- Apply the value of V_{bc} / V_{ce} in equation (8) to equation (1), we will get

$$h_{re} = 1 + \frac{V_{bc}}{V_{ce}} = \frac{h_{ib}\, h_{ob} - (1 + h_{fb})\, h_{rb}}{h_{ib}\, h_{ob} + (1 - h_{rb})(1 + h_{fb})}$$

- The simpler approximate formula is obtained by assuming $h_{rb} << 1$ and hob $h_{ib} << (1+h_{fb})$

$$h_{re} = \frac{h_{ib}\, h_{ob} - (1 + h_{fb})\, h_{rb}}{h_{ib}\, h_{ob} + (1 + h_{fb})} = \frac{h_{ib}\, h_{ob} - (1 + h_{fb})\, h_{rb}}{(1 + h_{fb})}$$

$$\boxed{h_{re} = \frac{h_{ib}\, h_{ob}}{(1 + h_{fb})} - h_{rb}}$$

2.17.1.2 To find h_{ie}

- By definition

$$h_{ie} = \left.\frac{V_{be}}{I_b}\right|_{V_{ce}=0}$$

- If terminals C and E are connected together in Fig. 2.32 (b), we have circuit shown in Fig. 2.33.

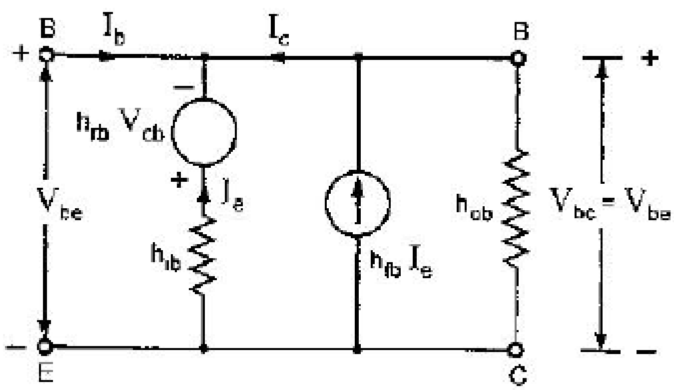


Fig. 2.33 Modified circuit of 2.32 (b)

- From Fig. 2.33,we see that

$$V_{cb} = -V_{bc} = -V_{be}$$

- Applying Kirchhoff's voltage law to the left hand mesh of figure 2.33, we have

$$V_{be} + h_{ib} I_e + h_{rb} V_{cb} = 0$$

- Combining the above two equations we have

$$I_e = -\frac{1-h_{rb}}{h_{ib}} V_{be}$$

- Applying Kirchhoff's current law to node B in Fig. 2.33, we have

$$I_b + I_e + h_{fb} I_e - h_{ob} V_{be} = 0$$

$$I_b = (1 + h_{fb}) \frac{1-h_{rb}}{h_{ib}} V_{be} + h_{ob} V_{be}$$

- Thus

$$h_{ie} = \frac{V_{be}}{I_b} = \frac{h_{ib}}{h_{ib} h_{ob} + (1-h_{rb})(1+h_{fb})}$$

- Since $h_{rb} << 1$ and $h_{ob}\ h_{ib} << (1 + h_{fb})$, so the above equation is reduced to

$$\boxed{h_{ie} \simeq \frac{h_{ib}}{1+h_{fb}}}$$

2.17.1.2 To find h_{fe} & h_{oe}

- To find the value of h_{fe} & h_{oe} , same procedure is used as to find h_{ie}.

2.17.2 Conversion formulae for h parameter from one configuration to other configuration

- Conversion formulae for h parameter from one configuration to other configuration is given in the below Table.

Symbol	Common emitter	Common collector	Common base	T equivalent circuit
h_{ie}	1,100 Ω	h_{ic} *	$\frac{h_{ib}}{1+h_{fb}}$	$r_b + \frac{r_e}{1-a}$
h_{re}	25×10^{-4}	$1 - h_{rc}$ *	$\frac{h_{ib}\,h_{ob}}{1+h_{fb}} - h_{rb}$	$\frac{r_b}{(1-a)r_c}$
h_{fe}	50	$-(1+h_{fc})$ *	$-\frac{h_{fb}}{1+h_{fb}}$	$\frac{a}{1-a}$
h_{oe}	25 μA/V	h_{oc} *	$\frac{h_{ob}}{1+h_{fb}}$	$\frac{1}{(1-a)\,r_c}$
h_{ib}	$\frac{h_{ie}}{1+h_{fe}}$	$-\frac{h_{ic}}{h_{fc}}$	21.6 Ω	$r_e + (1-a)r_b$
h_{rb}	$\frac{h_{ie}h_{oe}}{1+h_{fe}} - h_{re}$	$h_{fc} - \frac{h_{ic}h_{oc}}{h_{fc}} - 1$	29×10^{-4}	$\frac{r_b}{r_c}$
h_{fb}	$-\frac{h_{fe}}{1+h_{fe}}$	$-\frac{1+h_{fc}}{h_{fc}}$	− 0.98	− a
h_{ob}	$\frac{h_{oe}}{1+h_{fe}}$	$-\frac{h_{oc}}{h_{fc}}$	0.49 μA/V	$\frac{1}{r_c}$
h_{ic}	h_{ie} *	1,100 Ω	$\frac{h_{ib}}{1+h_{fb}}$	$r_b + \frac{r_e}{1-a}$
h_{rc}	$1 - h_{re} \approx 1$ *	1	1	$1 - \frac{r_e}{(1-a)\,r_c}$
h_{fc}	$-(1+h_{fe})$ *	− 51	$-\frac{1}{1+h_{fb}}$	$-\frac{1}{1-a}$
h_{oc}	h_{oe} *	25 μA/V	$\frac{h_{ob}}{1+h_{fb}}$	$\frac{1}{(1-a)\,r_c}$
a	$\frac{h_{fe}}{1+h_{fe}}$	$\frac{1+h_{fc}}{h_{fc}}$	$-h_{fb}$	0.980
r_c	$\frac{1+h_{fe}}{h_{oe}}$ *	$-\frac{h_{fc}}{h_{oc}}$ *	$\frac{1}{h_{ob}}$	2.04 M
r_e	$\frac{h_{re}}{h_{oe}}$ *	$\frac{1-h_{rc}}{h_{oc}}$ *	$h_{ib} + \frac{h_{rb}}{h_{ob}}(1+h_{fb})$ *	10 Ω
r_b	$h_{ie} + \frac{h_{re}}{h_{oe}}(1+h_{fe})$ *	$h_{ic} + \frac{h_{fc}}{h_{oc}}(1+h_{rc})$ *	$\frac{h_{rb}}{h_{ob}}$ *	590 Ω